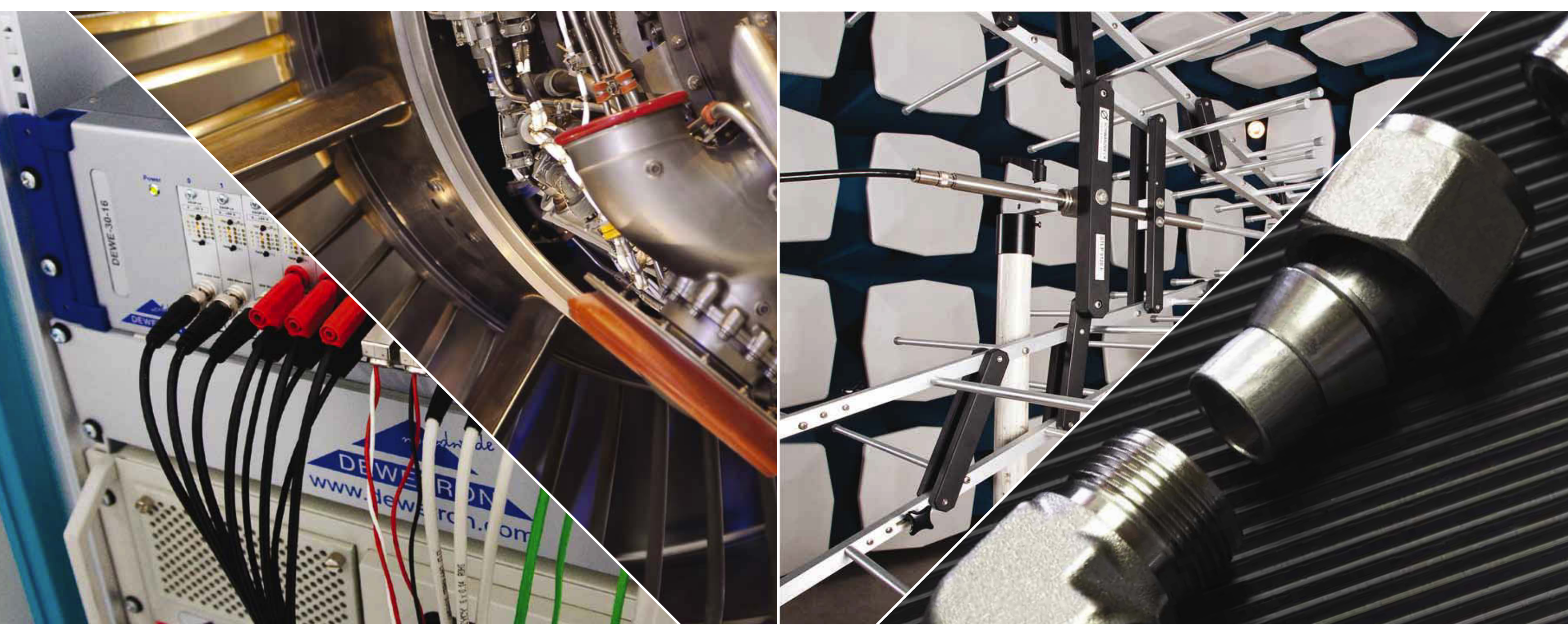
THE OFFICIAL MAGAZINE OF **AEROSPACE TESTING, DESIGN & MANUFACTURING EXPO EUROPE**

SHOWCASE 2014

AEROSPACE TESTING INTERNATIONAL

2014 SHOWCASE



Year-by-year, fiber-by-fiber

The great thing about the annual *Aerospace Testing Showcase* is that, unlike the regular magazine, the reader can gauge from the huge array of articles what prime changes, trends and technological developments have occurred over the past 365 days. Last year it was all about composites – and a year on it still is! Really, the testing of composites remains the leading element of testing that people are talking about.

One of the first things I do after arriving at the office is to check the aerospace news. Just on the day of going to press Boeing announced a deal with the company Hexcel to expand its joint factory Aerospace Composites Malaysia (ACM) by 40%. This is not minor news. ACM produces flight surfaces for all of Boeing's commercial programs, including the next-generation 737, 747-8, 767, 777 and 787 Dreamliner. It's a major announcement and shows the direction Boeing is taking.

ACM is the region's leading employer and is further expanding with extra equipment and cleanroom development. The added capacity is expected to be partially used to begin production of 787 fixed leading edge panels in 2014.

Zwick is just one company in the 2014 showcase that discusses composite materials in detail, noting how many standards there are for testing carbon-fiber structures. According to Zwick's Walter Lee, all these tests are described in international standards (ISO), in national and regional standards (ASTM, EN, DIN) and also in companies' own standards (Airbus AITM, Boeing BSS) and more. Proper calibration and maintenance of test equipment is required to meet industry standards such as A2LA and Nadcap. Lee goes on to say that there are currently more than 150 standards, some more than 30 years old, that describe the physical testing of fiber-reinforced composites!

Dr Ching-Tai Ng, from the University of Adeleide in Australia, describes in the magazine a ground-breaking project to develop a system that is able to provide quantitative identification of defects in CFRP. The research findings from the preliminary work show that 'Lamb wave' signals in CFRP not only contain information on the location of the defect, but also its shape and severity.

A study released this November by Research and Markets called *Global Aerospace Composites* states that it is the aviation market that is currently driving the multi-market adoption of composites, and is predicting that the aviation market will reach US$3.95bn by 2016 in that sector alone. (Although I am no analyst, I would say it could be much higher.) Commenting on the report, even an analyst from the automotive section of Research and Markets said: "The global general aviation market is expected to exhibit steady growth in the coming years."

Composite applications have expanded rapidly in aviation design, from the small secondary structures of some years ago to the more demanding flight-control surfaces, empennage assemblies, fuselage and wings seen nowadays. There is also expanding use of composites in helicopters and other rotary-wing aircraft.

There is a vast amount of development in testing techniques for NDT of polymer composites, some of which are discussed in the magazine, including thermography, tomography, acoustics, ultrasound, leak testing and strain. The A350 XWB was mentioned last year and it remains at the center of attention, as it was this year that it flew for the first time. It already looks as though Airbus intends to ramp up production of the A350 variants in its battle with Boeing to steal the market share away from the 787 and 777, and its biggest selling point is the advanced use of composites.

There will come a day when all civil aircraft are made of advanced composites. But for now it is their increasing use that is at the frontline of civil aircraft sales by the major players. The development of CFRP will change the face of aviation – and therefore testing – forever, but for that to happen an agreement on standards must be achieved sooner rather than later.

Christopher Hounsfield, editor

EDITOR Christopher Hounsfield (chris.hounsfield@ukipme.com)
ASSISTANT EDITOR Bunny Richards
PRODUCTION EDITOR Alex Bradley
CHIEF SUB EDITOR Andrew Pickering
DEPUTY CHIEF SUB EDITOR Nick Shepherd
PROOFREADERS Aubrey Jacobs-Tyson, Christine Velarde

ART DIRECTOR James Sutcliffe
ART EDITOR Louise Adams
DESIGN CONTRIBUTORS Andy Bass, Anna Davie, Craig Marshall, Nicola Turner, Julie Welby, Ben White

HEAD OF PRODUCTION & LOGISTICS Ian Donovan
DEPUTY PRODUCTION MANAGER Lewis Hopkins

PRODUCTION TEAM Carol Doran, Cassie Inns, Frank Millard, Robyn Skalsky

SALES MARKETING DIRECTOR Sally James (sally.james@ukipme.com)
PUBLICATION MANAGER Nick Barr (nick.barr@ukipme.com)

AUSTRALASIA BUSINESS MANAGER Chris Richardson (+61 4207 64110, chris.richardson@ukipme.com)

EDITORIAL DIRECTOR Anthony James
MANAGING DIRECTOR Graham Johnson
CEO Tony Robinson

Aerospace Testing International Showcase is published alongside the quarterly *Aerospace Testing International* by UKIP Media & Events Ltd, Abinger House, Church Street, Dorking, Surrey, RH4 1DF, UK. Tel: +44 1306 743744; fax: +44 1306 742525; editorial fax: +44 1306 887546.

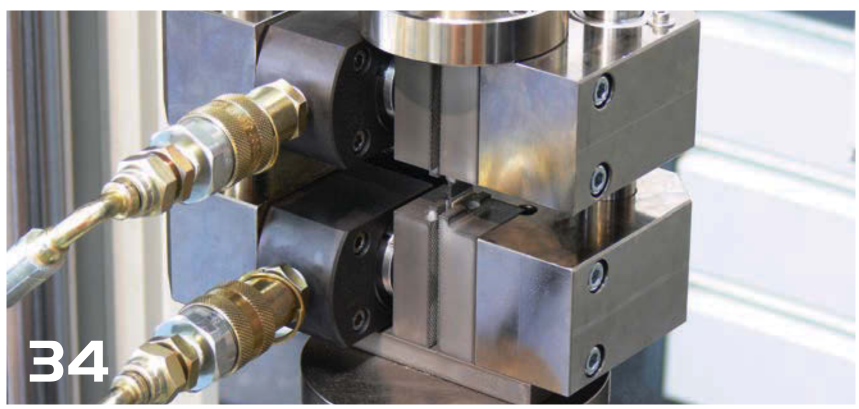
Printed by William Gibbons & Sons Ltd, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT, UK.

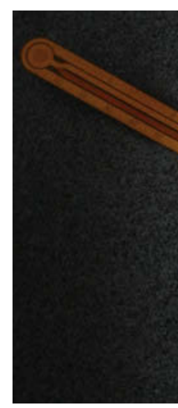
ANNUAL SUBSCRIPTION US$88

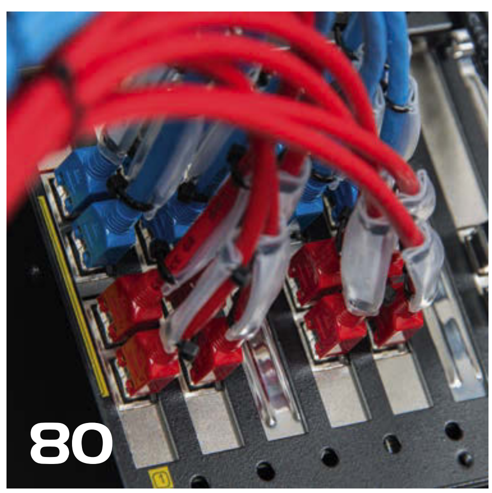
Average net circulation per issue for the period 1 January 2012 to 31 December 2012 was 9,663.
Member of the Audit Bureau of Circulations.

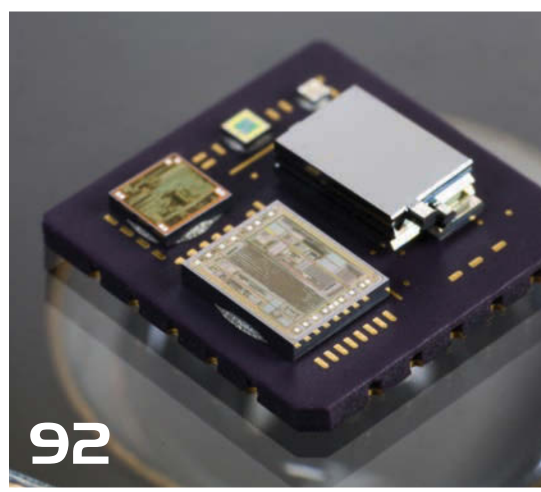
Published by UKiP MEDIA EVENTS

Contents

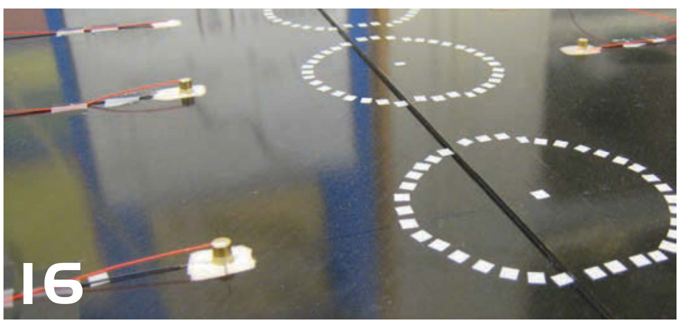









10


16


42
Capacitec

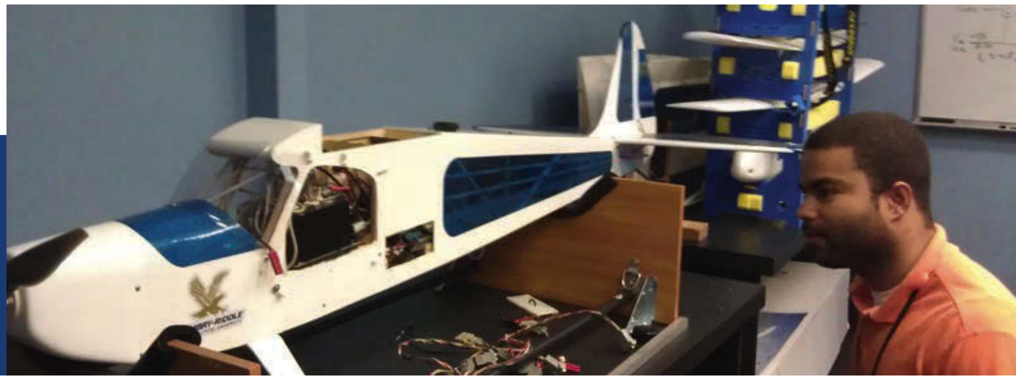

50


106

A lesson in UAS

A unique graduate program has been set up by Embry-Riddle Aeronautical University to develop the engineering workforce for unmanned and autonomous systems

BY RICHARD STANSBURY, PATRICK CURRIER AND HEVER MONCAYO



The unmanned systems industry is poised for an exciting phase of explosive growth due to advances in both the technology and the regulatory environment. Traditional sectors such as defense-oriented unmanned aerial systems (UAS) and spacecraft are expected to remain strong, but the real impact is expected to be in the civilian market. For many applications, the technological hurdles have already been crossed and the FAA is poised to remove one of the last major regulatory barriers with the Congressionally mandated 2015 UAS airspace integration.

The Association for Unmanned Vehicle Systems International (AUVSI) estimates the economic impact of the opening of airspace to be US$13.6bn in the first three years, with the creation of more than 70,000 jobs. By 2025, the unmanned aircraft industry is expected to grow to US$82bn and more than 100,000 jobs in sectors as diverse as law enforcement, precision agriculture and infrastructure monitoring.

Outside the aviation industry, the Google Cars have raised awareness of the technological possibilities in driverless cars. The automotive industry is currently implementing autonomous and assistive technologies, such as park assist and emergency braking assist. AUVSI is predicting that driverless cars could be on the road by 2022 and estimates that potential future economic impact could be in excess of US$200bn per year by reducing accidents and smoothing traffic flow.

Clearly, an industry with this type of growth potential creates a demand for engineers with the training and skills required to design and implement unmanned systems. As the term includes not only the vehicle but also elements such as the control stations, embedded computers, external sensors, mechanical end-effectors and datalinks, engineers must have a broad skill set beyond the traditional engineering disciplines. To address the need for engineers trained in unmanned systems engineering, Embry-Riddle Aeronautical University's (ERAU) Daytona Beach Campus kicked off a new Master of Science in Unmanned and Autonomous Systems Engineering (MSUASE) program in autumn 2013.

PROGRAM OVERVIEW

Over the past decade, ERAU has expanded beyond its traditional roots as the world's leading aviation and aerospace university to develop a reputation for delivering a hands-on curriculum embracing multidisciplinary science and engineering opportunities.

One of the major areas of expansion has been unmanned systems, leading to ERAU being the world's only university to compete in every collegiate robotic competition offered by the AUVSI Foundation, such as the Intelligent Ground Vehicle Competition and the Student Unmanned Aerial Systems Competition (see figure on left). ERAU also has one of three US teams competing in the International AUVSI/ONR Maritime RobotX Challenge and is developing an optionally manned Cessna 182 for the NASA Unmanned Aircraft Systems Airspace Operations Challenge (UAS AOP).

The new MSUASE program prepares its graduates to work in an emerging industry that designs, develops and supports systems that operate along a spectrum of autonomy from remotely controlled to human supervised to full autonomy. Its emphasis is on developing engineers with a strong interdisciplinary background in current and evolving engineering practices for unmanned and autonomous systems.

The program operates at the college level with faculty coordinators from the Electrical, Computer, Software and Systems Engineering (ECSSE) Department; Aerospace Engineering (AE) Department; and the Mechanical Engineering (ME) Department. By combining a curriculum across these three departments, the students are able to obtain a multidisciplinary exposure to the various subsystems that make up unmanned and autonomous systems. Through traditional theses, capstone projects and/or electives, specialization specifically tied to this new degree is available.

MULTIDISCIPLINARY CURRICULUM

The MSUASE program is structured around 15 credit hours of core courses and 15 credit hours from one of three possible options.

The first option requires six hours of advisor-approved electives and nine hours of thesis. The second option is nine credit hours of advisor-approved elective coursework and a six-hour, two semester, capstone design course. The third option, provided for students who may be unable to complete a project or thesis, is an additional 15 credit hours of advisor-approved elective course work.

The program's core is comprised of courses from each of the supporting departments. These include ME 503 – Unmanned & Autonomous Vehicle Systems; AE 527 – Modern Control Systems; EE 515 – Linear Systems; EE 528 – Sensors and Datalinks; and SYS 505 – Safety and Certification. Each of these captures a vital element of unmanned and autonomous systems operating in today's society.

The elective options of the program enable the students to work around their thesis topic or career interests. A total of 36 approved electives were established for the curriculum, including new courses developed for the program as well as graduate courses from the AE, ME and ECE programs.

LEFT: ERAU 'RoboSub' student unmanned aerial systems team at Patuxent River

ABOVE: Students in the UAS area of concentration will study topics such as guidance, navigation and control

> "THE UNIVERSITY IS INVESTIGATING THE USE OF AUTONOMOUS VEHICLES TO PATROL AIRPORTS TO MAINTAIN SECURITY"

The UAS area of concentration specifies a sequence of courses to replace the electives, including the two-semester capstone design project.

This project is an innovative aspect of the program modeled after ERAU's successful undergraduate programs, and will involve design and construction of a working UAS. Under this area of concentration, in addition to the 15 core credit hours of courses, the students take a focused 15 credit hours of courses related to UAS and UAS payload design and implementation, ending with the capstone design project. As shown in the small figure on the previous page, many of the projects involve hands-on experiential learning in the area of unmanned and autonomous systems engineering.

ERAU has a history of research in unmanned and autonomous systems research in the College of Engineering. The university is investigating the use of autonomous vehicles to patrol airports to maintain security as well as deter wildlife. An unmanned aircraft called Gale, under development for NOAA (as shown in Figure xx), is launched into tropical cyclones to provide in-situ measurements of the meteorological conditions inside the storm. A number of technology surveys, regulatory gap analyses and other analyses have been performed to determine the safest path for the integration of unmanned aircraft into the national airspace system. Other projects have involved the design and development of 3D-printed UAS airframes, investigation of novel flight modes, and development of unmanned ground vehicles for defense applications.

Numerous research opportunities exist for students entering a multidisciplinary graduate degree in unmanned and autonomous systems engineering. These include, but are not limited to:

- Development of custom robotic solutions to real-world problems (air, ground, sea and space);
- Sensor technology research and development;
- Collision-avoidance technologies (perception and avoidance algorithms);
- Robust communication technologies for unmanned systems;
- Autonomous navigation;
- Simultaneous localization and mapping (SLAM) of unknown environments;
- Human-robot/human-machine interfaces;
- Integration of unmanned aircraft into the national airspace.

Research will be supported both through grants to government agencies as well as through collaborations with industry, in line with ERAU's history of successful applied research. Research is expected to be multidisciplinary, multidomain and industry focused.

UAS CHALLENGES

Development of a degree program in unmanned systems is not without its challenges. The program must be designed to address the public safety and security issues, regulatory challenges and potential public perception issues.

One major challenge addressed in the development of a program involving unmanned and autonomous systems is addressing the security issues that can be associated with the subject matter. International students are a major market for all graduate programs, but to permit them to participate in this program, it is necessary to ensure that the necessary safeguards are in place.

The first concern to be addressed is the International Trade of Armaments Regulations (ITAR), which defines materials that are prohibited from

LEFT: ERAU students and faculty at the Intelligent Ground Vehicle Competition

BELOW: Gale UAS in flight

dissemination to foreign nationals. Many sensors, autopilots, software and documents used for unmanned systems are ITAR restricted. Projects funded by government agencies often require either security clearance or US citizenship, and many industrial partners have policies in place for sensitive material to which no foreign nationals are permitted to have access.

To avoid unauthorized dissemination to non-US persons, several precautions must be taken. First, physical and digital security of the restricted materials is maintained. Second, no courses within the program's core include ITAR materials, to prevent the need for alternative course offerings for ineligible students. Third, the curriculum includes an 'electives only' track to ensure a path of completion for foreign nationals who may have difficulty defining a thesis or capstone project where no non-ITAR, sensitive, or secret materials are present.

Finally, the program prohibits enrollment of foreign nationals from T-6 countries, including North Korea, Sudan, Cuba, Iran, Libya and Syria, as it is unlikely that the US State Department would permit their enrollment.

REGULATORY CHALLENGES

Another major challenge to be addressed is regulatory. The federal and/or state governments regulate unmanned vehicles, and while these regulations are important to ensure the safety of the public, some challenges create a considerable burden.

Currently, within the USA, UAS can only operate for research and development purposes under a Certificate of Authorization (COA), or waiver, if the aircraft is a public-use aircraft, or under a Special Airworthiness Certificate – Experimental (SAC-Exp) if it is not. Being a private university, ERAU can only qualify for an SAC-Exp. Further, unlike an autonomous car, which can be run on private property (i.e. off public roads), a UAS can only be operated in navigable airspace, all of which is controlled by the FAA.

This restriction greatly limits the type of hands-on projects that students can do as part of their coursework or as part of their thesis research. To address this, several approaches are taken. First, projects are identified in which a public partner can sponsor the project for a COA. Second, optionally piloted vehicles (a manned aircraft that can operate autonomously as an analog for an unmanned aircraft), or manned aircraft from ERAU's training fleet, can be employed for research applications such as evaluation of the various vehicle subsystems (controls, communications, detect-and-avoid, payloads, etc).

The regulatory environment is a large reason for the multimodal aspects of the program. Regulations are much less strict for ground-based and marine-based systems, enabling them to be developed and operated at less expense and with greater frequency. The program is able to leverage these platforms to develop and test technology that may eventually be applied in the aerial domain.

PUBLIC PERCEPTION

The public perception of unmanned and autonomous systems is highly varied across application domains and academic programs must be mindful of these concerns. Events such as AUVSI's Driverless Car Summit, held in Detroit in June 2013, indicate that politically and publicly there is a wide acceptance of the integration of autonomy, such as autonomous parking and smart braking into cars.

On the other hand, particular concern must be given to the public perception of unmanned aircraft. While the appropriate nomenclature for such systems is 'unmanned aircraft systems', which has been adopted by the FAA, the Department of Defense and ICAO, the media still uses the term 'drone'. This term harkens to military technologies, which have a strongly mixed public perception. This negative connotation greatly undermines many of the positive applications of this technology, including wildlife monitoring, atmospheric sensing, wildfire observation, infrastructure surveillance and commercial aerial photography.

"MANY INDUSTRIAL PARTNERS HAVE POLICIES IN PLACE FOR SENSITIVE MATERIAL TO WHICH NO FOREIGN NATIONALS ARE PERMITTED TO HAVE ACCESS"

At this time, an awareness and sensitivity to these perceptions is the only viable solution. Communication with the media requires a clear message regarding the nature of the subjects taught, and projects performed by faculty and students. The dissemination of research results and student activities demonstrating the positive aspects of unmanned and autonomous systems research is of utmost importance, as is educating students as to the importance of presenting a positive public image.

FILLING THE GAP

The introduction of the unique Master of Science in Unmanned and Autonomous Systems Engineering helps to fill a necessary gap to meet the workforce needs of a rapidly emerging industry.

Through a multidisciplinary approach to educating students, involving hands-on applications of these technologies, they will be prepared to develop these systems and their components, such as sensors and other payloads. Caution is required to ensure that the students have an awareness of how to develop safe, certifiable and legal systems to meet next-generation problems, but the program is expected to produce students who are highly capable and highly marketable to the burgeoning unmanned systems industry. ∎

BELOW FROM LEFT: Richard Stansbury, Hever Moncayo and Patrick Currier

Richard S Stansbury is an associate professor for computer engineering and computer science; Patrick Currier is an assistant professor for mechanical engineering and Hever Moncayo is an assistant professor for aerospace engineering at Embry-Riddle Aeronautical University, based in Florida, USA

Elemental advice

Icing in aircraft fuel systems can be studied using a laboratory assessment of the adhesive strength of accreted ice

BY MARK CARPENTER AND LIYUN LAO

"ANY WATER THAT IS PRESENT IN FUEL BEING LOADED ONTO AN AIRCRAFT SHOULD BE INVISIBLE TO THE HUMAN EYE AND CAN ONLY BE DETECTED BY CAREFUL SCRUTINY UNDER A MICROSCOPE"

The possibility of water entrainment and dissolution in aviation kerosene (jet fuel) and its subsequent precipitation to form ice in aircraft fuel systems has been known about for more than 50 years. Fuel system icing is believed to have been first cited as the cause of a jet aircraft accident in 1958 (Boeing B-52D crash at Ellsworth in South Dakota, USA), although it is probable there were previous unattributed incidents.

However, water in jet fuel is an elusive beast. Unless seriously contaminated, any water present is invisible to the human eye and is difficult to detect even under a microscope. Because of this, steps are taken in the supply and distribution of kerosene to keep supplies of fuel as dry as possible, which includes settlement stages in holding tanks, ultra-fine filtration, and removal of suspended or entrained water droplets using coalescing filter water separators. Filter monitors (which employ a media that swells in the presence of water) are sometimes used in the final stage prior to aircraft fueling and act as a further safeguard against inadvertent introduction of water into aircraft fuel tanks.

THE CHEMICAL ELEMENT

From a chemical viewpoint, kerosene is comprised of a large number of different hydrocarbon species but, as a whole, can be considered to be a non-polar solvent. Put simply, this means that water does not dissolve readily in kerosene. Measurements of water content show that most kerosene fuels will dissolve a maximum of 40-80ppm (parts per million) water at 21°C. The actual water content depends on ambient humidity, on the chemical composition of the fuel and the temperature; a warmer fuel can dissolve and hold more water in solution than a colder fuel.

In addition to dissolved water, kerosene can contain microscopic droplets of free water. The larger droplets (typically over 50µm in diameter) will settle in time due to gravity if the fuel remains quiescent. However, the settling velocity of smaller droplets (less than 10µm in diameter) is so low that they are unlikely to precipitate because of minute convection currents within a large body of fluid which keep them suspended. Guidance material for fuel handling systems accounts for this by permitting a maximum of 30ppm free water in kerosene at the point of loading onto an aircraft. Combining this with the dissolved water content means that at the point of aircraft fueling, jet fuel contains less than 100ppm water, and typical water content will be closer to 50ppm. In summary, any water that is present in fuel being loaded onto an aircraft should be invisible to the human eye (assessed via the 'clear and bright' test requirement) and can only be detected by careful scrutiny under a microscope.

The above factors have given rise to much speculation about the role and significance of the different forms of water found in jet fuel and the quantities that might cause problems in aircraft fuel systems. SAE and EASA test specifications require fuel system evaluation with significantly higher levels of water.

These elevated levels allow a margin of safety, and take account of pre-existing water in fuel tanks and water that might enter aircraft fuel tanks while in flight. Most aircraft fuel systems are open-vented, which means that moist air may be admitted into the fuel tank while airborne, even though the total quantities of water likely to be involved are small. The effect is likely to be most significant toward the end of a long flight, when wing tanks will be at their coldest and the aircraft descends to lower altitudes with warmer and moister air.

ABOVE: The Boeing 777 report at London Heathrow showed that water was in the fuel

BELOW LEFT: The jet has dislodged the accreted ice at the corner of the block submerged in fuel

BELOW RIGHT: Fuel has been drained to show the area of erosion

LEFT: **Military hydrant refueler truck**

LONDON HEATHROW INCIDENT

As an example of the magnitude of the problem, the report into the Boeing 777 incident at Heathrow in 2008 concluded that there were likely to be a few liters of water in about 100,000 liters of fuel initially loaded. This comprised of 3 liters of dissolved water and 2 liters of suspended/entrained water; there was also a small but unquantified amount of residual free water retained by ribs and stringers in the wing tank compartments.

At take-off, these amounts of water would have equated to a distributed average of about 50ppm, but as the flight continued, the relative proportion of water might have increased as fuel was consumed and water vapor was admitted via the fuel tank vents. Water admitted in this way might have amounted to a further 0.14 liter.

WATER BEHAVIOR

Against this backdrop, Cranfield University researchers have been examining the behavior of water in aviation kerosene, the way that water droplets are nucleated, and the subsequent transformation of water into ice. Tests have been performed at the microscopic scale (sample size less than 0.5ml) up to a laboratory bench-top scale (20 liters). Tests have mostly been carried out on fuels that conform to the Jet A-1 specification, or specifications that are closely related, for instance, Chinese No 3 and Russian TS-1 jet fuels.

One of the interesting findings, and contrary to most people's expectations, is that water in jet fuel does not necessarily transform into ice at 0°C. Tests under a microscope have shown that suspended water droplets may stay liquid, that is, become supercooled, at temperatures well below the nominal freezing point.

Just because a jet fuel has been cooled to below 0°C doesn't necessarily mean that ice crystals will be present. The second finding is that the solid that is formed when freezing occurs is not true water ice, but a complex mixture that typically contains between 10% and 30% water.

Part of the reason for this is that the ice growth tends to have an open, cotton wool-like morphology, which incorporates fuel within its structure. Having such an open structure, this form of ice tends to be broken up readily by turbulence within the fuel tank and is sheared into tiny fragments by impellers in fuel system pumps. The idea is that any crystals remaining in the fuel flow are melted as they pass through the fuel oil heat exchangers before being fed on to the engines.

STICKY ICE

The idealized scenario implies that ice crystals remain as discrete particles within the fuel flow. However, another factor has been identified, which is referred to as 'sticky ice' behavior and the 'sticky ice regime'; this has been proposed to account for the behavior of ice crystals in jet fuel at temperatures between -8°C and -20°C. The underlying reasons for sticky ice behavior are still being investigated. However, within this temperature band, ice crystals are more likely to bond to cold surfaces such as the wall of an aircraft fuel supply pipe if they come into contact.

The term used to describe ice bonding and accumulation is ice accretion. Ice accretion and its later sudden release from fuel system pipework, causing a partial blockage at the fuel oil heat exchanger, was believed to be the prime underlying cause behind the Boeing 777 accident in 2008. Because of this, there is interest in how strongly any ice may adhere to different surfaces and what conditions might cause sudden release rather than gradual melting.

Cranfield University researchers have considered a number of methods to determine the mechanical properties of the fuel/ice mixture and its bond strength on different surfaces. Possible methods have included the use of specially designed scrapers and ploughs to measure the adhesive, compressive, tensile and breaking strengths of fuel/ice mixtures. Apart from the very small forces involved, a challenging requirement is that tests have to be performed submerged in cold fuel so that the properties of the ice are not altered due to removal/sampling.

"A PERISTALTIC PUMP WAS USED TO DRAW COLD FUEL FROM THE FUEL TANK AND DIRECT IT BACK AT THE SELECTED TARGET"

INITIAL TESTS

Initial screening tests showed that the accreted ice was loosely adherent, which meant that several ideas were unlikely to yield meaningful measurements. An alternative approach using a controlled jet of cold fuel to assess the adhesive strength was proposed. Tests showed that a low jet velocity could be maintained and controlled accurately, and was well suited to the current application.

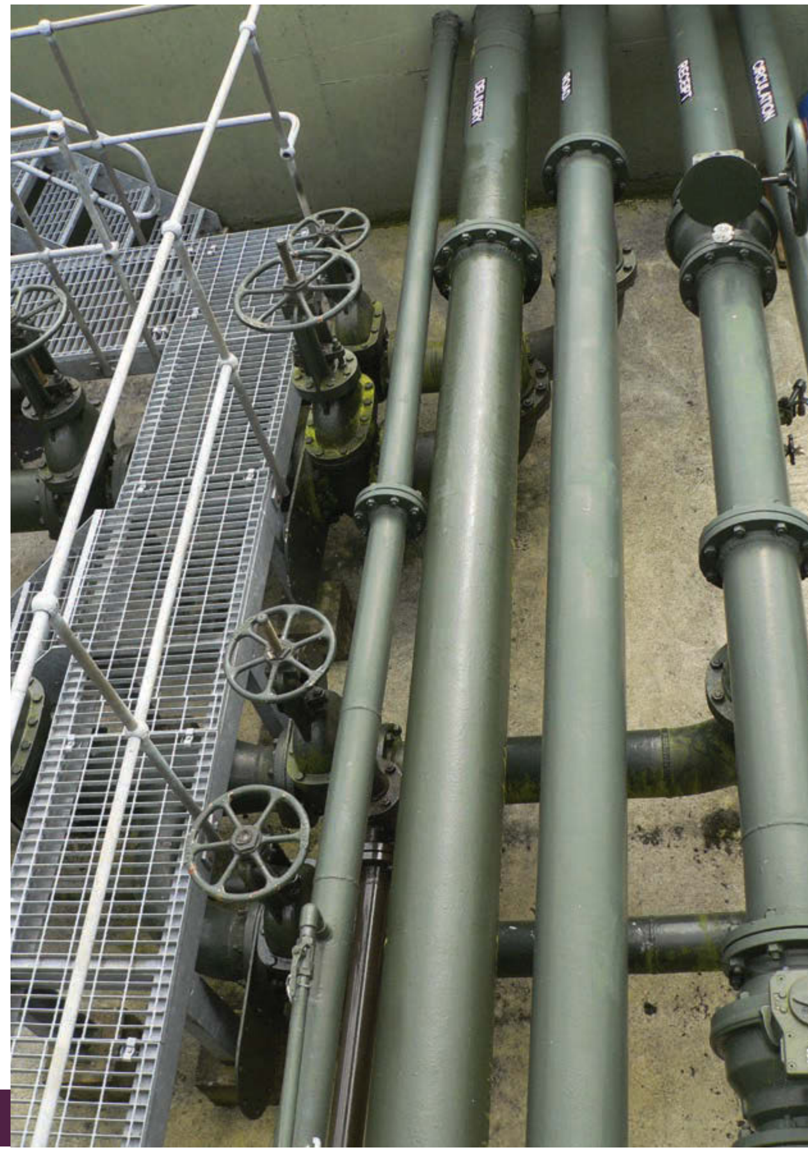
In this system, Jet A-1 fuel within a small tank (~20 liters capacity) was cooled and small additions of water made to encourage ice formation. Ice was allowed to accrete on an aluminum test block; once sufficient ice had accreted, the tests could begin.

In the test, a peristaltic pump was used to draw cold fuel from the fuel tank and direct it back at the selected target as a jet through a specially designed nozzle. The pump controller could be used to vary the fuel flow rate to give a mean jet velocity at the nozzle outlet of between 0.024 and 3.2m/sec. The jet was directed vertically downward with the nozzle positioned at a pre-determined distance from the target.

The jet nozzle is depicted in operation in the figure at the bottom left of page 11 while located above the test block submerged in jet fuel. Accreted ice on the block around the targeted corner of the test specimen has been dislodged. Trying to photograph the submerged system is not easy and the ice distribution is illustrated more clearly in the figure at the bottom right of page 11 after fuel in the tank was drained.

The adhesive strength of the accreted ice was estimated based on the velocity of the jet and the area of erosion. The Reynolds number of the nozzle is given by:

$$\mathrm{Re} = \frac{u_m\, d}{\nu}$$



RIGHT: Pipework and valving on the jet fuel distribution network

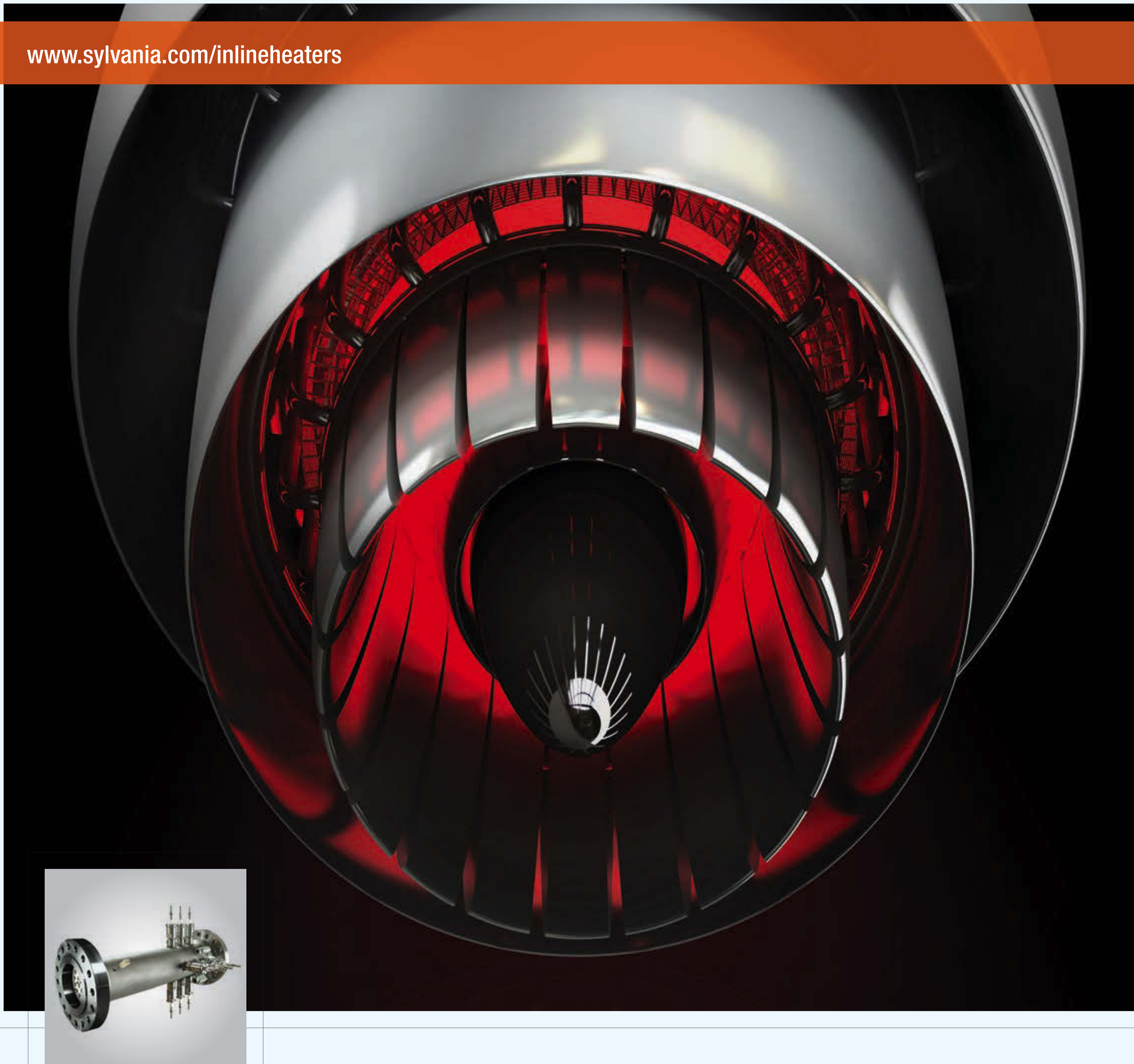
where u_m is the mean jet velocity, d is the bore of the jet nozzle and ν is the kinematic viscosity of the fuel. The center-line jet velocity, u, at a distance, x, from the nozzle is related by

$$u = \frac{3\ \mathrm{Re}}{32}\ \frac{d}{x + 0.05\ d\ \mathrm{Re}}\ u_m$$

Using these simple formulae, accreted ice was calculated to have a bond strength of just under $1\mathrm{N/m^2}$. This has been compared with aircraft fuel system data predictions suggesting ice bond strengths of between 0.5 and $0.9\mathrm{N/m^2}$.

Armed with this data, aircraft fuel system designers can predict the likely flow/temperature regimes that might give rise to ice accretion and sudden release, and modify systems to prevent a repetition of the events that led to the accident at Heathrow in 2008. ▮

Liyun Lao (left) is the senior research fellow in multiphase fluid systems, Process Systems Engineering Group, at Cranfield University. Mark Carpenter (far left) is a research fellow in fuels technology research, Chemical Safety, Fuels and Environment Group, at Cranfield University. Both are based in the UK



There's heat. Then there's jet engine simulation heat.

