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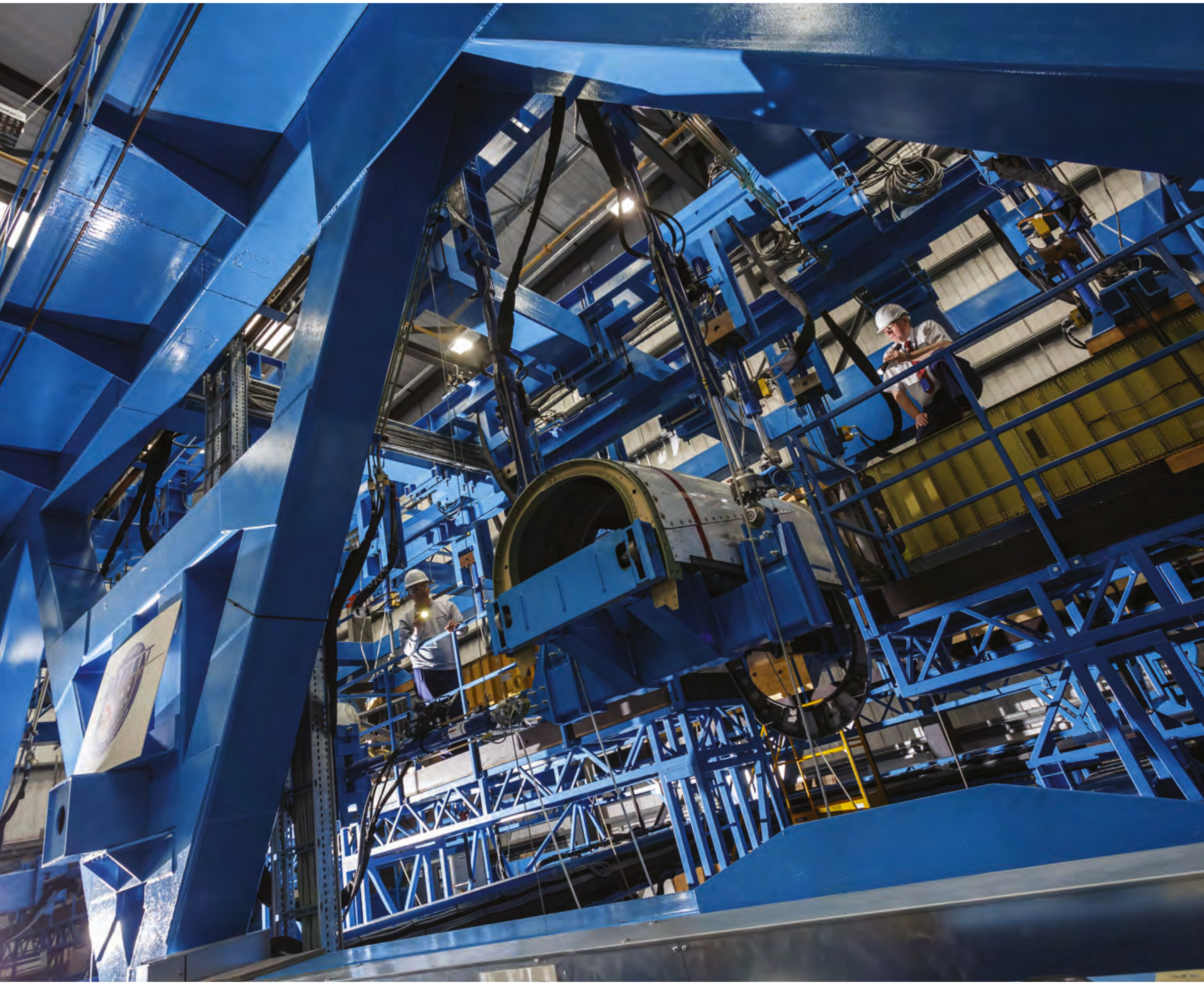

2016 SHOWCASE

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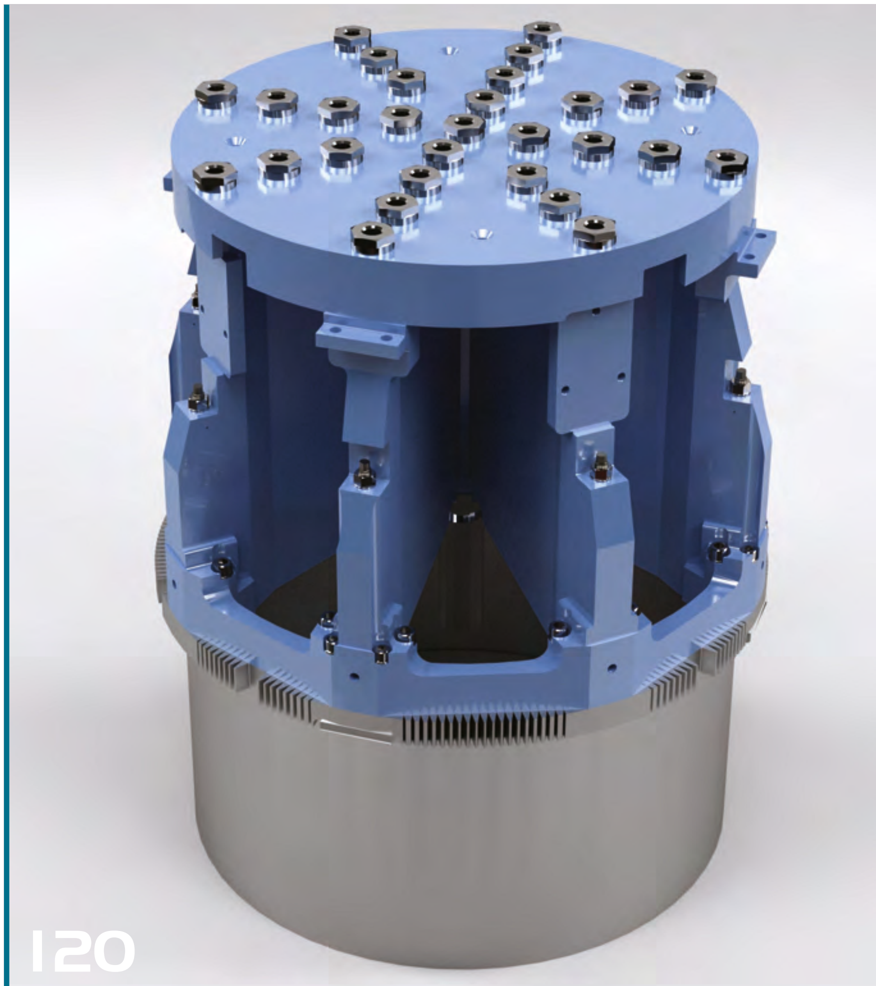

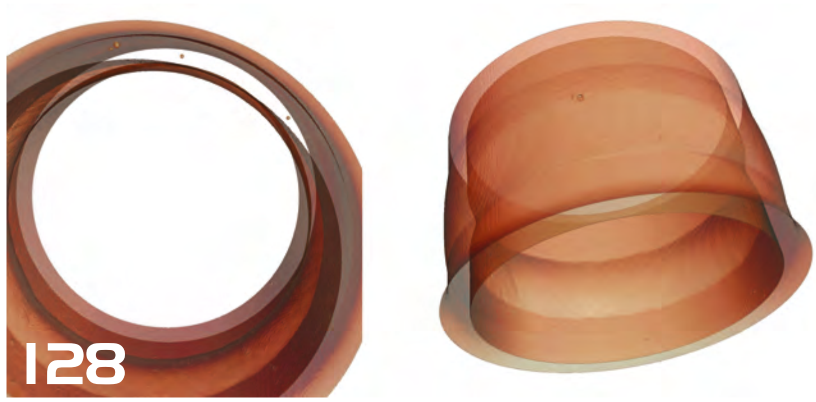


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INDUSTRIAL STRENGTH

If you are reading this magazine, it's safe to assume that you are either a test engineer or a test pilot, involved on a daily basis in the testing of aerospace components and materials, from the smallest widget to the largest airframe.