SYLVANIA Specialty Flanged Inline heaters reach an amazing 900°C on 1000+ PSI compressed air streams with industry-leading speed, compactness and temperature stability. That means our heaters are more than hot stuff; they are your best choice for any kind of aerospace testing. Systems range from 18kW to multi-megawatt and include control panels. So, if you want to see your ideas really fly, learn more about SYLVANIA heaters' superior performance at 1-800-258-8290 or email us at airheatersalessupport@sylvania.com.

SYLVANIA

DR CHING-TAI NG

CREST OF A WAVE

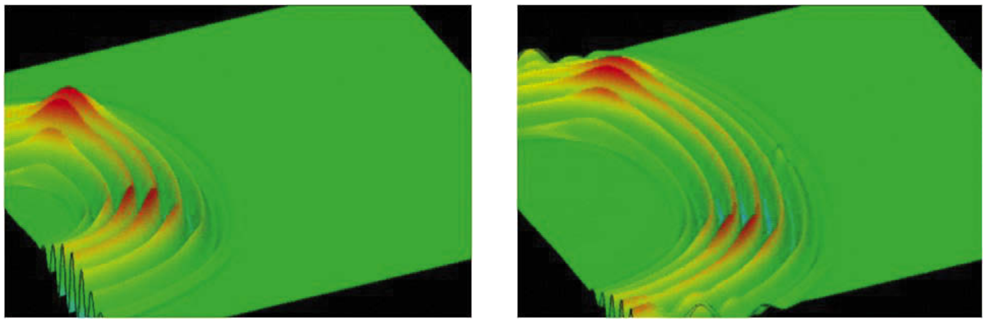
A research team at Australia's University of Adelaide is developing a new algorithm to reveal comprehensive defect information contained in measured Lamb wave signals, which leads to quantitative inspection of hidden defects

BY CHING-TAI NG

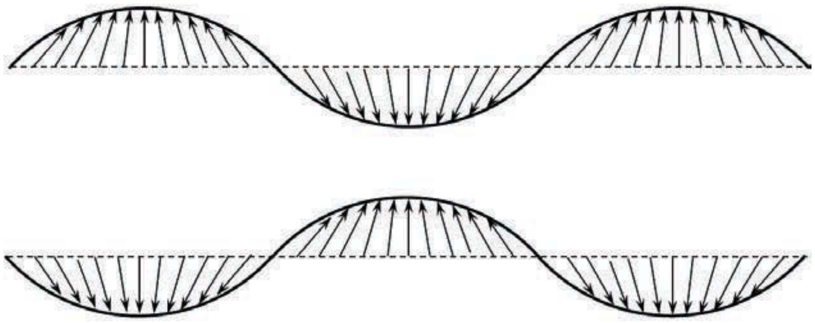
Carbon fiber-reinforced polymer (CFRP), also known as carbon fiber-reinforced plastic, is a composite material consisting of a matrix of plastic reinforced with carbon fibers. Although the separate materials forming the composite remain distinct, their combination produces a new material with characteristics totally different from either of the original substances. Because its lightness, strength and stiffness improve energy efficiency, CFRP is used widely in many fields, including the manufacture of sports equipment, aviation, civil and automotive engineering, and land and water transport.

For all these reasons, the use of CFRP in the aviation industry has attracted much attention in the past decade. The high stiffness-to-weight ratio provides aviation manufacturers with a material superior in many ways to traditional metallic materials, and in 2007 the Boeing 787 Dreamliner became the first aircraft to consist of more than 50% composite materials. The planned launch of the Airbus A350 XWB in 2014 will see the first long-bodied airliner with the fuselage and wings made primarily of CFRP.

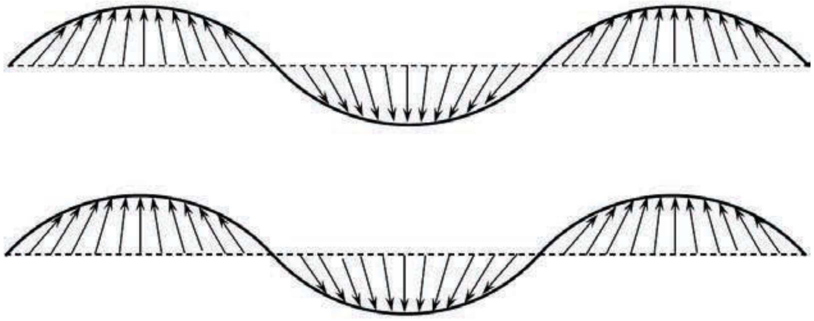
While the lightness and strength of CFRP have made it a popular material in aviation and other applications, it does possess several serious structural limitations. Unlike most of the structural metals, such as steel or steel alloys, the fatigue endurance limit of CFRP is unknown. Furthermore, it is also susceptible to delamination from accidental impacts or from the effects of machining in aircraft manufacture or maintenance. Delamination is a separation of adjacent subsurface laminae within the composite material, causing a major reduction in stiffness and strength. Bird strikes, hail and pelting by runway debris, as well as cyclic stresses during take-off, flight and landing, can all initiate delamination that remains invisible, even with careful inspection. Moreover, the aircraft manufacturing process and maintenance involving drilling and cutting can also produce undetected delamination.



ABOVE: Lamb wave generated, propagation and scattering at a delamination in CFRP



ABOVE: Symmetric mode of Lamb wave (side view of a panel)



ABOVE: Anti-symmetric mode of Lamb wave (side view of a panel)

USING NDT

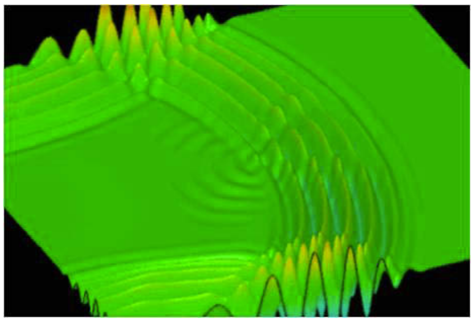
Current practice for inspecting fiber composites mainly relies on conventional non-destructive testing (NDT) methods, such as ultrasound and eddy currents, and requires access to entire composite sections rather than just a suspect area.

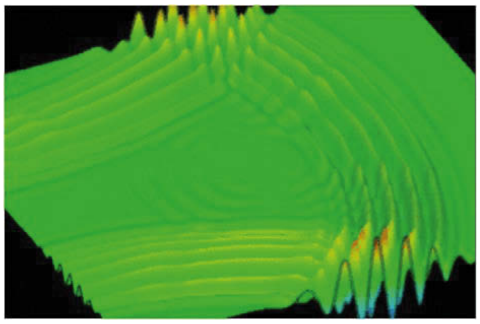
Using these methods to detect small, but serious, areas of damage is time consuming, expensive and inefficient. A research team at the University of Adelaide in South Australia is therefore developing a technique using Lamb waves that can provide a means of damage inspection for CFRP that is efficient, relatively quick and inexpensive, as well as able to quantify the damage. The project will run for three years and is supported by the Australian Research Council. Research began in March 2013.

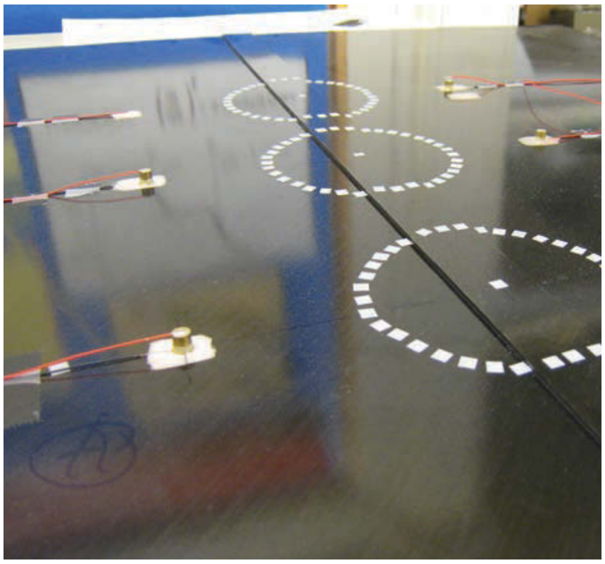
LAMB WAVES

Lamb waves (named after Horace Lamb, who first described them in 1917, and which have nothing to do

> "LAMB WAVES ARE SUITABLE FOR DEFECT INSPECTION IN THIN-WALLED STRUCTURES DUE TO THEIR HIGH SENSITIVITY TO SMALL AND DIFFERENT TYPES OF DEFECTS"







with sheep) are also known as guided plate waves. They are a kind of ultrasonic wave that propagates along thin-walled structures with free boundaries, such as plate or shell. They are either symmetric or antisymmetric in form. The average displacement of symmetric Lamb waves over the thickness of the structure is in the longitudinal direction, whereas the average displacement of antisymmetric Lamb waves is in the transverse direction.

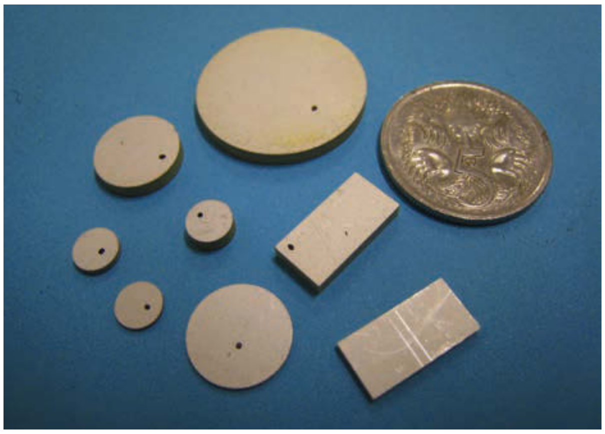
Lamb waves can be generated in CFRP in a variety of ways, such as by using ultrasonic probes, piezoelectric transducers, laser sources and inter-digital transducers, depending on application purposes, environmental conditions and the shapes of the structures being inspected. Extensive research has shown that Lamb waves are suitable for defect inspection in thin-walled structures due to their high sensitivity to small and different types of defects. They are able to propagate over long distances, and if generated as part of a transducer network, inspection can cover a large area of the structure. Moreover, Lamb waves can be transmitted into regions of a structure inaccessible to conventional inspection techniques, identifying defects that might otherwise escape attention. They can propagate in structures under water, in coatings and in insulation.

Compared with conventional ultrasonic testing, Lamb waves use smaller and flatter, lower profile transducers. It is feasible, in fact, to embed the transducers in the CFRP material, allowing continuous, real-time monitoring in aviation, as well as other applications. Since the propagation of the Lamb waves induces displacement across the whole thickness of the thin-walled structures, it is possible to detect surface and subsurface defects, such as delamination, in CFRP.

Lamb waves are very suitable for cost-effective, reliable and in-situ safety monitoring of CFRP structures. The technique being developed by the research team at the University of Adelaide will provide the means to conduct quantitative structural safety inspections using Lamb waves.

QUANTITATIVE STRUCTURAL SAFETY INSPECTION

While the benefits are many, Lamb wave propagation in CFRP is much more complicated than in metallic materials. CFRP is anisotropic. The material properties are dependent upon direction, unlike the uniform characteristics of isotropic materials.



ABOVE: CFRP specimen with piezoceramic transducers

BELOW: Piezoelectric transducers

This variability makes damage inspection techniques, most of which have been developed for isotropic materials, unworkable with CFRP. Understanding the fundamental physics of Lamb wave propagation in CFRP will pave the way for the successful development of quantitative and cost-effective structural safety inspection techniques for use with structures composed of CFRP.

PRELIMINARY WORK

The research team has already carried out an extensive investigation. Finite element analysis and laser Doppler vibrometer testing were used to numerically and experimentally investigate the physical phenomenon of the Lamb wave propagation and scattering phenomena at defects in CFRP. The study quantified the influence of the anisotropic nature of CFRP on the Lamb wave propagation and scattering characteristics at defects. The findings improved the fundamental physical insights of Lamb waves in CFRP and provided a strong theoretical basis in developing a quantitative and cost-effective inspection technique for CFRP.

Current developments have achieved an algorithm for processing the measured Lamb wave signals to determine defect locations in CFRP

BELOW: 3D scanning laser vibrometer

constructions. The inspection system consists of a function generator, amplifier, data-acquisition unit and distributed transducer network with a number of inexpensive (US$8 each) piezoceramic transducers.

The system requires a minimum of three transducers to determine the defect location. These are deployed around the area to be monitored. One of the transducers generates Lamb waves, while the others measure impinging waves. After post-processing of the Lamb wave data using the developed algorithm, a contour map can be generated to indicate the defect location. This provides an efficient and cost-effective inspection of large areas of selected structures.

ONGOING WORK

The ultimate goal of the project is to develop a system that is able to provide quantitative identification of defects in CFRP. The research findings from the preliminary work show that Lamb wave signals in CFRP not only contain information on the location of the defect, but also its shape and severity.

The research team is now working on developing an algorithm for post-processing the measured Lamb wave data that can reveal comprehensive damage information, such as the shape and severity of defects, contained in the measured data. At the end of the research project, a complete inspection trial will be performed to evaluate the reliability of the developed system and its capacity for quantitative identification of the defects in a CFRP construction or structural member, such as the cladding and trusses that make up an airplane's fuselage or wings, the tail or body of a helicopter, or the foils on a catamaran. The overall goal of the research, therefore, is to develop a system by which to achieve quantitative identification of small but serious defects in a complex anisotropic material, at the same time providing a tool by which to conduct real-time in-situ monitoring and long-term reliable safety inspection. This outcome will provide an important tool by which engineers can gather essential information when making decisions related to the status of a structure or structural member composed of CFRP, and prepare for remedial work if required. Lamb waves could also improve manufacturing quality control in any industry involving the manufacture or use of thin-walled structures. ∎

Dr Ching-Tai Ng is a lecturer in the School of Civil, Environmental & Mining Engineering at the University of Adelaide, Australia

KAI BOIARDT

FORMATION FLIGHT

It's time to kill the myth about the energy savings taken from flying in formation

BY KAI BOIARDT

It is a fairly regular occurrence that new research looks into how flying in formation can save energy. These studies are based on the very old assumption that big birds save energy when flying in V-formations. They assume that the birds make use of the area with upflow in the wingtip vortex created by the forward bird – the so-called 'vortex surfing'.

However, the area with an upflow in these vortices has a very narrow lateral distribution, and the rotation of the vortex creates very strong lateral disturbances.

Military flight instructors (I am one) teach pilots how to fly in formation and how to avoid the very disturbing wingtip vortices from the lead aircraft, so we are familiar with this problem.

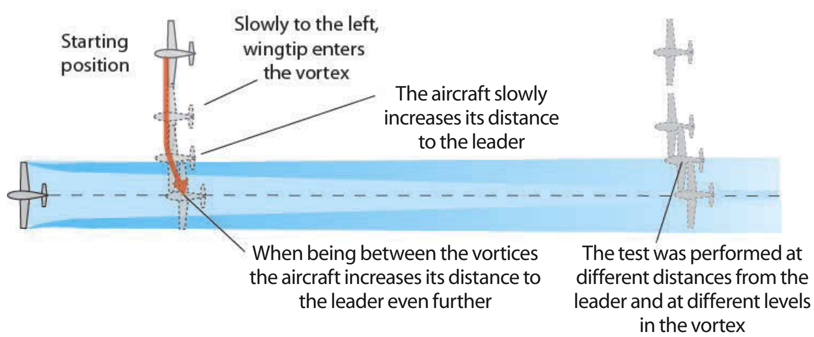
During a visit to Lund University's Department of Zoology and Ecology in Sweden, where tests were performed with birds in a wind tunnel, a doctoral candidate and his supervisor claimed that birds fly in formation to save energy – just like the bomber aircraft did during World War II. We were keen to give them practical experience of flying in formation, so we invited them to the flight school to fly with us in a formation flight, and see and feel the effects of flying close to, and in the wingtip vortices of, the lead aircraft.

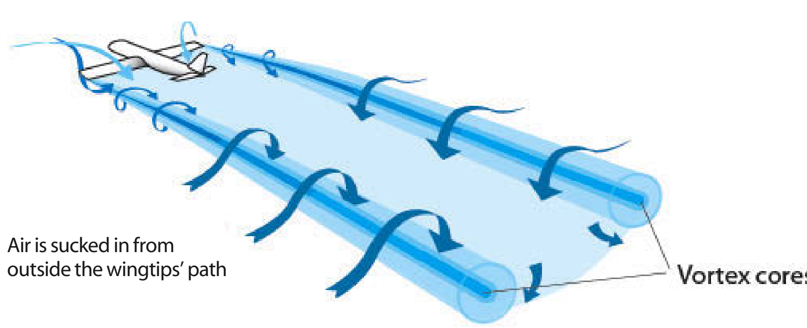
TEST FLIGHTS

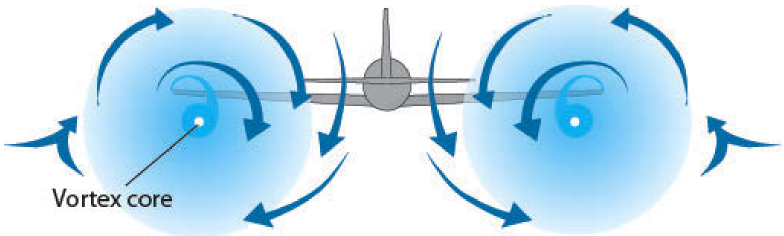
We thought through the tests carefully in advance in order to recreate a natural formation. This was done during glide flight, with the engines at idle to be certain that we really got the effects from the vortex without any risk that the use of engine power would affect the test results.

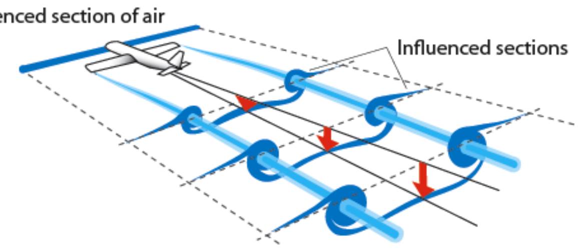
The second aircraft flew slowly sideways, entering the forward aircraft wingtip vortex from different distances behind. If there was to be a positive effect of being in different positions in the vortex, the aircraft would glide slightly faster than outside the vortex and glide closer to the leading aircraft. This never happened. Instead, the aircraft suffered lateral disturbances and was alienated from the leading aircraft.

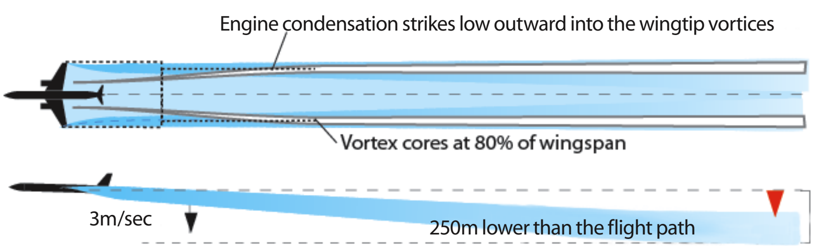
Both aircraft are gliding (engines at idle)

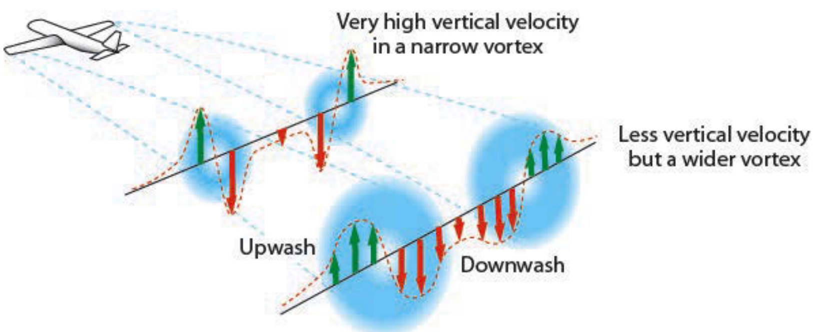


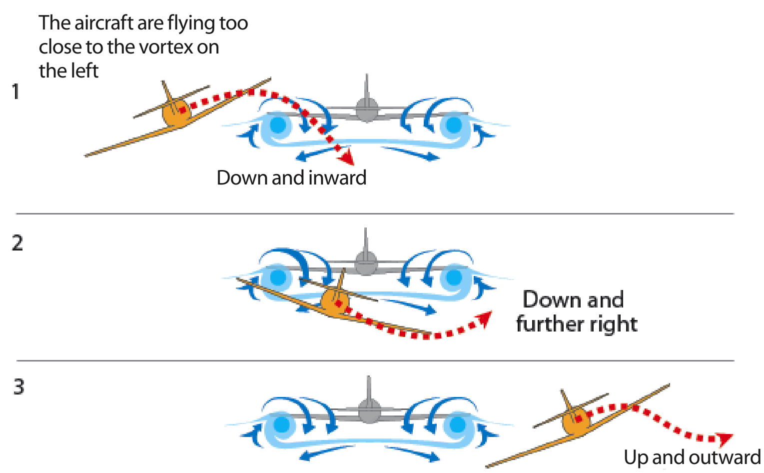


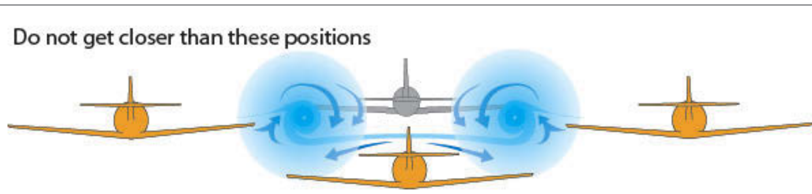












After the flight tests, the doctoral candidate and the supervisor changed their opinions. They started to use a specially designed wind tunnel to study the airflow around and behind the birds by means of laser beams and other sophisticated equipment. The research showed the same results: there is no way to save energy by flying in formation with another bird.

It is worth explaining why this is so and how wingtip vortices are created, the area they influence, and the effect of flying in formation.

BUILD-UP OF WINGTIP VORTICES

Wingtip vortices develop as a core for the whole circulation of air behind the wings. Undisturbed air from outside and above the space the wing has just left, starts to circulate around these wingtip cores in order to reduce the pressure difference created by the wings. The filling up with air makes the area influenced by the vortex greater, the farther the distance from the aircraft it is.

Seen from behind, the outer part of the vortex has an upwards flow, but the area between the vortices has a great downward flow. In fact, most of the area has a downward flow.

DISTRIBUTION OF WINGTIP VORTICES

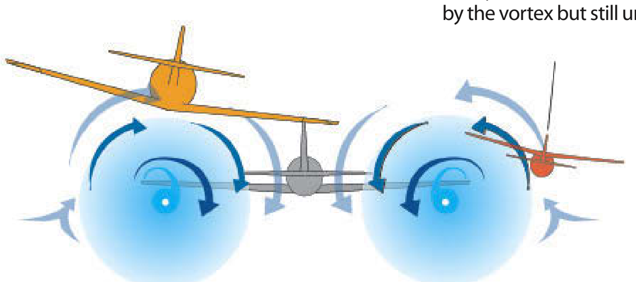
If one imagines that an aircraft is flying through a number of limited vertical blue sections of air, the air in these sections will be moved downward and into the vortex cores, as seen in the figure directly above, which shows three influenced sections behind the aircraft.

As can be seen in this diagram, the core of the vortex is only a small part of the wingtip vortex; and the downward flow is rather low giving a narrow downward angle. The distance between the cores is approximately 80% of the wingspan. The cores are parallel, but the horizontal span is only

$$\text{Vortex intensity} = \frac{\text{aircraft mass} \times \text{load factor}}{\text{TAS x wingspan x air density}} \times \text{constant} \qquad \text{Vortex length of life} = \frac{(\text{wingspan})^2}{\text{vortex intensity}} \times \text{constant}$$

Lateral and directional disturbances to the left

Lateral and directional disturbances to the right



Descent between the vortices

slightly wider than the wingspan of the generating aircraft. The whole area within the wake turbulence moves slowly downward at approximately 3m/sec (approximately 600ft/min) and in practice ends at approximately 250m (800ft) below the flight path.

What the diagrams on the previous page show are the vertical components of the flow at two different distances behind the aircraft.

Seen from behind, when flying through the wake area from left to right, there will be a change in the aircraft trim. In the left part of the left vortex, there will be a very strong upward flow component, but in the right part of the same vortex you will get a very strong downward flow component. The strongest downward flow is inside and near the wingtips.

Between the vortices at the same level as the vortex cores, only a small downward flow will influence the flying, but if going downward, the turbulence in the thin wake will be felt as vibrations in the aircraft. When entering the right vortex, a strong downward component, followed by a strong upward component, will be felt when leaving the vortex to the right. The circulation in the vortices is so strong that a flight near or within the area of wingtip vortices might be uncontrollable.

In order to fly in formation without being disturbed by the vortices, the nearest position should be roughly as illustrated in the bottom figure of the previous page. Going too near the vortices increases the drag due to the higher local flow speed in the vortex, and the created asymmetrical lift and drag causes control problems. Consequently, in order to save energy (fuel and control inputs), you should not fly in too tight a formation.

VORTEX INTENSITY

The vortex intensity depends on the following factors: increases with the weight of the aircraft and its load factor (high angle-of-attack), while it is reduced by high true air speed; low wingspan loading; and high air density (low angle-of-attack).

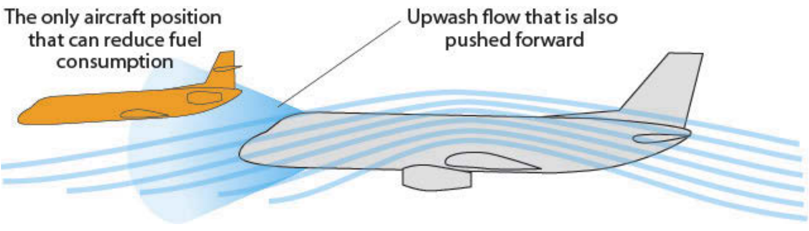
The vortices will decay due to the viscosity and friction of the surrounding air. The distance behind an aircraft where the vortices are harmless depends on the following factors: the length of life of the vortices from a heavy jet airliner is approximately two minutes; and the vortex intensity is nearly constant before they suddenly start to break up.

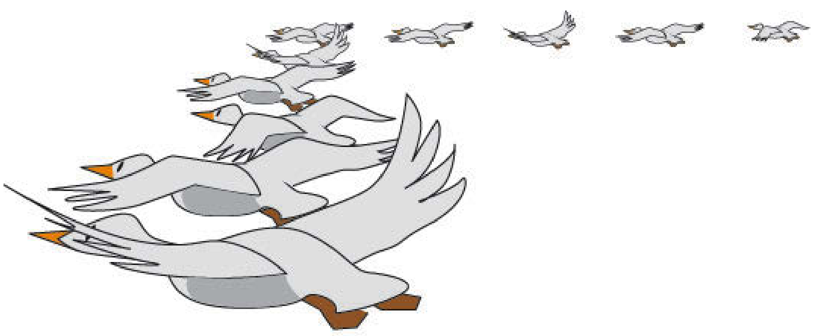
THE PROBLEMS OF VORTEX SURFING

An aircraft flying near a left wingtip vortex will experience a lateral disturbance to the left (left roll) due to the rising flow on its right side, and a directional disturbance to the right (right yaw) due to the higher local flow velocity in the vortex.

When flying straight above the left vortex core, a right roll will be generated due to rising flow to the left and descending flow to the right.

When it is between the vortices, the downward flow from the vortices' inner parts will make the aircraft start to descend. In order to get extra lift from the ascending part of a wingtip vortex, the wingspan of the rear





aircraft must be significantly shorter than the wingspan of the vortex-generated aircraft (see figures on previous page), but it will still cause a lot of control problems.

If the wingspan of the aft aircraft is equal to or greater than the vortex-generated aircraft, the downward flow in the vortex will cause lateral disturbances and may pull the aircraft downward.

THE BIRDS

When birds are flying in formation, there is another factor that makes the use of flow direction in the wingtip vortices hard to use: the birds' up and down wing-flutter, which is difficult to follow. In addition, the rate of the wing-flutter differs from bird to bird at a given speed due to their different masses, wing areas, feather plumage conditions, etc, and the vortices have different flow velocity in the up- and down-wing motions.

The only position where an aircraft or bird can use any upward flow from another aircraft/bird is in front of it, slightly above and near the aircraft/bird. In this area, there is an upward flow due to the generation of lift from the wings. Some air is also pushed forward. The effect of pushing fluid forward is sometimes used by dolphins, which can be seen swimming in front of a bow with minimum effort to maintain the same speed as the ship.

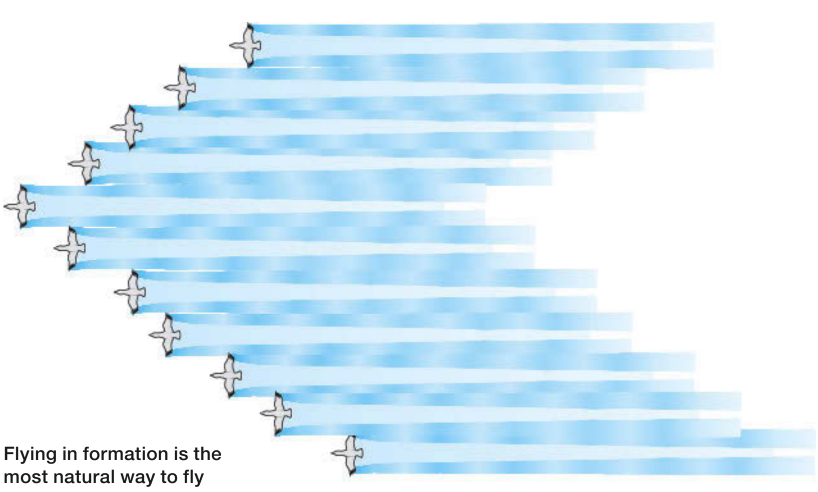
WHY DO BIRDS FLY IN V-FORMATION?

For military fighter pilots and flight instructors, the reason birds fly in V-formation is obvious. They do it for the same reason that pilots do it. It is the most comfortable way to keep a large group of aircraft or birds together without being disturbed by one another. It is natural to choose a position in which the other aircraft or birds are in the smallest visual section as possible – preferably in a position that gives a line slightly to the right or to the left. When not flying in a particular formation, the disturbances from the other aircraft/birds' wing vortices will be difficult to avoid.

The most comfortable position when flying in formation is to sit as close together as possible without being affected by the other wingtip vortices, slightly behind and at a practical angle. By being very close to the other aircraft/birds, it makes it easy to instantly be aware of any undesired change of position. Otherwise it can take long, energy-consuming corrections to get back into position again.

The V-formation is the most natural way to fly together when there are many aircraft or heavy birds following the same route. ∎

Kai Boiardt is a former fighter pilot, senior military and civil flight instructor, and teacher of aerodynamics at Lund University School of Aviation, Sweden. Some of the pictures are taken from his book, Principles of Flight, *edited by Nordian/London Metropolitan University/KLM flight academy*



Flying in formation is the most natural way to fly

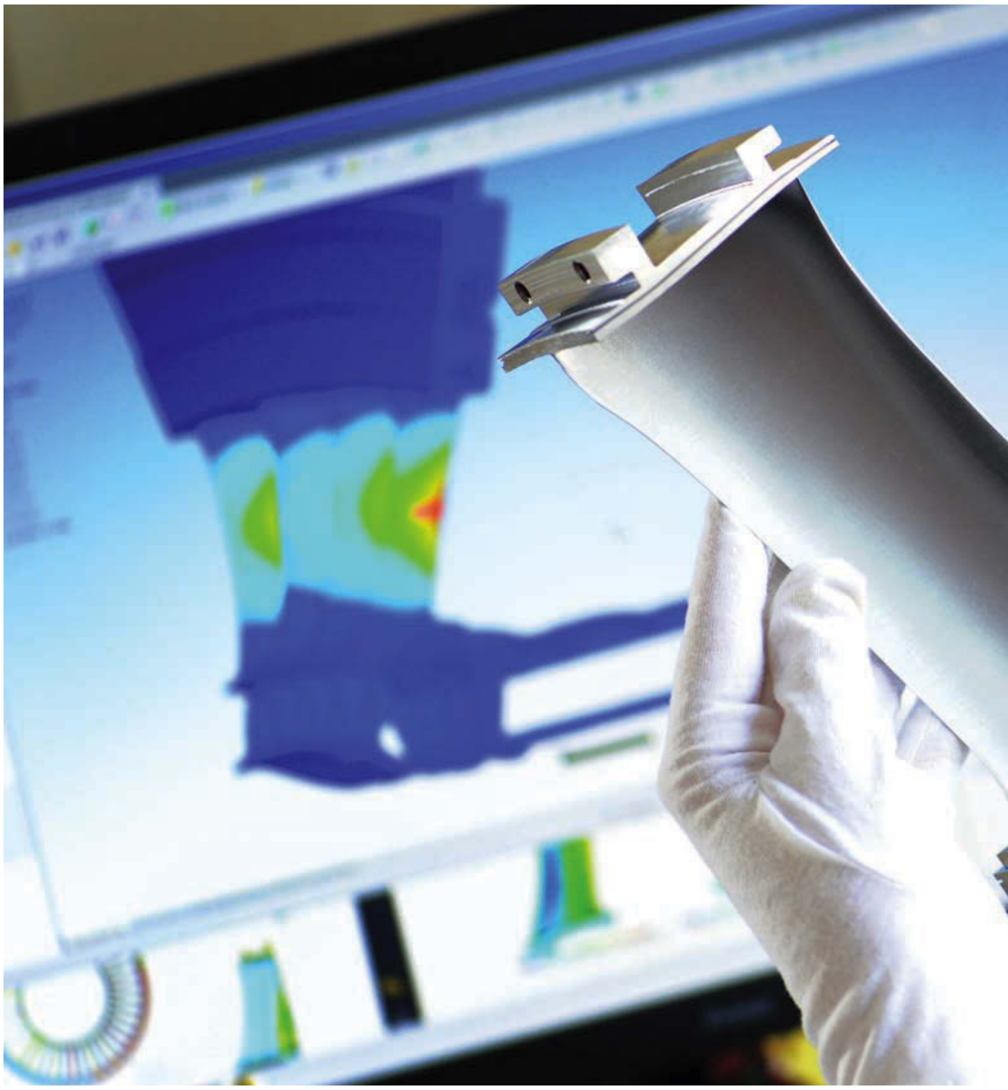
MICHAEL VIETS

RAYK SCHÖNBECK

HIGHLY TUNED INSTRUMENT

Modern engine and structural processes mean that measuring sensor systems have to work right from the start to the very end of aircraft testing

BY MICHAEL VIETS & RAYK SCHÖNBECK



Extensive ground and flight testing are now integral parts of the aircraft engine and structure development processes. With decreasing development times, components and complex machines have to be fitted with instrumentation quickly and cost effectively. That is why the application of measuring sensor systems must work right from the start and deliver high-quality, valuable data from the beginning to the very end of testing.

The essentials for successfully acquiring measurement data are the right choice of application method; first-class instrumentation; and the use of reliable, high-quality measurement technology. Usually, these individual steps are still performed by different departments or companies, or at different locations. This results in many internal and external interfaces having to be managed. Only a few companies, such as AneCom AeroTest, have the ability to carry out the entire job cost-effectively from one source.

Often, even the first step – consultancy or coordination with the end users, which involves selection of the suitable measuring processes, no longer takes place in-house. This leads to a separation of responsibilities. Consequently, discipline is required in terms of effectively putting feedback and lessons learned into practice. The results of consultancy work feed into feasibility studies and cost estimates, which are used as a basis for devising the corresponding specifications for the necessary measuring systems along with other technical requirements. In some cases, as many as three or four parties have been involved by the time the final specification has been created.

THE DESIGN STAGE

In actual fact, all specifications should be constructively incorporated in the design stage. Many companies reach their limits at this point. While typical design work is often carried out in-house, in most cases instrumentation design is passed on to subcontractors or external locations. This often triggers a long sequence of problems. Although close coordination between design, instrumentation design, tooling design, analysis and production specialists is absolutely essential, companies can struggle to achieve it. Lengthy communication times and channels also result in additional costs.

A quick solution to the many specific challenges, such as choosing the right application method and measuring sensor systems for the relevant base material (e.g. Inconel, Hastelloy, Udimet or titanium), now depends on the experience of specialists: are the right machines and cutting materials available? These are all characteristics acknowledged when machining increasing numbers of composite materials.

Complex, time-consuming communication channels are pre-programmed. At the same time, measuring technology specialists should also be involved, as often drawings and 3D models that end up being used in production or procurement can no longer be changed beyond this point. Consequently, manufacturing often takes place without sufficient integration of all relevant design aspects. The

> **"WHATEVER APPLICATION METHODS ARE CHOSEN, SUCCESSFUL INSTRUMENTATION OF THE COMPONENTS CAN ONLY BE CARRIED OUT BY WELL-TRAINED STAFF AND WITH DUE ATTENTION TO AND EXCLUSION OF ALL NEGATIVE EXTERNAL INFLUENCES"**

ABOVE: The design supports all CAD design and analysis requirements in order to develop test vehicles for aero- and gas turbine engines

downstream costs are set, and their extent cannot be changed even by the most skillful purchasers.

MEASUREMENTS

Whether it be total pressure or total temperature, static pressure, component temperature or engine speed, torque or component load – there are numerous measurements that must be recorded when testing engines. Depending on the temperature range the components are exposed to in test operation, different application methods are selected. For example, for strain-gauge applications there might be flame spray up to 1,200°C, liquid paste ceramic up to 700°C or epoxy cement up to 350°C.

Many pressure and temperature lines are installed on component surfaces by means of spot welding or adhesive bonding. However, on surfaces in a flow in the gas path, these lines may also be completely installed in the base material of the component, and the resultant cavities are sealed off using methods such as brazing or welding. Blockages can be reduced using this method. A wide range of instrumentation on the leading edges of components in an air flow (rakes, vanes, etc) is applied by means of brazing (torch or vacuum brazing) or laser-beam welding.

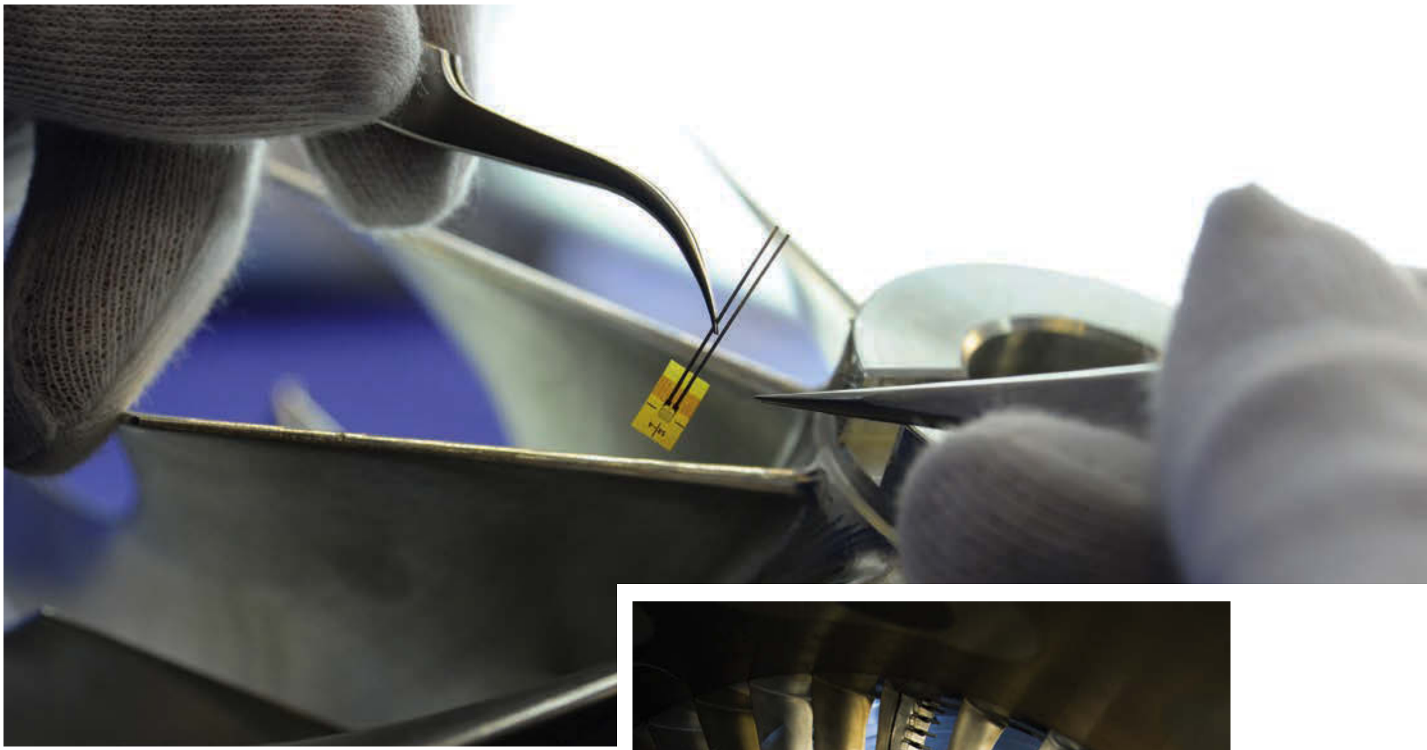
Whatever application methods are chosen, successful instrumentation of the components can only be carried out by well-trained staff and with due attention to and exclusion of all negative external influences. Specialists are required here, and many of these complex applications are beyond the capabilities of in-house employees, systems or premises. If the negative influences of oxidation of the component and brazing material are avoided in vacuum brazing, selection of the right cleaning method becomes one of the key factors when cleaning the component prior to instrumentation.