How do I know this? Because we send this publication only to those who have taken the time to individually request it, and who also fulfill our selection criteria – i.e. you must work in aerospace testing at a senior level with responsibility for program management, as well as specifying and purchasing test equipment.

So you'll be pleased to know that the issue you have in your hands right now – the *2016 Annual Showcase* – is packed full of nothing but aerospace testing-related facts, figures and features. Written for the industry by the industry, every word on every page is completely relevant to what you do, day in, day out.

Admittedly, this is a highly specialized sector, as is evident in the breadth of testing applications, technologies and programs covered in the following pages. From fatigue testing to full-scale structural testing, from EMC and lightning testing to environmental testing, and from wind tunnel testing to vibration testing, you'll find it all here!

As such, the *Annual Showcase* provides an excellent opportunity to 'test' the testing industry itself. What new trends and technologies are emerging? How are testing teams reacting to the challenges posed by new programs and developments?

Certainly the need for ever-lighter materials to reduce fuel consumption and improve operational efficiency continues to have an impact. Composites, although not exactly new to aerospace, remain a major influence, spurring a number of exciting new NDT inspection methods and tools. Exotic new engine alloys also require new inspection tools and testing technologies.

Beyond the growth in new lightweight materials, the market demand for ever-greater efficiency and improved emissions is also leading to a re-examination of actual propulsion means. A first wave of electric and hybrid aircraft is beginning to take shape – small in scale at this embryonic stage, but with huge implications for the testing industry that must ensure these aircraft are equally if not more robust than their conventional cousins.

For a first-hand account of the challenges involved, turn to page 16 to hear directly from those currently testing the new two-seater solar-electric flight trainer, Sun Flyer. "Test flying the Sun Flyer requires an adjustment to flight test protocols and techniques when compared with typical piston- or turbine-powered flight test articles," confirms Sun Flyer chief test pilot John Penney.

Another key trend is the demand for increased test automation, particularly with regard to NDT inspection, to help save time, reduce costs and speed up the test process. Automation and test program management software is also highly relevant to the full-scale test benches and 'iron birds' that major OEMs now invest heavily in to reduce the time and cost of actual flight testing.

However, some aspects of testing, by their very nature, move at a somewhat slower pace. Take our cover story, which examines the long-term, full-scale fatigue testing behind the Royal Australian Air Force's Hercules C-130 program. A C-130K full-scale fuselage fatigue test facility first went live in 2005, with a C-130J full-scale wing fatigue test facility following in 2009. They're still producing highly relevant data – something we hope to continue ourselves, with each and every *Aerospace Testing International* publication.

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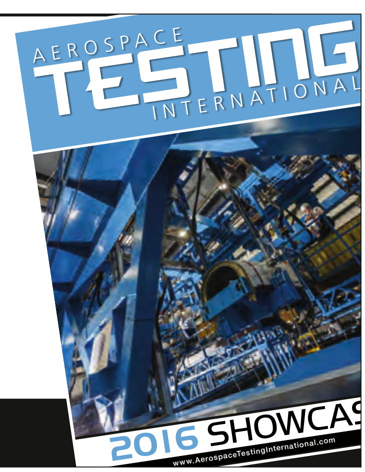


ALL AT SEA

2015 has proved to be a busy and record-breaking year for the team responsible for testing naval variants of the F-35 Lightning II

BY SYLVIA PIERSON

The F-35 Lightning II naval variants test team at the Patuxent River Integrated Test Force (PAX ITF) successfully passed numerous milestones in the F-35 test program during 2015. Since January (2015), the highly diverse cadre of PAX ITF technicians, maintainers, engineers, support staff and test pilots have flown more than 500 flights, logged more than 700 flight hours, and achieved almost 3,400 test points as they conducted developmental tests of nine F-35 naval variants. Most notably, the team paved the way for the Marine Corps' July 31 declaration of F-35B Initial Operating Capability and is progressing through the System Development and Demonstration (SDD) phase of the program at a brisk pace.

Based at Air Test and Evaluation Squadron (VX) 23 aboard Naval Air Station Patuxent River, the PAX ITF's five F-35B short take-off and vertical landing (STOVL) and four F-35C carrier variant (CV) aircraft typically operate along the Atlantic Test Ranges. The team also tests the aircraft on detachments to Edwards Air Force Base (AFB) and Naval Air Weapons Station China Lake in California, Eglin AFB in Florida, and aboard amphibious assault ships and aircraft carriers.

BLOCK 2B TESTING

The PAX ITF completed all the Block 2B (initial warfighting capability) test points to deliver an expanded envelope to the Marine Corps in support of its F-35B Initial Operating Capability (IOC) requirements during 2015. Successful Block 2B testing was a major enabler for the Marine Corps, resulting in its IOC declaration on July 31, 2015. In fact the team helped achieve F-35B Marine Corps IOC on the leading edge of the timeline the Marine Corps had established two years previously, on May 31, 2013, when it notified Congress of its anticipated IOC date:

"Marine Corps F-35B IOC shall be declared when the first operational squadron is equipped with 10-16 aircraft, and US Marines are trained, manned and equipped to conduct close

"SINCE 2010 THE PAX ITF HAS FLOWN MORE THAN 1,800 TEST FLIGHTS, LOGGED 2,544 TEST HOURS AND COMPLETED 12,800 F-35B TEST POINTS, DIRECTLY RESULTING IN THE USMC IOC FLIGHT CLEARANCE"

air support (CAS), offensive and defensive counter air, air interdiction, assault support escort, and armed reconnaissance in concert with Marine Air Ground Task Force resources and capabilities. Based on the current F-35 JPO schedule, the F-35B will reach the IOC milestone between July 2015 (objective) and December 2015 (threshold). Should capability delivery experience changes or delays, this estimate will be revised appropriately."

"Declaration of F-35B IOC is a major step forward, bringing fifth-generation warfighting capabilities to the Marine Corps," adds Commander Christian Sewell, Air Test and Evaluation Squadron (VX) 9 F-35 operational test liaison and F-35 Lightning II PAX ITF government flight test director. "Not only is F-35B IOC the dawn of a new era for the Marines, but it's also the culmination of years of hard work and dedication by more than 900 military, government and contractor team members assigned to the VX 23 F-35 PAX ITF. Since 2010 the PAX ITF has flown more than 1,800 test flights, logged 2,544 test hours and completed 12,800 F-35B test points, directly resulting in the USMC IOC flight clearance."

"Declaring IOC is an important step forward in a multi-year process as the Marine Corps upgrades its aging fleet of fixed-wing, tactical aircraft," adds Major Justin Carlson, F-35 Lightning II test pilot assigned to Air Test and Evaluation Squadron (VX) 23. "The F-35 still has major milestones ahead of it, and it will continue to grow for years to come, but integrating the capabilities we have now produces a giant leap forward in combat capability for the Marine Corps' tactical aviation community."

F-35C CARRIER SUITABILITY TESTING

As the team prepared to sail aboard USS Eisenhower (CVN 69) for the second phase of developmental test (DT-II) of the F-35C, it completed prerequisite shore-based catapults and arrested landings, a structural survey with mis-serviced landing gear, and

LEFT: The PAX ITF is now 100% complete with its second phase of F-35C testing, conducted aboard USS Dwight D. Eisenhower (CVN 69) from October 2-10, 2015 – the team conducted 66 catapults and 66 arrestments across 17 flights, logging 26.5 flight hours and achieving a total of 280 flight test points and 17 logistics test and evaluation (LT&E) test points

RIGHT: On May 5, 2015, Lt Chris 'TJ' Karapostoles conducted KC-10 strategic tanker testing during flight 385 of aircraft BF-02. The F-35B Lightning II STOVL variant is shown carrying a gunpod as well as AIM-9X and GBU-12 external stores. Lockheed Martin photo by Michael D Jackson

"TESTERS EXPOSED THE F-35B TO TEMPERATURES RANGING FROM -40°F (-40°C) TO 120°F (49°C)"

LEFT: As the F-35 Lightning II PAX ITF prepared for the second phase of F-35C sea trials from October 2-10, 2015, aircraft CF-05 conducts land-based Mk-7 arrestment testing during flight 134 on July 21

put the GEN III helmet-mounted display (HMD) hardware through 'shake, rattle and roll' tests. 'Shakes' are unique test events accomplished at the shore-based TC-7 Catapult and Mk-7 Arresting Gear sites, during which new aircraft hardware is tested to the aircraft limits for various shipboard conditions. Typically shakes testing is the last requirement prior to clearance for hardware to operate on the ship.