APPLICATIONS

All downstream preparatory processes, such as grit blasting, must be carefully selected and the blasting material used must meet the requirements of the base material. For a successful application, it is also essential to monitor and control the temperature and humidity at the instrumentation site.

Work should be carried out in laboratory conditions at this point, and the workstations must be clean and dust free. Optimum lighting conditions at the workstation help employees carry out this delicate work. Positioning of the sensors by hand – sometimes to within 0.10mm – demands extreme skill. Monitoring of the processes used, such as vacuum brazing, oven drying, etc, requires high-quality technical equipment so that successful implementation of the process can be examined at all times and also be included in the final quality documentation if necessary.

A final independent quality check ensures that the in-house zero-fault target is met. But how are strain-gauge applications checked in inaccessible areas such as drilled holes or cavities? How can it be ensured that static pressure lines are optimally mounted flush with the surface? How is it possible to check whether the vacuum brazing material and the base material have formed an optimum bond? Again, answering these questions requires all kinds of technical equipment or even a



RIGHT: This vane, provided with sensors from the Universal Fan Facility for Acoustics (UFFA), is a modular test carrier for the acoustic examination of jet engine fans

dedicated test laboratory, for example for destructive tests on test specimens.

The available measurement equipment is taken into account as early as the first step, when defining or specifying a measurement parameter. Availability can take various forms here: measurement equipment can be purchased or borrowed, and in the best-possible case it is even available in-house. Whether the measurement equipment is suitable for a measuring task can be assessed on the basis of many criteria: possible measurement uncertainty, resolution, number of channels and sampling rate are just a few examples. Of course, the measuring technology used should be suitable for the planned instrumentation and vice versa. As a rule of thumb, it can be reasonably assumed that the performance of measurement systems is proportional to the price.

RIGHT TECHNOLOGY, RIGHT APPLICATION

In practice, the selection of measurement technology is often driven by the required measurement accuracy for a specific application. For example, future aero-engine fans will have a relatively low pressure ratio and therefore a low temperature ratio. If the aerodynamic efficiency is to be determined with the help of the temperature differential, the latter must be measured very accurately to avoid an unacceptably high level of uncertainty in the efficiency calculation. Conventional thermocouples and the matching signal conditioners available on the market reach their limits at this point. On all testbeds worldwide, measurement technicians are focused on providing, configuring and operating the installed measurement equipment for the various tests. Comparability of results is a central requirement with measurements of all kinds. This is typically attained through calibrations traceable to national and international standards. If an in-house flow laboratory is available, most of the calibrations relating to the flow rate and anisotropy of flow probes can be performed.

ASSEMBLY

The last step before successful data acquisition is the assembly of the instrumented component in the machine. In-house fitters are often used here. Often, even these employees do not have the necessary experience in installing the special converted components. Some instrumentation lines react extremely sensitively to bending stresses; the corresponding measuring points must be linked to the right transfer points; installation on the machine must be adapted to the subsequent usage conditions; and all labels must be absolutely correct. All this must be taken into account as early as the design stage, and can then be done by special mechanics.

In practice, up to 10 parties, both internal and external, can ultimately be involved in the entire process from specification to acquisition of measuring data on the testbed. This does not even take into account the number of subcontractors for sensors, consumables and equipment, for example. Often it is necessary to contend with different time zones, which complicates the process, even if language barriers are hardly an issue these days. Every reduction in these many points of contact leads to cost optimization, reduced lead times and optimum use of all lessons learned from previous projects. The advantages of a central solution from service providers such as AneCom AeroTest are clearly apparent. This is why the developers of new aircraft engines and structures will be required to further optimize development costs and times, and select suitable providers accordingly. ∎

Michael Viets is manager of build and instrumentation and Rayk Schönbeck is manager of test and measurement at AneCom AeroTest, based in Germany

BRIAN DUFFY

LOADS OF CHOICE

Aerospace ground and flight test applications depend on load cells to ensure aircraft integrity and performance

BY BRIAN DUFFY

Within the world of aerospace and flight, stringent testing is essential to ensure structural and mechanical integrity of mechanisms during rigorous real-life performance. Whether the application is commercial or military, load cells' inherent flexibility in design and form factor – in addition to their overall robustness – makes them a dependable choice for a plethora of testing scenarios and environments.

With specially designed structures including multiple-bending beam, multiple-column and shear-web, the possibilities are nearly endless in creating load-cell profiles and/or configurations to withstand the most extreme testing challenges through all phases of aircraft development and use.

LOADED WITH OPTIONS

Multiple options for customization are what make load cells such a valuable tool in the world of aerospace testing. Custom load cell designs are often needed for specific applications. Depending on the function, load cells can be created in various sizes and profiles, with varying ranges, and for specific accuracy and sensitivity needs. This versatility offers invaluable flexibility for engineers.

One example of load cell flexibility is in the customized dual-bridge design, with two independent outputs on a single load cell. This design performs as two independent load (force) measurements from the same load cell. For instance, in airframe testing, the first load measurement can be used to control the loads applied to the aircraft. The second independent load measurement verifies what the load actually is, which is collected for data analysis, along with various other measurements on the airframe being tested. Basically it provides independent verification of the load. This is a key feature and benefit in certain applications. Typically load cells in airframe testing also have to compensate for off-center loading because they are mounted directly in-line with the hydraulic cylinder providing the load.

When it comes to effectiveness, load cells are hard to beat. They measure loads and transmit the data needed to validate components, products and complete aircraft to help ensure integrity and safe operation – a strict requirement within aerospace and flight applications.

For cost-conscious engineers planning to conduct a multitude of tests on the same component, load cells again make a great choice. They can be designed with a high fatigue life or long lifetime, offering greater reliability and longevity of use. Often they are able to maintain their performance through more than 100 million load cycling tests.

A robust design goes hand-in-hand with reliability. Load cells are built to last longer in tough applications. They can be constructed to compensate for various operational factors, which is particularly useful in flight applications. They can be built to withstand environmental factors such as g-forces and vibrations, as well as temperature and humidity fluctuations, chemicals and even physical impacts. Load cells are typically encased in an all-metal construction designed to protect the sensor from harsh environmental conditions and operating environments without degrading the sensing capabilities. As a result, key operating parameters and performance are maintained.

Load cells strive to perfect the often imperfect conditions within the aerospace world. They are engineered to compensate for off-center loading, allowing sensor functionality and performance despite less-than-ideal situations. Helicopter lift operation is one example. Several hook load sensors can be used to confirm a safe lift. The load cell design compensates for uneven loading, so even if the load is not applied directly through the primary axis of the load cell, it will still perform to specification.

Equally important in the aerospace industry is redundancy. Load cells can actually be designed with this feature, providing a back-up mechanism that helps maintain the mechanical

integrity of the flight control system where necessary.

By design, load cells have minimal deflection when fully loaded, while still retaining high load sensitivity. This feature is advantageous in applications such as throttle, wheel and pedal linkages that detect pilot input load on the aileron, rudder and elevator. Highly sensitive load cells enable the pilot to retain direct, active feedback to control the aircraft, while providing data to the flight data recorder and throttle control. The sensing element provides a direct link between pilot touch and immediate feedback to the plane's control systems. Aircraft autopilot situations are another example. A pilot who wants to take direct control of the aircraft need only take hold of the throttle to disengage the autopilot.

SUITABLE FOR ALL PHASES

From initial design and build stages, to pre-flight, structural and fatigue testing, in-flight testing and monitoring, and flight-qualified load monitoring and control, load cells play an integral role in confirming component performance and safety.

Within the initial design and build stages of aircraft, load cells are used to test components for strength, load endurance levels, component longevity and more. Components can include everything from seatbelts, to individual linkages, aircraft flaps and cockpit instruments. For the majority of component-testing applications, a standard load cell design can be used.

When it comes to pre-flight, structural and fatigue testing, load cells can be used to test airframe structural integrity, endurance and working life.

ABOVE: Load cells can be used for pilot load input, measuring the pilot's touch on the control stick and storing the data in the flight data recorder

LEFT: Load cells are used in pre-flight, structural and fatigue tests to measure frame structure integrity, as well as the endurance and operational life of a multitude of aircraft components

BELOW: A load cell is positioned on the far end of a boom and measures the load the aircraft exerts on the boom assembly during inflight refueling

The ultimate goal is to validate aircraft design and ensure that specified criteria are met. For instance, dual-bridge load cells are used for airframe testing. During in-flight testing and monitoring, load cells can be used to test and monitor airframe structural loads. For example, bolts and pins used at critical points of the airframe can be redesigned, fabricated and calibrated to perform as load cells and used to ensure that structural integrity is maintained.

“A HIGHLY CUSTOMIZED LOAD CELL CAN BE USED IN THE FLIGHT CONTROL SYSTEM FOR MANY EXTREME APPLICATIONS”

After new builds or designs pass the necessary performance testing and are ready for commercial or military applications, load cells can be used in flight-qualified load monitoring and control, or monitoring of the flight control system.

In commercial uses, load cells are designed for pilot load input. They are also used in the measurement of the pilot’s touch on the control stick. The load is measured and the data is stored in the flight data recorder. A redundant load path ensures the mechanical integrity of the linkage.

In demanding military applications, a highly customized load cell can be used in the flight control system for many extreme applications. One example is in-flight tanker refueling operations, where the load cell is on the extreme end of a boom and exposed to harsh environmental conditions. The boom system is used to track the aircraft being refueled and the load cell, as part of that system, measures the load the aircraft exerts on the boom assembly.

STANDARD OR CUSTOM?

Standard load cell structures, coupled with customization options, offer a load cell for nearly every aerospace testing application and challenge imaginable. But now what? Begin by understanding the application needs and parameters, and identifying the must-have features of the load cell. Depending on the requirements, there may be a standard design that fits the bill. If not, look for a supplier that can customize the design to fit the need. The most accurate, reliable and robust load cell available is vital in supporting a structurally sound and mechanically dependable aircraft. ∎

Brian Duffy is the global applications engineering manager for Honeywell Test & Measurement Products; http://measurementsensors.honeywell.com

COMPOSITES MEET CONSTRUCTION

The search for stronger, more lightweight materials for use in the aerospace industry is driving the development of new advanced composite materials

BY ALAN THOMAS

Aerospace materials are somewhat unique in that they are subjected to extremes in temperature, humidity and corrosive environments, as well as high fatigue loads. "All these add to the complexity of adequately testing the materials, since the test machine, at least in the area surrounding the specimen, is exposed to the same conditions as the material under test," says Bill Becker, aerospace industry manager for Zwick/Roell, an Ulm, Germany-based supplier of materials testing equipment and measurement software.

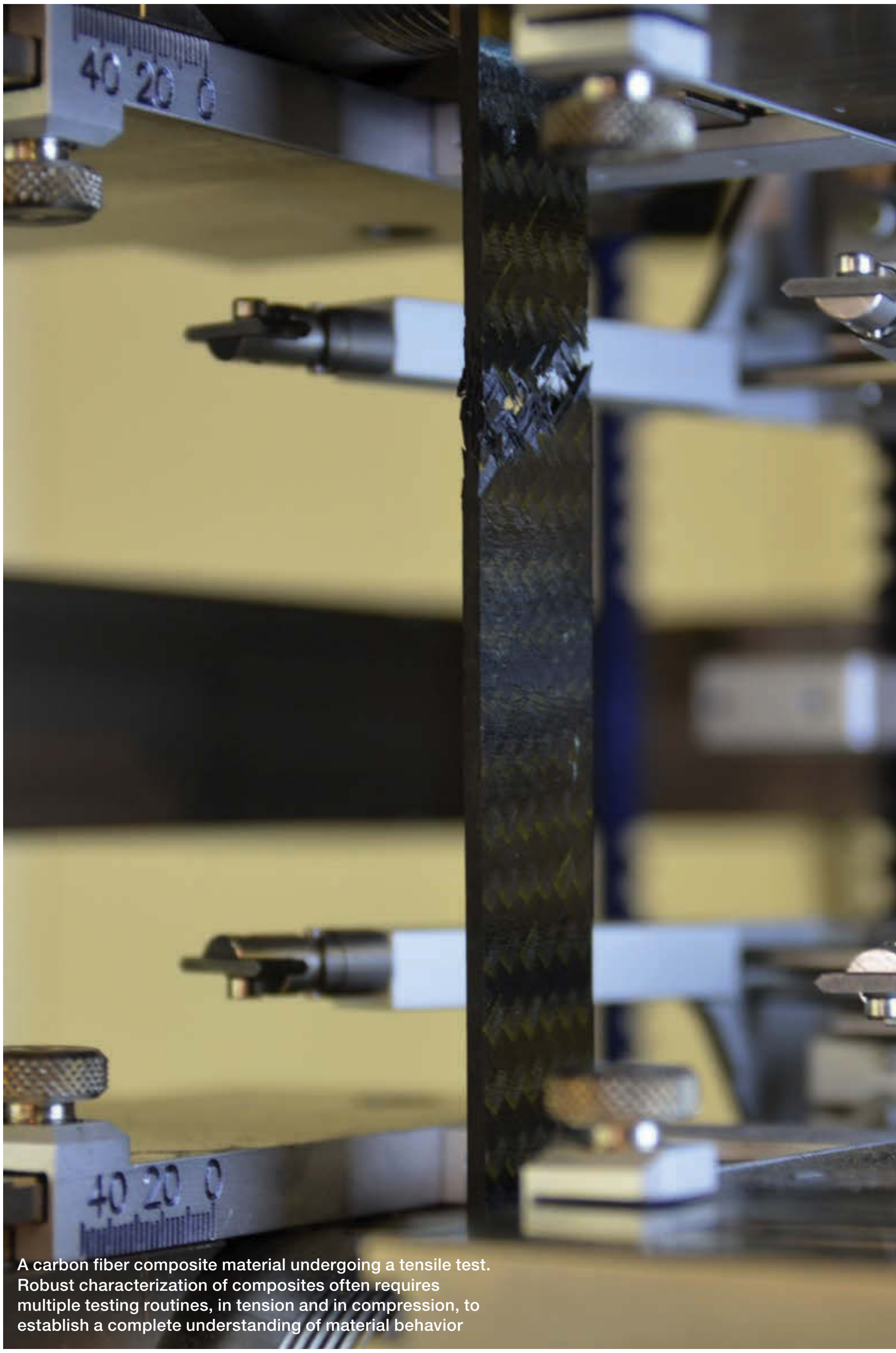
A key factor contributing to the advancement of novel composite materials is the growing ability to tailor materials to achieve specific properties. Robust characterization of those properties through physical testing is necessary to ensure composite materials are meeting specifications.

Composite materials are not isotropic. They exhibit different material properties and failure modes in different planes. At a minimum, the planes for any material properties in principal material axes have to be characterized. Fiber orientation in composites also makes measuring their properties disproportionately more complex than for other materials, such as metals and plastics.

"Fiber-reinforced composites provide high strength and stiffness in combination with low weight. They consist of thin fibers that are either directionally or randomly oriented, and therefore require different tests according to fiber orientation," Becker points out.

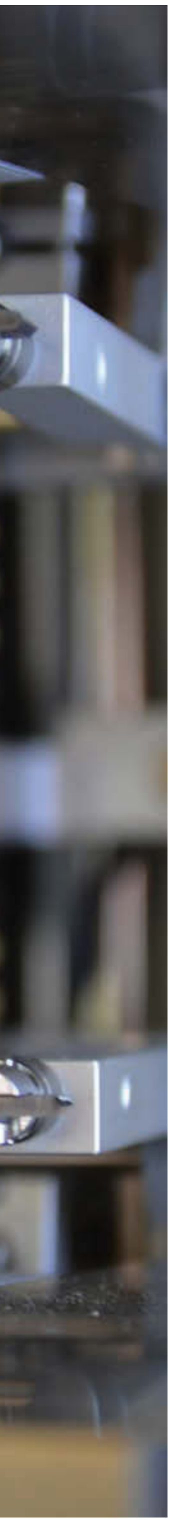
Interaction of failure modes, such as in-plane failure combined with delamination through the thickness of the component, creates additional complexities. As a result, typical uniaxial testing is not perceived to capture these important interactions. Test procedures must be designed to take such interactions into account.

The application of multiple test standards to support robust qualification of composite materials has become standard procedure among OEMs and their respective suppliers. There are currently more than 150



A carbon fiber composite material undergoing a tensile test. Robust characterization of composites often requires multiple testing routines, in tension and in compression, to establish a complete understanding of material behavior

> "BEST PRACTICES FOR RELIABLE TESTING OF COMPOSITES ARE SIMILAR TO THOSE USED FOR MANY OTHER MATERIALS INCLUDING THE NEED FOR TRAINED TESTING PERSONNEL"



standards, some more than 30 years old, that describe the physical testing of fiber-reinforced composites.

MATERIAL TRIALS

In addition to the international and national series of standards from ASTM, ISO, EN, and DIN, there are aerospace industry standards, developed by Airbus, Boeing, and NASA, as well as standards from associations that no longer exist, such as Suppliers of Advanced Composite Materials Association (SACMA).

Materials testing initiatives for fiber-reinforced composites must therefore take fiber orientation into account and apply different tests accordingly. These tests are described in international standards (ISO), in national and regional standards (ASTM, EN, DIN) and in companies' own standards (Airbus AITM, Boeing BSS). Proper calibration and maintenance of test equipment is required to meet industry standards such as A2LA or Nadcap, according to Walter Lee, regional aerospace manager for Zwick USA.

In the USA, test machines are usually calibrated to ASTM standards. Alignment is performed to ASTM E-1012. Proper testing alignment also requires good maintenance and proper housekeeping practices. "If grips are used, they must be kept clean and the wedges must be properly lubricated to avoid the possibility of misalignment with the specimen," Lee says.

Best practices for reliable testing of composites are similar to those used for many other materials including the need for trained testing personnel, thorough procedures and well-designed test equipment. "High-performance test equipment will give you reliable, accurate and repeatable data if thorough, standards-based procedures are consistently used by trained testing technicians and engineers," explains Lee.

As aerospace structural materials are subject to rigorous qualification procedures, the time horizon from conceptualization to commencement of

LEFT: Tensile testing samples

COMPOSITES PARTNER

In 2007 GMA-Werkstoffprüfung opened its CFRP test center in the north German town of Stade, in the heartland of the German composites manufacturing region.

The company is capable of supporting all major established standards (ASTM, ISO, Boeing, Airbus). As the properties of fiber composite materials are strongly dependent on fiber direction, fiber and matrix materials, and the fiber-matrix bond, a range of tests is required to establish a complete profile of material behavior.

GMA uses Zwick Allround-Line testing machines and a variety of Zwick test fixtures to perform more than 10 different tests (tensile, flexure, shear, and others) on composite materials. The tests are carried out up to a maximum force of 250kN, both at room temperature and in a temperature chamber (-70 to +250°C).

Significant factors influencing the properties of fiber-reinforced composites are the material comprising the fibers and the alignment of the fibers. Materials testing initiatives for fiber-reinforced composites must therefore take fiber orientation into account and apply different tests accordingly. In order to satisfy the varying requirements, companies and testing laboratories previously had to use a number of testing machine arrangements, some of which were very complex.

The new Allround-Line system from Zwick simplifies the process of managing the wide range of tests required for robust characterization of composites, as unique test fixtures enable numerous tests to be performed without changing the grips. This capability, in concert with dual test areas, enables test engineers to perform more than 20 different types of tests in compliance with over 100 standards using a single testing machine. The system for composites is available in 100 and 250kN versions.

Tests covered by the new solution range from determining interlaminar shear strength (ILSS), to V-notched shear tests to lap-shear tests. Also included are tests for fracture toughness and a static compression test to measure residual strength following targeted pre-damaging of a specimen (compression after impact).

Also possible is the combination of end and shear loading methods. The improved pressure distribution enables defined (and therefore valid) fracture values to be generated at higher compression strengths.

"A SUITE OF STANDARDS HAS EMERGED TO ADDRESS TESTING OF CARBON FIBER THAT HAS BEEN IMPREGNATED WITH RESIN, ALSO REFERRED TO AS PREPREG"

production easily runs 7 to 10 years. It is important to note that testing occurs at both the test specimen level and the component level. Test specimens are used to establish performance tolerances of various materials under consideration, while tests at the component level are often supportive of quality management initiatives as well as preparations for structural testing.

CARBON FIBER

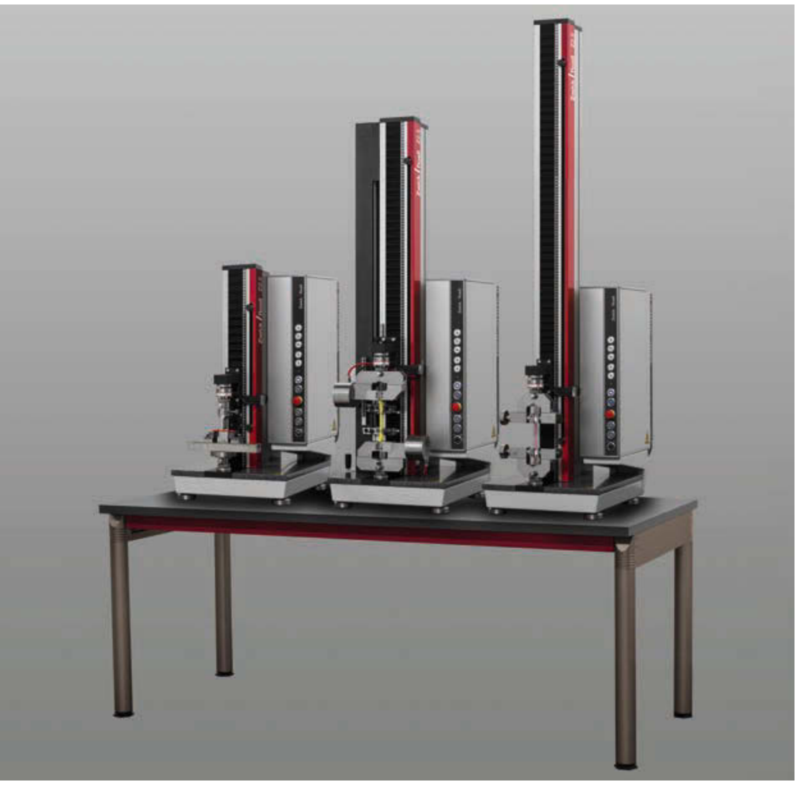
Carbon fiber, as a key element in fiber-reinforced composites, is subjected to tests that determine tensile properties as an input to materials specifications, qualification, database generation, and certification.

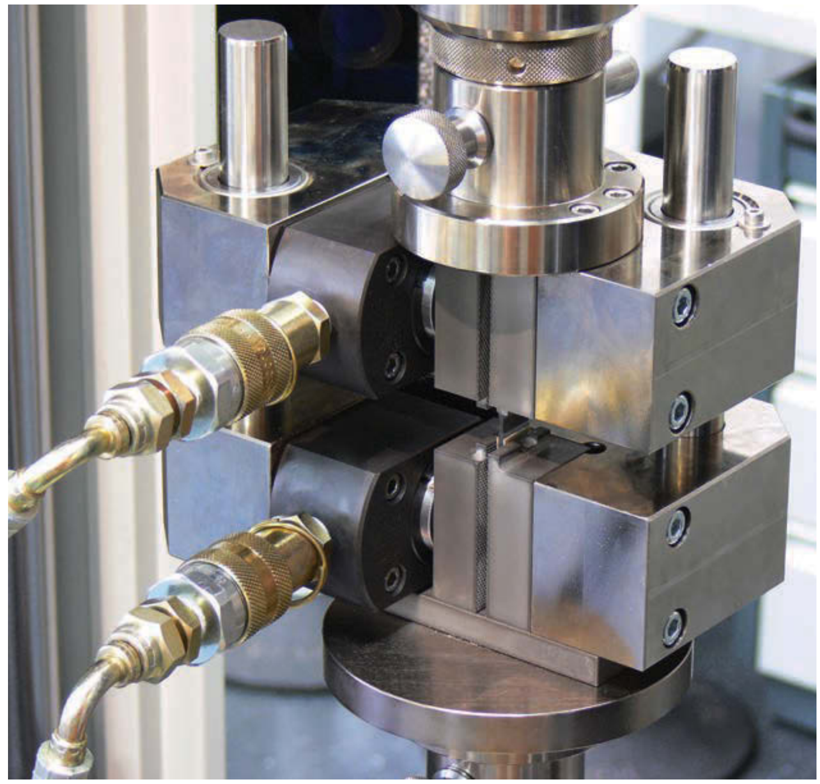
A suite of standards has emerged to address testing of carbon fiber that has been impregnated with resin, also referred to as prepreg. ASTM D4018-11, ISO 10618, and DIN 65382 describe the standard test methods for properties of continuous filament carbon and graphite fiber tows, and are used by major producers of carbon fiber such as Cytec Industries, SGL Carbon, and Hexcel. Major properties addressed by these testing standards are tensile strength, tensile modulus, and percent elongation.

A primary issue related to tensile tests on carbon fiber prepreg is the identification of a suitable clamping fixture. In many cases the specimen must be protected by tabs to avoid premature fiber breakage in the clamped area. Zwick lends support for selection of the appropriate grips and fixtures through the application engineering process and, if required, through the company's applications test laboratory in Ulm, Germany.

For carbon fiber tow tests up to 5kN, major manufacturers use single column zwicki-Line systems, which offer high levels of accuracy and a compact footprint (see image above right).

These systems represent tremendous value, as they may be used in concert with existing higher capacity systems. Manufacturers with high throughput requirements often dedicate zwicki-Line systems to performing tensile tests on carbon fiber





ABOVE: Single column zwicki-Line systems from Zwick deliver accuracy and reliability in uniaxial testing within a space-conserving footprint

RIGHT: The parallel-closing hydraulic composites compression fixture brings a high degree of rationalization to compression tests

LEFT: With requirements for testing at both the specimen and component levels, Safran Group has turned to Zwick for 50kN and specialized 600kN test machines

tows and focus higher capacity systems such as the Allround-Line suite of testing machines on compression or shear loading tests.

Testing of specimens at higher loads and in simulation of numerous failure modes is essential to the establishment of a complete properties profile for fiber-reinforced composites. Testing of specimens under various normal loading conditions such as tension and compression is critical, as is the evaluation of a specimen's response to shear loading.

SHEAR AND COMPRESSION

In addition to normal tension and compression loading condition tests, typical tests conducted on fiber-composite specimens include shear, end and end-loading compression, plain, open-hole and filled-hole tensile, as well as open-hole compression.

These tests characterize the three normal stresses in a nine-component stress tensor. The six shear stresses of this tensor can be found by specific test methods such as the ±45° in-plane shear test, the v-notch shear test, lap shear test or, for the materials qualification, the short beam shear test.

Compression testing enables measuring properties of the entire composite in addition to fiber strength. The challenge lies in inducing compression deformation up to material failure if possible, without buckling. This means avoiding bending in a flat, planar specimen.

End loading was developed from the compression test on plastics to ASTM D 695. During the compression process, the specimen is located between two support plates designed to prevent buckling. Boeing developed the method further to ensure that guide elements were positioned at right angles to the compression surface.

During a shear loading test, load is applied via tensioning clamps, enabling determination of compression modulus and compressive strength in a single test sequence. The method calls for monitoring flexure, which must not exceed a value of 5 or 10% (depending on the standard) in the range between 10 and 90% of total compression.

There are complexities present in compression testing. Fixtures used in compression tests can obstruct access to the specimen, complicating strain measurement. In addition, wedges must be kept quite clean and uniformly lubricated to ensure sufficient axial load transmission. The complexities involved in conducting these tests frequently lead to occurrences of excessive specimen flexure.

One solution to the problem is offered by the hydraulic composites compression fixture (HCCF) developed by Zwick. Using the HCCF, access to the clamped specimen remains excellent (figure above). The clamping procedure is greatly simplified and eliminates wedge movement during the test. Wedge movement has an undesirable tendency to amplify any bending moments arising. In addition, the HCCF may also be used to combine the loading test method described in ASTM D 6641.

Exotic alloys and composites will each be used in aerospace applications for the foreseeable future. The best material to specify for a particular application will be determined by the load requirements, material and production costs, and the elements to which it will be exposed – such as extremes in temperature or corrosive environments.

Alan Thomas is aerospace marketing manager at Zwick Testing Machines Ltd. based in the UK

BOB METZ

TAKE THE STRAIN

Dual-bridge strain gauge load cells have a major impact on the structural and fatigue test practices carried out on aircraft

BY BOB METZ

Full-scale structural and fatigue testing of aircraft is performed to accelerate the lifetime testing process on airframes by varying the load, pressures and temperatures that the aircraft will experience during operations. Testing of this nature is used for static and durability tests, damage tolerance verification of design, flight certification testing and performance testing of flight vehicles. This test method requires the use of dual-bridge strain gauge load cells mounted to hydraulic actuators.

Historically, multibridge load cells were used in the aerospace industry to provide a redundant output signal to combat reliability issues. The load cells are used for active force feed back to hydraulic servo controllers that drive the aircraft structure during tests in a 'closed loop'. The difference between the two bridge outputs can be monitored and, if they exceed preset load limits, the test is shut down to a neutral position in a controlled manner. The load cells are also used for measuring and recording the force level in a data-acquisition system.

FULL-SCALE AIRFRAME

Most structural and fatigue testing of aircraft occurs on a full-scale airframe, where the structure is cycled through taxi, pressurization, take-off, climb out, flight maneuvering, descent, final approach, landing and depressurization. This is repeated multiple times and, when run non-stop, can simulate thousands of airframe hours and tens of years of aircraft life on the structure. Fatigue testing of aircraft is not limited to the entire airframe, but includes subassembly (see figure on the right) and component testing such as landing gear shear pin and fatigue cycling, flight control actuators, landing gear door connecting rods, propulsion system components, fan blades, shafts, fasteners and 'iron bird' control simulation testing.

Load cells are also used for landing gear drop testing to simulate loading and performance of the landing gear. In this test, the landing gear is raised to a pre-determined drop height and

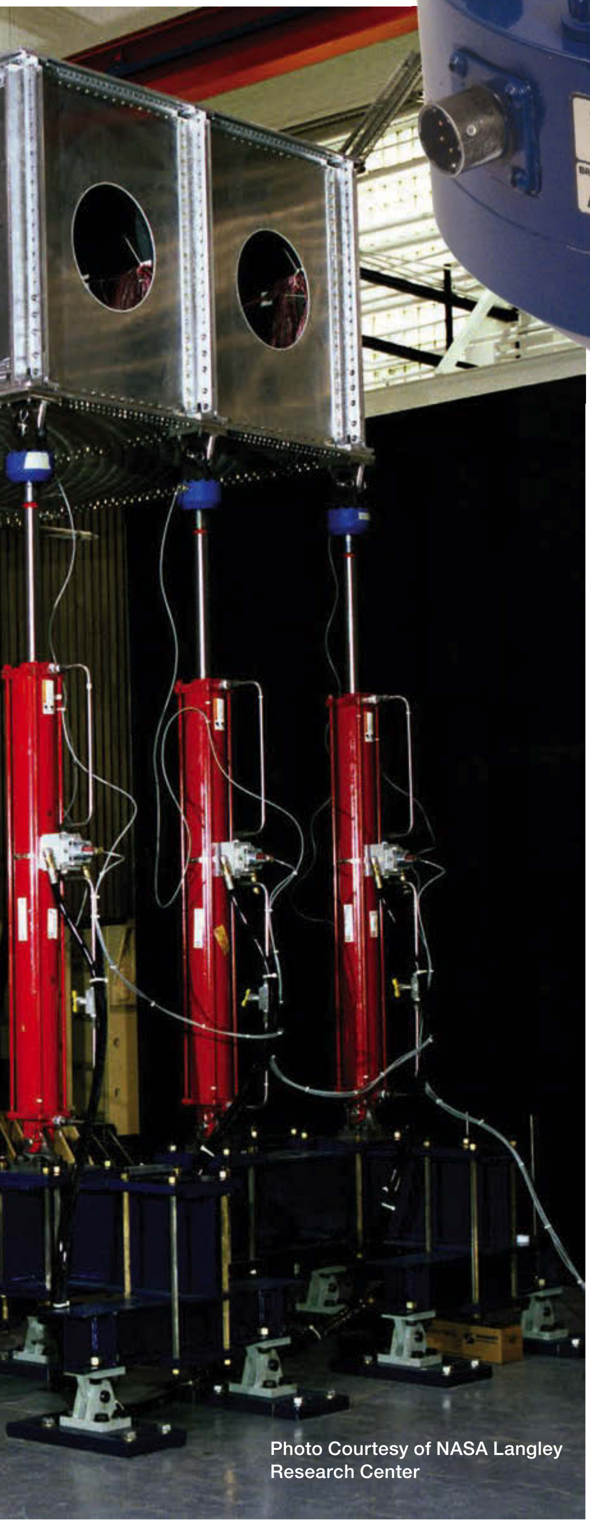


Photo Courtesy of NASA Langley Research Center

locked into position. Next, the wheel is rotated with a friction drum to a speed that simulates the forward motion experienced during touchdown. Finally, the landing gear is dropped at a controlled rate similar to an actual aircraft landing and data is captured with load cells integrated into the test system. Additional measurements are often required in the test, such as shock absorber pressure and acceleration shock measurements. Typically, triaxial piezoelectric accelerometers are mounted on the landing gear to obtain shock response measurements and pressure transducers which are used to measure the dynamic pressure response inside the shock-absorbing struts.

The 1400-00ADB load cell series from PCB Piezotronics (see figure above) includes a dual-output feature for structural and fatigue testing of aircraft.

The dual-bridge output provides sensor redundancy and the ability to provide the necessary load feedback to hydraulic actuator servo controllers. The dual-bridge load cells are manufactured using a shear-web design and take the form of a cantilever beam (see images on next page). In order to minimize structural deflection, the load cell structure has been designed with a cross-section optimized to the rated load to be carried. Strain gauges are placed on the sides of the beam at the neutral axis, where the bending stress is near zero. The state of stress on the beam side is one of pure shear, acting in the vertical and horizontal direction. This makes for a stronger fatigue-resistant design and has less error due to eccentric loading, creep, and off-axis or side loading. A moment compensation process is employed along with the required thermal compensation to reduce any remaining measurement errors to a minimum.

ABOVE: Dual-bridge load cell Note: PCB load cell is supplied with integral load base

LEFT: Example of a laboratory-based structural test

LOAD CELL TECHNOLOGY

Dual-bridge load cells are available with standard capacities ranging from 5,000 lb to 100,000 lb (25kN to 450kN), with many other ranges available. They are prepared for shipment with A2LA accredited calibration in accordance with ISO 17025 in both tension and compression directions. Another calibration element is the shunt calibration resistor, which can be overlooked when making a last-minute load cell purchase.

Shunt calibration simulates the mechanical input to a transducer by unbalancing the bridge with a fixed resistor placed across, or in parallel with, one leg of the load cell's Wheatstone bridge. It is a method of periodically checking the gain or span

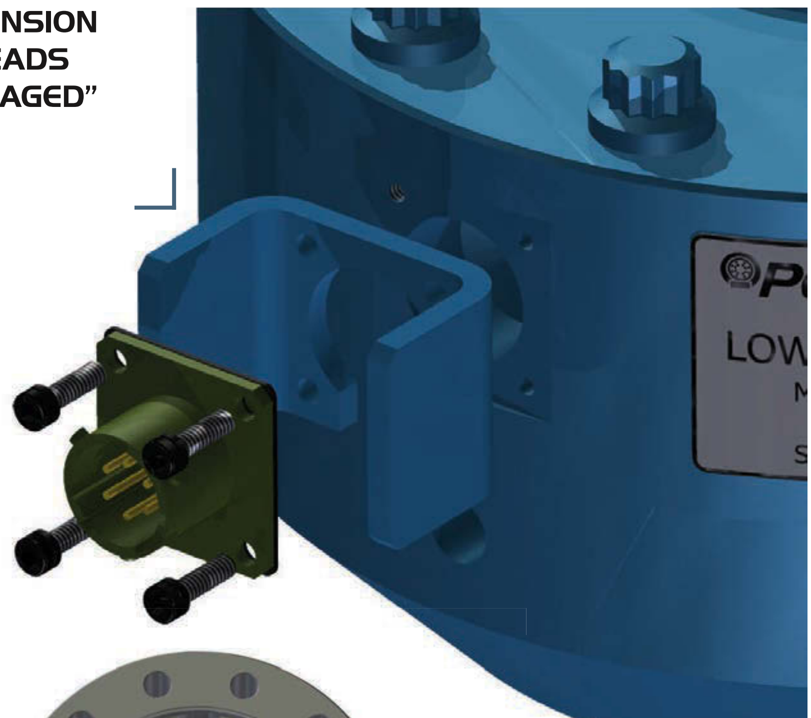
"THE DUAL-BRIDGE OUTPUT PROVIDES SENSOR REDUNDANCY AND THE ABILITY TO PROVIDE THE NECESSARY LOAD FEEDBACK"

> "ONCE THE PRELOAD TENSION IS RELEASED, THE THREADS WILL BE SECURELY ENGAGED"

of a signal conditioner, which is used in conjunction with a strain-gauge based transducer, without exposing the transducer to known, traceable, physical input values. If required, adjustments can then be made to the signal conditioner to ensure accurate measurement results.

Recognizing that a majority of load cell damage occurs at the electrical connection, protecting the electrical connector on the side of the load cell from damage during installation is essential. Connector protectors are simple and effective devices that can save the load cell from the most common damage source – a wrench that slips during installation on the hydraulic actuator. The connector protection (see figure top right) installs using the same electrical connector hardware and extends out past the connector.

The final thing to consider is mounting the load cell to the hydraulic actuator. As the load cells will be cycled in compression and tension during the entire airframe or component test, pre-tensioning studs should be used to eliminate the backlash associated with loose joints. The studs typically thread into the load cell and lock the threads in position when connected to the end of the hydraulic actuator. Installation of the load cell starts with tension preloading the load cell to 120-150% of full-scale capacity and lightly tightening a jam nut to lock in the preload on both the load cell and base tension rods. Once the preload tension is released, the threads will be securely engaged. Failure to preload the attachment rods/fixtures can result in damage to the threads on the load cell and base during cyclic load tests.



TOP RIGHT: Connector protector

ABOVE: PCB shear web load cell design

FATIGUE-RATED LOAD CELLS

Fatigue-rated load cells are specifically designed for component durability and fatigue test machines where highly cyclical loading is present. These rugged load cells are extremely resistant to extraneous bending and side-loading forces. They are used for material testing, component lifetime testing and structural testing.

All fatigue-rated load cells are guaranteed against fatigue failure for 100 million fully reversed cycles. Load cells with dual outputs can be used for closed-loop control of airframes and fatigue testing of subassemblies and components. Things to consider when installing such load cells are pre-tension studs for proper load cell performance, connector protection to avoid costly downtime, and shunt calibration resistors for periodic online calibration checks. Remembering these items is essential for minimizing errors and lost test time. ■

Bob Metz is the senior product manager for PCB Piezotronics, based in New York, USA

BRYAN MANNING

REFILLING THE GAP

Can optimized Gapman reduce cost in the aircraft CFRP shimming process?

BY ROBERT FOSTER AND BRYAN MANNING

In the March 2011 issue of *Aerospace Testing International,* an article entitled *Filling the Gap* introduced the Capacitec Gapman Gen3 technology. It covered the Gapman Gen3 portable electronic gap measurement system for aircraft applications, which has replaced the feeler gauge method at all major commercial aircraft manufacturers worldwide.

To date, the Gapman Gen3 has achieved a gap measurement/shimming operation schedule five times faster than the feeler gauges. Additional benefits are reduced overall cost, enhanced structural integrity of aircraft components, and a gap measurement database to assist in process improvement. As an added benefit, it reduces lead times while measuring more gaps without the risk of manual data transfer.

Continuous customer feedback has driven development of additional features that further increase ROI and reduce gap measurement and shimming times. The new Gapman Set to Standard calibration software processes enable the Gapman Gen3 to be more easily recalibrated for a wide variety of target material combinations, such as CFRP (rough and smooth surfaces) and metal (painted or non-painted surfaces).

THE BACKGROUND

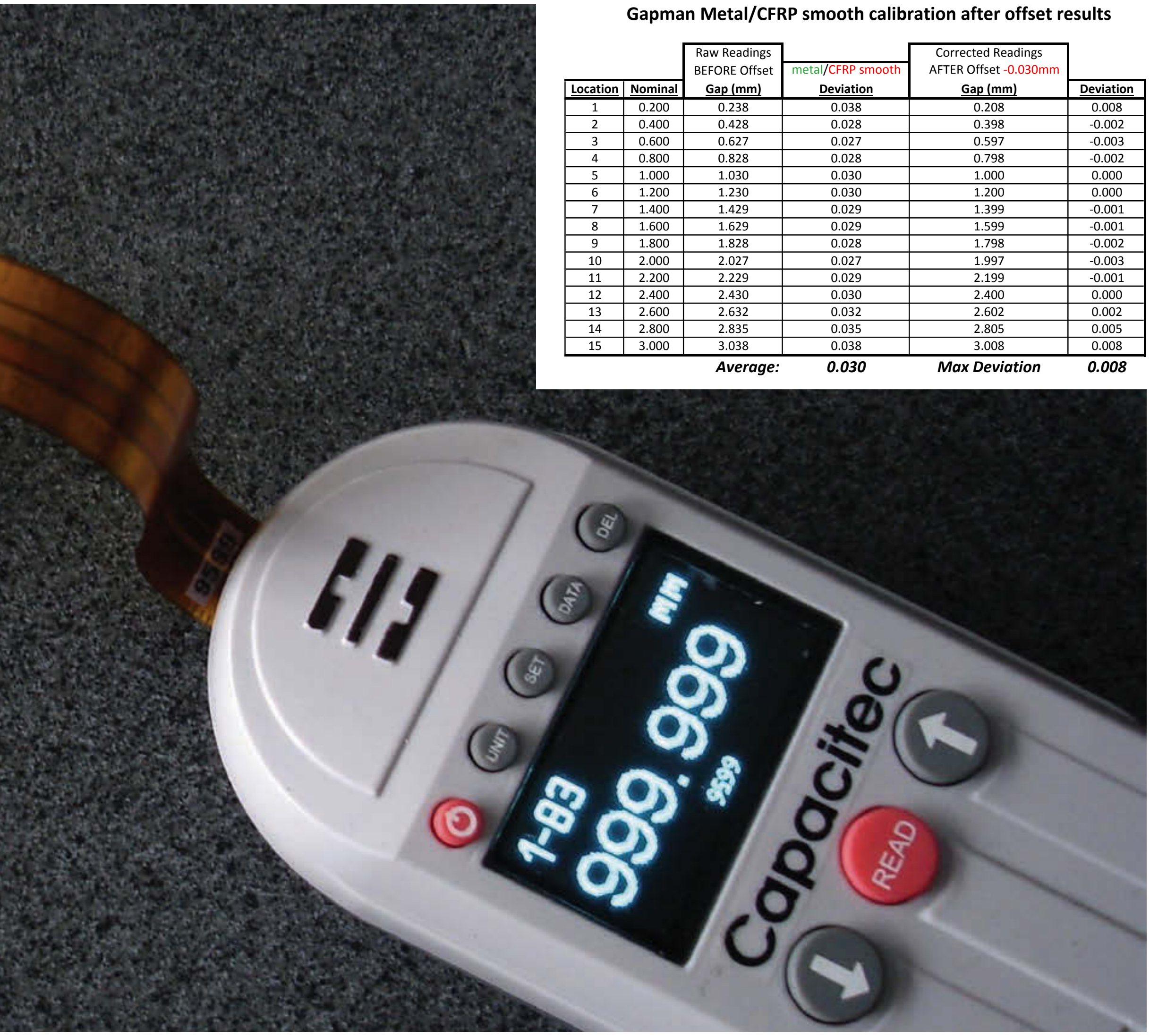
The Gapman system functions using non-contact capacitive gap measurement. The physics behind this sensing technology is that there are three factors that can influence the reading. The first is the gap that the users are trying to measure. Second is the sensor spot size, which is typically constant. The third is the dielectric constant between the sensor and the conductive target surface. This is a combination of the air gap (characteristically constant) and the dielectric surface material on the conductive target, which can vary due to the plastic resins, glass laminate surfaces or paint between the conductive target and the sensor face. These coatings cause slight variability due to the thickness and dielectric constant values. It is worth concentrating on the dielectric coating materials that cause this variation and affect the accuracy of the measurement. The focus is on the use of CFRP painted, smooth or rough surface resins as compared with painted or clear metal. Fortunately these coatings are uniform through the manufactured structures being measured.

To minimize or eliminate gap measurement errors, aircraft users must have a rigorous policy of matching calibrations to the various target combinations. These dedicated calibrations take into account the particular influences of each pair of gap targets. This matched combination provides a traceable solution for metrology calibration labs because they know that the data is certified to lab standards. The downside to this approach is the added time to support these multiple Gapman calibrations. An additional concern is the ability of calibration labs to build well-controlled flat painted or CFRP targets. They are very costly to produce and it is difficult to control the flatness to the typical 25-50μm tolerances using readily available matched CFRP material as standards for calibration. These targets are typically cut from available stock and can have excessive radii. The preferred metrology sample flatness goal is 1μm for calibration target standards.

> "TO DATE THE GAPMAN GEN3 HAS ACHIEVED A GAP MEASUREMENT/SHIMMING OPERATION SCHEDULE FIVE TIMES FASTER THAN THE FEELER GAUGES"

Gapman Metal/CFRP smooth calibration after offset results

Location	Nominal	Raw Readings BEFORE Offset Gap (mm)	metal/CFRP smooth Deviation	Corrected Readings AFTER Offset -0.030mm Gap (mm)	Deviation
1	0.200	0.238	0.038	0.208	0.008
2	0.400	0.428	0.028	0.398	-0.002
3	0.600	0.627	0.027	0.597	-0.003
4	0.800	0.828	0.028	0.798	-0.002
5	1.000	1.030	0.030	1.000	0.000
6	1.200	1.230	0.030	1.200	0.000
7	1.400	1.429	0.029	1.399	-0.001
8	1.600	1.629	0.029	1.599	-0.001
9	1.800	1.828	0.028	1.798	-0.002
10	2.000	2.027	0.027	1.997	-0.003
11	2.200	2.229	0.029	2.199	-0.001
12	2.400	2.430	0.030	2.400	0.000
13	2.600	2.632	0.032	2.602	0.002
14	2.800	2.835	0.035	2.805	0.005
15	3.000	3.038	0.038	3.008	0.008
		Average:	***0.030***	***Max Deviation***	***0.008***



ABOVE: Gapman Gen 3 electronic feeler gauge with integral flexible sensor wand

INSET FAR LEFT: Metal-to-metal calibration fixture

INSET LEFT: Metal-to-CFRP gap measurement

FIGURE 1 (ABOVE RIGHT): Test results of the new 'set to standard'

METAL-TO-METAL

A solution to this problem is available from Capacitec, combining the Gapman Set to Standard software with a simple baseline metal-to-metal calibration. When used in conjunction with certified metal calibration blocks as targets, well-controlled, highly repeatable certified gap measurement can be achieved.

Capacitec performed a study comparing the metal-to-metal calibrations with a variety of different target materials, focusing on CFRP combinations. The results showed that 80% of the deviations from the readings are simple offset value adjustments.

The table in Figure 1 shows how the company has successfully taken advantage of the Set to Standard process using a series of custom offset adjustments correlating to the target material and finish. This figure specifically shows the differences between the baseline metal-to-metal calibration and the subsequent nominal gap readings between metal-to-CFRP smooth combined targets.

A unique best-fit offset, derived from the standard deviation for each material type, can be applied if the user requires tight linearity (25µm or better). If the linearity is not as stringent (50µm or better), one single average of all best-fit offset adjustments across all material combinations may work. The data shows that by applying this best-fit offset (31µm/0.030mm average deviation) to any of the data will result in greatly improved linearity of 8µm (0.008mm), as shown in the right-hand side of the table. CFRP-to-CFRP rough glass targets, tested but not shown here, represented the largest deviations (about 100µm) in output due to the unique surface dielectric coatings of the materials used (and not being conductive metal). The compromise of making just an offset adjustment leaves a slightly higher residual non-linearity due to the slope variation of the material combination. Engineers can investigate whether this offset-adjusted variation meets the requirements of their particular assembly. This new approach to certified gap measurements creates added efficiency of the complete shimming process.

Furthermore, a new Gapman Gen3 wireless option has a higher level command set of communication protocols to enable an external software program to adjust the Set to Standard offset of any material combination (CFRP-to-metal, etc) being measured at any location. Customer-designed database software could apply this offset value by communicating via the wireless option. Calibration check standards can also be used in production to validate proper operation without the additional cost burden of special composite standards for each gap target combination.

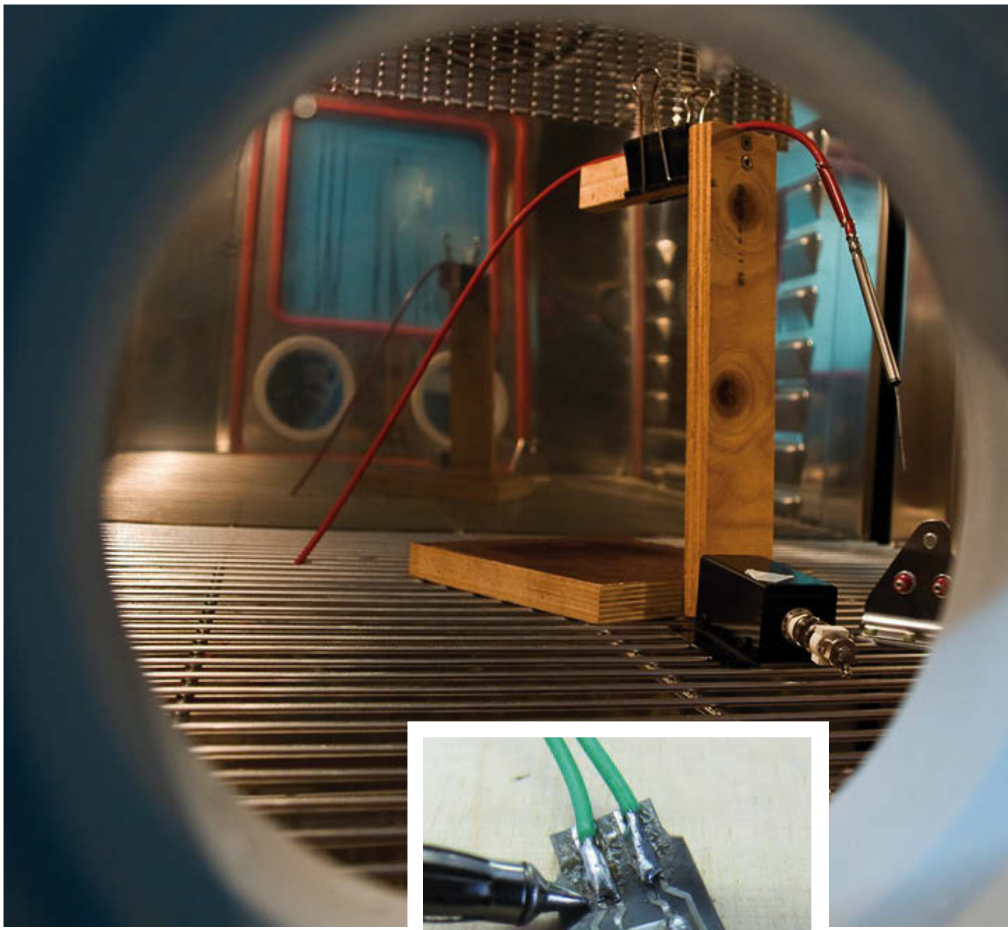
The Gapman Set to Standard calibration process can have a major impact on improving gap measurement and shimming process throughput. It also improves the quality of calibration recertification as it is based on known metal/metal standards while reducing the time it takes to certify under normal metrology cycles. ▮

Robert Foster is president of Capacitec and Bryan Manning is commercial director of Capacitec Europe; www.capacitec.com

ATTENTION TO DETAIL

The founder of a German company at the heart of aviation component testing says it is the small detail that counts

BY DAUTEC STAFF

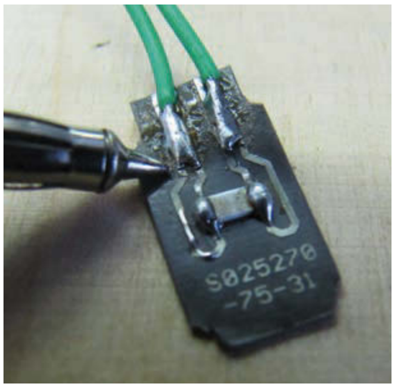


It was a little flicker that made a decisive difference. Hans-Jörg Dau briefly left the room at the end of a vibration test on a Logolight carried out in an external laboratory. When he came back, he asked the young employee who performed the test if anything had happened. "No, everything is okay," was the reply. And then, as if it was totally unimportant: "It did flicker once very briefly just now."

The component would still have passed the test. It was still fully functional, that is, it was lit. Nevertheless, Dau had the test repeated. The error occurred again. In addition, hairline cracks appeared. Although the component would still have officially passed the test, "The airline would certainly have complained if the Logolight had started to flash like a disco ball at night on the taxiway," notes Dau. Dau is now the founder and managing director of Dautec, which has been offering services related to aviation component testing for 10 years.

Over that time, the focus of the company has broadened. Initially, the emphasis was on planning, coordinating and verifying tests to ensure that the most essential features in new or modified components were tested. Today, Dautec runs a laboratory where test series can be carried out for external customers at the Lufthansa Technik base. In addition, the company works with various regional and national test laboratories. It advises certified manufacturing and development businesses and supports them in the planning, structuring and implementation of tests – ones necessary for aviation certification and those which ensure long service life, fewer signs of wear and greater failure security during ongoing flight operations. "When required, we make an offer for the complete test process, including logistics, laboratory costs, witnessing, evaluation and documentation," explains Dau.

He continues, "We increasingly realize how important it is to keep the entire lifecycle of the component and its integration in the overall airplane system in view when configuring such tests." This is the only way to ensure that tests that are specifically relevant for certification or that may provide additional useful knowledge about the use of the component during flight operations are actually performed.



The earlier this test configuration is included in the development process, the smoother the qualification and certification process becomes. This is why increasing numbers of customers include the company directly in the pre-development phase. Of course, this applies even more to everything that is 'flight critical'. Reworking due to failed qualification tests can lead to massive costs and loss of valuable time.

Dau knows the entire process based on his own experience. At the start of his career, he was a development and testing engineer at a large supplier. He

FAR LEFT: Temperature and humidity testing

CENTER LEFT: HASS and HALT testing, temperature change rate up to 70K per minute

LEFT: EMV test at Dautec

LEFT: Broken temperature pad after 40 minutes x-axis vibration

BOTTOM LEFT: Skills will be increased by regular employee training

was also a pilot and even operated his own regionally based airline for several years under the name 'dauair'. As an investigator for the BFU (German Federal Bureau of Aircraft Accidents Investigation), he evaluated accidents and knows only too well the horrendous consequences of technical and human mistakes.

All this experience flows into the work of the company: "Everyone who starts with us goes through a comprehensive training program," reports Dau. In this way, every member of the 10-member team can be deployed in various areas in addition to their existing specialization. Nearly all of Dau's employees have completed aviation-based studies and further qualifications, such as pilot licenses.

It is frequently the case that, for example, interior components wear out or – in the case of in-flight entertainment – stop functioning more rapidly than would have been expected from the test results. According to Dau, this requires a sort of "Stiftung Warentest" – a company that can independently test these components to verify the validity and soundness of the implemented test series. Even though an aircraft on ground (AOG) event may not necessarily be the consequence of device failure in this case, such defects are annoying for airlines because they reduce the trust that passengers have in their quality consciousness.

"The manufacturers in this sector are under enormous time and cost pressure," says Dau. "At the same time, some test specifications are issued in too much of a hurry and are then neither realistic nor even implementable. Subsequent corrections once again cost unnecessary time."

It is also sensible for the company to be included at the beginning of the process, to optimally plan and design the test configuration right from the start. The tests at the end of product development are stressful not only for the components, but for all participants involved in the process. Dau explains: "We want to remove this stress as far as is possible from our customers." The earlier his company is involved in the development chain, the easier this is. Optimally, so-called pre-testing should be implemented after the design and construction phase and before the qualification tests necessary for certification. This procedure also means greater planning and cost security for customers. Quite frequently, several years may pass between the comprehensive offer and the actually implemented test phase.

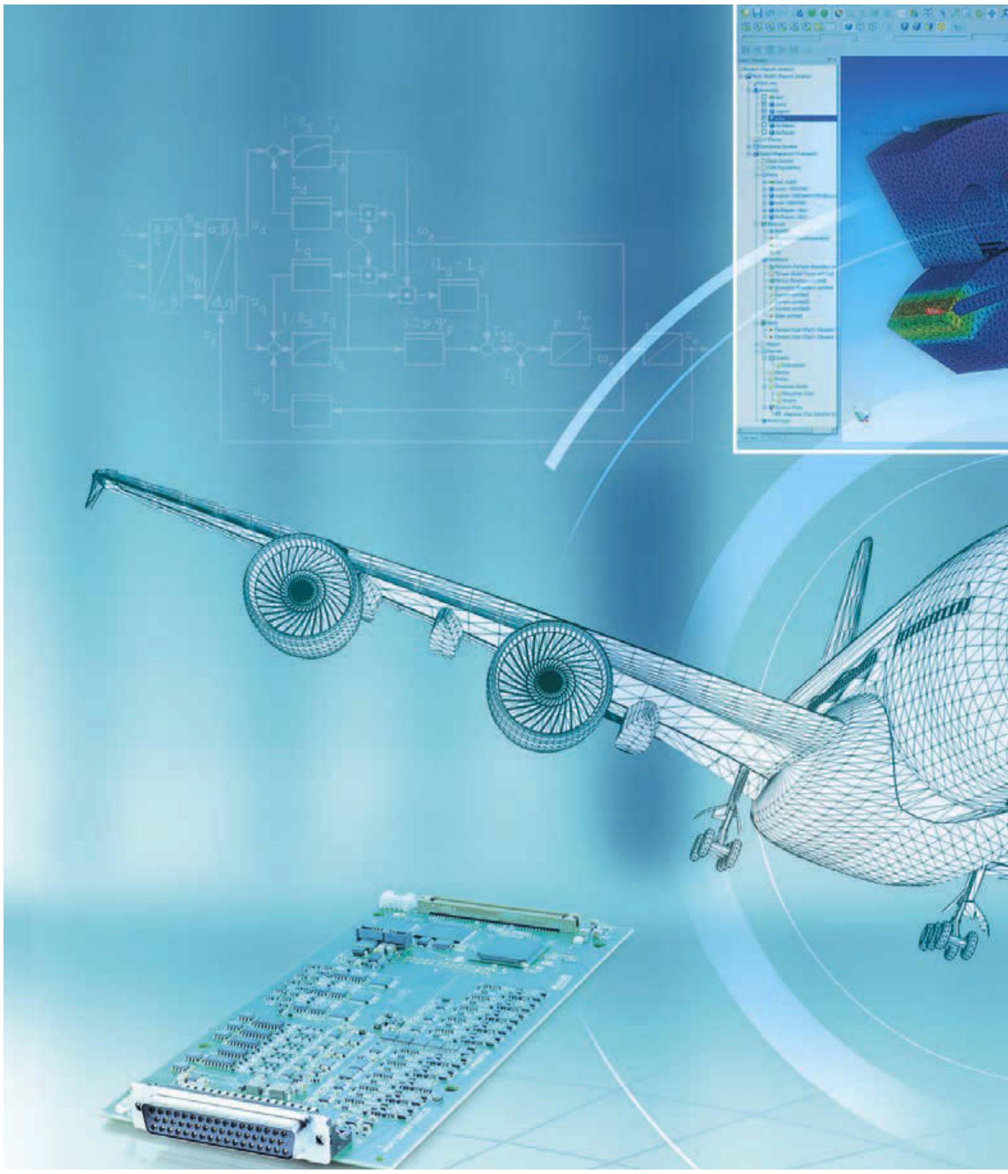
As proven aviation experts, the Hamburg-based team can ensure, alongside other laboratories on the Lufthansa Technik base, that the smallest of irregularities are not overlooked in the testing and that all relevant facts and parameters are taken into account. "We ensure that an aviation expert is present during every test; a person who understands and takes into account not only the test but also the airplane system," promises Dau. Only this can ensure that data is correctly interpreted – even a small flicker of a Logolight just before the end of a test.

"WE ENSURE THAT AN AVIATION EXPERT IS PRESENT DURING EVERY TEST; A PERSON WHO UNDERSTANDS AND TAKES INTO ACCOUNT NOT ONLY THE TEST BUT ALSO THE AIRPLANE SYSTEM"

SIMULATION OF ELECTRIC MOTORS

There is a drive to replace traditional hydraulic heavy systems with electrical ones, leading to real-time hardware-in-the-loop technology for the More Electric Aircraft (MEA) movement

BY DR ANDREAS HIMMLER



More Electric Aircraft (MEA) is a movement that promotes the replacement of traditional hydraulic fluids and compressed air to drive non-propulsive aircraft systems. Electrical systems are often favorable due to a notable reduction in weight and therefore fuel consumption. They also often bring benefits with regard to performance, integration and maintenance.

However, MEA is a challenge to the design, development and testing of electric actuator technology. Two fundamental components in this are the electric motor and associated electronic controllers. Here we focus on the hardware-in-the-loop (HIL) technology required for testing these components.

HIL TESTING

After the functions of the electronic control units (ECUs) associated with an electric motor have been developed and implemented on the production ECU, they have to be tested thoroughly. With HIL simulation, it is easy to cover all the different motor varieties and their ECUs.

There is a fundamental difference between HIL testing of controls for electric motors and controls for other actuators: the ECUs controlling the electric motors provide the actuation power directly. This is unlike other applications, where thermodynamic or hydraulic power is controlled by means of low auxiliary power coming from the ECU.

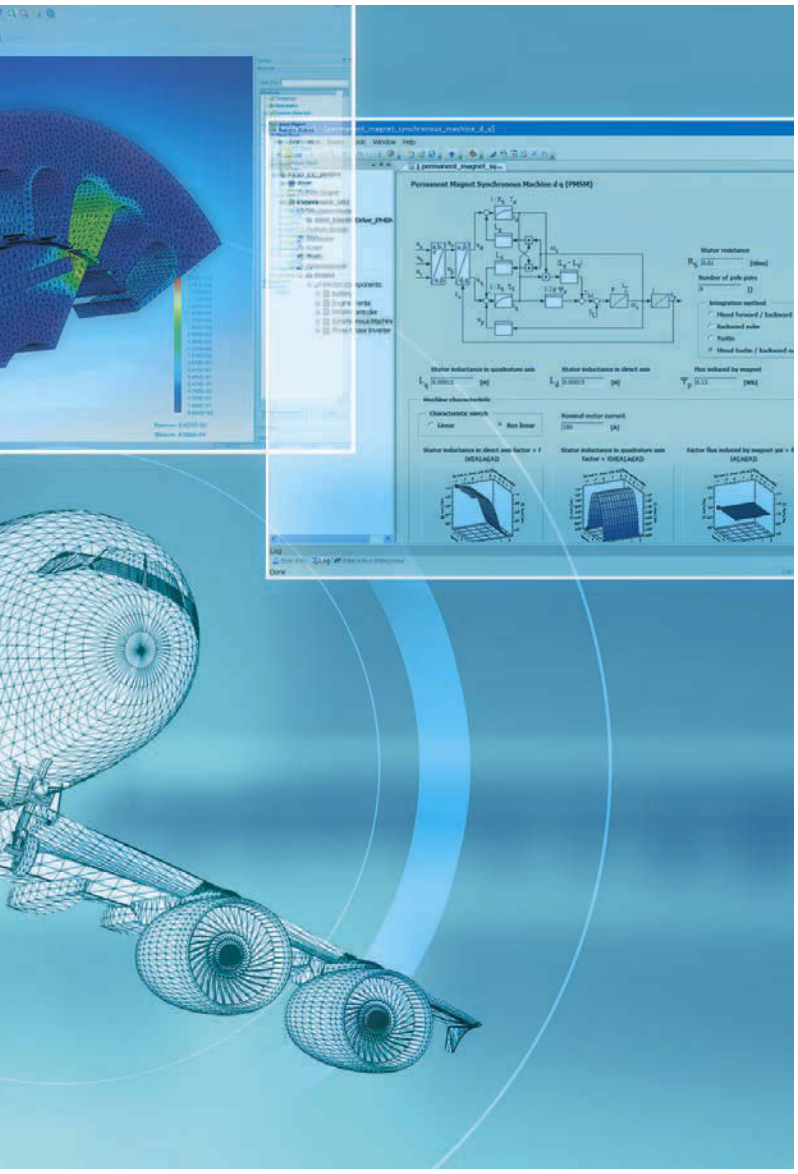
In addition, electric motors have become more and more powerful in a wide range of applications. Therefore, special solutions are needed for interfacing the ECU with regard to high power levels and high dynamics, and special I/O is required, for example for encoders and resolvers.

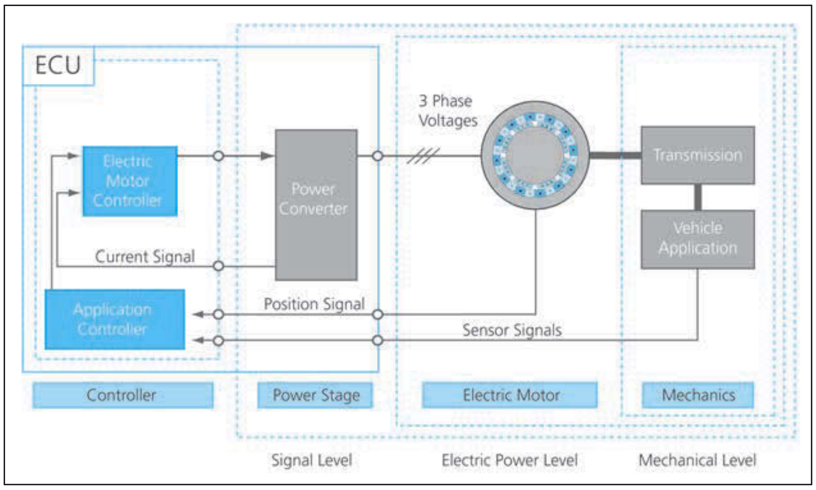
Control units for electric motors are often incorporated into complex and distributed vehicle functions, so it is essential to test their interaction with other ECUs.

HIL INTERFACES

When the control unit is interfaced on signal level, the power electronics, the electric motor and the mechanical environment have to be simulated. This gives a very scalable simulation environment, as parameters can be set flexibly regardless of power level. A prerequisite for this testing is full access to the motor model, and there must also be access to the inside of the ECU.

If the HIL tests for an electric drive system have to include the power stages, testing has to be performed at electrical power level. One way is to operate a real drive motor on a test bench. Another is to simulate the electric motor at the electrical power level. This involves simulating the electrical behavior of a real motor by mapping the real terminal voltages and currents and feeding them to the ECU. Compared with a mechanical drive test bench, a purely electrical test bench of this kind is easier and safer to operate. Tests can be run at a very early stage,





ABOVE: **Interfaces for HIL tests of electric drives**

even if the real drive motor is not yet available. Moreover, it is also possible to simulate different motor types. Unlike mechanical test benches, these simulators have no restrictions on dynamic processes.

CONVENTIONAL HIL SIMULATION

In many application cases with electric drives, the controller simply measures the motor current and calculates the control algorithms once or twice per switching period in synchronization with the pulsewidth modulation (PWM) frequency. There is a long-proven approach for the real-time simulation of this kind of low-rate synchronous sampling. It requires that the calculation of the motor model and the synchronization mechanism are executed synchronously to the PWM period, in order to avoid subharmonic frequencies. Mean value motor models (plant models) are calculated on the real-time processor of the HIL system. During this process, the output signal can often be updated only once per PWM cycle. The particularly time-critical I/O calculations are executed on a field-programmable gate array (FPGA), thereby reducing the load on the processor.

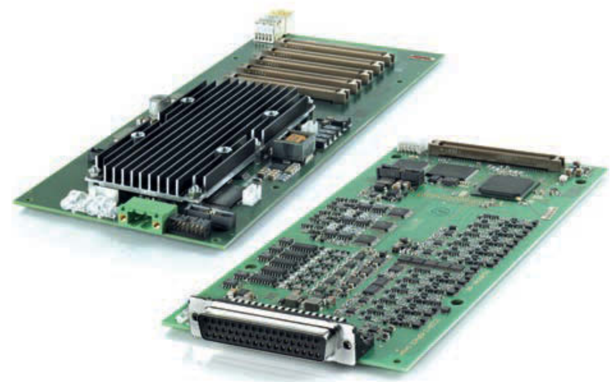
In a typical use case, simulation models such as the ASM Electric Components models from dSPACE running on SCALEXIO HIL simulator technology (see overleaf, top left) are used for simulating the electric components. The gate driver signals (typically PWM signals) coming from a controller are measured by the user-programmable FPGA I/O base board and a plugged-on I/O module, and calculated motor current signals are sent back to the controller by means of analog voltage signals. In addition, the necessary position sensor signals for the ECU are provided.

"THE DEVELOPMENT OF CONTROLLERS FOR DYNAMIC, HIGH-PRECISION ELECTRIC VEHICLE ECUs IS SOMETIMES BEYOND THE SCOPE OF CONVENTIONAL HIL SIMULATION OF ELECTRIC DRIVES"

ADVANCED HIL SIMULATION

The development of controllers for dynamic, high-precision electric vehicle ECUs is sometimes beyond the scope of conventional HIL simulation of electric drives.

An advanced real-time simulation requires the signals to be calculated and output much more frequently than



TOP LEFT: **Example of a HIL simulator based on SCALEXIO technology**

ABOVE: **Electronic load module for voltages up to 800V**

LEFT: **User-programmable FPGA I/O module for use with SCALEXIO HIL technology**

once per PWM cycle. This can be achieved by running not only the I/O model on the FPGA, but also the entire plant model, since FPGAs achieve very high sampling rates. Low harmonics can be ignored with this approach, even without synchronization. In comparison to processor-based models, the measurable latency between the hardware input and hardware output is typically reduced from 25-30µs, to about 1µs. The simulated current values are output every 100ns. Together, all of these factors lead to a significantly more precise and more stable simulation.

Such a high-resolution simulation makes it possible to simulate the PWM-induced current ripple in inductances, improve the precision of the simulation of high frequencies, and represent the closed control loops with a simulator exactly and stably. In addition, using FPGAs simplifies the real-time representation of the non-linear effects of power electronic components.

For advanced real-time simulation of an electrical system, dSPACE provides the ASM Electric Components Library for processor-based simulation and the XSG Electric Components Library (closed-loop simulation components) for FPGA-based e-motor simulation both on signal and on power level. They run on a dSPACE FPGA board such as the DS2655 FPGA Base Module shown in the figure on the right. Applications can range from electric drives and inverters for closed-loop simulation with an electric drive controller, to a complete electrical system.

The XSG electric component library is also supplemented by enhanced I/O functions on the DS2655 FPGA Base Module and its I/O modules, for example for timing analysis and capturing digital input sources.

ELECTRONIC LOAD MODULES

The HIL emulation of electrical machines, such as motors or generators, requires electronic load modules. They need to work as both a current sink and a current source to provide bidirectional current flow, that is, generating or consuming real current on ECU motor outputs. In addition, they need to be optimized for high-speed operation.

The concept of an electronic load emulator can be used for simulating all types of motors. The physical properties of each motor, such as motor inductivity, torque generation and power consumption, are represented very realistically.

For variable inductivities (such as in an interior permanent magnet motor, or with saturation effects), mean values have to be used in the load emulator due to the constant substitute inductivities. Nevertheless, correct representation of the torque and the power is possible.

There is a range of different electronic load modules, each optimized for a different voltage range. The figure above shows a load module for up to 800V. Smaller modules exist for maximum voltages of 30V and 60V. ∎

Andreas Himmler is product manager, hardware-in-the-loop Testing Systems, dSPACE, based in Germany

MARTIN GRATTON

GOING GREEN

A new system has been developed to recycle energy from engine tests and convert it into electrical power

BY MARTIN GRATTON

From the beginning of the modern aviation era, engine test facilities (ETFs) have been burning fuel and all that energy has been lost.

What would happen if we could harness the energy of the high-velocity air behind a gas turbine engine operating inside a test cell? At Canadian-based MDS, the question has been asked repeatedly over many years. Clients see the vast amount of fuel being burned and wonder if there is any way to recover that energy. In response, MDS has created a viable energy recovery system that will revolutionize the way the industry uses engine test cells in the future. To understand the approach, one must be familiar with the history and current state of test cell design and the pressures our clients face in terms of 'going green'.

CURRENT SYSTEMS

While gas turbine ETFs have become more sophisticated and capable of testing larger and larger engines, there have been very few breakthroughs or revolutionary changes to their design in the past several decades. Turbofan engine test facilities all operate along the same principle: the engine exhaust flows into an ejector tube that entrains critically important secondary air, i.e. test cell bypass flow that goes around the engine, not through it, and guarantees smooth flow into the engine. All that air then flows out through the exhaust components and into the atmosphere.

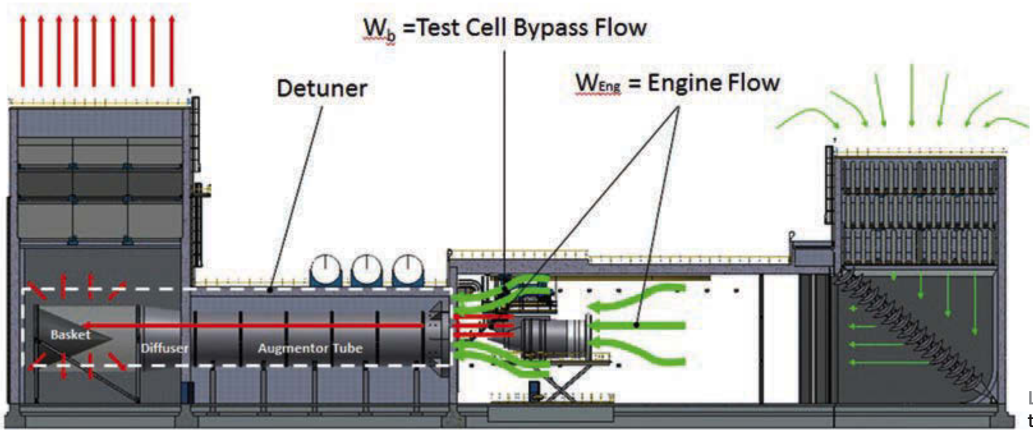
That flow, by virtue of its mass and velocity, carries with it a tremendous amount of kinetic energy that is forever lost.

REGULATORY PRESSURE

Many clients (engine OEMs) and maintenance, repair and overhaul (MRO) organizations are coming under increasing ethical and regulatory pressures to reduce their energy consumption and carbon footprint in an effort to reduce overall production of greenhouse gases.

Attempts to do this by turning down thermostats and replacing

Artist's rendering of the Kinetic Energy Recovery system



LEFT: Conventional test cell aerodynamics

incandescent light bulbs with compact fluorescents, while certainly worthwhile, have ignored the elephant in the room: What about that huge gas turbine engine out back consuming vast quantities of BTUs and producing little in return? What if we could do something useful with all that wasted energy?

"THE KER IS A TURBINE PLACED BEHIND THE ENGINE THAT CONVERTS THE KINETIC ENERGY IN THE AIRFLOW INTO USEFUL MECHANICAL ENERGY, WHICH IS USED TO DRIVE A GENERATOR"

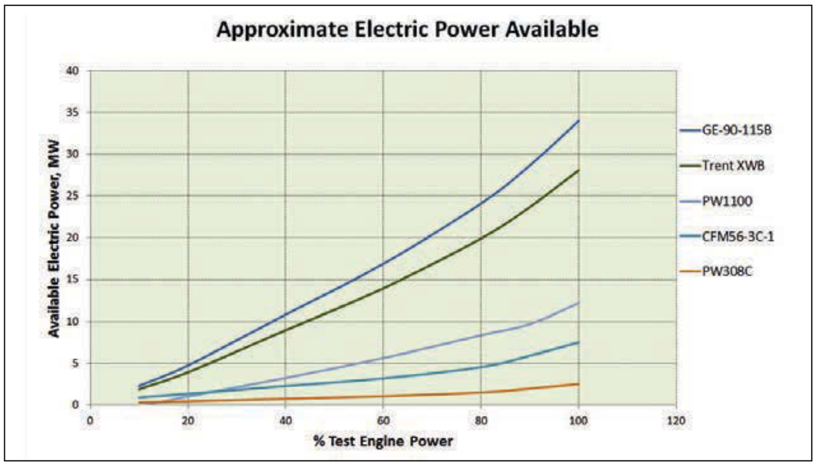
A SOLUTION

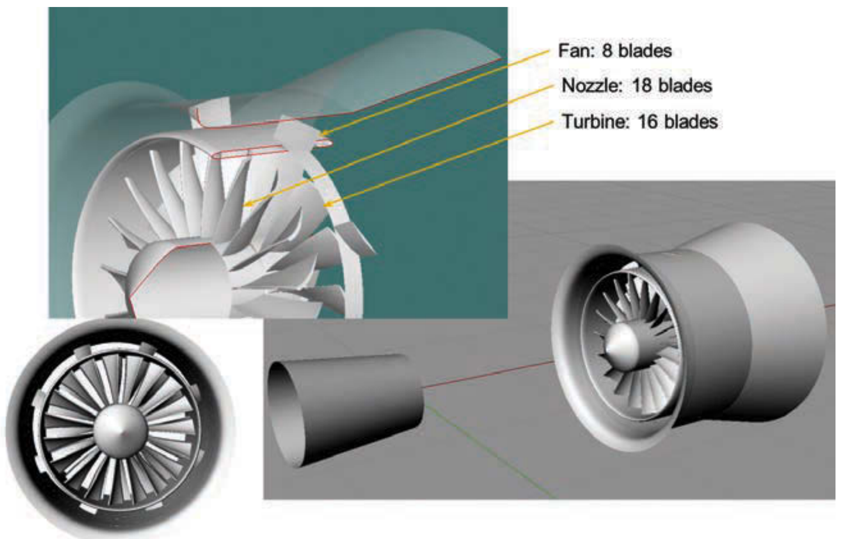
MDS has designed and patented a device that can capture most of that kinetic energy. It is called the Kinetic Energy Recovery system, or KER. In simple terms, the KER is a turbine placed behind the engine that converts the kinetic energy in the airflow into useful mechanical energy, which is used to drive a generator. The generator then converts this mechanical energy into electrical energy. However since the KER also replaces the common ejector, which produces the highly desirable test cell bypass flow, it also contains a fan component that will maintain a critical balance between what goes through the engine and what goes around it (the all-important 'test cell bypass ratio'). By carefully matching the turbine with the fan, and controlling them through the generator load, we can guarantee that the tested engine will run smoothly and in a repeatable fashion.

In designing the KER, MDS has worked within the constraints expressed by its clients. Some of the more critical points are:

- The KER cannot affect engine performance;
- The engine and test cell performance must be as – or more – repeatable than the current state-of-the-art in test cell design;
- The KER must be robust and reliable;
- It must be affordable and pay for itself in a reasonable time.

Based on these requirements, MDS set out to work with in-house and outside experts to come up with a concept that not only achieves the above targets, but also solves a few other problems. It turns out that the KER also allows larger engines to be tested in existing test cells that are 'maxed-out'. And because it removes much of the energy from the flow, noise (and in particular low frequency noise known as infrasound) are greatly reduced, therefore requiring less acoustic treatment in the exhaust stack. And since the long augmenter tube on the back end has been eliminated, the new test cells will be shorter as well. The KER also lends itself to emissions scrubbing and heat





RIGHT: Conceptual design of KER

recovery as it enables the hot engine exhaust to be segregated from the cool, clean bypass air, although this is not planned for the first version. Lower-cost test cells, combined with the new revenue stream from selling power back to the utilities, will result in a net cost saving (capital and operating).

HOW MUCH POWER CAN BE RECOVERED?

Using conservative assumptions for the turbine, fan, driveline and generator efficiencies, it is predicted that there will be maximum net electrical power outputs of roughly 8-10MW for a CFM56 class engine, and 30MW for a GE90 class. This electrical power can then be used by clients within their own plants or sold back to the utilities.

R&D funds have already been invested in conceptual and preliminary design activities aimed at assessing and solving technical and commercial risks. For instance, much effort has been spent on determining the optimum control scheme to ensure repeatability, and assessing the usefulness of variable geometry to expand the operating range (not just from minimum to maximum power, but also from small to large engines in a given test cell). MDS has also performed studies to understand the trade-offs between fixed and variable speed operation, and further studies looking at advanced gearbox and driveline designs. The aero design of the fan and turbine blades have been completed and the ideal numbers of blades and nozzle vanes for both have been determined.