The team's primary DT-II goal was to generate at-sea data in support of phase II development of Aircraft Launch and Recovery Bulletins. They also conducted afterburner catapult shots, Delta Flight Path (DFP) approach mode performance testing with a four-degree glideslope, day and night Gen III helmet testing, max catapult shots with full internal weapons load, maintenance engine runs, Integrated Power Pack (IPP) and engine runs in the hangar bay, catapult minimum energy shots with internal stores, and night approaches and arrested landings.

The shore-based mis-serviced landing gear tests and completion of all DT-II objectives clear the envelope for operational F-35C pilots to conduct future day and night carrier qualifications. The PAX ITF is now 100% complete with its second phase of F-35C testing, conducted aboard USS Dwight D. Eisenhower (CVN 69) from October 2- 10. The team conducted 66 catapults and 66 arrestments across 17 flights, logging 26.5 flight hours and achieving a total of 280 flight test points and 17 logistics test and evaluation (LT&E) test points.

These efforts follow the history-making F-35C Initial Sea Trials conducted from November 3-14, 2014, when the team landed two F-35Cs aboard an aircraft carrier for the first time and completed 124 catapult launches and 124 arrested landings with zero one-wires and no unintentional hook-down missed arrestments (bolters) during its first at-sea period.

F-35 CLIMATIC TESTING

The Pax River ITF team completed climatic response testing by operating an F-35B in the world's largest environmental testing chamber, the McKinley Climatic Laboratory (MCL) at Eglin AFB. Testers exposed the F-35B to temperatures ranging from -40°F (-40°C) to 120°F (49°C) and meteorological conditions such as wind, solar radiation, fog, steam, humidity, rain intrusion/ingestion, freezing rain, windblown rain, icing cloud, icing build-up, vortex icing and snow – the extreme conditions stated in the F-35 Lightning II's operational requirements. They conducted 60% ground operations and 40% flying operations, including engine runs and simulated flight in both conventional and STOVL modes with up to 40,000 lbs of thrust. The climatic tests certified the F-35 as an all-weather fighter and the aircraft returned to a rigorous tempo of flight test without any indication that it had been through such a wide array of temperatures and meteorological conditions.

LEFT: During flight 336 of aircraft CF-01 on February 25, 2015, Major John Dirk conducts an F-35C Lightning II asymmetric external stores flying qualities test above NAS Patuxent River

F-35B SKI-JUMP TESTING

The F-35B made eight land-based ski jumps as the ITF's joint US-UK ski jump team validated the design and maneuverability of the F-35 to conduct ski jump operations. The tests mark the beginning of testing to determine the aircraft's compatibility with British and Italian aircraft carriers and facilitate the regeneration of the UK carrier strike capability.

WEAPONS SEPARATION TESTING

The ITF completed a successful block of F-35B weapons separations, which included the first AIM-120 shots from stations 4 and 8 of the internal bomb racks and the final inert SDD store separation test with an AIM-120 released from an F-35C on September 19, 2015. The remaining four F-35C SDD AIM-120 releases will feature live rocket motors. Each weapons separation matched simulation models very well, which expedites the clearances of future weapons and employment envelopes.

September 23, 2015 marked the first time that an external store weapons separation test was conducted for the entire F-35 Lightning II program. The PAX ITF test team released four GBU-12 Laser Guided Bomb inert test assets from the F-35C external wing weapon pylons of aircraft CF-02. Released individually during four test runs on a single flight over the Atlantic Test Ranges, all four weapons performed successfully as predicted by extensive wind tunnel testing and computer analysis. The control room team ensured a high margin of safety throughout the test event by reviewing each GBU-12 separation event and confirming that it was safe to proceed to the next release point. The quadruple weapons separation also demonstrated the team's test efficiency by accomplishing four flights' worth of test work in a single flight. Meanwhile, the ITF also began multi-phase testing of the 500 lb dual mode F-35 Block 3F, UK-specific Paveway IV precision-guided bomb.

ABOVE: Pax River ITF conducts the first-ever ski jump of an F-35 Lightning II during flight 298 of aircraft BF-04 aboard NAS Patuxent River on June 19, 2015

WET RUNWAY, BRAKING VALIDATION AND HIGH CROSSWIND TESTING

ITF testers proved the aircraft can stop safely in extreme weather conditions and validated the aircraft envelope out to a 25-knot crosswind with high asymmetric air-to-ground loadings. Even in a maximum asymmetry configuration (up to 26,000 lb·ft) with weapons stores on one wing, the aircraft performed well – in fact, the high asymmetry and crosswind required little additional attention from the pilot.

F-35 STRATEGIC TANKER AND F/A-18E/F AERIAL REFUELING TESTING

The PAX ITF successfully completed strategic tanker testing with Air Force KC-10 and KC-135 test assets and began testing with the F/A-18 E/F Super Hornet as a shipboard organic tanker. The team completed testing on the Wing Air Refueling Pod (WARP), Multi-Point Refueling System (MPRS), Boom Drogue Assembly (BDA), and centerline hose in clean wing, asymmetric store loading, and maximum gross weight configurations.

HIGH ANGLE OF ATTACK (AOA)

The PAX ITF team conducted more than 70% of high AOA testing for the F-35B and F-35C variants during 2014, completing initial envelope expansion, intentional departures testing, and departure resistance testing in symmetric air-to-air and landing configurations and beginning asymmetric air-to-air and asymmetric air-to-ground testing. ITF test pilots flew the aircraft to increasing AOAs (+180° to -180°), culminating in intentional dynamic departures and tailslides.

RIGHT: Four GBU-12 laser-guided bomb inert test assets were released from the F-35C external wing weapon pylons of aircraft CF-02 during external store weapons separation testing

While purposely saturating the flight control system through as aggressive as possible departures, the aircraft remained remarkably robust, with control laws promptly resolving the dynamics and consistently recovering the aircraft without pilot interaction. The performance of the flight control system has given operators confidence that the full envelope of the aircraft is available for total exploitation in a dynamic combat scenario.

F-35 STOVL MODE TESTING

The PAX ITF continued to expand the STOVL envelope last year in the clean wing configuration and with symmetric and asymmetric external stores. Flying qualities testing featured semi-jet, short take-off and jetborne modes to clear the aircraft for take-off and landings and airspeeds as low as 70kts with 24,000 lb of asymmetry and jet borne with 10,000 lb of asymmetry. The team performed rolling vertical landings (RVL), creeping vertical landings (CVL), vertical landings (VL), high altitude CVLs and VLs, slow landings (SL), and short take-off (STO) tests with nominal winds and crosswinds of up to 25kts. Test pilots reported that flying qualities during asymmetric testing were nearly identical to those in symmetric testing.

MISSIONS SYSTEM TESTING

Conducted in parallel with flight sciences testing, the Pax River ITF team tested the F-35's ability to accomplish its tactical mission and operate safely in all flight regimes. As it conducted mission systems testing in the STOVL environment, it achieved daytime STOVL distributed aperture system (DAS) testing during VLs, night-time DAS, night vision camera (NVC) testing with the GEN III helmet-mounted display (HMD), main runway-aided conventional take-off and landings, SLs, and STOs as well as aided STOs and VLs during field carrier landing practice sessions at an expeditionary airfield.