Even more importantly, the problem of transmitting large amounts of intermittent power into the grid has been solved. By using emerging smart grid technologies, MDS will be able to create a constant power feed to either the client's internal grid or the utility's.

The system will be able to restrict the amount of energy put into the grid. The user will define how much power the grid can accept and the control system will divert the excess power to load banks, a storage system or both. Once the storage is full, any excess power will be diverted to the load banks. And once the engine is pulled back to idle, that stored energy will be put back into the grid. This will give complete flexibility of operation, without limitations.

MDS says it is truly excited to be in a position to revolutionize the way turbofan gas turbine engines will be tested in the coming years and to respond to growing environmental goals. While there is still some important work to be done, we are confident that the major challenges have been identified and addressed, and we are now ready to build and test the first prototype unit.

The patented KER technology will enable ETF operators around the world to reduce their carbon footprints while at the same time reaping the benefits of recovering and selling large amounts of electricity and having more compact and quieter test cells. ∎

3D rendering of the KER

Martin Gratton is chief engineer with MDS Aero Support Corporation, based in Canada

RAIMUND
TRUMMER

SIGNAL CONDITIONING

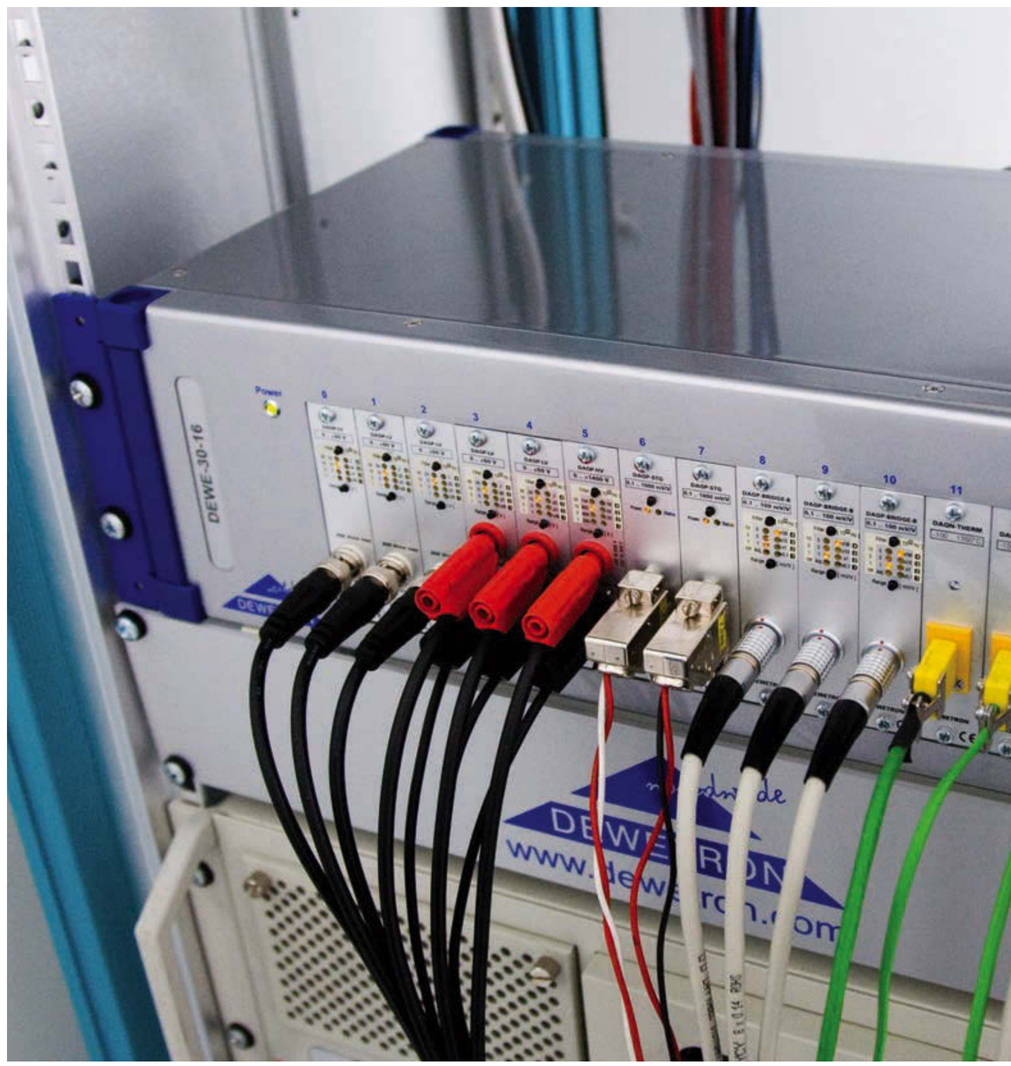
A system has been developed that can record from numerous sources while incorporating the need for fine test and measurement data

BY RAIMUND TRUMMER

Making good measurements starts with precise analog signal conditioning, which must be suitable for a variety of sensors, including strain gauges, accelerometers, force sensors, pressure, load and flow sensors, thermocouples, as well as voltages and currents. Test and measurement systems usually require recording capabilities for many more sources than the analog sensors, such as ARINC and MIL-STD-1553 databuses, counters, digital inputs, gyro sensors, GPS and video streams.

Dewetron manufactures test and measurement instruments with all these capabilities and also a sophisticated software suite. Besides the synchronization of all these vastly different signals, one key factor for robust results are the analog signal conditioners. These are called DAQP modules (programmable data acquisition module), and are an essential part that provides single-channel modularity within the systems, but can also be used in a standalone environment.

Many owners of existing measurement systems or test stands use the DAQP series analog isolation amplifier modules to boost the performance of their systems or to extend the lifetime of old test stands. DAQP modules offer isolation, easy configuration, high accuracy and a conditioned signal output of either ±5V or ±10V. Plugged in to a DEWE-30 chassis, they are the perfect signal conditioning solution for any system with analog inputs. System integration is very simple, too. The hardware is matched to the input connector type of the A/D input, and besides the included configuration software, there are ready-to-use 'drivers' available for popular software packages such as LabVIEW and DASYLab. For those who have programmed their software on their own, a programmers' manual is available to enable flawless integration.



CASE STUDY

Extension of the lifetime of old test stands by upgrading the signal conditioning has been carried out by Astrium in Germany.

Astrium is one of the leading European civilian and military aerospace industry companies, with 18,000 employees worldwide. It is a subsidiary of the European Aeronautic Defence and Space Company (EADS), which is Europe's largest aerospace and second-largest defense concern.

In the 1980s, Astrium built its test beds with amplifier modules from two different companies. But, 30 years on, Astrium was confronted with the problem that those same amplifiers were no longer available; not even spare parts to repair faulty units. Therefore it had to look for a new provider, making a broad market evaluation. Among other companies, Astrium found Dewetron and received a DEWE-30 rack with several DAQP-STG amplifiers for benchmark tests. After several months of rigorous selection processes, Dewetron won the contract to provide the technical solution according to Astrium's test bench requirements. It found out that the isolated universal DAQP-STG amplifiers had the best price-performance-ratio among all analyzed amplifiers. Juergen Kuhmann, software architect at Astrium, says, "The DAQP-STG is the amplifier with the best

ABOVE: The new drivers enable the use of LabVIEW on Dewetron measurement instruments

RIGHT: Assembly of a high-speed universal HSI-STG module

ABOVE: The perfect signal conditioning solution: A DEWE-30-16 with DAQP modules, which have conditioned signal output of either ±5V or ±10V

price-performance-ratio we could find, and we did a broad market evaluation."

An additional convincing fact was that the amplifiers are suitable for about 95% of all analog input types and were originally developed for NASA. At the end of 2008, Dewetron built a 600-channel system with STG modules for NASA's mobile launch platform.

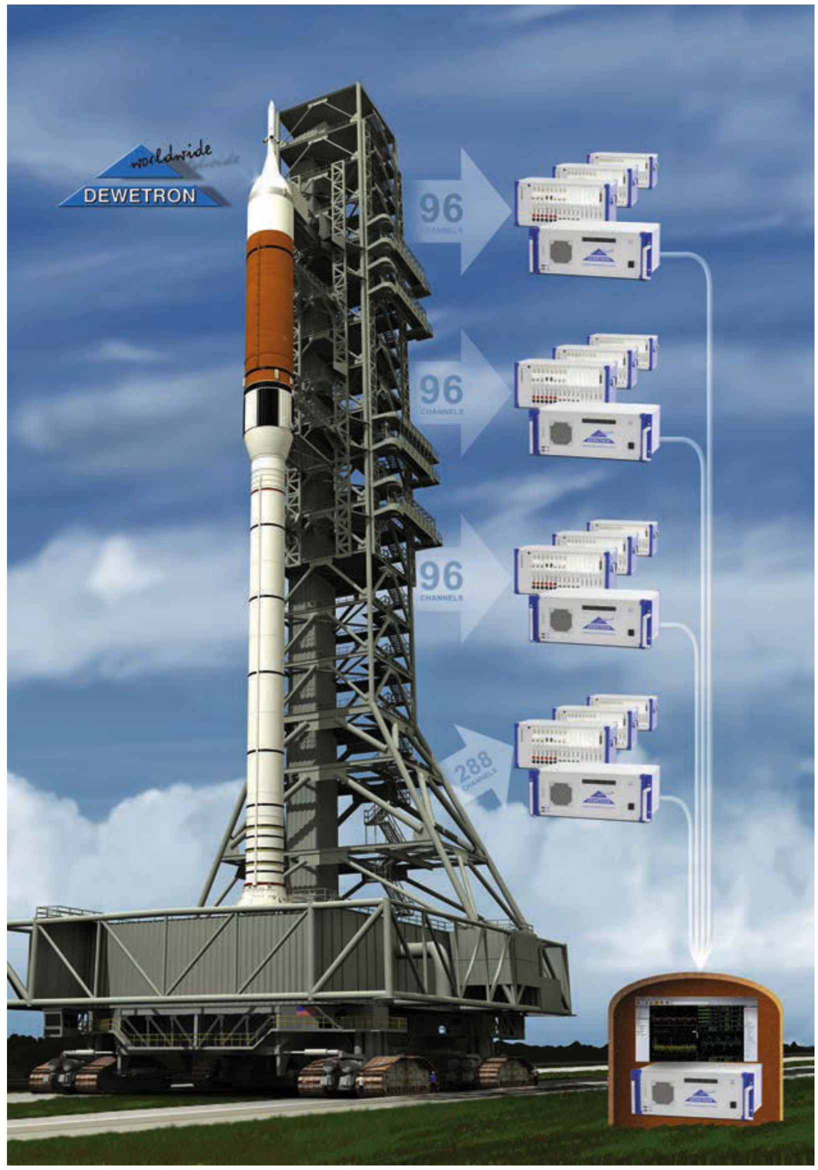
Currently Astrium, DLR and others in the aerospace industry are replacing their old signal conditioners with the universal DAQP-STG amplifiers in their European test centers for rocket- and satellite engines. They are used for testing of satellite positioning control systems in Germany, as well as for the Ariane testbeds for rocket engines. Ariane is a series of European civilian launch vehicles for use in space launch. Ariane rockets launch from the Guiana Space Centre at Kourou in Guiana, where many DAQP-STG amplifiers are in use. The control centers with the measuring equipment are underground in earth bunkers, which require a distance between the sensor and the amplifier of between 200m and 500m.

UNIVERSAL MODULE

DAQP-STG is the flagship model. When it was originally developed for NASA in 2008, the key criteria was that all the sensors must work with one single amplifier, and that's why the DAQP-STG became a powerful universal module. It is primarily designed as a high-end bridge amplifier, and accordingly meets all requirements for strain gauge/bridge sensors.

One key feature is that any sensitivity can be freely programmed and is set in hardware accordingly. Finally, the DAQP-STG offers 13 predefined measurement ranges from ±0.1mV/V to ±1,000mV/V in bridge mode; but any sensitivity within the

RIGHT: Dewetron system with STG modules are used for NASA's mobile launch platform



minimum and maximum limits can be set, for example 2.27mV/V. This lets users benefit from the full dynamics of their measuring system.

PROGRAMMABLE RANGES: AN EXAMPLE

The load sensor scaling is 2.14mV/V for its full scale of 200kg (this is what the sensor datasheet shows). Assuming a common bridge amplifier, there is a ±2mV/V range and the next best is ±5mV/V. So the module is set to ±5mV/V to avoid possible overloads, which means that only ~21% of the full range selected is being used and the ±5V output signal always stays between 0 and +2.14V. Considering a 16bit A/D digitizer (which is set to ±5V all the time), the maximum resolution that can be achieved with this sensor is 14g.

By using the DAQP-STG in the same setup, and setting the input range to exactly 2.14mV/V – and subsequently using the full dynamic of the 16bit ADC – a resolution of 3g can be achieved. Almost five times better.

In combination with MSI (modular smart interfaces), this single isolation amplifier enables the connection of ~95% of all common sensors. Supported input types are voltage, current, strain gauge, bridge sensor, piezoresistive bridge, IEPE, RTD, resistance, potentiometer and temperature. In any setup, there is high isolation for the signal input, the sensor excitation, and even the TEDS lines, to guarantee robust and high-quality measurement results. Obviously a wide range of applications are covered by only one module type.

A/D CONVERSION AND OPEN SYSTEM STRATEGY

There are also cases where the replacement of the signal conditioners is not sufficient to fulfill the increased requirements in terms of measurement accuracy. In such cases, the 'upgrade kit' also needs to include A/D cards.

Based on seeing this again and again, it was decided to use an 'open system' strategy. Until 2012, the high-accuracy DEWE-ORION series A/D cards were made exclusively for Dewetron's own systems, but in the consequent execution of the new open system strategy, the ORION cards also got drivers for LabVIEW and DASYLab, and are now available to be integrated into existing third-party systems. Users take advantage of a whole series of ~30 ORION cards, which have one thing in common: a separate ADC per channel so as not to compromise with 'simultaneous sampling'. The cards are available from 4 channels to 32 channels per card, with 16-, 22- or 24bit resolution. Sampling rates range from 100kS/s per channel to 10MS/s per channel. ∎

> **"THE DAQP-STG IS THE AMPLIFIER WITH THE BEST PRICE-PERFORMANCE-RATIO WE COULD FIND AND WE DID A BROAD MARKET EVALUATION"**

Raimund Trummer is the product marketing manager with the company Dewetron, based in Austria


Synchronized
Signal Conditioning
worldwide
DEWETRON
Analog inputs
Counter
Video
ARINC-429, MIL-STD-1553
GPS, IRIG, absolute timing
Inertial data
Chapter 10
PCM data stream
19:48:37.9
DEWE2-A4
TRION Series Modules
NASA
TECH BRIEFS
2012 Product of the Year
Test & Measurement Solutions
Direct link to the new
Application brochure
DEWETRON Ges.m.b.H | Parkring 4 | 8074 Grambach | +43 (316) 3070 | info@dewetron.com | www.dewetron.com/aerospace

CHRIS JONES

MADE TO MEASURE

An analysis of non-contact displacement measurement reveals the pros and cons of different technologies

BY CHRIS JONES

When measuring displacement, there is often a trade-off between the benefits and limitations of each particular displacement measurement technology. With this in mind, it is important to compare the four primary methods of non-contact displacement measurement.

Today, aerospace manufacturers and suppliers need to measure more accurately, often to submicron or nanometer resolutions, and against difficult surfaces or materials such as metals, composites, ceramics, plastics and machined components – many of which cannot be touched during measurements.

For those involved in aerospace R&D, development and test programs, non-contact displacement sensors enable the measurement of different parameters, including vibration, gaps, surface profiles, runout and position. These sensors come in a wide variety of shapes, sizes and measurement principles. In practice, as well as eddy current and laser triangulation sensors, capacitive and confocal sensors are now widely used in many research, production, quality and inspection environments. It is therefore critical that engineers have a greater understanding of the strengths and limitations of each measurement principle when selecting the most appropriate one for their application.

THE EDDY CURRENT PRINCIPLE

The eddy current measurement principle is an inductive measuring method. A coil is supplied with an alternating current, which causes a magnetic field to form around the coil. If an electrically conducting object is placed in this magnetic field, eddy currents are induced, which form an electromagnetic field according to Faraday's law of induction. The controller calculates the change in energy transferred from the sensor coil to the target material and converts this into a displacement measurement.

The benefits here are that this method can be used on all electrically conductive, ferromagnetic and non-ferromagnetic metals. The size of

Above: Eddy current measurement principle

Left: Micro-Epsilon's embedded coil technology (ECT) sensors

Below: eddyNCDT – Micro-Epsilon's range of Eddy current sensors

> **"AS WELL AS EDDY CURRENT AND LASER TRIANGULATION SENSORS, CAPACITIVE AND CONFOCAL SENSORS ARE NOW WIDELY USED IN MANY RESEARCH, PRODUCTION, QUALITY AND INSPECTION ENVIRONMENTS"**

Left: Laser triangulation measurement principle

Below: optoNCDT – Micro-Epsilon's range of laser-based optical sensors

the sensor is relatively small compared with other technologies and the operating temperature range is high (up to 650°C). The technology is high accuracy, high speed, and is immune to dirt, dust, humidity, oil, high pressures and dielectric materials in the measuring gap.

However, output and linearity depend on the electric and magnetic features of the target. Therefore, individual linearization and calibration is required. Maximum cable length is typically 15m and the diameter of the sensor increases as the measuring range increases.

THE LASER TRIANGULATION PRINCIPLE

In this principle, a laser diode projects a visible point of light onto the surface of the object being measured. The diffusely reflected light reflected from this point is then projected onto a CCD/CMOS array by a high-quality optical lens system. If the target changes position with respect to the sensor, the movement of the reflected light is projected on the CCD array and analyzed to determine the exact position of the target. The measurements are processed digitally in the integral controller and then converted into a scaled output via analog (I/U) and digital interfaces such as RS232, RS422 or Ethernet and EtherCAT.

Benefits of laser triangulation sensors include a small beam spot; very long measuring ranges are possible; the sensor measures virtually any target material; and there is a high stand-off between sensor and target. New innovations include the use of blue lasers to measure glowing targets.

The method is limited by a relatively large sensor design (compared to confocal, capacitive and eddy current sensors) and a relatively clean optical path is required for the sensor to operate reliably. In addition, for specular (mirrored) surfaces, specific sensor alignment/calibration is required.

THE CONFOCAL PRINCIPLE

This technology works by focusing

Far left: Confocal chromatic measurement principle

Left: Confocal IFS – Micro-Epsilon's confocal sensors for displacement, position and thickness

Below: Capacitive measurement principle

Inset: capaNCDT 6200 – Micro-Epsilon's high precision capacitive measurement systems

polychromatic white light onto the target surface using a multilens optical system. The lenses are arranged in such a way that the white light is dispersed into a monochromatic light by controlled chromatic deviation. A certain deviation is assigned to each wavelength by a factory calibration. Only the wavelength that is exactly focused on the target surface or material is used for the measurement.

Diffuse, specular and transparent surfaces can be measured. With transparent materials such as glass, a one-sided thickness measurement can be achieved along with the distance measurement. Also, because the emitter and receiver are arranged in one axis, shadowing is avoided.

Confocal offers nanometer resolution and operates almost independently of the target material. A very small, constant spot size is achieved. Miniature radial and axial confocal versions are available for measuring drilled or bored holes.

Restrictions of the technology include the limited distance between the sensor and target.

THE CAPACITIVE PRINCIPLE

With the capacitive principle, sensor and target operate like an ideal parallel plate capacitor. The two plate electrodes are formed by the sensor and the opposing target. If an AC current with constant frequency flows through the sensor capacitor, the amplitude of the AC voltage on the sensor is proportional to the distance between the capacitor electrodes.

An adjustable compensating voltage is simultaneously generated in the amplifier electronics. After demodulation of both AC voltages, the difference is amplified and output.

Because the sensor is constructed as a guard ring capacitor, almost ideal linearity and resolution against metal targets is achieved. The technology also offers high temperature stability, as changes in the conductivity of the target have no effect on the measurement. Capacitive sensors can also measure insulating materials.

The technology is sensitive to changes in the dielectric between the sensor and target, and so operates most effectively in clean, dry applications.

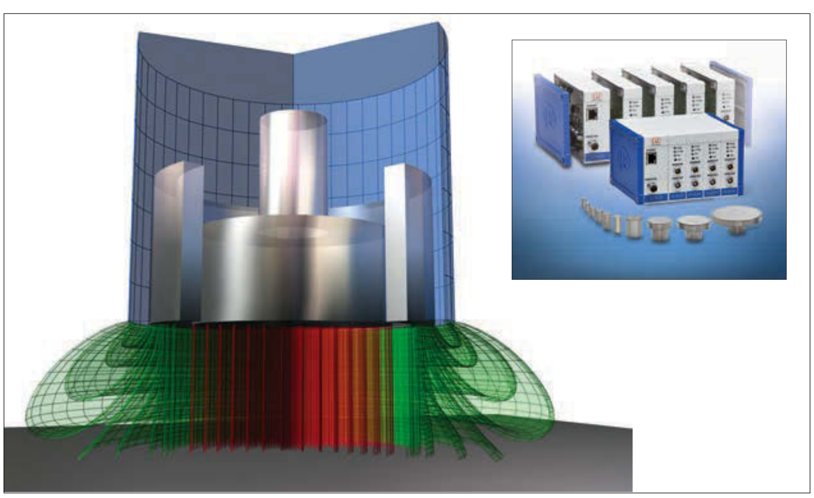
TRENDS AND INNOVATION

Growth in the use of non-contact displacement measurement has fueled the development of new sensor designs based upon the above technologies. Current trends indicate that smaller, compact and intelligent, integrated electronic sensors are now required. Smarter, more sophisticated algorithms are an integral part of the sensor system, giving higher accuracy and more reliable measurements. Sensors also need to be stable and robust to cope with high temperatures and withstand a range of harsh, challenging environments. Applying these technologies is also of paramount importance as they need to seamlessly integrate into the measurement process and allow easy setup and configuration. Sensor manufacturer Micro-Epsilon has developed a range of digital interfaces including Ethernet and EtherCAT, along with SDK libraries and codes, to allow integration into most data acquisition and software analysis packages.

In the past five years, Micro-Epsilon has continued to raise the bar in terms of innovation and development of non-contact displacement measurement. The company's next-generation of eddy current sensors, for example, use a patented embedded coil technology (ECT), which overcomes the previous limitations of discrete coil windings. The eddyECT sensor coil uses new inorganic materials to embed the coil, which enables hermetically-sealed, ultra-compact designs. This provides almost unlimited scope in terms of the external design and geometrical shape of the sensors. These sensors also offer extreme mechanical robustness, resulting in longer service intervals and higher temperature stability. The complete circuit electronics can be integrated into the sensor, providing an even more compact measurement solution if required.

The sensors are also suitable for harsh operating environments, including high vibration, impact shocks and high operating temperatures (-193°C to +650°C). Sensors have been produced with extremely low thermal drift and with temperature errors of less than 20 parts per million per unit of Kelvin (20ppm/K).

Micro-Epsilon's sensors can be found in a variety of aerospace and defence RD&T applications, including non-contact sensors for: optical missile testing systems, various rotor blade measurement applications, measuring vibration/load on aircraft wings, aircraft steering systems and landing gear, and miniature lightweight thermal imaging cameras for UAVs. ∎



Chris Jones is the managing director of Micro-Epsilon UK Limited


OLE THORHAUGE

SHAKING THE SYSTEM

Vibration test systems have delivered precise force for more than 20 years. High-quality servicing is vital to keep them up to standard and prevent unplanned downtime

BY OLE THORHAUGE

Of the 10,000 LDS vibration test systems around the globe, most are in near-constant use. Day in, day out, for up to about 20 years, they exhaust the life out of any test object by precisely condensing a lifetime's stresses into a few hours. In such intense test schedules, the system needs to be tough on a level that most equipment doesn't have to come close to. Year after year, it must reliably deliver accuracy whenever it is demanded, with the absolute minimum of disruptive downtime.

DEMANDING APPLICATIONS

Each one of Brüel & Kjær's systems includes all the components needed for every conceivable vibration testing requirement. Input for modal testing and ground vibration testing of fuselages is provided by shakers ranging from the smallest permanent-magnet ones you can hold in your hand, right up to water-cooled behemoths giving 289kN force.

Validating components such as turbine blades and avionics – sometimes in cleanrooms and interfacing with environmental chambers – needs specific cooling arrangements. For simulating the service life of subassemblies such as landing gear, fuel probes or complete UAVs and missiles, special arrangements are required such as larger heads, slip tables and shaker combinations. A large choice of configurations is needed to provide the high force, acceleration and size range necessary to support and test objects in the safest, most accurate way. Considering that these high-force systems can deliver over 600kN and some support payloads of 6,000kg, special requirements extend to large seismic masses beneath the system that prevent it destroying the very buildings they stand in.

"With such demanding requirements, it is little wonder that most of our aerospace customers choose installations on a project basis," says Brüel & Kjær's aerospace program manager, Noel Brown. "For these, we manage the entire project and deliver all the necessary support and service according to all relevant standards. With controllers, amplifiers, transducers, structural analysis software and integrated data acquisition systems, Brüel & Kjær makes every component in the system. Add our spare parts supply, servicing agreements and regular user training, and we give customers a single point of contact for all vibration test requirements," Brown explains.

UP TO AEROSPACE STANDARDS

Standards that influence vibration testing of air and space vehicle components require test machines that unquestionably adhere to them as well. Test machinery must precisely impart the prescribed force, shock and acceleration, making accuracy critical for satisfactory testing. And second only to that is durable accuracy – test systems must be irreproachable throughout their working life. You

"A SYSTEM IS ONLY AS STRONG AS ITS WEAKEST PART, AND IN ANY SYSTEM SMOOTH INTERACTION BETWEEN EVERY PART IS VITAL FOR OPTIMAL PERFORMANCE OF THE WHOLE"

ABOVE: **LDS vibration test systems have been made in Royston, near Cambridge, UK for more than 50 years, in the largest vibration test system factory in the world.**

LEFT: **Dual-shaker combinations are typically used to test missiles and UAVs. Brüel & Kjær's comprehensive range spans from 9-400kN force shakers, and even quad-shaker combinations capable of over 600kN that are typically used for satellite testing**

don't want their performance deteriorating over time.

A system is only as strong as its weakest part, and in any system smooth interaction between every part is vital for optimal performance of the whole. If one part breaks down quickly or wears unevenly, the whole system's accuracy is affected. Complex and costly components can break down and shorten the system's lifetime.

As they have been for more than 50 years, LDS vibration test systems are made in Royston, near Cambridge, UK, in the largest vibration test system factory in the world. Here, every tiny component is taken very seriously. "An example is the field coils of our shakers," says assembly technician Dave Walker. "They have a clear coating that improves their performance, because you can see that there is no porosity or bubbles. We want our customers to see the quality and workmanship in our products. Even the resin used by Brüel & Kjær has been developed with a consulting test house to obtain the optimal endurance – both dynamically and under tough temperature variations."

MAINTENANCE FOR DURABILITY

Even lovingly crafted shakers can't work endlessly without diligent maintenance, but with effective servicing they outlast even controllers and amplifiers. A good example is an LDS V875 shaker that has run the equivalent of 16 hours a day for 12 years (more than 74,131 hours since 1999). And the only reason it is still working as dependably as new is thanks to a regular service plan, where major maintenance is carried out every three years, and minor maintenance every other year.

Maintenance agreements keep your system constantly operating at optimal

AN OLD HAND

A good example of an efficient shaker is an LDS V875 that has run the equivalent of 16 hours a day for 12 years (more than 74,131 hours since 1999).

Covering everything from tiny to huge vibration test systems, Brüel & Kjær offers a complete service from project installation to setup and training – and now comprehensive maintenance plans

capacity through regular servicing at scheduled intervals, which also gives plannable downtime. The maintenance agreements that are set up guarantee a fast response to queries and problems, and in the event of unforeseen incidents, ensure a fast response from expert, factory-trained staff with access to locally held inventories of spare parts – with a large, durable organization behind them.

"Above all, maintenance agreements give you peace of mind that your investment is protected by people who know more about LDS systems than anyone in the world," explains Andrew Turner, Brüel & Kjær's head of operations for the LDS range. "They let you concentrate on your core activities, safe in the knowledge that a trusted, large and dependable organization will oversee your test system's health. Our service technicians know the systems intimately and have direct access to the people who design and build them in the factory."

BATTLING BAD SERVICING

With reliability a number-one concern, Brüel & Kjær is fighting the problems caused by some third-party service agents and inferior, non-OEM spare parts. "We have discovered a lot of systemic problems and poor performance that stems from spare parts manufacturers lacking the correct tolerance information, and using inferior materials," says LDS service manager Steve Goodwin. "We've actually seen armatures rewound the wrong way, and had to sort them out to get the shaker running again. For that customer it was definitely a false economy."

Turner adds, "Maintenance by Brüel & Kjær people is the difference between ordering something anonymously and cheaply – and living with the consequences – or going to an established OEM shop where they know you and you trust them to look out for your best interests. In the first case, you have no clear product provenance, no face-to-face communication, and a limited relationship. In the second, you look into the eyes of people you know, who bring a wealth of highly specialized knowledge – or know where to get it – and who care enough about your actual unique situation to recommend things you might not have thought of. And who will be there for decades to come. This all contributes to prolonging the system's operational life. That is true value."

CONSISTENT SERVICE

The company has substantially cut the number of third-party service providers it endorses to service LDS products. Now, it says, only selected 'certified partners' are authorized to service LDS shakers, and must use clearly labeled genuine spare parts from the LDS factory. As Christophe Sinsou, Brüel & Kjær's director of sales for Europe, says, "In the past, some distributors have only been able to offer quick fixes to problems. By going through Brüel & Kjær or our certified partners, consistency is guaranteed, so everyone can get effective corrective actions everywhere needed."

Brüel & Kjær has also expanded the number of its own service personnel, and rationalized its resources to serve customers better – wherever they are. All Brüel & Kjær service teams are reorganized into field service and support specialists to help clients get routed more easily t o the advice they need, and get the skills they need on site, when they need them. ∎

Ole Thorhauge is product manager for the LDS range at Brüel & Kjær Sound and Vibration Measurement, based in Denmark


safety in test > safety in flight
TESTFUCHS
Test Equipment
for Aerospace
The latest generation of
GENERATOR TEST SYSTEMS
eliminates the gearbox
Cost savings due to
UNIVERSAL GCU
Mobile and fixed test systems for all kinds of
civil and military aircraft components.
Everything from one source - from
concept to comissioning and
lifelong after-sales support.
TEST-FUCHS GmbH / Test-Fuchs Strasse 1-5 / A-3812 Gross-Siegharts
T +43(0)2847 9001-0 / F +43(0)2847 9001-299 / office@test-fuchs.com
WWW.TEST-FUCHS.COM


prisma
Digital & Phased Array Flaw Detectors
Thickness Gauges
Ultrasonic Transducers
Coating Thickness Meters
Ultrasonic Scanning Systems
MPI Solutions & Dye Penetrants
Ultrasonic Couplant, X-Ray Film & NDT Accessories.
Contact us to discuss your NDT & Inspection applications.
Tel: +44 (0)1908 316345 Email: sales@sonatest.com
Applications include:
Manufacturing Defects, Delamination Detection, Composite Inspection, Impact Damage Assessment, Corrosion Inspection, Large Area Scanning & WheelProbe Technologies
twitter follow us @sonatestltd
Sonatest
www.sonatest.com

INDUCT-A-RING SHAKERS

A new and improved vibration and shock system is now available

The Unholtz-Dickie T2000 shaker, available with either 2in (51mm) or 3in (76mm) pk-pk stroke, now comes with power amplifiers rated up to 720kVA output. This combination produces staggeringly high acceleration (220g-pk) and velocity (>280in/sec) output. Specific breakthrough performance examples include 180g rms random on a 10 lb (4.5kg) load, 96g peak sine on a 160 lb (73kg) load, and 100g peak/11ms half-sine shock pulse on a 650 lb (312kg) load.

Why haven't numbers like these been available before? What improved technical design component has made this radical increase in vibration and shock ratings possible? The answer can be found by looking closely at the T2000 shaker armature – called Induct-A-Ring.

INDUCT-A-RING DESIGN

The T2000 shaker's armature is air cooled and solid metal throughout, with power transferred to its solid aluminum driver coil by induction. The Induct-A-Ring design thereby eliminates the three soft spots in conventional 'wound coil' armature designs: first, an epoxied multi-turn (water-cooled) driver coil; second, a flexing AC current lead that has to carry 1,000A or more; and finally, flexing water hoses that deliver critical coolant to the driver coil – all three being asked to operate reliably in a high displacement, high acceleration vibration environment.

Stationary AC coils rigidly mounted within the massive iron structure of the T2000 shaker body are directly coupled to the power amplifier output. Amplifier output power is transferred to the actual moving armature through highly efficient inductive coupling between the fixed AC stator coils and the single-turn driver coil on the armature frame. Electrically, the internal coil configuration of the T2000 behaves essentially like a transformer with a single-turn secondary. The advantage of being able to deliver hundreds of kVA of power amplifier output to the moving armature's driver coil, without the need for a flexing current lead, is enormous. Removing this current lead from the picture creates a step-change in armature reliability.

AIR-COOLING THE ARMATURE

Another inherent benefit of the Induct-A-Ring design is the ability to air-cool the driver coil, therefore eliminating the flexing water hoses required by conventional, high-force armature designs. AC currents that flow in the Induct-A-Ring single-turn coil travel primarily along its outer surface due to the well-known 'skin effect' that applies to AC current conductors. Since the resulting heat resides on the surface of the solid driver coil, forced air cooling using a remote blower is practical. Elimination of the closed-loop water-cooling hardware (especially the flexing water hoses) used in conventional armature designs again scores a major breakthrough in reliable operation under extreme vibration conditions.

ABOVE: **Close-up view of T2000 IAR armature**

MAIN: **T2000 shaker on pedestal base**

THE SLINKY EFFECT

One of the best known bits of folklore in the vibration testing industry is the failure mode of wound coil armatures known as the 'slinky effect'.

When the generated force acting on the wound driver coil of a conventional armature exceeds a critical point, the coil separates from the armature frame – the fractured epoxy joints fail further until the coil may then break free from the armature frame completely, resulting in a catastrophic shaker failure. When the operator later attempts to remove the armature by pulling the frame vertically out of the shaker, the no-longer-attached driver coil often reveals itself as an elongating helix dangling from the armature frame – the dreaded slinky effect. The T2000 Induct-A-Ring armature is immune to this condition by virtue of its solid metal construction, which has no windings or epoxy joints employed in the force-generating driver coil. ∎

This article was compiled by engineers from Unholtz-Dickie, based in the USA

ESMERALDA
CUEVAS

AIR AND FIRE

Air-coupled ultrasounds and thermography demonstrate very effective NDT inspection techniques

BY ESMERALDA CUEVAS

Materials, manufacturing processes and associated non-destructive testing (NDT) methods for quality assurance are in a continuous state of evolution, especially in the current aeronautical industry. Spanish company Tecnatom has been involved with NDT, and in particular with aeronautical components, for the past 15 years.

The use of non-cured material is continuously being reassessed within the aerospace sector. One important consideration for the inspection of non-cured components within the aeronautical industry is the fact that contamination of the material must be avoided. This is why the methods of inspection must ensure no contact with the material before the curing phase. Tecnatom has extensive experience in the use of several NDT techniques and innovative techniques such as thermography and air-coupled ultrasounds.

INSPECTION METHODS

In this study, five different samples were specifically manufactured: four of them with different compaction processes and different compaction grades, and the fifth one with six inclusions at different depths ('inclusions' are small parts made of a different material. Their intention is to simulate defective, delaminations or foreingn bodies). Sample dimensions were 300 x 300mm with 30 plies (around 7.5mm). The size of all the inclusions is 10 x 10mm.

An examination of the samples confirmed that the objective was to determine whether different compaction levels and inclusions could be detected in non-cured and cured samples with NDT.

Initially, different inspection methods were considered in order to determine which method was the most suitable for inspecting non-cured samples where no contamination (no contact) was possible. These methods were applied to the inspection of non-cured samples, with different results. Initial determination of material properties was needed in order to

Different combinations of cameras and technologies were used on non-cured samples, including ultrasound

define the inspections. Final analysis of these studies concluded that thermography and air-coupled ultrasounds were the preferred methods to be used for inspection purposes in order to ensure no contamination to the material and higher reliability and efficiency in detecting the defects.

INFRARED THERMOGRAPHY

In order to cover a wider testing framework, Tecnatom decided to use different cameras, excitation methods, inspection techniques and strategies for inspections of non-cured samples. Evaluation of the inspection results using specifically developed post-processing tools has helped to obtain better quality in the final results, and to define the final inspection parameters. Several algorithms have also been considered to facilitate the defect detection.

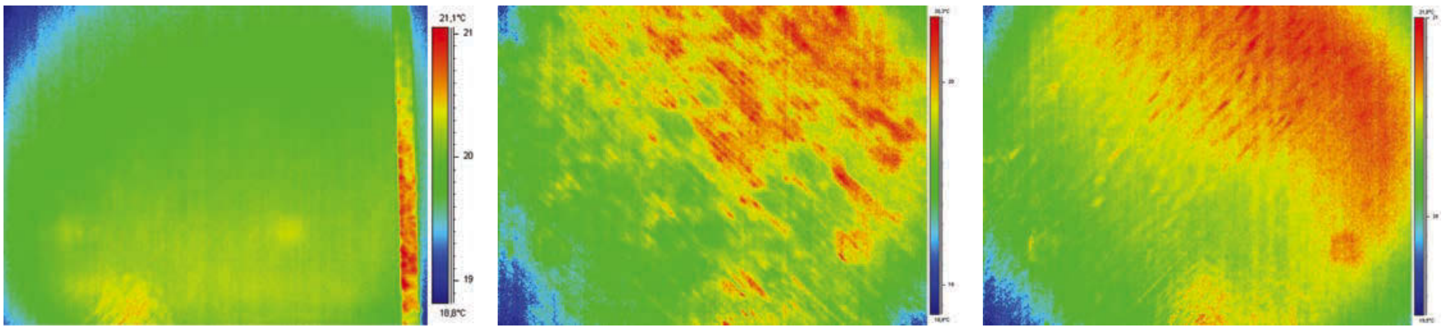
There are three thermographic NDT techniques currently in use for the detection and measurement of defects in composites, such as impact damage: pulsed flash thermography (PT); pulsed transient thermography (PTT); and lock-in thermography (LT).

The selection of the final technique is based on the sample material and thickness, and the test environment. The specific selection of camera type also varies widely, from cooled to uncooled, depending on the required spatial and thermal resolution.

Following a previous analysis, research has been especially focused on PT, in which energy sources are used to pulse-heat the specimen surface. The specimen is heated from one side, while thermal data is collected either from the same side (reflection mode) or from the opposite side (transmission mode). Defective zones will appear at higher or lower temperature with respect to non-defective zones on the surface, depending on the thermal properties of both the material and the defect. The temperature evolution on the surface is then monitored in transitory regime using the infrared (IR) camera to obtain thermogram sequences that can then be processed later.

ARTIFICIAL DEFECTS

The tests were carried out during 'prepreg' lay-up manufacturing. During this process, artificial defects were inserted in layers 2, 15 and 28 (on samples with 30 layers and 7.5mm thickness). The samples were inspected after every layer, in order



ABOVE: Inclusions detected in non-cured sample. From left: third layer t1, fourth layer t2, eighth layer t3

to determine what the maximum number of layers was.

The external thermal stimulation of the inspected sample surface was performed by a 1,500W halogen lamp at a distance of less than 1m and varying pulse duration from t1 to t3 (above). The temperature evolution of the surface sample was recorded by the IR camera.

Once the results from all the inspections had been analyzed, it was concluded that defects had been detected with a maximum of six layers during the prepreg manufacturing process. With this testing, Tecnatom concluded that flash heating and frequencies over 100Hz do not provide better results in terms of depth detection or resolution.

INFRARED THERMOGRAPHY FOR CURED SAMPLES

Considering the particular defectology present in these specimens, the results were analyzed in a comparative way by subtracting the results and studying the contrast. The inclusions were detected.

Cured samples were inspected by pulsed thermography and also lock-in thermography, and the results were processed by the fast Fourier transform (FFT) algorithm leading to the pulsed phase thermography (PPT).

In this mode, the FFT of the original digital thermal signal was performed to analyze the experimental temporal data series in a frequency domain. Therefore, computed phase diagrams are obtained – these are particularly interesting because they are practically unaffected by heating problems such as reflections with the surroundings, emissivity variations and non-uniform excitations. For this reason, the images analyzed from now on will be phase images.