JOINT PRECISION APPROACH AND LANDING SYSTEM (JPALS) TESTING

The PAX ITF is currently testing JPALS, which will equip the F-35 with a precision and non-precision approach capability at the ship, as well as a means of aligning the inertial navigation system (INS) without a cable – similar to radio frequency alignments in legacy aircraft. Pilots will primarily rely on JPALS during night-time and inclement weather carrier landing operations.

The PAX ITF has tested the alignment and non-precision capability of JPALS in the field. The F-35C completed the first non-precision JPALS approaches in August. The system worked as designed, providing stable TACAN-like course guidance as well as automatic final bearing indication. The PAX ITF tested the alignment and non-precision approach capability during the F-35C's second phase of developmental test (DT-II) aboard USS Dwight D. Eisenhower (CVN 69) from October 2-10. ∎

Sylvia Pierson is F-35 Lightning II naval variants public affairs officer, Pax River Integrated Test Force

PROGRAM UPDATE

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

The F-35A conventional take-off and landing (CTOL) variant is a multi-role, stealthy strike aircraft replacement for the US Air Force's F-16 Falcon and the A-10 Thunderbolt II aircraft, complementing the F-22A Raptor. The F-35B STOVL variant is a multi-role stealthy strike aircraft to replace the US Marine Corps' AV-8B Harrier aircraft. The carrier-suitable variant (CV), the F-35C, equips the US Navy and US Marine Corps with a multi-role, stealthy strike aircraft to replace the F/A-18 Hornet and complement the F/A-18 E/F Super Hornet.

On September 1, the F-35 Lightning II surpassed 40,000 combined flight hours between F-35 military fleet aircraft and system development and demonstration (SDD) test aircraft. The F-35 operational fleet features 112 aircraft (105 US and seven international partner aircraft) and the F-35 Test Fleet features 18 aircraft (six F-35A, seven F-35B, five F-35C). Currently nearly 200 F-35 pilots and nearly 2,000 maintainers from the USAF, US Navy and US Marine Corps, the Netherlands and the UK have been qualified through the F-35 training system.

SUNSHINE STATE

The team behind the solar-electric Sun Flyer flight trainer aircraft reveals the unique test protocols underpinning its development and certification

BY GEORGE E BYE

In the second quarter of 2015, Boeing announced a staggering projection, that more than 558,000 new commercial pilots will be needed by the year 2033 [Source: Boeing's '2015 Pilot & Technician Outlook']. With the current fleet of Cessna and Piper flight training aircraft in the USA now decades old, the time has come to get serious about finding a sensible solution to this training challenge.

Last year, my colleagues, Charlie Johnson, Alexandre Couvelaire, John Knudsen and I co-founded a company to develop a practical electric-powered, solar-electric augmented aircraft to serve the aviation flight training market. Both Charlie and Alexandre have distinguished backgrounds in aviation. Charlie Johnson is the former president of Cessna and an advocate of electric propulsion for general aviation (GA), and Alexandre Couvelaire is the former Euralair and Mooney CEO. John Knudsen is a former FAA attorney and later the co-founder and president of Adam Aircraft.

The certified two-seat trainer is called the Sun Flyer, and assembly began in June 2015 on the first prototype Sun Flyer aircraft. We have selected Arion Aircraft, based in Shelbyville, Tennessee, USA, to help build the initial prototype trainer. Arion produces the LS-1 Lightning line of aircraft.

WHY ELECTRIC?

Why did we select an electric-powered, thin-film solar cell augmented aircraft to address flight training challenges? Over the past 10 years, technology has advanced considerably. Driven by cell phones and other personal electronic devices, as well as the ever-progressing automobile industry, there are major strides being made with electric motors, batteries, solar cells, and the software that manages these electric propulsion systems. Technological achievements with battery energy densities now enable flight endurance to be measured in hours, rather than minutes.

In addition, the Sun Flyer engineering design team is taking advantage of four key design elements

BELOW: Artist rendering of the two-seat Sun Flyer solar-electric training aircraft. An initial prototype trainer is currently under construction

"TECHNOLOGICAL ACHIEVEMENTS WITH BATTERY ENERGY DENSITIES NOW ENABLE FLIGHT ENDURANCE TO BE MEASURED IN HOURS, RATHER THAN MINUTES"

LEFT: Further artist rendering of Sun Flyer

that make the Sun Flyer's low operating costs and improved performance possible. The first element sees efficient lightweight electric motors and controllers combined with lithium-ion batteries. The battery cells are configured in packs, which can be swapped out with ease and efficiency. The second element is supplemental energy from lightweight solar cells affixed to the wing skin and a regenerative propeller. The third element is a sleek, low-drag fuselage with long-wing (high aspect ratio) advanced aerodynamics. The fourth element is a very light, carbon composite aircraft structure.

The task of bringing the solar-electric Sun Flyer to market is immense, but imperative to the next generation of aviation. The challenges of testing, let alone certifying, a new aircraft have been well documented. I am pleased to report that in the USA, the FAA has been enthusiastically interested, and collaborative in every step of the process.

The Sun Flyer aircraft will be certified under FAR 21 and will be standard category, day-night VFR, with a target gross weight of less than 1,700 lb. It is intended to be a sharp, high-performance aircraft that will not be a compromise on performance, given a projected climb rate of over 1,000fpm.

"TEST FLYING THE SUN FLYER REQUIRES AN ADJUSTMENT TO FLIGHT TEST PROTOCOLS AND TECHNIQUES"

Flight testing an electric airplane is not new to our design and test team. From 2010 to 2012, several members were involved with a research project that converted a Cessna 172 to electric propulsion. Extensive testing, including more than 20 flight tests, was conducted on the aircraft. In addition, our team has been involved in the development of several solar-electric unmanned aircraft systems, including the small unmanned aircraft system (UAS) called Silent Falcon, which is now in low-rate initial production.

The best practices of these legacy programs have been incorporated into the comprehensive test program for Sun Flyer, which consists of four components: prove total electric energy storage to attain sufficient flight endurance for pilot training applications; qualify a suitable electric motor and computer controller that provide the performance and durability required for sustained aircraft use at reasonable cost; demonstrate peak power, total energy capacity, and temperature range suitability for use onboard the aircraft; and flight test the Sun Flyer prototype aircraft to validate design components.

MEET THE TEST PILOT

To date, the single-seat technology demonstrator for Sun Flyer (a modified 'E1' aircraft from German company PC-Aero) has undergone extensive ground testing and initial flight testing. The Sun Flyer engineering and flight operations team includes chief test pilot, John Penney.

Penney has been a professional experimental test pilot for more than 30 years (and a member of the SETP since 1984), with experience on programs including the LearFan 2100, the Adam Aircraft A-500 and A-700, and the Collings Foundation Me-262 replica program. Penney has also undergone flight testing with NASA on research projects, such as Low Visibility Landing and Surface Operations (LVLASO), Runway Incursion Prevention Systems (RIPS), and Synthetic Vision Systems research. Penney is known for flying 'Rare Bear' to four Unlimited National Championships at the Reno Air Races and flying and testing various classic jet and prop warbirds as president of MiG Masters LLC.

"Test flying the Sun Flyer requires an adjustment to flight test protocols and techniques when compared with typical piston- or turbine-powered flight test articles," says Penney. "Mainly it is in cognitively making mental parallels in electric motor and system parameters from measured data, to those data recorded in otherwise 'conventional' piston driven propulsion systems. For instance, a kilowatt is a direct measure of power (horsepower), amps is akin to manifold pressure, and voltage is aligned with RPM. In theory, an electric motor is able to deliver as much power in kilowatts at 50,000ft as it does at sea level! Electric motors don't lose one inch of manifold pressure per thousand

PROGRAM UPDATE

Aero Electric Aircraft Corp (AEAC) is planning to offer the first certified US-sponsored, practical, all-electric airplane, Sun Flyer, serving the aviation flight training markets. Assembly has commenced on the initial two-seat prototype Sun Flyer solar-electric aircraft trainer, and the airplane is being developed at Centennial Airport near Denver, Colorado, USA.

Solar energy collection from solar cells affixed to the composite wing skin produces electric power that is combined with lithium-ion batteries to run the electric propulsion system, which directly drive the multiblade composite propeller. Engine performance is controlled by an electronic control unit, which ensures optimal use of the energy stored in the batteries. The electric design features reduced cooling drag compared with a conventionally powered aircraft, and the nose frontal area is reduced due to a smaller motor size and cooling intake. Propeller efficiency is improved by using additional blade area when compared with an internal combustion engine aircraft.

Perhaps most compelling about Sun Flyer is the projected 'fuel' cost of US$1 of electricity per flight hour, compared with between US$25 and US$65 for leaded aviation fuel per flight hour for a typical trainer.

feet like a normally aspirated piston engine! And lastly, kilowatt-hours of battery capacity are like gallons of gas in the tank!"

Human factors are perhaps one of the most significant challenges to establishing the test protocol on an electric aircraft. The onboard data acquisition system populates the flight data display, which provides multiple pages of data. However, the flight display and motor parameter symbology must provide for rapid, top-level, data interpretation.

Once the test pilot establishes electrical propulsion system parameter monitoring procedures, the integration and testing of the electric propulsion system into the Sun Flyer flight test article does not differ significantly from 'conventional' test articles.

Pilot safety features required for Sun Flyer include motor and system redundancy (should certain components fail), back-up control electronics, and an electronic diagnostic monitoring system. Electric motors require respective controller software to manage lower RPM operations typical with aircraft propeller speeds. They offer serviceability at lower cost and greater diagnostic simplicity, which translates to improved reliability and lower chance of catastrophic failure. Electric motor problems, such as bearing failure, are more predictable with electronic monitoring equipment.

The Sun Flyer test approach uses the traditional flight test profiles for systems testing, but includes a few steps unique to electric propulsion as opposed to internal combustion engines:

Step 1: Pre-flight and walk-around. Check battery and motor connectors.

Step 2: Startup. Arm electric motor and perform integrity check of motors and batteries. Be aware of the safety concern that there is no noise associated with motors being armed.

Step 3: Taxi and run-up. There are no idle indications, but the pilot must still monitor RPM, temperatures, voltage and battery kilowatt hours. An interesting side note is that there is no 'idle' RPM for electric motor systems. If the throttle is brought back to the idle stop, the motor stops! This has elicited inquiries from ATC such as, "Is everything okay?"

Step 4: Take-off. Monitor RPM and motor and battery temperatures, check for appropriate ventilation in hot environments.

Step 5: Cruise, approach and landing. Monitor collection of solar energy and use of battery energy for the most efficient flight.

Step 6: Shut-down. Monitor state of charge and motor temperature. The current air-cooled motor may need to run at a low RPM for a short period of time to properly cool.

"THE SUN FLYER TEST APPROACH USES THE TRADITIONAL FLIGHT TEST PROFILES FOR SYSTEMS TESTING, BUT INCLUDES A FEW STEPS UNIQUE TO ELECTRIC PROPULSION"

ELECTRIC FUTURE

In closing, while the system architecture for an electric general aviation airplane may be considered less complex than traditional propulsion systems, the testing regimen must be that much more rigorous, comprehensive and thorough because it is a new system intended to bring the aviation industry into a new operational environment.

Penney feels that the concept of electric powered aircraft in certain aviation arenas is the future for our aviation industry: "Introducing electric powered aircraft to the primary flight training environment is a realistic first step for finding ways to integrate this technology on an even wider basis for its future employment in aviation. Hybrid and pure electric automobiles are expanding their exposure in the automobile industry and with the traveling public.

"Similarly, with the potential economy of operation following testing, development and employment of electric powered aircraft that will be the outgrowth of the Sun Flyer electric aircraft technology demonstrator, the flight training industry and the general aviation industry in general will see untold economic benefits from the direction our Sun Flyer flight test program is going."

George E Bye is founder, chairman and CEO of Aero Electric Aircraft Corp

TIME WILL TELL

Health monitoring is an essential aspect of long-term, full-scale fatigue testing, as borne out by Marshall Aerospace's long involvement with the Hercules C-130 and test programs being conducted for the Royal Air Force and the Royal Australian Air Force

BY JOSEPH BERNACKI

Long-term, full-scale fatigue testing on aerospace structures, airframes and parts thereof, provides critical information to design engineers, OEMs and fleet operators alike regarding the performance of flight-critical components over their projected lifespans.

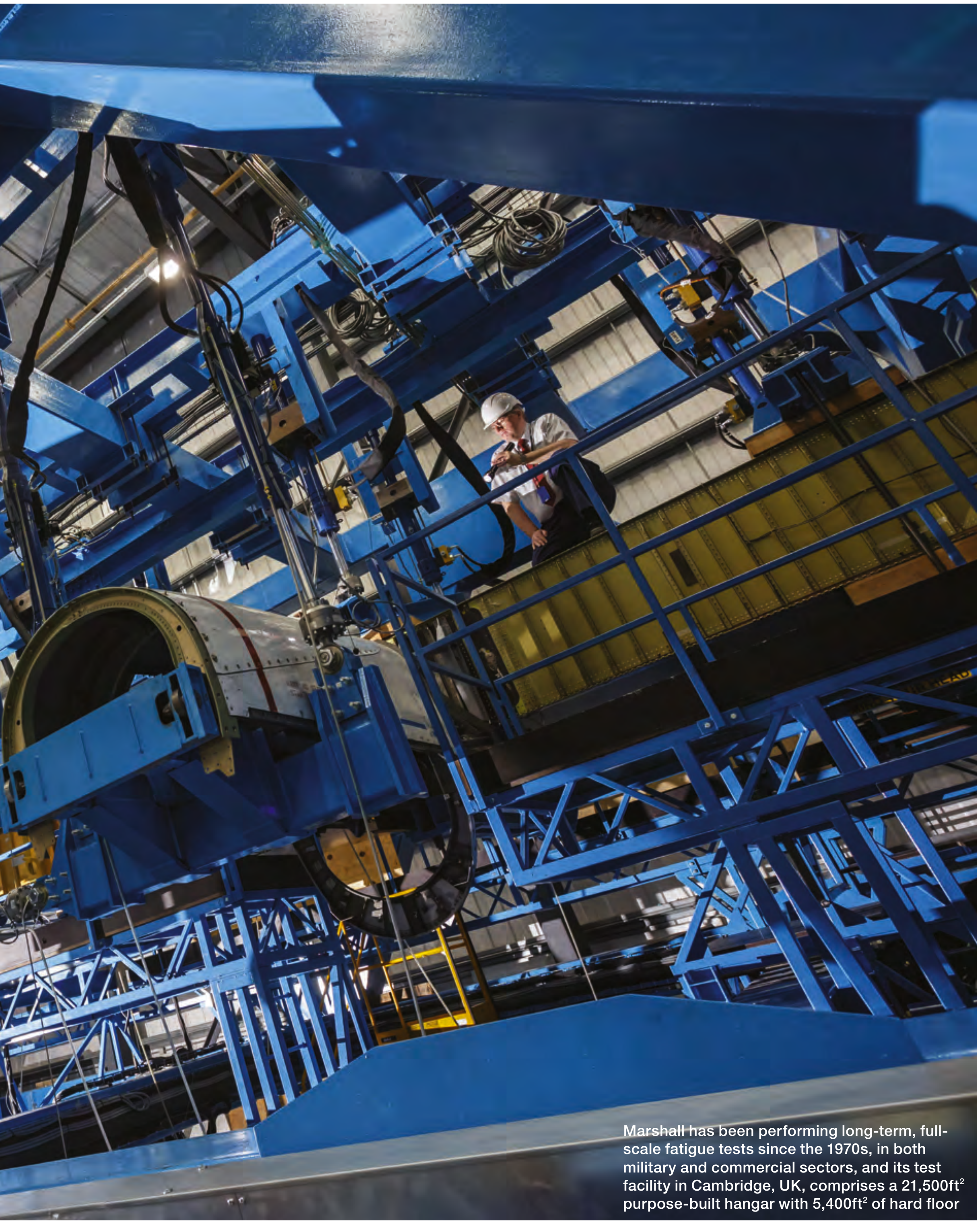
Such testing provides confidence that aircraft will be able to successfully and, more importantly, safely achieve their required number of flight cycles. It also allows for standard maintenance activities to be planned and preventative maintenance activities identified, thus increasing aircraft serviceability and minimizing downtime. Long-term, full-scale fatigue testing also has the ability to provide evidence to extend the lifespan of individual components, in order to allow fleet operators to use aircraft for longer – potentially plugging critical fleet capability shortfalls.