From the analysis of the phase images obtained (see images on next page) it was observed that detection of all the defects at different depths is obtained with transmission mode and PPT.

DATA PROCESSING TECHNIQUES

Tecnatom has improved the final results by applying specific data processing techniques that optimize defect detection.

The principle component analysis (PCA) is a statistical technique for synthesis of information. Its objectives are: firstly to reduce the number of variables in a data set to a smaller number, losing as little information as possible; and secondly to highlight differences and similarities between data. Tecnatom is using this technique as standard for data acquisition and analysis. This technique reduced noise level, facilitating defect detection. Some statistical parameters have been used for this process: the 'skewness' is the third standardized moment of a distribution. The term 'moment' is used to represent the expected values of different powers of a random variable. It is used to determine the degree of data that accurately fits with regard to a particular type of distribution.

The 'kurtosis' is the fourth standardized moment of a distribution. It is generally defined as a measure that reflects the degree to which a distribution is peak shaped. In particular, the kurtosis provides information about the height of the distribution in relation to the standard deviation value.

Polynomial fit and derivatives are based on the TSR technique (thermal signal reconstruction). This is a filtering method that sensibly improves the results of the thermographic inspections by adjusting the temperature time history of each pixel to a degree polynomial.

Tecnatom has concluded that the results obtained by applying data acquisitions by thermogaphy, enhanced with the use of these data processing techniques, have a high level of reliability and quality.

However, a complementary second technique, based on ultrasonics, has been also used for testing the specimens.

> "CURED SAMPLES WERE INSPECTED BY PULSED THERMOGRAPHY AND ALSO LOCK-IN THERMOGRAPHY, AND THE RESULTS WERE PROCESSED BY THE FAST FOURIER TRANSFORM (FFT) ALGORITHM"

AIR-COUPLED ULTRASONICS

ABOVE: Phase images obtained using a setup of 'error'. From left: Reflection mode (pulse heating: t6); transmission mode (pulse heating: t8); lock-in mode (pulse heating t5, 3 cycles, fadq=20Hz)

AIR-COUPLED ULTRASONICS

This NDT was only applied to test non-cured samples. Although Tecnatom is already using air-coupled systems for inspection, a detailed experimental study of the properties of the uncured laminated prepregs was performed in order to determine the velocity and attenuation of ultrasonic waves in the non-cured material. Then, the inspection strategy was defined in order to perform the ultrasonic acquisition data while the sample was manufactured. Air-coupled ultrasound probes, mechanical devices, electronics, materials and inspection schemes were specifically defined in order to ensure the final results.

INITIAL MEASUREMENT

Ultrasonic properties of un-cured prepreg plates were initially measured in the frequency range 0.5 to 1.0MHz. This revealed that the prepregs exhibit a relatively low ultrasonic velocity (about 1,300m/sec) and an extremely high attenuation coefficient: 600Np/m at 0.6MHz that increases rapidly with the frequency.

This huge attenuation coefficient makes it extremely difficult to inspect these materials at frequencies over 1MHz. Therefore a low frequency was selected (0.25MHz) to mitigate the influence of the attenuation.

However, even with the selection of this low frequency, the challenge faced by the air-coupled ultrasonic technique is very demanding as it needs to be transmitted through the sample and the metallic mold where it is manufactured. Therefore, highly sensitive air-coupled (peak sensitivity at -25dB) and wide-band transducers were designed and manufactured. Wide-band is important because it eases the isolation of the transmitted signal from other reverberations produced in the transducers/sample cavities.

THE TEST PLAN

Tecnatom has developed a specific testing plan to explore the possibilities of two NDT techniques in the inspection of non-cured material, for quality assurance during the manufacturing process.

Five samples were considered for this study – four of them with different grades of compaction, and a fifth one with inclusions. Different inspection strategies with thermography and also air-coupled ultrasounds were carried out in order to determine those levels of compaction, but no directly relevant results were obtained.

Concerning thermography, the following conclusions were obtained:

- Using a LWIR camera along with halogen lamp in reflection mode, superficial defects (up to six layers) can be detected, whether cured or non-cured samples are inspected;
- Better results were obtained with halogen lamp excitation;
- Several sampling frequencies were evaluated, concluding that better results in depth detection and in resolution are obtained with frequencies lower than 100Hz;
- Post processing of raw data helps considerably for data evaluation.

After completing all the inspections with non-cured and cured samples, and with thermography and air-coupled ultrasounds, it was concluded that non-cured samples can be inspected with both inspection strategies with no material contamination, and detecting inclusions in the near surface, up to six layers for thermography and four layers for air-coupled ultrasounds.

This study opens the way for the inclusion of these two techniques as complementary to the previous ones applied to quality assurance. The company Tecnatom is already working on this and will be able to offer these innovations in the future, in the automated inspection systems that have been serving manufacturers in the aerospace sector for the past 15 years.

"ULTRASONIC PROPERTIES OF UN-CURED PREPREG PLATES WERE INITIALLY MEASURED IN THE FREQUENCY RANGE 0.5 TO 1.0MHZ"

Esmeralda Cuevas is head of NDT techniques for aerospace with Tecnatom based in Spain

DR JIM HONE

DRIVING MOBILE DYNAMICS

In modern aerospace trial environments, keeping test systems small, lightweight and low powered enables data transfer to be much more portable

BY JIM HONE

Dynamics testing is becoming more mobile. Today, with multinational corporate engine development program partnerships, and far-flung altitude, cold weather and noise test sites, even relatively large systems are expected to be deployed remotely, away from the customers' usual operations for days, weeks and sometimes months at a time. In some cases customers expect relatively standard equipment to be used on board a flight test aircraft for one test and to then return to base for more standard test cell use.

At the same time customers are demanding larger channel counts, higher bandwidths of operation, and universal signal conditioning, both at home base and remotely, in most cases with full on-site monitoring and analysis facilities, and often with remote links back to base for quick review and further analysis.

It is also important for systems to be small, lightweight, low powered to enable easy battery/generator use, and yet rugged enough to be used in potentially harsh environments. Of course cost is an issue, and customers are coming to expect these multifunctional, physically small systems to be no more costly than more traditional fixed measurement installations.

Finally, they want solutions which can be transitioned between local and remote use with little or no personnel or technical effort.

This is quite a list of requirements. Is this even possible?

During 2013 alone, the UK-based company HGL has seen requirements for systems that include long-term autonomous and manned flight test operations on aircraft as diverse as light passenger planes to 747, A380 and most recently A350 flying test beds; large scale noise measurement on the Joint Strike Fighter program at Edwards AFB in California, and most recently the provision of a truly mobile 544 channel dynamics solution for single or multiple simultaneous system use around the globe.

Requirements such as those listed above drive integration and miniaturization across the industry. Sometimes this leads to esoteric solutions based on extremely embedded and leading-edge technology, which can be financially and operationally expensive if it fails to meet expectations. However, going down the completely COTS route, while less expensive, often fails to meet the size, performance, robustness and multiuse requirements.

THE PC VERSION

Requirements can be met through a combination of modular PC technology, Ethernet connected data acquisition modules, and embedded signal conditioning. Together with simple and accessible software interfaces, open data formats and innovative software applications, it is now possible to achieve virtually any testing application.

The key to the success of this approach is the humble PC, which is capable of incredible processing performance, at low cost, and has a wealth of third-party applications and programming tools available for it. However, these are not PCs that most people would recognise; they are embedded PC modules based on form factors such as Com Express, which at 100 x 80mm is truly tiny. High-performance yet low-power Core i5 and i7 versions are readily available and typically dissipate less than 20W at full load, leading to simple cooling solutions including conduction through the chassis.

Coupled with modern high-capacity solid-state drives (SSD), built-in gigabit network switches and Ethernet-based acquisition cards with miniature signal conditioning, it is perfectly feasible to produce a 32-channel, universally conditioned, acquisition module in a 19in x 3U x 10in form factor with enough CPU power to also configure, calibrate, control, real-time monitor the system and perform post-test analysis and reporting – a true all-in-one measurement system, not merely a recorder.

Modules of this nature are ideal for small channel count and portable use, and if the correct architecture is used can be scaled up easily to many hundreds of channels.

This was one of the challenges presented to HGL Dynamics in 2013 – to provide a high-performance

modular solution that could provide portable/mobile dynamics measurement solution of 448 channels (or more) with multiple monitoring stations for use with the development of the LEAP engine. Furthermore, the solution had to be compatible with systems already purchased by the customer in 2005-8 and be able to produce data compatible with the customer's international partners. Additionally, the solution was expected to be able to be run as a single system or be split into multiple smaller systems for use anywhere on the globe.

ABOVE: **Universal Conditioned Eagle32 acquisition module**

PROBLEM SOLVED

The solution comprises a number of the company's new Eagle32 acquisition units, which incorporate the attributes described above in an easy to use rack-mount 3U chassis. The realization of this unit required a reduction in size from the already small, existing systems by over 60%. The conditioning cards alone reduced from $200cm^2$ per channel to $200cm^2$ for eight channels. The weight of the unit is 9.9kg, a reduction of 70% and light enough for easy transportation by air across the world.

Finally, the unit dissipates only 80W for 32 channels; it was nearly 500W for the previous generation. This means that even a moderate 128-channel system can be operated from a very small generator for truly remote operation.

Each unit is entirely capable of operating autonomously as a 32-channel system with support for twin displays, keyboard and mouse on the rear panel, and enough internal SSD storage to operate at full bandwidth (100kHz) for 9-18 hours. Captured data can be simply archived onto an external disk, or an Ethernet-connected data management system.

"THE UNIT DISSIPATES ONLY 80W FOR 32 CHANNELS; IT WAS NEARLY 500W FOR THE PREVIOUS GENERATION"


JSF first vertical landing. Photo: Lockheed Martin

THE BIGGER SYSTEM

For larger channel count systems, the Eagle32 reverts to a front-end only role and is connected, usually in pairs, to a more powerful Core i7 based PC with terabytes of local storage, and 8-16GB of RAM but still in a small, easily transportable package weighing less than 30kg. Multiples of these units can be simply Ethernet-connected to provide systems of many hundreds of closely synchronised channels that can be set up in minutes.

A complete autonomous 448-channel system capable of running for an indefinite period anywhere worldwide weighing under 600kg and fitting into less than 70U of rack space, is entirely feasible. The network architecture allows simple support of remote links via VPN or a trusted internet connection, which then allows data analysis operations to be performed from the home base, reducing the headcount sent to the remote test site, and hence costs.

With the rapid increase in processor power available from the modern Core i7 CPUs, it is also possible to write data, during acquisition, in multiple formats simultaneously, including HGL, DATX, EDAS Raw and Matlab. This is vital on joint projects where the partners use different data-format standards.

JSF CASE STUDY

The same technology, albeit in a slightly different form factor, was used

"EACH MODULE IN THE SYSTEM WAS WATERPROOFED AND CAPABLE OF OPERATING TO 45°C, ALTHOUGH SOME SHADING WAS PROVIDED TO REDUCE THE DIRECT HEATING EFFECT OF THE SUN"

in the high Mojave desert Edwards AFB test location in summer 2013, together with a number of other vendors on a JSF noise test.

The challenges in this case were linked more to the extreme environmental conditions (30-35°C) on an open airfield site, being close to the engine exhaust (between 5m and 50m) during full power and afterburner tests. The test location was 3,000 miles from the customers' home base in Maryland, requiring all the systems to be shipped to site, so small size and weight was important. Also the open airfield site powered from generators meant power efficiency was even more important than with the 448-channel system described above.

The solution used was based around the HGL Dragonfly modular system, made up from a number of eight-channel acquisition bricks with IEPE conditioning (for the microphones), CPU modules (Core i7 conduction cooled), and HGL Power Over Ethernet network switches. As shown, the 128-channel system was broken into 32-channel modules each with a CPU, POE switch and four Dragonfly modules, one of which included a GPS receiver for synchronization. These modules were placed close to the rear of the plane, many meters apart, meaning that as well as being exposed to environmental conditions they were also subject to quite intense (around 150-160dB) acoustic energy from the engines.

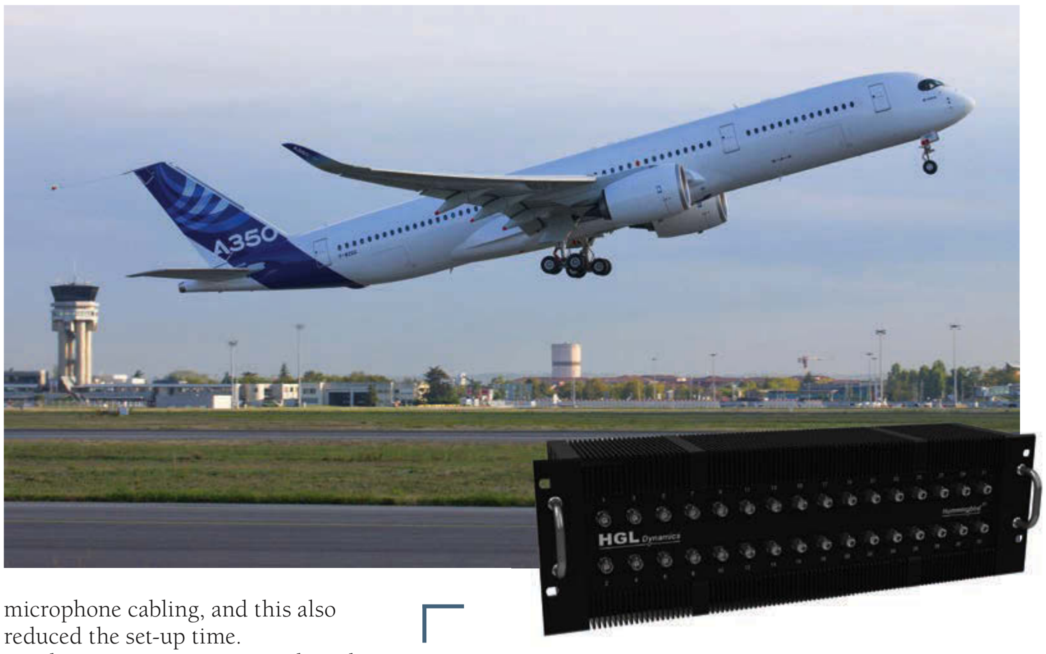
The distributed nature of the system meant that much shorter microphone cables could be used, improving signal quality and saving costs and set-up time. Synchronization was better than ±50ns between any two channels, thanks to the built-in GPS receivers, and each CPU included enough space on an internal SSD to store up to nine hours of data. Additionally each module in the system was waterproofed and capable of operating to 45°C, although some shading was provided to reduce the direct heating effect of the sun. Power consumption of the entire system was 250W, enabling operation from a very small generator.

ABOVE: Dragonfly modular system with waterproof connectors

As mentioned previously this test was carried out in conjunction with a number of third-party test groups, each with their own equipment.

While all were successful in achieving their goals, every other measurement system on site was based on large rack-mount PC computers with conventional drives, with no real environmental protection, and generally with integrated acquisition cards, all at a central location. Additionally signal conditioning was predominantly provided in separate rack systems at the central location, meaning that cable runs were 100-500m.

The benefits of the distributed system were clear. A very small footprint and weight (<50kg for the entire system), plus much less cabling, reduced transport costs considerably. Power consumption was a tiny fraction of that consumed by more traditional systems, which in turn led to simpler cooling strategies in the hostile environment. Data quality was also improved due to the short nature of the



LEFT & INSET: The Hummingbird 32 is currently installed on the A350 flight test aircraft

BELOW LEFT: 96 channels of mobile, universal conditioned data acquisition in 2013

BELOW RIGHT: 96 Channel System in 2010

microphone cabling, and this also reduced the set-up time.

The CPUs, acquisition cards and signal conditioning used for this solution are identical to those described for the 448-channel large-scale system and the 32-channel flight test system for the A350. The software and data formats supported are also the same. The main difference is the chassis the equipment is mounted in, which is tailored to match the needs of each customer.

THE FUTURE

Truly large-scale portable and mobile dynamics systems are now possible. So what does the future hold?

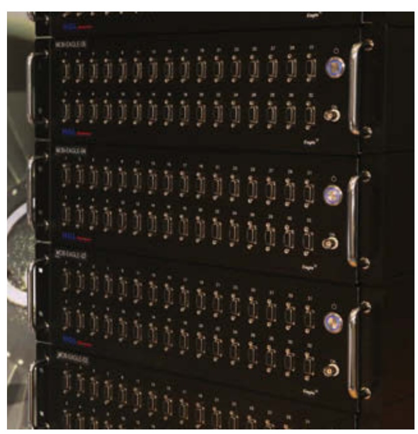
Undoubtedly the power and performance of embedded CPUs, such as ARM-based devices and field programmable gate arrays (FPGAs), will further reduce the reliance at the front-end on high-power PC modules. This will reduce the power dissipation requirements and thermal footprints of the systems further, but possibly not the physical size, as that is now largely determined by the human-friendly connector sizes.

However, smaller autonomous front-end modules that are small enough to attach to the cooler parts of engines or airframes and can be wired up at the factory, will make remote operations even simpler as only the data storage and post-processing elements will need to be transported. SSD technology is moving at such a pace that it is foreseeable that in the near future the terabytes of storage needed for days of acquisition will fit snugly inside the chassis of a single portable computer.

The age of truly large-scale, cost-effective, mobile dynamics testing has arrived. The next challenge will be in analyzing the vast wealth of data generated by these simple-to-achieve, remote large-scale tests. ∎

Dr Jim Hone is a director of HGL Dynamics Limited, based in the UK

"THE NEXT CHALLENGE WILL BE IN ANALYZING THE VAST WEALTH OF DATA GENERATED BY THESE SIMPLE-TO-ACHIEVE, REMOTE LARGE-SCALE TESTS"



DIETER KONNERTH

BERND MATTNER

INTEGRATING THE NET

Integrated Modular Avionics (IMA) will be the backbone of a centralized aircraft data communication network

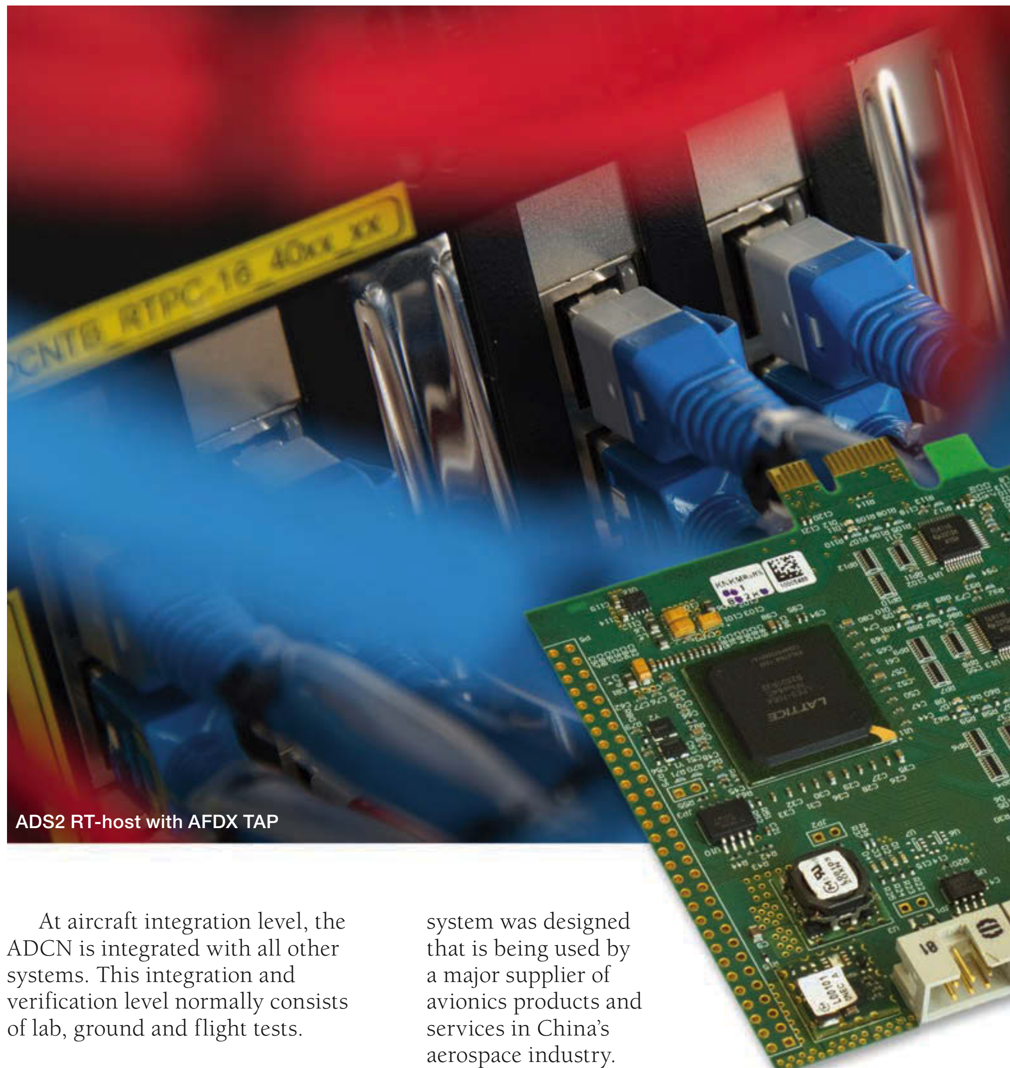
BY DIETER KONNERTH AND BERND MATTNER

Typical IMA-based aircraft architectures consist of computing devices, the aircraft data communication network (ADCN) and distributed signal interface devices. The definition of IMA resources is the reusability of standardized hardware equipment, network technology (ARINC 664) and software applications. These can be combined into systems with different specifications and for various aircraft. To realize this flexibility, the IMA resource can be adapted to the required needs with specific configuration data.

In an IMA-based aircraft, the ADCN is one of the most complex parts that integrates various systems and transports data of different criticality and rate. As the entire functionality of an IMA-based architecture depends on the correct behavior of the ADCN, it is important to have confidence in the ADCN functionality at an early stage of the aircraft development process. For that reason, integration and verification of the ADCN are done on multiple levels.

At the equipment functional level, the network components are verified to function properly within their usage domain. The next level is the equipment configuration verification. At this level, the required functions of a network component are verified with reference to a specific configuration.

The next levels of verification are done with focus on the complete network. The ADCN configuration is subject to a static verification through mathematical analysis on a network model. A dynamic verification of a network should be done at the end of integration testing at ADCN level to validate the static verification results. At this level, the entire network – all ARINC 664 switches in the real aircraft system configuration – is available as real equipment. The end system behavior is simulated and the network performance (for example, timing, data loss) as well as required network capability (for example, data loading, simple network management protocol (SNMP) support) is verified.



ADS2 RT-host with AFDX TAP

At aircraft integration level, the ADCN is integrated with all other systems. This integration and verification level normally consists of lab, ground and flight tests.

TEST SYSTEM APPROACH

Integration problems of an ADCN are discovered with all other system equipment connected and operating. As the ADCN integration normally is realized at aircraft level, this is very late in the aircraft development process. It is common sense that errors detected at this stage are very expensive.

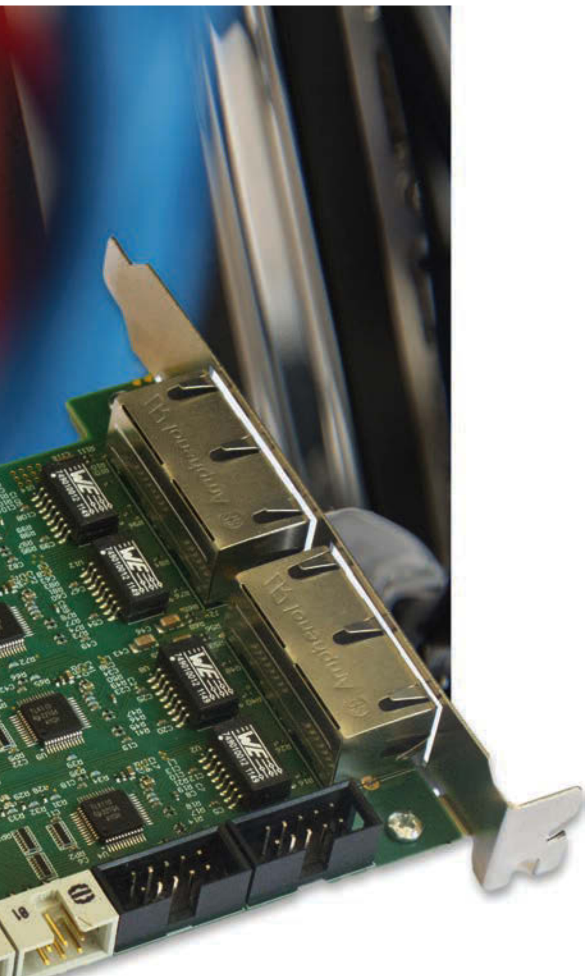
It is for this reason that TechSAT, a company with a great deal of experience in AFDX (ARINC 664) technology and integration facilities for the aerospace sector, together with its partners, decided to revolutionize its approach to AFDX integration and verification. As a result, an ADCN test system was designed that is being used by a major supplier of avionics products and services in China's aerospace industry.

Some major requirements for such a test system are derived from the static verification that shall be validated. Hence the test system has to provide capability to test that a timing schedule of a network configuration is valid as well as that the network real-time behavior is deterministic.

To legitimate the effort for another integration and verification test system at ADCN level, it has to provide added value. For that reason, the test system has to support the verification of functionality that is not covered by static verification. With the ADCN test system, different operational states,

AIRCRAFT COMMUNICATION

The IMA-based aircraft architecture is one of the major solutions to meet the demands of short time-to-market and the requirement for cost-effective aircraft development and operation. New large commercial aircraft, such as the Boeing 787, Airbus A350 and COMAC C919, have already been realized with IMA-based architecture. Some of the regional jet manufacturers are now interested in the IMA-based approach. More and more aircraft system suppliers feel impelled to provide their products as an IMA resource. For that reason, it is important to find effective solutions in order to integrate and certify IMA-based architectures.



such as normal operation, power up or reset can be tested. Further aspects that can be investigated are health monitoring and time synchronization.

One of the major benefits of a test system at the ADCN level is the ability to verify the robustness of the network. With simulated end systems, it is easy to inject nearly all kinds of errors and to check the network behavior in case of data errors or failure modes where one or more switches fail.

The test system architecture should be scalable to the size of the ADCN (for example, number of switches or end systems).

TEST ARCHITECTURE

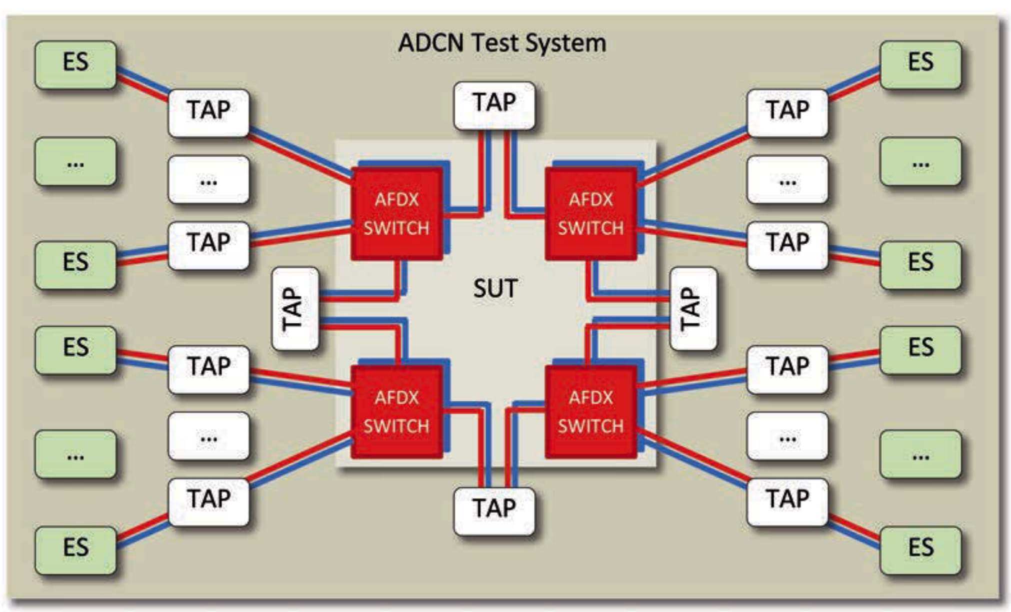
All the requirements are achieved in a very modular design that in the end led to the need to develop a dedicated TechSAT AFDX Test Access Port (TAP) with two feed-through Ethernet interfaces and to revise the TechSAT TimeMaster system.

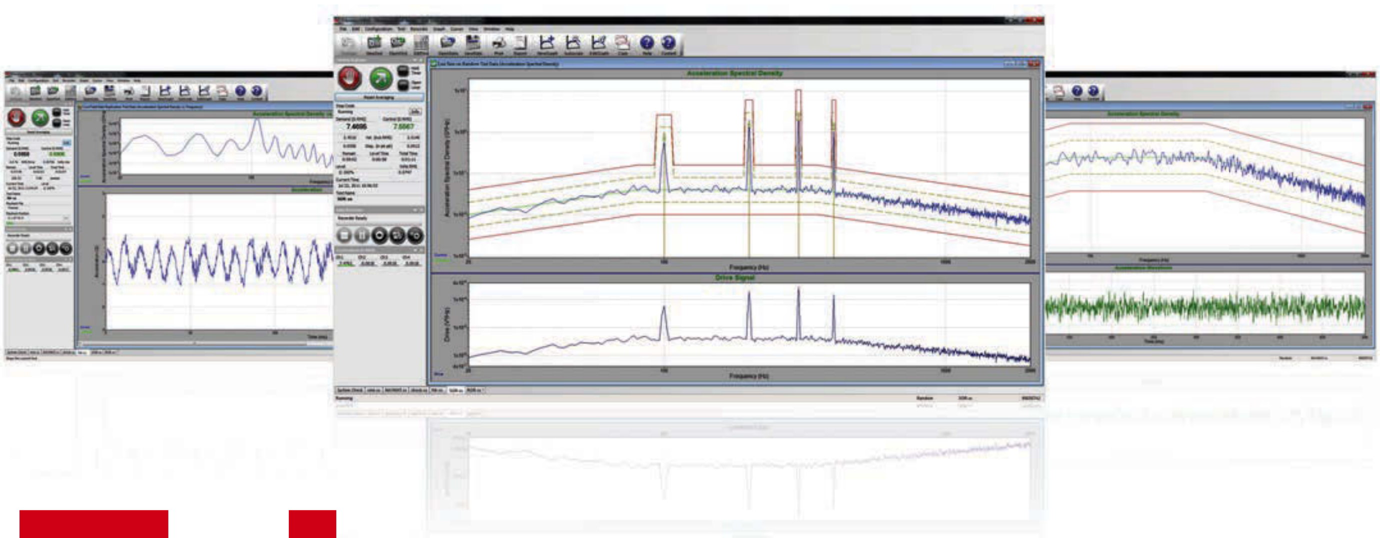
One AFDX TAP is designated to each network hardware connection to monitor the ARINC 664 traffic in the ADCN. All AFDX TAPs are hardware time-synchronized for data time-stamping. ARINC 664 boards with dedicated end system simulations that can be loaded with a configuration corresponding to the referring end system interface control document (ICD) are provided to autonomously perform end system network traffic.

The test architecture is configured in such a way that it can be used for ADCN integration with test systems from subsystem level over the ADCN level to the aircraft integration level in a laboratory. To increase the usability of the test system, an ADCN Test Suite – an automated test procedure – is provided that supports verification of all aspects of the ADCN. Most of the Test Suite is generated from the aircraft ICD. ∎

Dieter Konnerth is director of research and development and Bernd Mattner is project manager at TechSAT GmbH, based in Germany

BELOW: **ADCN test architecture for the AFDX network**





Take Control

...with the industry's best controller.

Don't trust the brains of your testing operation to just anyone. Trust Vibration Research to provide fast, easy, flexible setup and reporting with user-friendly interfaces, flexible graphing options, predictive field data replication, data sharing, remote operation, and a wide range of software features. And our controllers integrate seamlessly with any shaker. If you're looking to take control of your testing environment, visit us at vibrationresearch.com.

Plus, we back our work with a 100% guarantee of satisfaction — if you're not happy, we'll take it back.

VIBRATION RESEARCH

JARED VAN BUREN

MIXED-MODE TESTING

What is 'Sine on Random' testing and when should this testing method be used? The answers are quite simple

BY JARED VAN BUREN

Sine on Random is a common form of mixed-mode testing. It is a test mode in which sine and random vibrations are performed simultaneously to simulate sources where both modes are present in the ordinary service of the device under test.

In the real world, sinusoidal and random vibrations often exist and occur simultaneously. In a Sine on Random test, the underlying energy is being generated in a random form, but there are certain sinusoidal vibrations present that exceed the g levels seen in the random profile to such a degree that they need to be part of the test profile to provide a more accurate representation of the in-service environment.

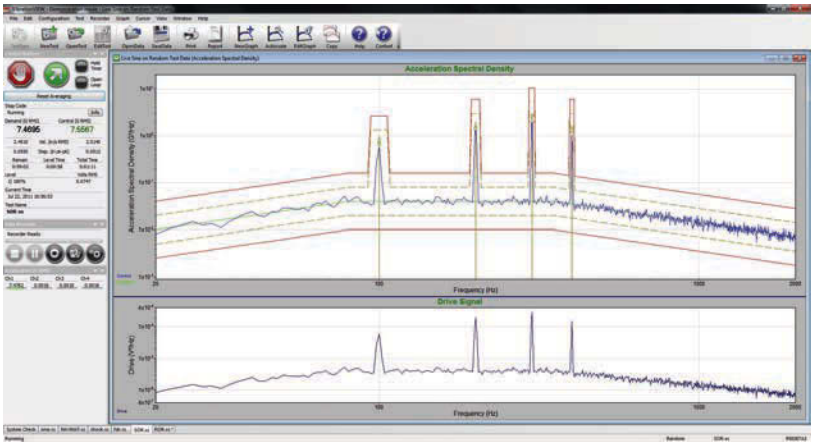
In certain circumstances, the sinusoidal vibration is minimal and is less important to the overall test. In other cases, the sinusoidal vibration that affects the device being tested has an impact on the underlying background random, and should be recognized as an important part of the test procedure. The sine tones that are superimposed on the random profile in a Sine on Random test can be fixed-frequency or sweeping, depending on the most common in-service experience. If sweeping tones are used, they are often narrow frequency sweeps at approximately ±5% of the center frequency.

All aircraft, whether fixed wing, rotor or rocket-propelled, have a base random energy inherent when in service. In addition, there is also a sinusoidal element present that cannot be ignored when testing. The sinusoidal vibration typically comes from the turbine engine or rotor blade, and is present at various frequencies. Most of the components in an aircraft will benefit from mixed-mode testing. Instruments, connectors, batteries and other common components of aircraft are all subject to both sinusoidal and random vibrations simultaneously, and are subject to failure from these vibrations. For this reason, Sine on Random is the best application for testing components in many aerospace applications.

The Blackhawk helicopter requires state-of-the-art testing to ensure safety and successful missions

A common and extremely harsh application of Sine on Random testing is the helicopter gunfire test. The helicopter is subject to a common random vibration, but when gunfire is introduced, a very noticeable high g sinusoidal vibration is infused into the environment. Devices that have only been tested using one method or the other may at first appear to be able to withstand this new environment created by gunfire from a helicopter. Since the Sine on Random testing method better represents the real-world conditions, this would always be the preferred test procedure.

So how do you establish the correct profile to run on your shaker? There are two common methods to consider in establishing your test profile. The first is to run the requirement as spelled out in the MIL-STD-810G specifications. The MIL standards are applicable and easy to use, whether the device under test is to be used in a military or civilian application. In addition, many of the test articles are the same, or similar, whether used in a military or civilian environment. The second common method for determining your Sine on Random profile is to record field data, and by using a variety of analysis tools, you can establish the test characteristics required to create an applicable test profile. This second method is more complex and the analysis requires substantial tools and skills.



Live Sine on Random profile test data screenshot (Acceleration Spectral Density)

Jared Van Baren is a sales engineer at Vibration Research, based in the USA

ARNE BREHMER

CARSTEN KELLNER

A BRIGHT IDEA

'Orange' avionic dataloggers log CAN bus data for flight tests in pursuit of sporadic errors

BY ARNE BREHMER AND CARSTEN KELLNER

Commercial airplanes are entering a new era in terms of the growing number of electronic components they contain. The systems, which are becoming increasingly more complex, need to be tested extensively in the laboratory and in flight trials. Dataloggers can make an important contribution in debugging and error analysis. However, they must fulfill the stringent technical and regulatory requirements of the aerospace industry.

Many requirements need to be considered in the development of modern aircraft cabins. First and foremost, all safety standards must be satisfied. Passengers have come to expect a very high level of comfort and comprehensive infotainment services, the crew needs ergonomic workplaces, and airline companies need fuel-efficient and economical aircraft. This can only be achieved by the continually growing use of electronic modules, in which the various functionalities are implemented in software.

USE AREAS OF CAN

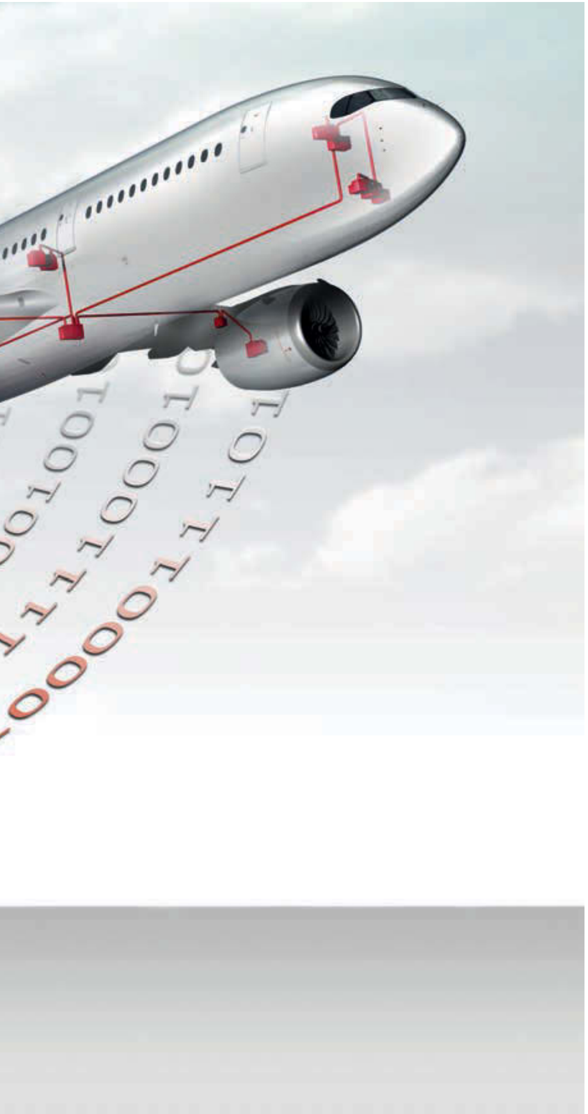
The CAN bus continues to gain in importance in networking LRUs (line-replaceable units) for cabin and aircraft systems. CAN is typically used in the system areas of air-conditioning, doors, fire detection, cabin management, aircraft galley and waste water.

The galley has a number of noteworthy electrical consumers with its refrigeration compartments, convection ovens, coffee makers and trash compactors. However, the amount of electrical energy that can be generated on board the aircraft is limited. That is why an intelligent power management system is used to prevent galley modules from all running at full load simultaneously. The Galley Master Control Unit does this by controlling all galley electrical consumers over the CAN-based Galley Databus. Power management distributes the available electrical energy within milliseconds, so that food and beverage services can run without interruption while not exceeding the defined maximum power consumption limit. The communication system is specified by the ARINC standardization organization and is used in the development of new civil aircraft. ARINC 810 defines the physical interface, while ARINC 812 defines services and protocols for coordination of the galley modules.

GROWING COMPLEXITY

Along with an increase in the number of subassemblies, the number of potential sources of error increases as well. The growing complexity is not only a challenge to development and production, but also to debugging and error analysis efforts. In addition to laboratory tests, wide-ranging flight tests are necessary. Here, the systems are tested, systematically and reproducibly, under the use conditions in which they will later be tested with customers.

These flight test trials are extremely time-consuming and expensive. Airbus, for example, uses five test aircraft to conduct flight test trials and obtain approval for the new A350, and several thousand flight test hours are



conducted. Flight test installations (FTIs) for new aircraft programs are also extensive and complex. However, the initial focus of flight test datalogging is on safety-critical systems such as the Flight Control System and Environmental Control System. Convenience functions in the cabin are not tested until later. The FTI might not log all data, messages and signals of the convenience-relevant systems in their entirety, depending on the specific test strategy. Therefore, it makes sense to utilize additional small, mobile dataloggers. This enables acquisition of the specific and extensive test data that is needed to enable a detailed analysis. The test personnel can look for specific causes of functional errors and evaluate them in relation to specific operating states.