However, long-term, full-scale fatigue tests need – themselves – to be monitored to ensure the test equipment is not degrading, and thus compromising the validity of the data collected from the test items.

PROVEN EXPERTISE

Based in Cambridge, UK, Marshall Aerospace and Defence Group has been performing long-term, full-scale fatigue tests since the 1970s – in both military and commercial sectors. The company's test facility comprises a 21,500ft^2 purpose-built hangar with 5,400ft^2 of hard floor. It is equipped with specialized rigs and machinery for component and full-scale equipment testing, currently holds NADCAP, UKAS and ISO 9001 accreditation, and provides customized test solutions (covering design and manufacture through to analysis and reporting). Examples of full-scale components tested include undercarriages, flaps and various control surfaces, payload release mechanisms and fuel probes and tanks. A variety of composite (material) components has also been tested.

The company has particular expertise in relation to the Hercules C-130, and Marshall was the world's


Marshall has been performing long-term, full-scale fatigue tests since the 1970s, in both military and commercial sectors, and its test facility in Cambridge, UK, comprises a 21,500ft^2 purpose-built hangar with 5,400ft^2 of hard floor

first fully OEM-approved C-130B-H service center and the world's first C-130J heavy maintenance center. Marshall has been carrying out full-scale fatigue testing on C-130 components since the 1980s and the test facility is currently home to two full-scale C-130 fatigue test rigs: a C-130K full-scale fuselage fatigue test (FFT), which went live in 2005; and a C-130J full-scale wing fatigue test (WFT), which went live in 2009. Bar a few breaks for scheduled inspections (representative of in-service ones) and minor repairs, the FFT ran for nine years and the WFT for six.

One may be forgiven for thinking that once a test is developed – following the considerable up-front effort of calculating load spectra, rig design, installation and commissioning – it is simply a waiting game during which the data is amassed and analyzed. Not true. It is essential when conducting any program scheduled to run over a number of years that the test itself be monitored.

Such monitoring will typically include ensuring that loads are being applied correctly and consistently. It is also necessary to verify the responsiveness of the test equipment and correct for its degradation over time.

DATA TRENDING

The C-130J full-scale WFT is a prime example of a long-term fatigue test program that is required to run for many years at a very high level of accuracy, and therefore warrants a comprehensive trend monitoring process (TMP) to ensure that high accuracy is achieved and maintained.

The WFT is housed in a self-reacting frame on which 40 actuators are mounted to apply load to the test specimen along with an airbag loading system. The test is controlled by a proportional-integral-derivative (PID) control system and has a comprehensive data acquisition system recording strain readings from hundreds of strain gauges installed throughout the test specimen.

The load spectrum was developed in-house by Marshall from data

RIGHT: **The wing fatigue test rig comprises 40 actuators and hundreds of strain gauges**

gathered – and which continues to be gathered – from in-service aircraft.

The WFT was contracted to meet Defence Standard 00-970 requirements in relation to actuator absolute accuracy, actuator repeatability from test block to test block, and on actuator dynamic effects. Also, the RAAF specified that a trend monitoring process would need to be actively reviewed, checked and formally reported for every load line applied to the test article; where a 'load line' is a unique state of wing loading.

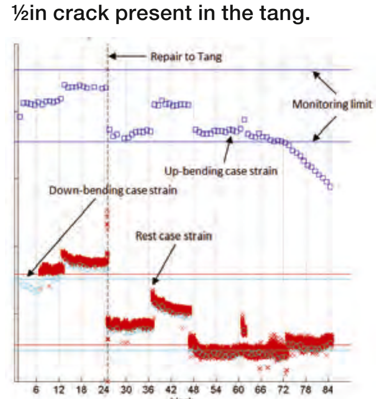
This report is issued every 'superblock', which is equivalent to 3,000 flying hours and consists of more than 750,000 load lines. Throughout the planned duration of the fatigue test program of 20 superblocks, this requires more than 15 million separate load lines to be individually checked for accuracy and repeatability and reported on.

To achieve these monitoring goals, Marshall developed software to automate the production of the reports and summary plots. Behind these reports, soft copy annexes contain thousands of HTML-generated plots covering the detailed response of each actuator and strain gauge that can be queried if a metric summary indicates a possible issue.

Also generated is a strain gauge follow-on report in which any strain gauge showing anomalous behavior can be assessed and classified, so that possible damage development can be identified. The follow-on report is also used to confirm the health of the strain gauges and their ability to function as expected; and to provide a secondary data source for evaluating actuator performance (if needed).

STRAIN TRENDING DATA: MICRO-STRAIN VERSUS TEST BLOCK

The enclosed figure shows an engine truss-mount tang strain gauge result for three load lines repeated over many test blocks. It can be seen that over time the strain reading under a wing up-bending case started to drift beyond warning limits, while the others were essentially unchanged. This could be symptomatic of the strain gauge being in the vicinity of a crack that would open in up-bending but closed in down-bending. Here, the drop in strain could be due to load dropping in the member due to the increased flexibility compared with the surrounding structure. In this case, it was found that when inspected at Block 84, there was a ½in crack present in the tang.



LEFT: The actuators in the wing fatigue test rig apply load to the test specimen along with an airbag loading system

For the WFT, the primary test fidelity and health requirements stemmed from Def Stan 00-970, Part 1, Leaflet 37, which highlights the high sensitivity of fatigue test fidelity to the loading accuracy and repeatability. In summary, the loads should be: accurate to within 3% of maximum demanded load for each load line; repeatable – in that load lines in a test block should be within 2% of the particular applied load or 0.5% of the maximum demanded load, whichever the greater, as each block is repeated; and free from dynamic effects such that accuracy or repeatability are achieved throughout the structure.

While the details of the accuracy and repeatability requirements can take some work to develop, it is the dynamic effects requirement for which it can be difficult to establish a suitable measurement metric.

Essentially, the 'a priori' assumption used when developing the loads for the test is that the test article is in equilibrium for every applied load line. In reality, when a load line is applied to the test article it is in motion (accelerating/decelerating), and the assumption that Total Force equals Mass times Accelerations equals Zero is therefore not strictly correct. Furthermore, if the frequency of the wing fundamental vibration modes couples with the load application rate, then loading away from the actuators may not reflect that which is intended.

"UNLESS THERE IS A SYSTEMIC ERROR IN THE LOADS, THEN ACCURACY AND REPEATABILITY ERRORS ON INDIVIDUAL ACTUATORS WILL TEND TO AVERAGE OUT. THIS MEANS THAT COMPLIANCE WITH THE STANDARD'S SUGGESTED LIMITS WILL GENERALLY LEAD TO AN EXTREMELY HIGH FIDELITY ON A MULTI-ACTUATOR TEST"

By assuring accuracy and repeatability, to the levels given in the Def-Stan, of the individual actuators, the effect on the resulting wing internal loads for any given multi-actuator test should have a significantly higher accuracy/repeatability. Put another way: unless there is a systemic error in the loads, then accuracy and repeatability errors on individual actuators will tend to average out. This means that compliance with the standard's suggested limits will generally lead to an extremely high fidelity on a multi-actuator test.

These high standards may not be the industry norm, but putting together tools to report metrics against every load line in the test allows Marshall to provide objective evidence of how well the test meets the requirements, enables any deterioration in performance to be quickly identified, and allows for the benefits of any corrections to be measured objectively. For example, deteriorating servo-valves can be identified through trend monitoring checks, and remedial actions confirmed.

TAKING THE STRAIN

One aspect of health monitoring that has been found to be very useful is the use of strain gauge monitoring in critical areas to identify incipient damage prior to failure.

For instance, while it was thought at the start of this one particular long-term test that identifying developing cracks from strain gauge data (prior to failure might be possible) it was not something that would prove practical. However, after failures on the test article, and where a subsequent review of the data clearly showed signs of significant shifts in strain gauge response prior to failure, it is now a key activity to review gauge results for signs of shifts that may indicate early signs of cracking.

ABOVE: C-130J full-scale wing fatigue test – strain gauges are installed throughout the test specimen

Accordingly, methods were developed to monitor all WFT strain gauges to look for signs of drift over the course of the fatigue test. When gauge readings exceed a monitoring limit, then the strain gauge response is investigated and an inspection carried out in the area in question to look for signs of cracking or degradation. A gauge reading drifting over time and exceeding a limit does not guarantee that cracking or damage is present, but has proven to be a valuable damage detection tool.

In order to demonstrate that the dynamic effects are small, Marshall developed a method to compare strain-survey strain data from low-speed running with that measured at full running rate; however it was found that this method only measured the natural variability in loading seen from block-to-block on the test. Therefore a new method was developed – called the strain phase monitoring (SPM) method.

This new method considers the Force equals Mass times Acceleration (F=Ma) effects separately, and concentrates on showing that, for strain gauges on the wing, the peak strain occurs at the point when each load line is achieved, meaning that there is no phase lag and no overshoot. For the F=Ma question, it was shown that for the peak accelerations seen on the test article, the equivalent force error was negligible.

Another use of a comprehensive trend monitoring system is in understanding the effects that deteriorating equipment, specifically servo-valves, have on test repeatability. Marshall has been able to show clearly the effects of deteriorating servo-value units and to demonstrate if a replacement has improved test performance.

The TMS also provides an excellent measure of whether other remedial actions, such as the introduction of dither, have had the desired effect. This ability has been coupled with a robust maintenance schedule that sees rig equipment regularly calibrated, inspected or replaced. Such activities are commonplace within the world of fatigue testing, but when coupled with the test health monitoring tools, the difference in terms of test performance can be quantified.

Ensuring test health is maintained on a multiyear, multi-actuator, full-scale wing fatigue test is not trivial. Measuring and understanding any trends requires dedicated tools and adherence to a comprehensive maintenance schedule.

Many of the things that have been learned over the years on this and other extensive test programs relate to test health, and were the drivers behind Marshall's development of a bespoke trend monitoring system. This system provides valuable information on the running of the fatigue test, flags issues before they occur, and allows the impact of rectification to be objectively measured.

Joseph Bernacki is senior test engineer with Marshall Aerospace and Defence Group

ACKNOWLEDGEMENTS

The complexity of the program detailed in this article means that contributions have come from a spread of organizations and individuals. The following should be acknowledged for their contributions: RAF C-130J Project Team; RAAF Directorate General of Technical Airworthiness; QinetiQ Airworthiness and Structural Integrity Group; and the Aircraft Structures Branch Aerospace Division, Defence Science and Technology Group, Australia (which was instrumental in the development of the WFT trend monitoring process).

CHAMBER MADE

The National Research Council Canada shares its latest innovations in structural full-scale testing

BY DANY PARASCHIVOIU AND MARKO YANISHEVSKY

Some within the aerospace industry believe that analysis and modeling will eventually replace testing ranging from coupons to structural full-scale tests (SFSTs). Unfortunately, in spite of improved analysis capabilities, testing requirements continue to be of paramount importance to the certification of new aircraft. As OEMs implement new composite materials and hybrid structures in aircraft designs to be lighter and more cost-efficient, modeling and simulation provide the basis of structural design. However, the complexity of understanding and predicting the performance of these novel structures throughout all service conditions is not sufficiently mature to assess static performance of new material configurations, let alone fatigue durability and residual strength at end of life. Therefore, testing is still viewed by certification agencies throughout the globe as the gold standard for proof of structural compliance as outlined in existing regulations.

Aircraft durability and damage tolerance (DADT) tests broadly fall into three categories: initial proof of concept, certification and life extensions. Initial proof of concept tests are typically requested and performed by some OEMs to evaluate new designs prior to certification by civil aviation authorities. Certification is viewed as a strategic capability by the major OEMs, and most perform their structural tests in-house to verify the new designs and correct design errors as soon as they are known. Typically, these are conducted using well-established testing technologies. Innovations and new testing technologies beneficial to OEMs and operators tend to be developed by research labs and specialized test suppliers of SFSTs. Achieving representative tests is more difficult than merely applying fatigue load spectra in a hangar at a relatively constant room temperature and humidity, even if the loading is performed accurately.

As a national laboratory, the National Research Council Canada

LEFT: CF-18 H-stab fatigue test underway at NRC

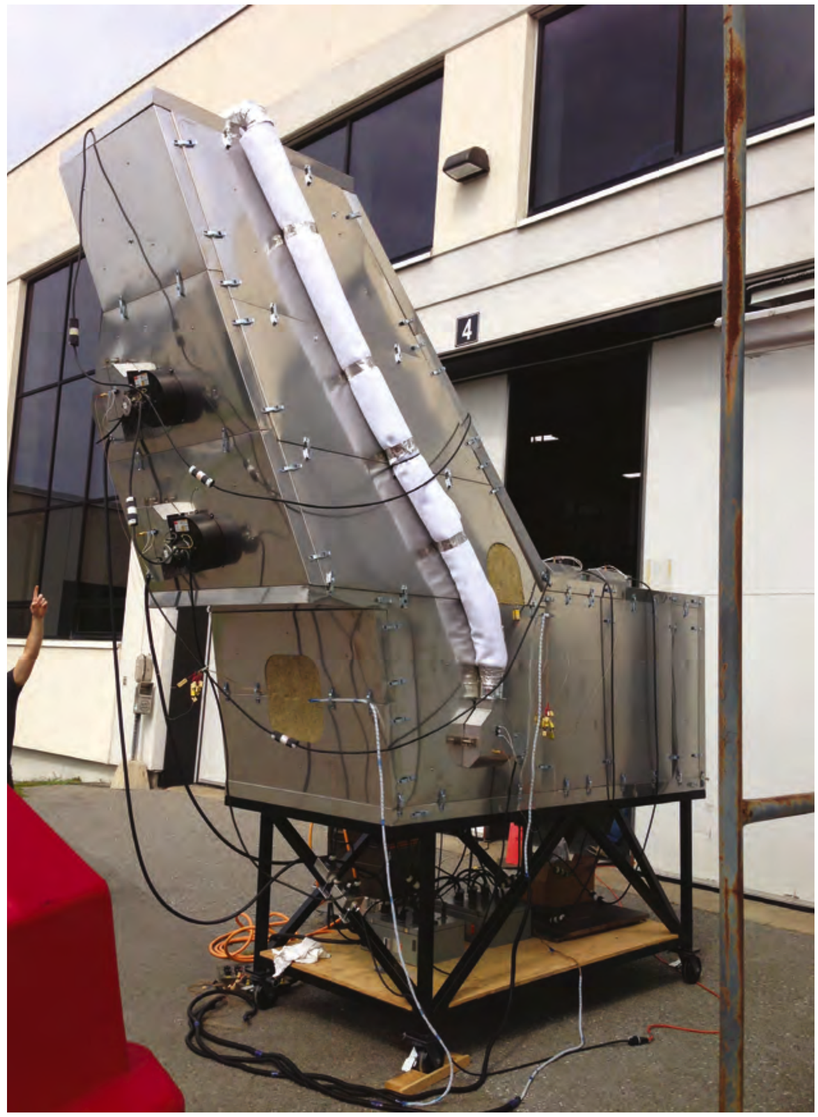
(NRC) is continuously seeking to improve existing testing technologies and developing new ways to be more cost-effective in testing, while being representative of actual service usage. Some efforts are being driven by OEM and client requirements directed at reproducing environmental effects that affect the life of aircraft structures, such as temperature, humidity, corrosion, loads accuracy, test speed, and dynamic and buffet loading. Efforts are also being made to reduce overall test durations by developing purpose-built test rigs, investigating accelerated load introduction and test controls, integrated counterbalancing, novel instrumentation, inspection triggering procedures, and minimizing downtime.