HIGH LEVEL OF REQUIREMENTS

Equipment that is used to test aircraft must meet the especially stringent requirements of the aerospace industry. Above all, they must assure conformance to requirements related to electromagnetic compatibility as formulated in RTCA DO-160E.

The test equipment must operate without any interference, and it must be constructed so that it does not affect systems aboard the aircraft under any circumstances. Furthermore, it must operate safely and reliably even under the extreme temperature and pressure conditions that occur in aircraft. A rugged housing must reliably protect the system from environmental factors such as dust and moisture, even under harsh ambient conditions. The test units must survive high-voltage surges caused by lightning without damage, as well as vibrations that can occur during tests on the runway, in turbine tests or in flight maneuvers. The same applies to the typical acceleration loads and fluctuations in temperature and pressure. The overall system must be designed so that no small parts such as screws or covers can detach and become lost in the airplane. Ideally, a mounting plate should be used to join the test equipment to the airplane. Paint in a signal color makes it easy to recognize which components are part of the test equipment and are not intended for regular operation.

In addition to the mechanical design, the device's electronics must conform to the special requirements of the aerospace industry – they must operate with absolute freedom from interference and must not influence bus communications under any circumstances. Suitable design measures must be taken to insure that the system does not start any activities on the bus, even in the event of hardware or software errors or total device failure. An unpredictable external influence also must not result in any effects on the communication technology. Freedom from interference is tremendously important, because otherwise removal of the test equipment would represent a system modification.

ABOVE: **The GL1020FTE datalogger is a special flight test device that is used to record avionic bus communication**

LOGGING MEASUREMENTS

Vector has more than 20 years of experience in the testing, simulation and analysis of individual control modules, networks and distributed systems in the CAN field. This comprehensive know-how was an ideal prerequisite for developing the GL1020FTE Avionic Logger (above figure). Serving as a foundation was the compact GL1000 datalogger, which has been used successfully in automotive field testing for many years now. It can log two CAN channels simultaneously plus an additional four analog inputs. The ring buffer lets users choose between long-duration logging and event-triggered logging.

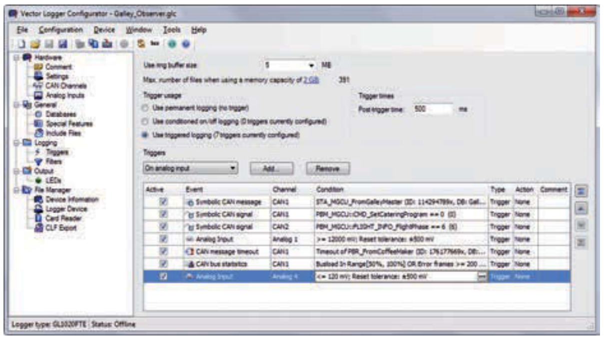
Engineers at Vector intentionally decided to base their logger design on a device series that had proved itself rather than develop an entirely new logger. The GL1020FTE underwent advanced development with regard to its housing, electronics and software so that it would fulfill the especially stringent requirements of aerospace engineering – maximum reliability and a very high level of electromagnetic compatibility (EMC).

The datalogger is equipped with a rugged housing, which was specially developed for use in aircraft, even outside of the pressurized cabin. The datalogger is easy to recognize as a piece of test equipment at a glance because of its RAL 2004 Pure Orange paint color. It is mechanically sealed. A welded Gore-Tex membrane which lets air through but not moisture is used for pressure equalization. The Avionic Logger is designed for ambient temperatures between -40°C and +85°C, and it can be operated up to a flying altitude of 36,000ft. It fulfills aerospace engineering requirements related to EMC. The datalogger itself does not emit any significant electromagnetic noise, and its operation is unaffected by typical ambient electromagnetic interference.

FLEXIBLY CONFIGURABLE

In test flights, the GL1020FTE is installed directly at the point at which the CAN communication should be logged. That may be in the cabin, in the cargo hold or in the wing. Its compact dimensions of 208 x 120 x 37mm, including assembly plate, allow the device to be installed in even the tightest of spaces.

The Avionic Logger can simultaneously log two CAN channels and up to four analog inputs. Simultaneous means time-synchronous, so that the user can directly evaluate the time relationships between different events. Vector offers various software tools for this purpose. The logger works on Layer 2 of the CAN protocol and can also acquire error frames, bus load and bus timing (time sequence of messages). The baud rate and the CAN channels to be logged are parameterized as fixed values. The logger has a maximum start-up time of 300ms to ensure that all data is acquired from the start. To save data, the logger has a permanently installed SD (HC) memory card with 8GB of memory, or it can be equipped with memory for storage of a maximum 32GB.



LEFT: Setting up trigger conditions in the Vector Logger Configurator

The data is logged either continuously or event-triggered. Continuous long-duration logging is used if an entire process needs to be acquired, or if sporadic errors have not yet been localized. This type of logging results in larger volumes of data. In event-triggered data acquisitions, the user defines extensive filter and trigger conditions. In this method, the data is acquired continuously and is constantly written to a ring buffer until the defined event occurs. The user can define the size of the ring buffer and the action to be executed when the trigger event occurs. If this action is to immediately close ring buffer and save its data, then the saved data, which is available for later evaluation, precisely matches the data stream up until the trigger event. If a post-trigger time was parameterized, the signals in the ring buffer are logged after the trigger so that data before and after the trigger time point is saved. Writing to the ring buffer is continually repeated until the next trigger event. This logging principle reduces data volume significantly compared with continuous logging.

User-defined states can be indicated directly on the device by four configurable status LEDs. The logger has four analog inputs for acquiring analog values such as temperatures. They are led to a plug connector and have an input range of 0-16V. The maximum sampling rate is 1kHz.

The GL1020FTE is configured using the Vector Logger Configurator (above figure). This user-friendly software can be run on any standard Windows computer. Its connection to the logger is via a USB 2.0 interface. The user can quickly and easily configure logging tasks with triggers, filters and ring buffers using the configurator's graphic user interface. CAN identifiers, symbolic messages and signal values may be selected directly for use as filter and trigger conditions. The Logger Configurator also supports CANdb databases. CANdb has become established as a de facto standard that is broadly used for symbolic description of communication relationships in a communication matrix. The user can work much more efficiently with plain text names and symbols than with cryptic byte values. The data can be read out over the connection to the logger and be converted to different formats, for example BLF, ASC and MS Excel. Various analysis tools such as CANoe, CANalyzer, CANape and CANgraph from Vector, as well as suitable solutions from third-party suppliers, may be used for offline evaluation of the logged data.

The datalogger is supplied with 28V DC over the electrical system and is designed for voltage peaks of up to 33V. In addition, it can buffer voltage drops lasting as long as 200ms, such as those that typically occur when switching over the aircraft's systems from ground power to the generator of the auxiliary turbine (auxiliary power unit). Specially developed for use in aircraft, the datalogger works autonomously in the background, and it does not require any test personnel to be on board to operate it. Together with modern analysis tools, it lets engineers perform efficient error analysis, and it supplies feedback for further development steps. ∎

ABOVE: Simple observation of the data traffic and comprehensive network analysis with CANoe.CANaero

Dr Arne Brehmer and Dr Carsten Kellner are from Vector Informatik GmbH, based in Germany

GARY MUZZEY

THE HEAT IS ON

One company has studied the importance of open-coil technology for effective high-temperature testing for aviation and aerospace

BY GARY MUZZEY

High-capacity electric 'in-line' air heaters, as an integral part of a compressed air system, are used throughout the aviation and aerospace industry for R&D simulation of the high-temperature and high-pressure conditions produced by an aircraft turbofan compressor. Open-coil electric heaters provide the optimum heating solution for rig testing as compared with traditional sheathed (tubular) heating elements.

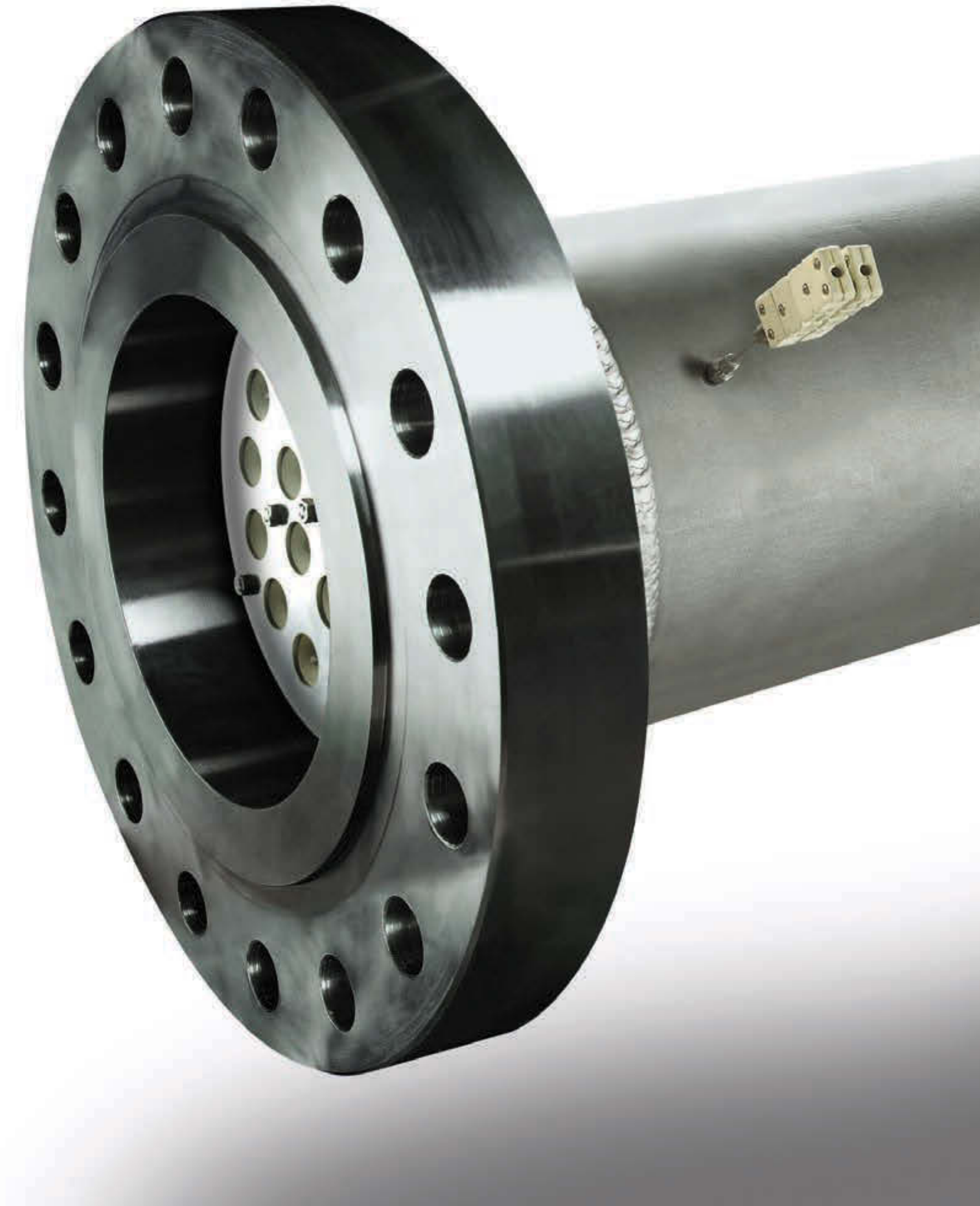
A turbofan engine's compressor stage generates the high-temperature and high-pressure air that directly feeds the internal combustion process, and indirectly feeds the environmental control systems via high and low 'bleed' ports in the compressor stages. These environmental control systems use a system of air cycle machines (ACMs), flow-control valves and heat exchangers, to provide a clean pressurized cabin air environment for passengers.

TRADITIONAL HEATER TECHNOLOGY

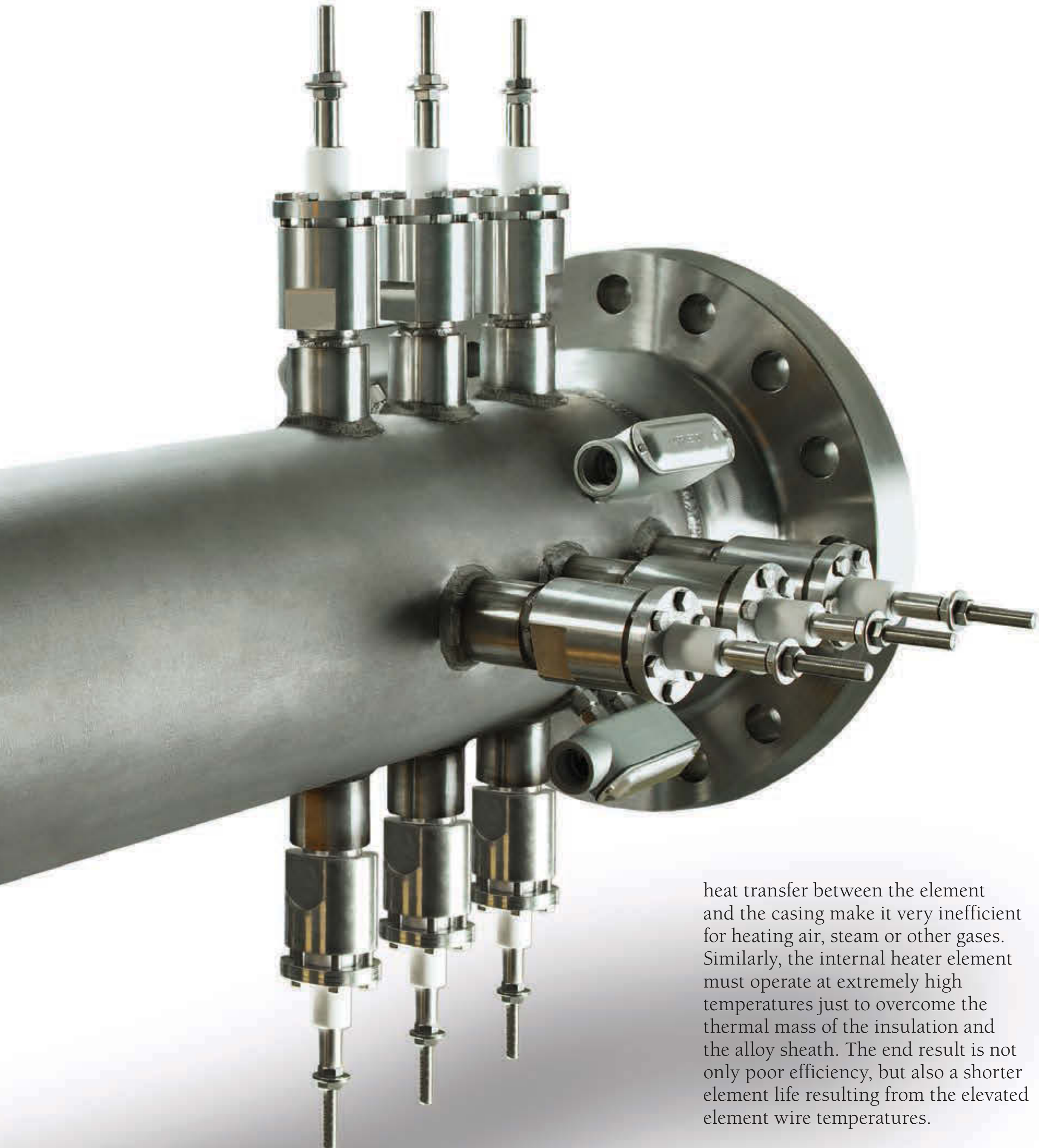
Manufacturers of turbofan engines, ACMs, flow-control valves and other auxiliary equipment need a compact, efficient and controllable system to provide pressurized hot air to enable their development of new products. Similarly, FAA-certified repair stations also need this capability to provide pass/fail testing as part of the routine service and repair work on the ACMs, valves and other components, which is necessary to extend the operating life of aircraft.

Historically, the aviation industry used sheathed element electric heaters to heat the compressed air for testing (Figure 2). The iron alloy (FeCrAl) resistive heater element is a wound helical coil encased in an insulation material, typically magnesium oxide, which in turn, is encased in a steel alloy tube (Incoloy, etc). This basic construction is very similar to what you would find on an electric stove/cooker element.

This protective construction surrounding the heater element is ideal for heating liquids or corrosive gases, but the high thermal mass and poor



"THE DEMANDS OF AVIATION AND AEROSPACE CUSTOMERS ARE MORE CRITICAL THAN THOSE OF OTHER INDUSTRIAL CUSTOMERS"



ABOVE: Sylvania in-line heater, 10in diameter, 400kW

© P.I.Corp

heat transfer between the element and the casing make it very inefficient for heating air, steam or other gases. Similarly, the internal heater element must operate at extremely high temperatures just to overcome the thermal mass of the insulation and the alloy sheath. The end result is not only poor efficiency, but also a shorter element life resulting from the elevated element wire temperatures.

OPEN-COIL TECHNOLOGY

In contrast, the preferred solution for air or gas heating is to use an open-coil heater (Figure 3), which allows the airstream to make direct contact with the element, greatly improving the heat transfer. There are several advantages:
• The heating element actually operates at a lower temperature to produce a given air temperature. The result is improved element life due to less thermal stress on the heater wire;
• The safe maximum process air temperature can be much higher while maintaining the long life of the element. This gives more operating flexibility in the demanding test conditions typical of aerospace and aviation;
• The time to reach operating temperature and/or cool down the heater during a typical operating cycle is much shorter, enabling much more productive use of the heating equipment, under more flexible and dynamic operating conditions;
• The higher watt density in an open-coil heater allows for a much smaller overall package, reducing weight, floor space and the need for heavy rigging equipment to install and service the unit.

CONTROL METHOD

Open-coil heaters require faster-responding control systems for safe operation. This can easily be achieved with modern power- and temperature-control systems. Key components to a good control system include the use of a phase-angle-fired or burst-fired (zero crossing) SCR power controller, PID loop temperature controller, and high-limit safety devices. These control systems can be easily configured for remote or local operator access. Figure 4 shows an example of a typical control setup for a Sylvania in-line heater with open-coil elements.

In this configuration, one K-type thermocouple probe is used for process temperature control, while another separate probe is used for a high limit. At the heater inlet is a flow-sensing device to ensure the system does not operate unless a minimum flow rate is achieved through the heater. The combination of these devices ensures a safe, reliable system.

APPLICATION TO AEROSPACE INDUSTRY

Larger open-coil in-line heaters are commercially available to handle the extremely high pressure and flow requirements needed by the aerospace industry. For example, air mass flow rates as high as 100 lb/min (1.7 lb/sec) can be heated to 1,000°F (538°C) using the 400kW Osram Sylvania heater (Figure 1), at pressures up to 300psi and beyond. The compact 10 x 60in pipe is easy to install into existing compressed-air lines and can be positioned much closer to the test articles. By placing the heater indoors and close to the test article, the system is much more convenient and accessible, and the heat losses and start-up time are greatly reduced.

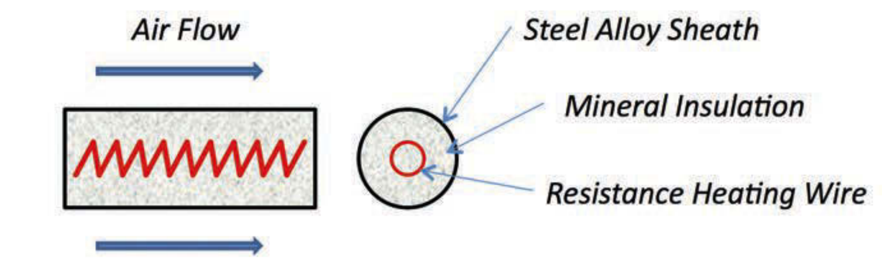


FIGURE 2: Sheathed element

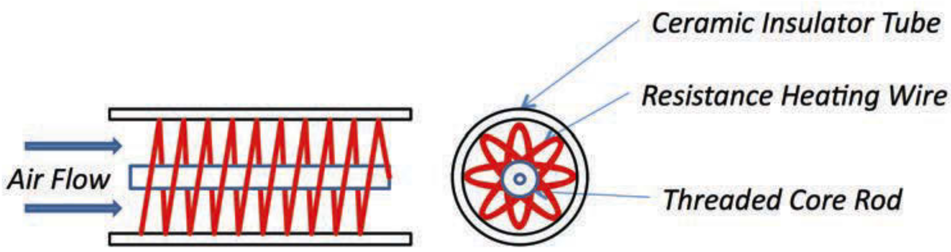


FIGURE 3: Open coil element

SIZING AND SELECTING AN OPEN-COIL HEATER

A number of considerations must be given to sizing and selecting an open-coil heater. Of primary importance is specifying the temperature rise needed across the heater, and the air mass flow. A simple formula for sizing the heater power is given by:

$$kW = SCFM \times (Delta\ T)/3000$$

where SCFM is the mass flow-rate in standard cubic feet per minute, and Delta T is given in °F across the heater. When determining the temperature rise across the heater, the customer should take into consideration the heat losses that occur between the heater and the test point. This may require a higher heater temperature to reach a desired process point temperature.

The next step in selecting a heater is to know the maximum static pressure to which the heater will be subjected in order to correctly specify the pipe and flange material. Depending on temperature and pressure conditions, the materials can vary from common 304 stainless steel to aircraft-grade alloys, which is a major driver in the overall unit cost.

Below are some features to indicate when specifying a heater unit:

• Required temperature range – typical Sylvania open-coil electric heaters can produce up to 1,400°F (760°C) in standard designs and 1,652°F (900°C) in custom designs;
• Pressure ratings – typical electric heaters can withstand up to 600psi (40 bar) standard and up to 1,100psi (75 bar) in custom designs;
• Code requirements – for US customers, either ASME Section VIII Div. 1 or B31.3 (process piping);
• Code requirements – for EU customers, Pressure Equipment Directive (PED) certification;
• Special control requirements;
• On-site start-up assistance or training.

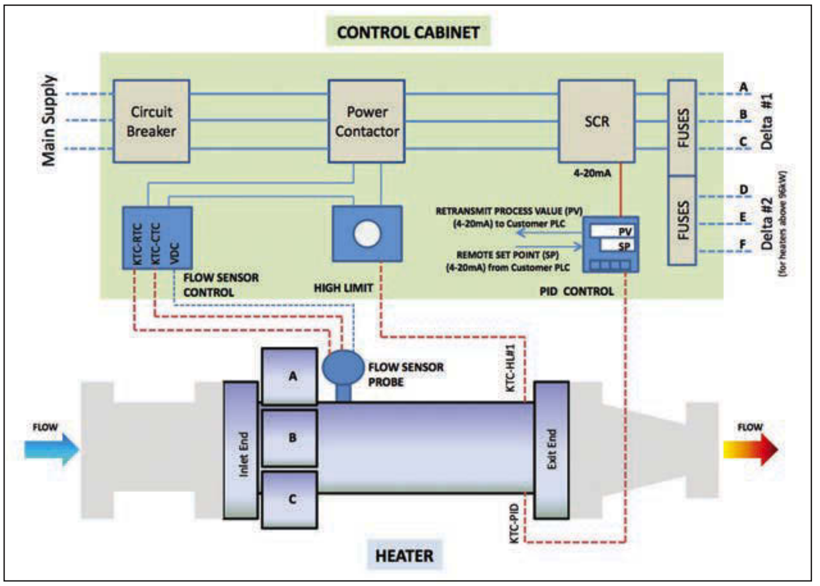


FIGURE 4: Air heater control system

The demands of aviation and aerospace customers are more critical than those of other industrial customers. So when selecting a new heater system, it is essential to select a partner who has the right products and experience for the job.

Gary Muzzey is the principal engineer with Osram Sylvania Products, based in Exeter, New Hampshire, USA

PHILIPPE
KREBS

ACCELERATE AEROSPACE MARKET

MEMS accelerometers are making a big impact in a number of areas, including the automotive and consumer markets, but are also increasingly seeing implementation in high-end military and aerospace applications

BY PHILIPPE KREBS

In the majority of cases, the development of successful products is driven by high-end requirements, very often issued from the military and aerospace markets, before being spread into more standard volume applications. How many revolutionary products are the result of aeronautics or spatial development?

The success of MEMS is following a contrary path. MEMS motion sensors were first developed and accepted for general industrial applications before being introduced into high-end markets. The driver of this technology toward success has been the ability to produce repetitive performance at very high volume (batch manufacturing), at well controlled costs for competitive pricing compared with traditional solutions. All these products are considered standard COTS (commercial-of-the-shelf) items.

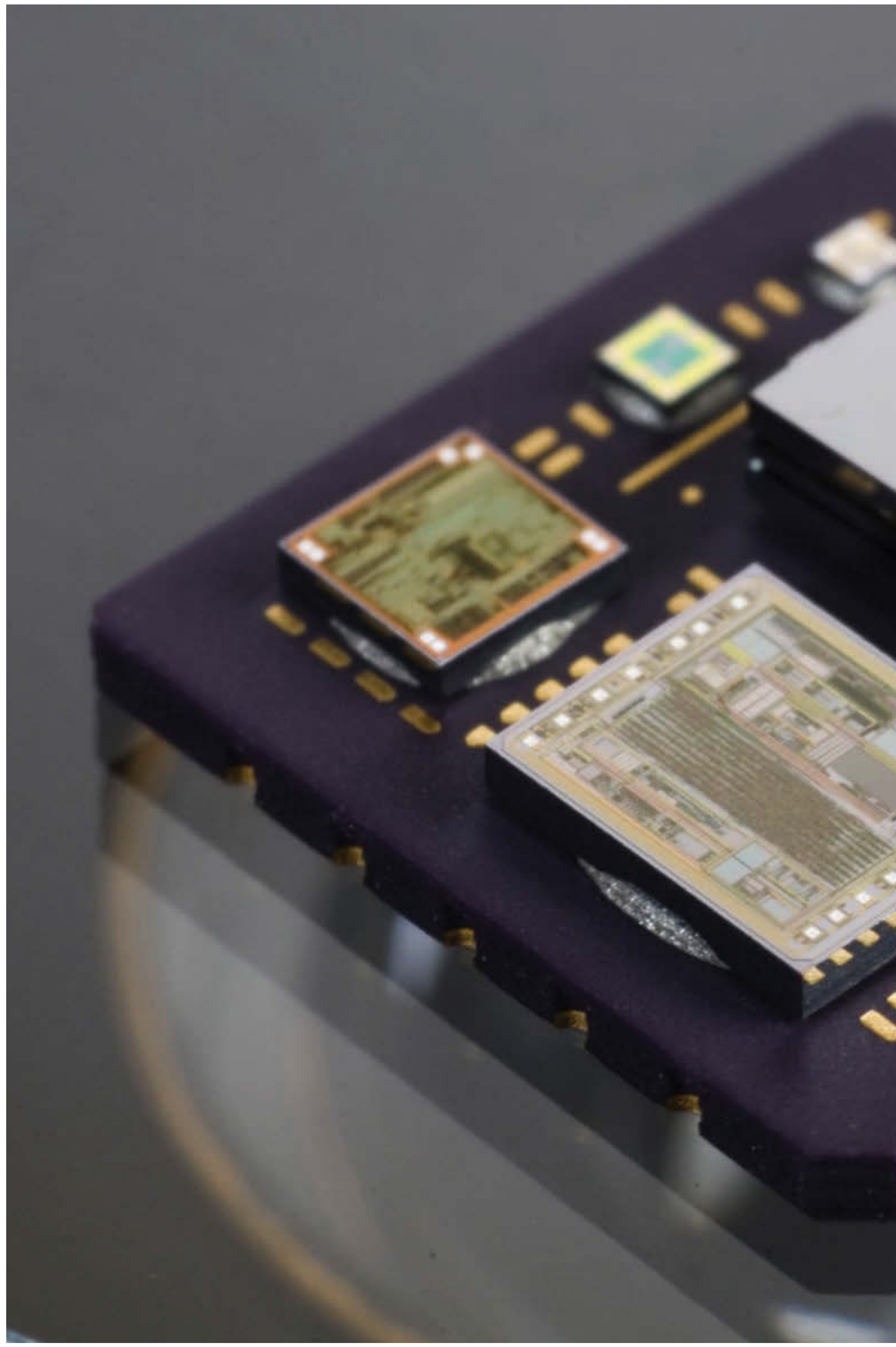
MEMS MOTION SENSORS FOR AEROSPACE TESTING

On top of these advantageous characteristics, MEMS motion sensors offer features such as the ability to withstand harsh environments and very high reliability.

As a consequence, advanced markets are keen to benefit from these COTS products and integrate them into high-end applications. This is especially true for military and aerospace companies that see an opportunity to benefit from the advantages of the technology in their mid- and high-volume applications and programs. Replacing fragile, expensive, large and power consuming electromechanical accelerometers or optical gyros with MEMS solutions is considered an advantage and is even opening doors for innovative applications.

TECHNICAL QUALIFICATION AND DEVELOPMENT

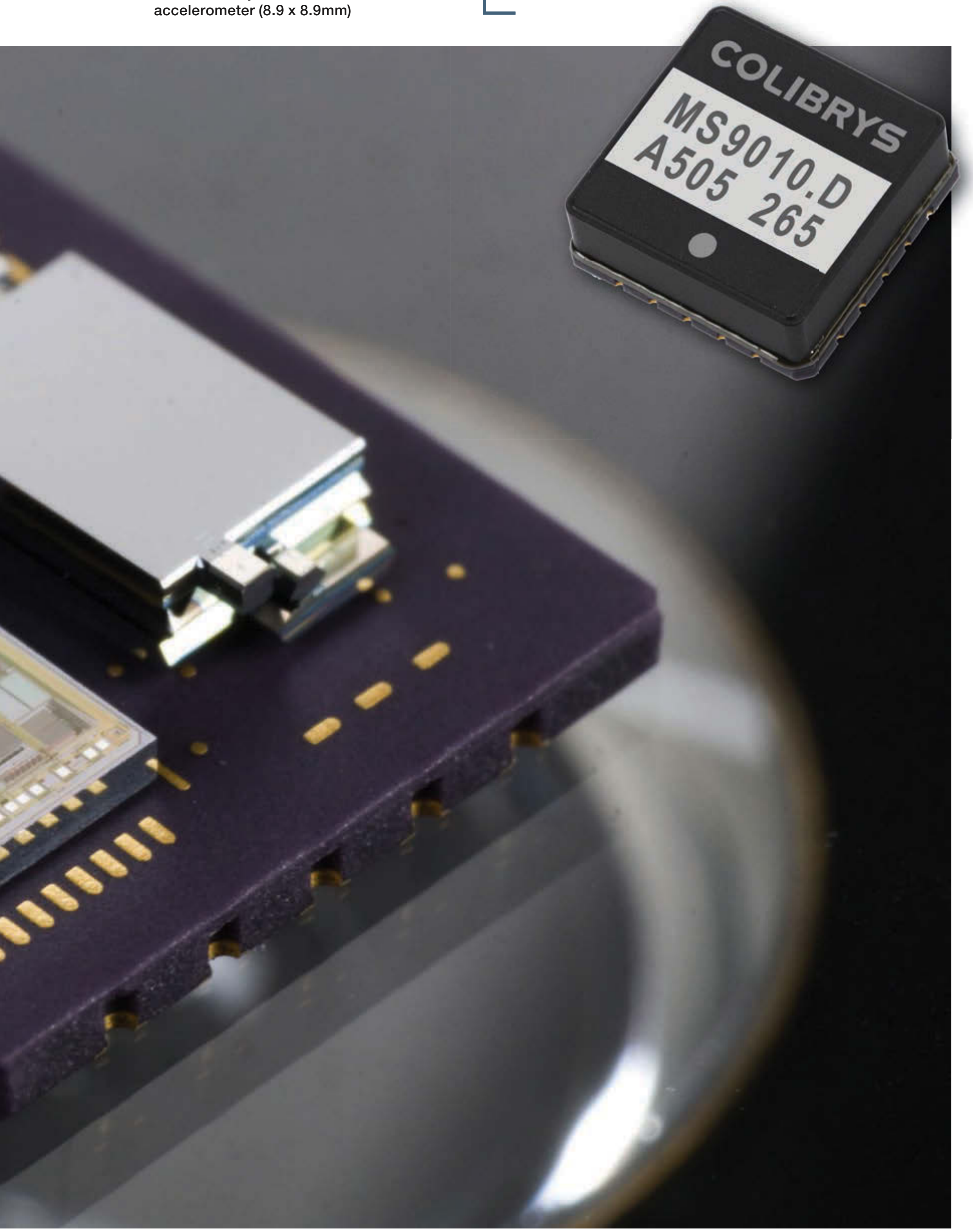
Qualification of an accelerometer for industrial applications is generally less demanding and less complete than full qualification for a military/aerospace product. The specification is simpler, some parameters are just not required and the temperature range is generally reduced. This means that the selection



> "THE SUPPLIER OF MOTION SENSORS FOR MILITARY/AEROSPACE APPLICATIONS MUST BE READY TO RESPECT STRICT RULES IMPOSED BY THE MARKET OR THE APPLICATION"

BELOW: Open view of a Colibrys MEMS capacitive accelerometer (MS9000 family)

INSET: Colibrys MS9010.D MEMS accelerometer (8.9 x 8.9mm)



of a COTS product for a military/aerospace application is accompanied by complementary requirements that impose extra qualification work, extra commitments and consequently extra risks for the supplier.

Qualification of a product for some advanced applications is sometimes only possible if special care has been taken during the original development.

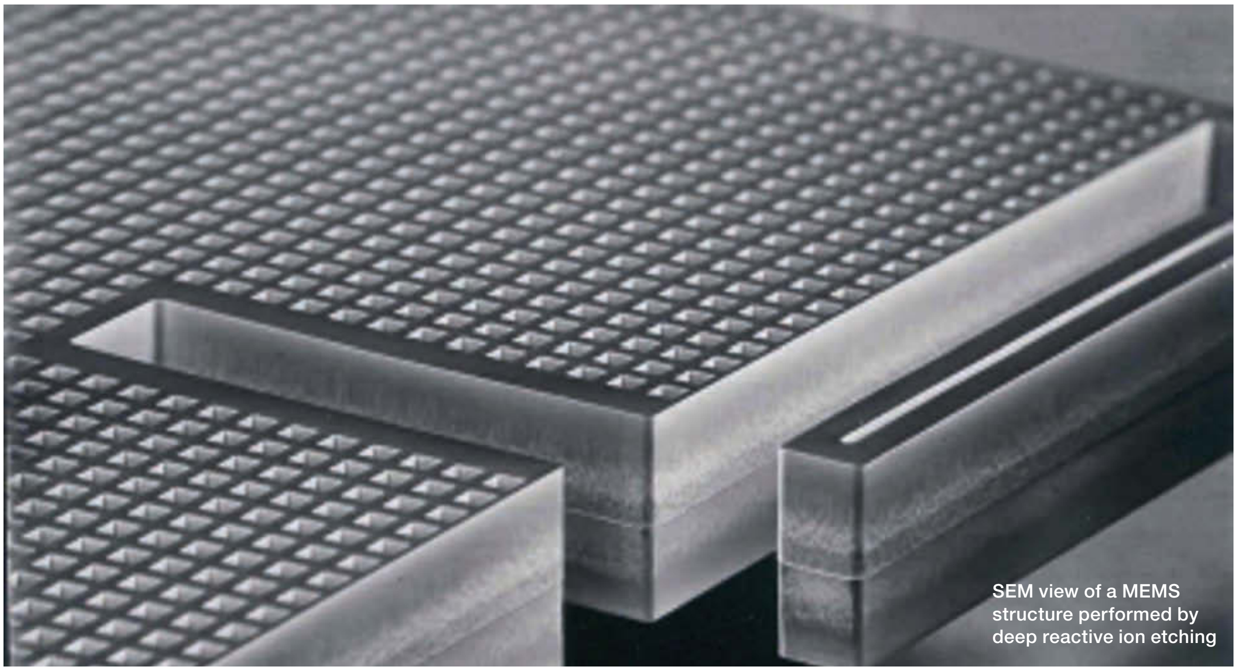
A typical example is DO178 certification. To conform to this software requirement specification, the product development has to adhere to a strict process. Such requirements cannot easily be achieved retroactively and can simply prevent a user from selecting a COTS accelerometer.

BUILD STANDARDS AND COMMITMENTS

Choice of materials and the quality of selected components can affect the compatibility of a motion sensor to an application. Traditional, simple and low-cost plastic packaging, largely used for high-volume solutions, is not compatible with military/aerospace applications that require hermetic sealing to protect the sensor against humidity and ensure long-term reliability. The compliance of the packaging and sealing process with MIL standards and the selection of ceramic or metallic packaging can be mandatory for the qualification of high-end motion sensors.

The supplier of motion sensors for military/aerospace applications must be ready to respect strict rules imposed by the market or the application. The quality system in place must ensure full traceability of the product and long-term storage of test data. The company must also sometimes commit to long-term supply that can easily exceed 10 to 20 years and, even more importantly, guarantee that once qualified, the product will remain unchanged. This last requirement is probably the most critical as it imposes conditions on the supplier that restrict its freedom to change the product, even for better performance.

The Swiss company, Colibrys, designs, develops, manufactures and sells MEMS accelerometers to



SEM view of a MEMS structure performed by deep reactive ion etching

a wide range of markets and is recognized as a world-leading provider of high-performance accelerometers. Its proprietary standard high-performance MEMS-based products are developed for selected niches in high added-value markets, focusing on applications requiring high-precision and high-reliability measurement of acceleration in harsh environments.

Even if products are initially developed for industrial applications, they are targeting high-end applications, so special care is taken during the development and qualification of Colibrys COTS products to make them much more compatible with military/aerospace requirements.

The company's MEMS accelerometers are specifically developed to meet high-end performance by design and not through expensive and time-consuming screening or selection. They are produced in medium volume (a few hundred thousand per year) in a well-controlled manufacturing environment, ensuring high yield for repetitive advanced performance.

COTS PRODUCTS FOR ADVANCED APPLICATIONS

Colibrys standard accelerometers are classified as inertial, tilt, seismic, vibration and shock sensors. They are proposed as high-end COTS products and have been selected and qualified for advanced requirement applications in the military/aerospace, instrumentation and energy markets, even if the systems were initially developed for high-end industrial applications for other industries.

INERTIAL PRODUCTS AND APPLICATIONS

Very precise measurement of acceleration and rotation is key to determining accurately, and without external reference, the position, orientation and velocity of a moving object. The principle finds interesting civilian applications such as GPS back-up, guidance and navigation in agriculture, guidance of blind people, and positioning of rescuers in mines or burning buildings.

Colibrys products (MS8000, MS9000, HS8000 and the latest RS9000) have been successively qualified in military/aerospace for inertial measurement units and attitude heading reference systems for high-precision guidance and navigation in the air, on the surface of the earth or under water.

TILT PRODUCTS

Accelerometers are extensively used as tilt sensors or inclinometers to determine slope, elevation or 'the depression of a reference plane' with regard to gravity. The first MEMS tilt sensors have been initially qualified for drilling applications – more precisely MWD/LWD (measurement/logging while drilling) – where their robustness under harsh environments can clearly make a difference compared with traditional solutions.

Tilt – or pitch and roll – indicators have also been successfully qualified for high precision platform stabilization (antenna, camera, radar), automatic gun stations and range finding, where MEMS sensors (MS9001, MS9002 and the latest RS9002) differentiate themselves through their resolution and absolute accuracy (or combined total error), taking into consideration linearity, hysteresis and stability under environmental conditions (vibrations, shocks and temperature).

VIBRATION APPLICATIONS

Precise and stable vibration measurements are required in many applications. The aim of these wide dynamic measurements is to assess a modal shape and its stability or to monitor and measure a given vibration level to be able to reduce its impact and improve comfort, increase durability or anticipate preventive maintenance in the fields of research, development, production or test. A large number of industrial machines, as well as large constructions such as bridges, building and dams, are equipped with vibration or shock sensors that enable the structure to be monitored and provide warning for preventive maintenance.

These same sensors (VS9000) are also good for measurements in civilian and military aircraft, helicopters, land vehicles and submarines, enabling the precise assessment of vibrations.

MEMS technology and MEMS products offer great competitive advantages to large number of markets and are enablers of some incredible industrial revolutions. There is a great opportunity for high-end markets, such as military/aerospace, to integrate this technology and benefit from the financial and technical advantages.

Colibrys has moved into this area to become a provider of high-performance COTS accelerometers, bridging the gap between non-compliant, low-cost standard products and expensive custom solutions for advanced applications. ∎

Philippe Krebs is the product line manager for inertial products at Colibrys, based in Switzerland

JOHN VUKELICH

PRESSURE TESTING TUBULAR SYSTEMS

With so many space restrictions on aircraft, which connection method is actually the best?

BY JOHN VUKELICH

Modern aircraft use tubular systems for conveyance of fuel, hydraulic fluid, water and air. Typically, a system contains tubes, connectors and control-related components. As such, these systems are frequently tested after assembly to ensure that all connections have been properly made. Often, they are pre-assembled somewhere on the aircraft, which can create space restrictions for performing the tests. So what are the best ways to connect test apparatus to these assemblies for leak and proof tests?

LEAK/PROOF TRIALS

Leaks in assemblies can be detected by performing a leak test using an instrument measuring very small pressure changes. Helium or hydrogen is normally used because their small molecular size enables the gas to escape even the smallest leak path. In a pressure decay test, the assembly is pressurized higher than atmospheric level, and the instrument monitors the assembly for any decrease in pressure over time. Conversely, a vacuum decay test would involve pumping air from the tube assembly below atmospheric level, and monitoring for any pressure rise that occurs over time. An alternative to pressure monitoring is a trace gas monitor, or 'sniffer'.

This device can monitor leak rates, as well as help identify the location in the assembly where a leak is occurring. It is critical that the method used to connect tube assembly to pressure source does not create a leak path at that connection point.

Proof testing is carried out to ensure that a tubular assembly will perform properly when at, or even above, its planned working pressure. Since working pressures of 4,000psi (276 bar) are common in aircraft, proof testing above that value is required. Liquids and inert gases are used for this type of testing. Safety is a greater concern at higher pressures, so the connection method chosen must remain secure during testing.

Typically, the pressure source and instrumentation used for testing are somewhat portable, and can be brought near the tubular assembly. In some cases, the tubular assembly may be tested before installation on the aircraft, and this may allow bringing the assembly to the pressure source. In any case, the pressure source ends up near a termination point in the tubular assembly.

Two methods of connecting this source to the tube end are prevalent today, and both should be considered. The first is a single-use swage fitting that seals and holds the tube by mechanically driving into the outside diameter of the tube during assembly. The second method is a multi-use hydrostatic testing tool, which seals the outside diameter using an elastomeric part, and grips the outside diameter using a segmented collet.

EVALUATING METHODS

Choosing the best connection method involves evaluation of many factors. Is the tool or fitting compatible with test media and pressure requirements? Will the user have enough space to make the connection? Is it safe and easy to use? What is the total cost of this connection method?

Swage fittings are compact, readily available and inexpensive. They are compatible with most test media, and provide a reliable seal that can

> **"HYDROSTATIC TEST TOOLS ARE MULTI-USE DEVICES THAT CAN SEAL AND CLAMP ON A TUBE WITHOUT CAUSING ANY DAMAGE TO THE TUBE END"**

ABOVE LEFT: **Sample tubes with end features**

ABOVE RIGHT: **Tube with swage fitting: the cut-off end is discarded and the remaining tube requires rework**

accommodate pressures up to 10,000psi (689 bar). Installing them on a tube end usually requires wrenching or an assembly tool, but can be done in only a few seconds by an experienced user. When the tube end is in a confined space, attention must be paid to whether space is available for using the assembly tools. Assembling this fitting does cause permanent deformation of the tube's outside diameter, and this is the biggest disadvantage. That tube end must be cut off after testing is complete, which creates scrap and the possibility of introducing foreign matter into the tube. The newly cut off tube end also needs to be reworked before further use. Because of these extra steps, the total time involved can be substantial, as is the time in which the tubular assembly is not capped off.

Hydrostatic test tools are multi-use devices that can seal and clamp on a tube without causing any damage to the tube end. This eliminates the tube rework step, which saves time, reduces scrap and avoids foreign matter. After testing, the tube is ready for final assembly. These tools are very easy to use, and can be connected to the tube in approximately one second, without any other tools needed. They are simple to slide onto the tube end, and an internal spring makes the collet pre-grip the tube, holding the tool in place until testing begins. The elastomeric component provides a leak-free seal, and the collets grip securely at any test pressure because the tool is designed to increase grip force in proportion to increased test pressure. A disadvantage of hydrostatic test tools is the larger size compared with swage fittings. They also have higher initial cost, and are not as readily available as swage fittings.

COST CONSIDERATIONS

Both the tools and fittings are available in many sizes to match the various tube diameters used throughout the aircraft. In order to test every tube assembly used on the aircraft, there will likely be several sizes of hydrostatic test tool or swage fitting that must be purchased and made available for the testing program. If there are several different tube assemblies on the aircraft using the same diameter tubing, then a single hydrostatic test tool can be used in many locations, therefore making it a more cost-effective choice.

With all the various tool and fitting sizes, another consideration is how those connectors attach to the pressure source. The pressure source will have a hose on its outlet, and that hose has some type of end fitting. Is that fitting compatible with the inlet end of hydrostatic test tool or swage fitting? Can it be quickly attached and detached when changing sizes? A quick disconnect coupling can be used to speed up changeover between different-sized hydrostatic test tools. Add it in-line at either end of the pressure hose, and size changes can be done in seconds.


Hydrostatic test tool with plain tube connected to hose and quick disconnect

END FEATURES

Tubes with plain ends are the most prevalent, but sometimes tube assemblies have a termination with a bead, flange, or other feature. These features present challenges for gripping and sealing. Standard swage fittings and hydrostatic test tools are designed for plain-end tubes, but a custom design may be possible for tubes with termination features. Hydrostatic test tools have been built that seal on the tube inside diameter or end face, and grip on or beyond the termination feature.

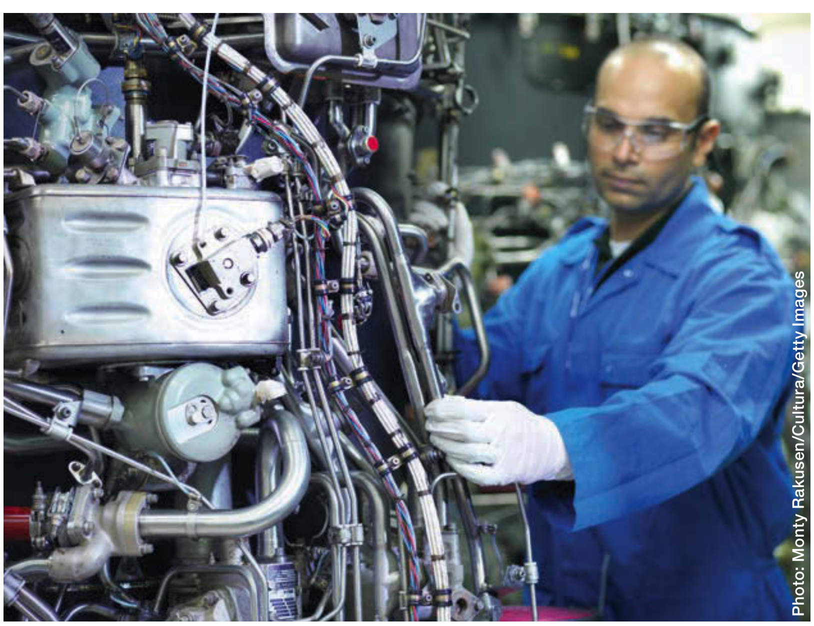


Photo: Monty Rakusen/Cultura/Getty Images

Aircraft have a large number of tubular systems, and since each system is unique, it should be evaluated separately. After this is done, it should become apparent whether a hydrostatic test tool or swage fitting is best suited for each location. There may even be a situation where something other than these two common connection methods makes the most sense. The key to determining the preferred connection method is to look at all the factors involved, and determine which best meets the requirements for safety, reliability, ease of use and total cost. ∎

John Vukelich is a mechanical engineer with Airmo Inc Pressure Technologies, based in the USA

JASON ROBBINS

CRITICAL COMPONENTS

Using x-ray images to non-destructively test engine turbine blades has been proven to be an essential tool

BY JASON ROBBINS

Most would agree that manufacturing a modern jet engine is a challenging task. These machines are constantly evolving, and are required to be more fuel efficient, lighter in weight and more powerful, while becoming quieter and cleaner for the environment. This is an extremely difficult combination to achieve.

A critical part at the heart of these amazing inventions is the high-pressure turbine blade (HPT). These are specially cast, nickel-based superalloy parts designed to operate in an environment hotter than their own melting temperature. These parts are located in the most hostile area of an aircraft engine, and it is not any easier for the surrounding blades in the low-pressure and compressor areas.

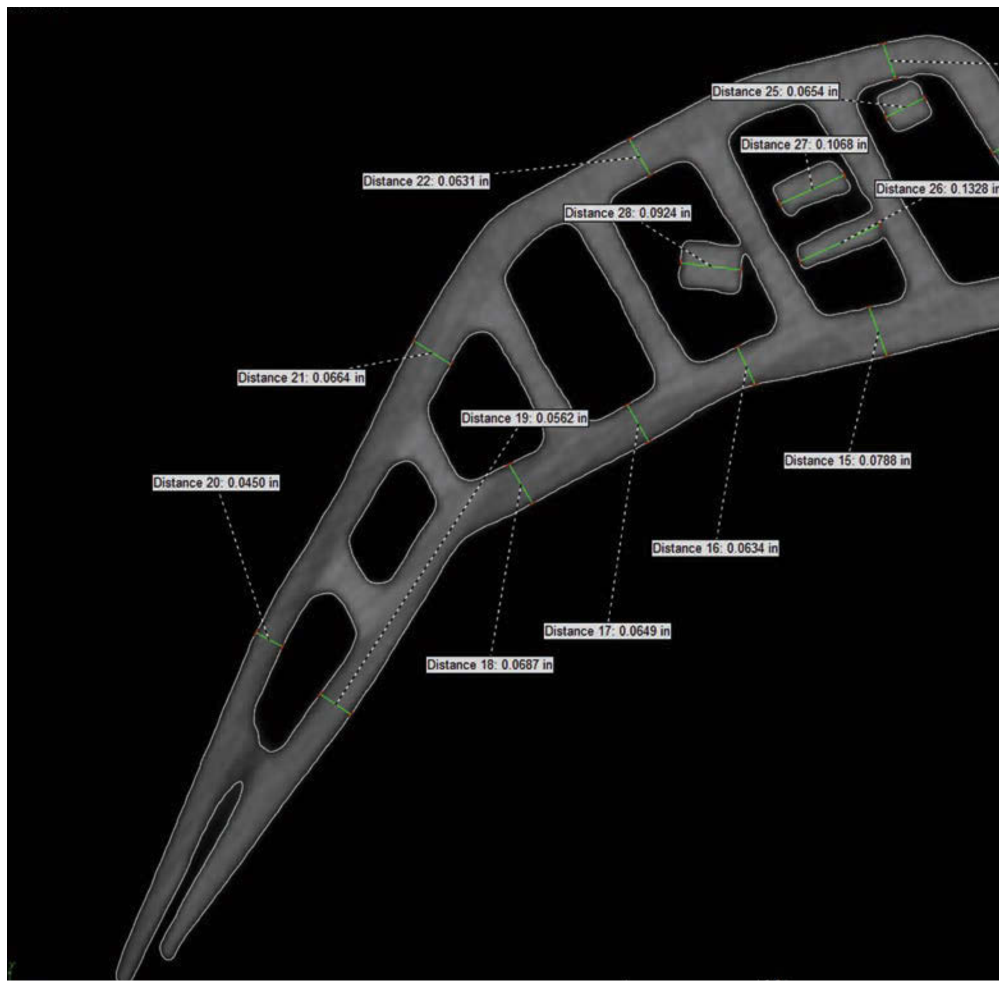
Special manufacturing techniques such as directional solidification and single crystal production methods (combined with sophisticated cooling designs, turbulators and coatings) enable these parts to survive in this brutal environment, all the while spinning at tens of thousands of revolutions per minute.

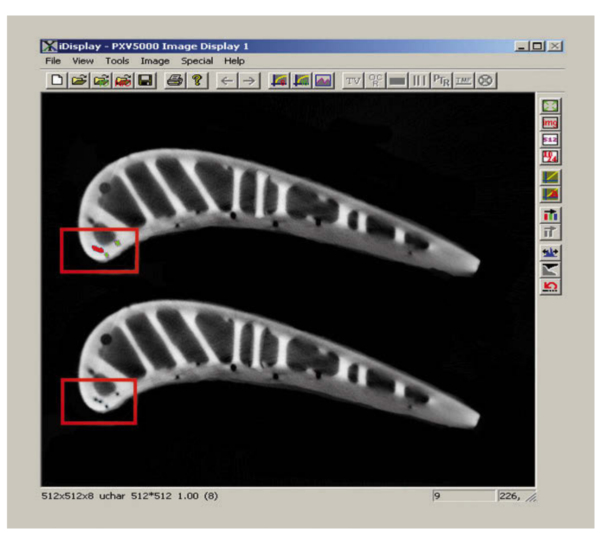
As with most complex, safety-critical parts, the more daunting the manufacturing task, the more vital the testing process. Failure of these parts while in service is not an option. These are intricate castings subject to porosity, cracks, inclusions, shrinkage, gas holes, etc, and vulnerable to challenges in machining such as merged holes and over-shots in the laser drilling process.

X-RAY TECHNOLOGY

Destructively testing the critical inner structures of these parts is an option; however, it requires large sample sizes, is time-consuming, is expensive, and cannot be accomplished on 100% of the parts. It is just not practical in most cases.

Using x-ray technology to non-destructively test these parts has been proven to be a valuable tool and a viable option for many years. X-ray images allow inspectors to validate and control the manufacturing process, verify dimensional requirements





ABOVE: Defect analysis and wall thickness measurement in a CT image according to MAI

LEFT: Automatic defect recognition in a 3D CT image

FAR RIGHT: picture of the object and X-ray image with HDR (highly dynamic radioscopy) technology

(before and after machining), and also enables them to check welding quality for in-service maintenance procedures.

Conventional x-ray film and computed radiography (CR) methods have been historically acceptable solutions, but have limitations in the production world. The higher costs, environmental disposal concerns, and availability of film are the first hurdles. Longer inspection times associated with the manual nature of both inspection types, along with the complex workflow and processing time/effort for the films or imaging plates, can make these manual solutions cost-prohibitive. This is especially true when higher volumes are required.

Recent changes within the world of digital radiography (DR) have provided an alternative to x-ray film and CR, giving manufacturers a chance to appreciate superior inspections coupled with significant cost savings.

Aside from the fact that many digital panel providers, system integrators, and even the x-ray tube manufacturers have all advanced their capabilities in the x-ray inspection arena, it was the acceptance of the industry's leading manufacturers and standard organizations that actually paved the way for the integration of this technology. Most of the world's leading aircraft and engine manufacturers have joined together to help draft standards to ensure the proper use of this technology. ASTM, MAI (metals affordability initiative), Nadcap, etc, all have relatively new standards and best practices designed to ensure the correct implementation of the system.

BLADE TEST SYSTEMS

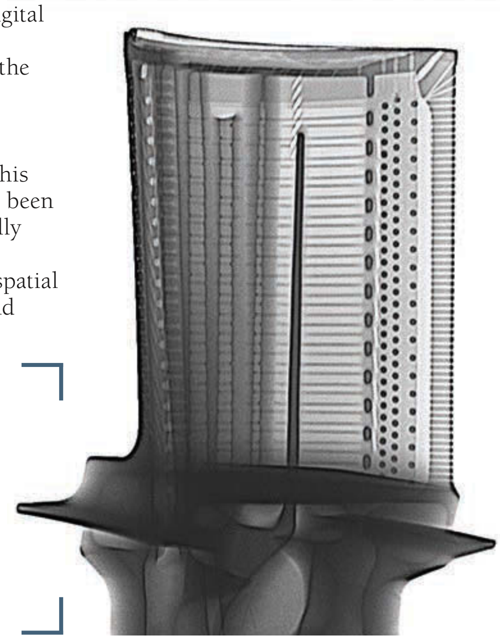
Several x-ray system providers have already offered a variety of solutions to turbine blade and engine manufacturers to ensure the integrity of this critical component. For instance, Yxlon has installed several types of x-ray inspection systems utilized in various steps of engineering and production. These include inspecting the wax molds used in the manufacturing process of turbine blades, standalone manual x-ray systems installed to help analyze the castings in real time, and computed tomography (CT) systems enabling R&D to visualize/measure the internal details of these parts in 3D.

Even complex robotic systems designed for the required speeds and strict demands of high-volume production have been implemented in several locations.

These existing systems are designed to handle these complex x-ray requirements, and as a result of standardization efforts in the aerospace industry, they are now routinely accepted by all the top engine and aircraft manufacturers.

These standards have also been designed to allow images generated on any supplier's system to be archived digitally in DICONDE format (Digital Imaging and Communication in Nondestructive Evaluation), and the images can also even be shared between systems provided by competing companies.

To facilitate the transition to this digital world, software tools have been designed and built to automatically measure and ensure acceptable imaging parameters – including spatial resolution, contrast sensitivity and



"SOFTWARE TOOLS HAVE BEEN DESIGNED AND BUILT TO AUTOMATICALLY MEASURE AND ENSURE ACCEPTABLE IMAGING PARAMETERS"

signal-to-noise ratio (SNR). These are all critical measurements of image quality and acceptability. Measuring and monitoring these parameters is required by industry standards, and automated reports can be generated easily to comply with the appropriate ASTM standards that ensure compliance.

Now that all this technology is readily available, the next challenge is to measure its value, and then consider how to manage its integration into a production facility.

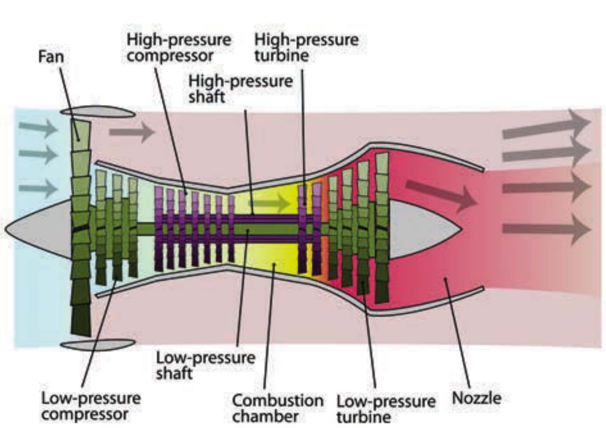
ECONOMIC FACTORS

The calculation regarding the return on investment (ROI) is normally straightforward, and most often results in the conclusion that film replacement is a clearly attractive and cost-effective solution. When film, chemicals, disposal and significant labor costs are virtually eliminated, the investment can quickly make sense. For example, a large aerospace component manufacturer realized an ROI of less than one year with its automated DR production system, but in the end this wasn't the biggest challenge – it was the actual implementation and end-customer acceptance that posed the most difficulty.

For many early adopters, the highest hurdle turned out to be the final implementation of this new technology into their existing processes and production environment. This included considerations for digital x-ray training and experience hours for the Level 3 radiographers, developing new digital techniques for their parts, achieving compliance with industry standards and customer specifications, acquiring Nadcap acceptance for their new procedures and systems, and then negotiating through the final customer approval process. Now, with these hurdles better understood, a solid plan for integrating this latest technology can be constructed and followed prior to system implementation, resulting in a much smoother approval process and an even faster ROI.

"THE HIGHEST HURDLE TURNED OUT TO BE THE FINAL IMPLEMENTATION OF THIS NEW TECHNOLOGY INTO EXISTING PROCESSES AND PRODUCTION ENVIRONMENT"

ABOVE: **Typical x-ray system for production inspection of turbine blades**



BELOW: **High pressure turbine blades are located behind the combustion chamber. Source: Wikepedia**

To this end, choosing an x-ray system vendor with the experience, knowledge, capability and consultative know-how of this technology is critically important. Replacing film with the latest digital technology is not as easy as plug-and-play, but with the right partnership and implementation strategy it is quite manageable and clearly profitable.

CONSULTATIVE APPROACH

What does the future hold for vital inspections of these complex castings? New materials such as composites and ceramics are finding their way into these engines and will require new inspection approaches. With CT x-ray systems continuing to get faster and more affordable and having higher accuracy, it will pave the way to replacing conventional CMM (computerized maintenance management) systems in some applications. In addition, the evolution of automatic defect recognition software will help operators make even better and more reliable decisions by using inspection algorithms to help process these complicated images.

Complex parts, such as turbine blades, require innovative solutions in order to keep up with the demanding requirements of these applications. Production inspection for higher volumes also offers unique challenges that can require complex automation, powerful software and other tools designed to help the operator ensure a high quality and efficient inspection. Adopting this new approach to filmless x-ray may seem daunting at first, but once understood can be implemented smoothly and profitably. ∎

Jason Robbins is business development manager at Comet Technologies, Yxlon Division, based in the USA


THOMAS FLICKER


DAVID DEAN

END OF THE GEARBOX?

A modular design can ensure that a test bench is able to deal with the high load devices used across the modern test industry

BY THOMAS FLICKER AND DAVID DEAN

With the arrival of the A380 and the B787 aircraft, power generating technology has fundamentally changed. These new high-speed generators have set a challenge for the testing community. The company Test-Fuchs accepted this engineering challenge and initiated a project to design a test system that would meet the high speed/high load challenges and also address universal long-term problems with the gearbox.

The design and manufacture of generator test benches has become one of the core skills of the Austrian company. Since the 1960s the technology and the aircraft applications have rapidly developed into the high-speed/high-load devices that are currently on the market.

In partnership with customers, the Test-Fuchs design team developed a direct-drive system that exceeded the OEM specifications but also removed the troublesome problems with the gearbox.

The test bench was designed using the Test-Fuchs modular concept, which offers variants, modules and UUT (unit under test) options. The concept also allows the arrangement of an ideal test solution for the customer's fleet requirements. The modular design has proved exceptionally interesting for the large fleet operators because the automatic system reduces development costs but still provides the advantage of customization. Customers get their own tailored-to-fit personal test system.

GENERATOR TEST BENCH

The concept for generator test benches provides the very latest technology for the drive units and load units, creating a competitive advantage for the customer. The true innovation was in the new direct-drive test system and the electronic controls between the generator test stand and the UUT. This concept has been proved in non-aerospace applications, but the real challenge was in developing the required control system. It has been fully researched and has undergone many months of testing in the Test-Fuchs research department.

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 the 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 and fast coupling system that reduces the installation time of the units considerably. In addition to manual testing with automation, the system is capable of fully automated test runs. The modular design was not only applied to the hardware of the test system itself, but the software also follows a modular concept and can therefore easily be adapted to all customer requirements in a minimum amount of time.


ABOVE: System unit under test

UNIQUE HYDRAULIC SYSTEM

One of the features of this new design is a completely flexible hydraulic system, making the maintenance easier and faster, again saving costs for the customer.

Test-Fuchs has developed a completely new generation of generator test benches, which will become the company's flagship testing system 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 models from Embraer, Bombardier Q400 and CRJ, Airbus and Boeing. ∎

Thomas Flicker is project manager of the generator test stand and David Dean is sales manager, UK


LEFT: Generator test bench LMP90IB

DR ERIK SCHWARZKOPF

TOOLS OF THE TURBINE TRADE

The latest thermomechanical fatigue techniques verify service-life analysis of new turbine designs

BY ERIK SCHWARZKOPF, PHD

Driven by global demands for increasingly efficient engines and more flexible power generation, new turbine designs must address challenges that did not exist a generation ago. Increased efficiency requires higher operating temperatures and new materials, that are resistant to oxidation and creep under these conditions. Additionally, the need for more flexible duty cycles and performance improvements means that such materials must be more resistant to thermomechanical fatigue damage. Most importantly, these improvements must be achieved without compromise to turbine cost and reliability.

As a consequence of changing design philosophies, conventional methods for estimating the service life of turbine components are no longer appropriate for all cases. While new methodologies are needed to predict life at the higher temperatures and for more flexible duty cycles, they must first be tested and verified before they can be trusted to replace traditional approaches.

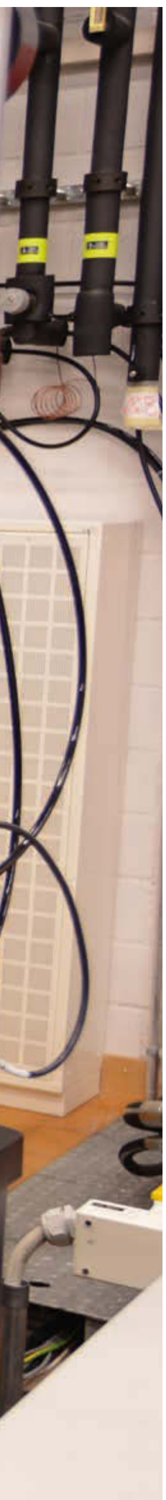
Empa, a Swiss federal research institute located in Dübendotf, near Zurich, is breaking new ground in this field. Using an innovative service-cycle, component-feature specimen thermomechanical fatigue (TMF) testing approach involving superimposed high-frequency vibration, Empa researchers are able to accurately simulate turbine operating conditions and verify the effectiveness of new prediction methodologies.

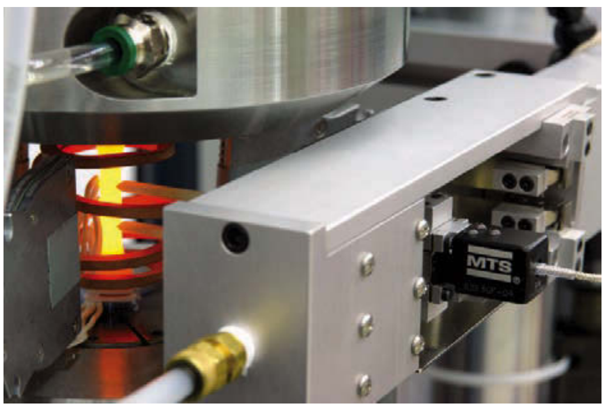
"TMF testing has traditionally been used for material characterization," says Dr Stuart Holdsworth, head of the High Temperature Integrity Group at Empa. "We are using the results of such tests to form the basis of advanced material deformation and damage modeling concepts and, most importantly, for benchmarking the effectiveness of new high-temperature assessment procedures for predicting component lifetimes."

DAMAGE PROCESS

New turbine components are designed to run as hot – and therefore as efficiently – as possible, but not so hot

Empa researchers are employing an innovative TMF approach to simulate close-to-actual turbine operating conditions and verify the effectiveness of new prediction methodologies





ABOVE & LEFT: **Empa's TMF applications require compact, low-mass extensometers capable of running at both high frequencies and high temperatures, and high quality induction coils and enhanced cooling controls to achieve precise temperature control in aconsistent, repeatable fashion**

that constituent materials exceed their property limits. In order to avoid premature failure of components at high temperatures, it is therefore necessary to also fully account for time-dependent damage processes such as creep and oxidation, and their interaction effects on fatigue damage accumulation.

Simple creep or creep-fatigue studies focus on how materials react when controlled at steady high or alternating load and high temperature. However, this does not accurately reflect actual turbine service duty, where loads and temperatures fluctuate. Different turbine materials respond in different ways, depending on how often the turbine is powered up and down, how long it runs, and how many cycles are completed.

"The increasing tendency toward two-shift operation in the 1990s, and the subsequent increased adoption of combined-cycle units, prompted the need for more flexible operation and increased turbine start/stop expectations," Holdsworth notes. "Now the requirements are even more demanding. There are strong pressures to use renewables, and power turbines have to fill in the gaps when the wind doesn't blow and the sun doesn't shine. Operating cycle requirements are now very different from what they were 30 years ago."

Just as power-plant turbine cycles are changing, so are those of jet engines used in short haul and regional aircraft, which experience shorter times between takeoff and touchdown. The shorter wings and narrower bodies of these aircraft mean that the vibratory stresses in these engines are very different from those in larger, long-haul aircraft.

Turbine manufacturers must be able to predict with confidence how long each component will last over this evolving array of possible duty cycles. Knowing the weakest link enables manufacturers to avoid over-designing, optimize new designs for reliability, and establish efficient maintenance schedules that focus on points of potential vulnerability.

This is why Holdsworth and his team devised an innovative approach to high temperature turbine component assessment, involving non-linear finite-element component analysis and creep-fatigue damage analysis, as well as an effective means to benchmark test and verify their predictions.

"TURBINE MANUFACTURERS MUST BE ABLE TO PREDICT WITH CONFIDENCE HOW LONG EACH COMPONENT WILL LAST OVER THIS EVOLVING ARRAY OF POSSIBLE DUTY CYCLES"

ADVANCED MODELING METHOD

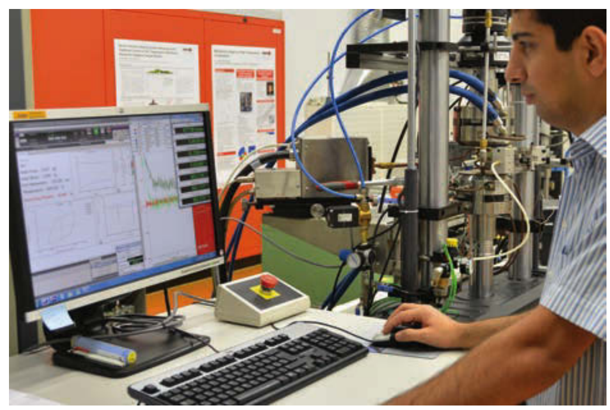
The analysis technique follows an iterative process, starting with an initial creep fatigue assessment of specific turbine components. Advanced non-linear finite element analysis is used to determine stress/strain states and critical locations in these components during service duty. Based on this information, the team can make predictions about the component's lifespan.

To determine the accuracy of these service-life predictions, Holdsworth's team developed a service-cycle component-feature TMF testing methodology that can replicate on the actual component the same thermal and mechanical stress/strain states identified in the initial analysis. This process is then repeated, with results used to optimize the analysis procedure until it is verified to predict service life accurately.

To perform its tests, the Empa laboratory uses two servohydraulic test systems from MTS capable of running complex TMF tests. The capabilities of these systems, their accessories, and their digital controller and software architectures accommodate two unique aspects of Empa's approach to TMF testing.

The first is the ability to reproduce precisely the critical stress/strain states of the component under actual

LEFT: Empa's service-cycle component-feature specimen TMF testing methodology requires a test system capable of switching from mechanical strain control to load control within the same cycle, while superimposing high-frequency vibrations



RIGHT: A flexible programming environment allows the creation of highly customized wave shapes, as well as a single multi-segment cycle with two separate control modes

turbine operating conditions. To do this, the test must switch from mechanical strain control to load control within the same cycle, which requires an unprecedented degree of test flexibility. Advanced compensation techniques enable precise servovalve control. In addition, MTS TestSuite software enables operators to create highly customized wave shapes that incorporate the proper sequence of ramps and holds, as well as a single, multi-segment cycle with two separate control modes.

"We need total flexibility to reproduce the thermomechanical stress-strain cycles experienced at critical locations in gas and steam turbine blades or rotors in uniaxial specimens," Holdsworth says.

The second unique aspect of Empa's approach is the ability to superimpose high-frequency vibrations on relatively low-frequency cyclic stress/strain conditions to simulate, for example, the gas bending loads on turbine aerofoils superimposed on cyclic centrifugal loading. The variation in gas pressure on the aerofoil is due to the cyclic interaction of moving and stationary blades, while the cyclic centrifugal loading is a consequence of the operating duty conditions of the turbine. Again, the control architecture of the MTS test solution delivers the processing speed and programming flexibility required to add these vibrations to the TMF test and create a highly realistic simulation of the turbine's service environment.

REFINED HARDWARE

Extensometry poses another challenge. TMF tests typically do not involve large contact force extensometers due to the risk of indentation of metallic specimens at high temperatures and consequent premature crack initiation. In the same way, high-frequency tests will often cause extensometers to slip, causing an interface failure that compromises test-data accuracy. For Empa's work, MTS developed a compact, low-mass extensometer capable of running at high frequencies and high temperatures.

As with any TMF test, minimizing temperature gradients in the specimen is another concern. By using the highest quality induction coils and enhanced cooling controls to improve thermal consistency, Empa has been able to achieve precise temperature control in a consistent, repeatable fashion. Cooling is fully integrated with the control architecture so that the necessary adjustments can be made automatically during the test. In addition, the controller features multiple channels for temperature control to accommodate complex wave shapes. The ultimate beneficiaries of Empa's approach to TMF testing are manufacturers of gas and steam turbine components and structures, as well as the aircraft and power plant operators who deploy them.

Because Empa can now generate and verify more accurate service life predictions that align with how turbines will actually be operated, manufacturers can develop and optimize new designs with confidence and end users can be equally confident the turbines will meet their requirements for performance, reliability, efficiency and safety. By helping to push the envelope of turbine design, Empa is enabling turbine manufacturers and their customers to respond to global demands for more energy-efficient systems. ■

Erik Schwarzkopf is an R&D engineer and staff scientist with MTS Systems Corporation, based in the USA

RETO HUBER

CAUGHT IN A FLASH

Latest generation high-speed aviation test cameras must work in a system network, meaning greater customization for the job in hand

BY RETO HUBER

ABOVE: AOS camera (circled) on landing gear of Dassault nEUROn UCAV
Photo: Dassault Aviation/V Almansa

High-speed cameras that can record store separation or other events during test flights are commonly used measurement systems in today's development process. The data collected by these camera systems delivers important feedback for designers and test engineers for improvement or validation of systems. After the traditional 16mm film-based cameras have been replaced by first-generation digital high-speed cameras, new requirements to deliver high-speed video data of new 'hot spots' arise fast.

Space is always limited in airborne applications, which makes it essential that the shape of the camera is adapted to the application. Furthermore, these new-generation cameras must be able to operate in a network together with other components, such as airborne recorders or mission controllers. Demands like this on mechanical and electrical systems has initiated an approach for a customized camera system.

DESIGN OF THE CAMERA

In a complex system, such as in a fighter aircraft, it is essential that the camera adapts to the aircraft and not the aircraft to the camera. This is true for the electrical and control interface, as well as mechanical outlines of the camera.

An application may require that a camera is designed to have the connectors straight out in the back. Other mounting positions require having the connectors coming out sideways for a 90° view. Some positions may require recessed lens mounting due to space limitations in the mounting area. A lens sticking out of the camera does make the whole ensemble larger than it has to be. On first impressions, it is best to have three individual designs. Of course, all designs must meet the environmental and EMI specifications to be aircraft-ready; and sometimes it is highly desirable to have aircraft-specific connectors on the cameras for ease of integration.

Camera designers have to cope with these requests. One approach is to have a semi-customizable camera platform where functionality and identical operation of each camera is assured; where the cameras perform reliably under the given environmental conditions; and where the cameras are commercially attractive to the user.

To achieve this, a camera design must first meet a high degree of flexibility in terms of electronic design. Such modules satisfy the highest possible adaptation to mechanical design demands to make the camera fit in the space required. Interface parts must be easy to adapt to given connectors and power requirements coming from the aircraft. Such a camera design approach is highly beneficial to the users. The camera sensor part is always equipped with the same sensor, giving the same optical performance for all views and making later image analysis more efficient, rather than taking different types of sensors with new parameters.

SMART CAMERA FEATURES

With such a camera design in place, the question of how to operate such systems, monitoring different scenes under different conditions, must be addressed. Smart features in the camera can be used to give the camera a maximum of standalone operation – not interfering with the flight operation, but providing the precious image data required. These features are pre-programmed on the ground by flight engineers, and once the camera powers up, it takes the recordings according to these parameters. No network control or data transfer to a control unit is expected.

For cameras intended to work in a network environment, it is important to standardize their communication setups. A very recent idea in flight video data capturing is to network cameras via a central control unit. In such a case, the captured sequences

ABOVE: AOS Q-MIZE EM high-speed camera with recessed lens mount

> "FOR LATER ANALYSIS OF TEST DATA, EASY-TO-ACHIEVE CORRELATION BETWEEN VIDEO AND OTHER DATA IS IMPORTANT"

are downloaded to the control unit and new commands are sent to the camera for the next take. For such an approach, the GigE Vision standard is an easy-to-implement and versatile communication protocol.

This standard is being extended by the IRIG committee at present to make it even better suited to airborne applications. The protocol allows enhancing of video data collection during the flight. For instance, during a certain period, a live stream with a standard 30fps is recorded directly in the control unit. When the test requires high-speed recording, the data is buffered in the camera and sent to the control unit on demand or transferred to the internal non-volatile camera memory. These memory portions are accessed later on the ground, or in flight by the control unit when requested via the network. The user benefits from a camera with an extended GigE Vision standard for exchangeability of cameras in the same network, independent of the make of the camera.

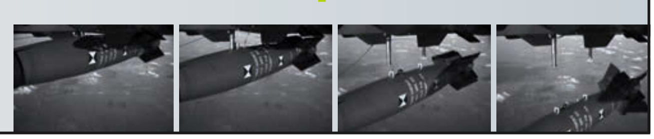
DATA FORMAT

For later analysis of test data, easy-to-achieve correlation between video and other data is important. Synchronization to IRIG-B or GPS signals is nowadays standard. Until recently, users had to cope with many different data formats, sometimes in the manufacturer's proprietary format, making exchange of data complicated. Here, the IRIG-106 data format offers a viable base for all data gathering and later analysis.

A common data format eases the use of analysis tools; and a secure correlation of measurements, taking into account different sensors and cameras, is achieved. In the end, it is a very economical way to produce results and gain insightful information – and maybe even more important, it makes comparison of measurement data simpler.

Semi-customized cameras are beginning to make an impact in inflight image data acquisition, offering the perfect fit for each application, but remaining economical. ▮

Reto Huber is the engineering manager for AOS, based in Switzerland



INNOVATE FOR TOMORROW

The University of Nottingham is leading a research project to integrate novel technologies

BY HERVÉ MORVAN

Aircraft are just one subsystem operating within a global air transportation 'system of systems'. We know that there are considerable pressures on the aerospace industry by government and society to meet demand while developing aircraft that are more environmentally friendly, through increased performance and reduced carbon emissions. There is also an increasing demand for quieter aircraft, and as cities develop, the need for air transport to become a good neighbor is becoming more acute.

There is therefore a pressing need for a research approach that looks holistically at the whole air transportation system. The University of Nottingham's Institute for Aerospace Technology (IAT) is launching a major international research project that seeks to develop a series of technologies to meet the future requirements of the aerospace industry.

The aim is to develop an integrated air transport vision and investigate core technologies associated with reducing the impact of and optimizing air transport. The project, known as the Integration of Novel Aerospace Technologies (INNOVATE), has won €3.8m (US$5.1m) of funding from the Marie Curie Innovative Doctoral Programmes (IDP). INNOVATE has a strong international, academic and industrial interdisciplinary dimension, with partner businesses and researchers from across Europe participating.

The outcome of INNOVATE will be the development of a series of specific technological advances at different levels of technology readiness, which will link up to underpin a demonstrator that integrates the benefits of the various research strands and embodies the system vision developed by the early stage researchers (ESRs) and the IAT team engaged in the program. This second stage of integration and demonstration is key here, and will go beyond what is traditionally aimed for in universities.

Key topics that will be covered by INNOVATE are: propulsion technologies; airframe and control technologies; ground operations; and navigation and communication technologies. These will then lead to integration and a virtual demonstrator.

Beyond the science and technology, one of the main aims of INNOVATE is to train the next generation of highly skilled engineers and scientists. The ESRs dominantly come from an engineering background, but there are also mathematicians, computer scientists, navigation or human factor specialists and, unlike the traditional PhD model, where they would mainly be working in research silos, these students will be working as an interdisciplinary unit to meet common problems. Through this model, we will be delivering a new breed of engineers and scientists who also understand that their expertise needs to fit into industrial systems, and we firmly believe that this kind of integrated approach will be critical to delivering innovation to the marketplace in future.

Each ESR will develop novel technologies leading to PhDs. Every core technology activity will occur in one of our world-leading research groups or centers for gas turbines; power conversion and electrical machines; materials and structures; additive manufacturing; geospatial sciences; computer sciences; and human factors. This will all take place under the supervision of two leading academic experts for every ESR.

The team will engage in a collaborative activity, as part of 'WP5 – Virtual Demonstrator', to integrate the technologies and propose a holistic model of a future air transport system for aircraft and operational systems. The integration stage will reproduce industrial design and validation processes to deliver training and awareness of multidisciplinary approaches to the team. ∎

Dr Hervé Morvan is director of research for the Institute for Aerospace Technology (IAT) based in Nottingham, UK

ABOVE: **Research fellow Dr Richard Smith, looks at the integrity of materials. The instrument is a Spatially Resolved Acoustic Spectrosity (SRAS)**

INDEX TO ADVERTISERS

GE
Measurement & Control

RotoArray

The Power of an Immersion C-Scan System in the Palm of Your Hand

The RotoArray is a portable, manually operated, phased array, ultrasonic inspection device which can be connected to any suitable phased array flaw detection instrument to allow rapid scanning of a wide variety of materials and components.

It is especially well suited for scanning composite and aluminum aerospace components and can provide A, B & C-scan images that are achieved with the simplicity of a handheld probe and with performance rivaling that of a full immersion C-scan system.

Please visit **UTprobes.com** for more information.

GE imagination at work