ENVIRONMENTAL EFFECTS

Environmental effects are an important consideration because most new aircraft involve some level of hybrid material construction. OEMs, operators and regulators would all like to ensure that the aircraft have been designed and proven to account for these effects. The development costs to do so are high, particularly if optimized design and minimization of structural weight are also to be achieved. With the help of airworthiness authorities, such developments provide an additional opportunity to reduce the 'safety' factors imposed on fatigue testing.

Typically, aircraft will experience temperatures ranging from -50°C (-58°F) at altitude to in excess of 60°C (140°F) on tarmac. Parts adjacent to engine exhaust can have higher temperatures affecting their life.

NRC has conducted low temperature tests in commercial custom-built environmental chambers, or chambers designed and built in-house that use compressed gas or liquid nitrogen to produce temperatures as low as -200°C (-328°F). The operation and temperature control are achieved using digital controllers, blower fan systems and temperature source control with feedback from thermocouples applied directly on the test articles. Most composite and hybrid materials experience significant property changes when exposed to low



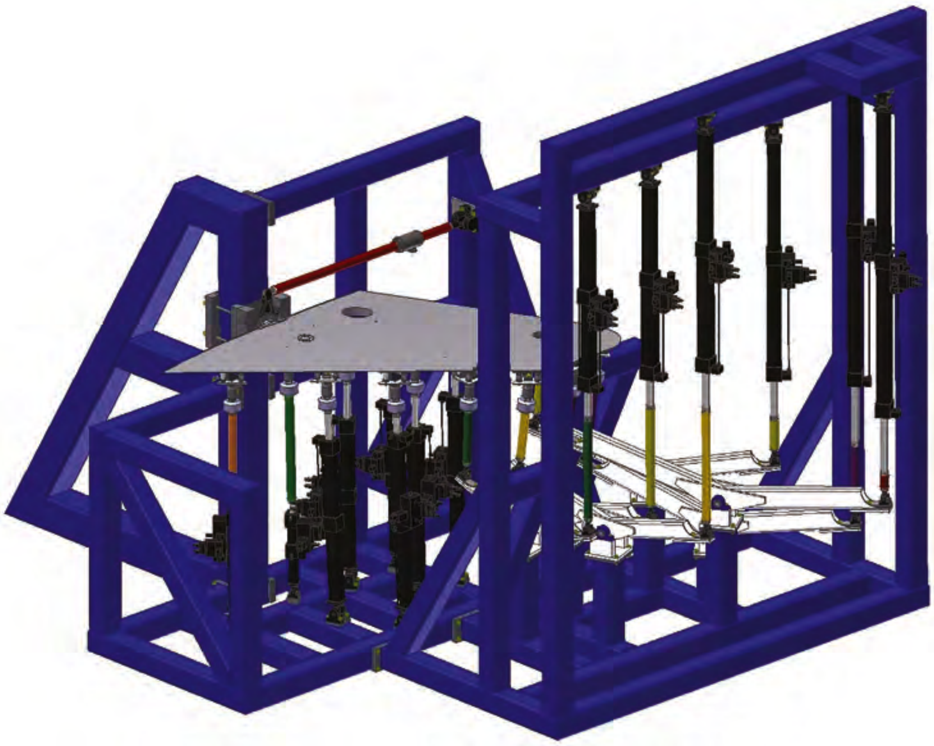
RIGHT: An NRC full-scale purpose-built high-temperature enclosure during commissioning

temperature environments. To date, the effect of low temperatures on material performance/failure modes is analytically difficult to predict. The challenges to conducting low temperature fatigue testing for long periods of time are numerous, but not insurmountable: access to a continuous supply of liquid nitrogen; proper enclosure of the test chamber in the laboratory; proper hydraulic actuator and load cell isolation; and dealing with condensation during temperature cycling that may result in ice build-up on the test article if appropriate isolation is not achieved.

NRC has engineered, designed and built several custom environmental chambers for static and fatigue SFSTs requiring higher temperatures. Due to difficulties in controlling humidity at elevated tests, most client requirements have so far opted to apply relatively higher dry temperatures that exceed the hot wet conditions experienced by the composite structures in service. Some tests have required a relatively high constant temperature of 121°C ±5°C (250°F ±10°F) during durability assessments and up to 177°C ±5°C (350°F ±10°F) during residual strength static testing. These require power ranging from 10kW to 60kW, while undergoing fatigue cycling, to replicate the service environment for these structures. An important feature of these high-temperature tests is an NRC-developed system for controlling temperature zones within the chambers. This control system, originally developed for both air (convection) and contact style (conduction) heating for co-bonding and secondary bonding/mating of composite structure, incorporates multiple over-temperature shutdown mechanisms, both mechanical and computer software, giving the ultimate in fidelity and protection to valuable test articles.

SFST tests requiring fire conditions can be conducted at the NRC's National Fire Laboratory. The Burn Hall can handle sustained fires of up to 20MW producing temperatures up to 300°C (572°F). The facility operates the FAA sanctioned NexGen Jet-A fuel fired burner, to demonstrate compliance with the powerplant fire protection requirements of Transport Canada (TC) and the Federal Aviation Administration (FAA) based on the FAA's fire protection requirements. Fire test services include the development and planning for custom requirements outside the standard guidance provided by regulatory authorities. A recent fire test request involved testing of a wing engine mount subjected to a 1,093°C (2,000°F) flame to achieve a fireproof rating in combination with critical flight load cases.

Environmental effects affect metals, composites and hybrid structures in different ways. For metallic structures, one such failure mechanism is environmentally assisted cracking under static and fatigue loads. NRC has conducted long duration tests in saline mist and alternate immersions in salt water environments to account for this life-reducing environmental effect. In addition to temperature, humidity levels and even UV are environmental life-reducing factors for composites and hybrid structures. Exposure to UV is becoming a more recent specific concern to unmanned air vehicles



LEFT: Example of tension-compression load application perpendicular to the test article surface

(UAVs) that have a long to very long autonomy while operating at medium to high altitudes. Although exterior paint usually offers sufficient protection to UAVs, concerns regarding the adverse effects of long-term exposure to UV on fatigue life remain valid.

“BY OPTIMIZING PURPOSE-BUILT TEST RIGS, THE USE OF OVERHEAD STRUCTURES IS MINIMIZED, REDUCING THE COST OF MANUFACTURING, ASSEMBLY, AND RECONFIGURATION OF THE TEST RIG FOR RESIDUAL STRENGTH TESTING”

DYNAMIC LOADING

Dynamic loads can induce fatigue damage, and are currently dealt with in a suboptimal way. One of the main reasons for introducing dynamic loading accurately on SFSTs is to reduce the safety factors that vary between 4 and 10 lifetimes for unmonitored dynamically loaded structures. NRC is currently investigating techniques to apply larger numbers of damage-inducing dynamic loads with higher fidelity. Alternatively, monitoring dynamically loaded structural usage effectively could reduce safety factors required to obtain typically 1/1000 probability of failure rates. NRC is investigating structural monitoring and dynamic load introduction on test articles.

NRC’s existing multi-actuator loading systems can apply multiple loads, operating independently at differing amplitudes and frequencies. Actual dynamic load application frequency is dependent upon the test article, although the system is capable of applying variable spectrum loads at greater than 3Hz, with higher rates potentially achievable dependent on displacement and structural resonance characteristics. Some effort is being expended to develop tools to characterize the overall test system modal response, to ensure that dynamic modes, while being applied at higher frequency, remain representative. Other avenues being explored include using existing hydraulic systems with new control techniques and/or electrodynamic shakers.

TEST RIG DESIGN

NRC’s most current test rig designs have been simplified by combining the use of equal area actuators with an internally developed novel compact tension-compression ‘whiffle tree’ loading system. By optimizing purpose-built test rigs, the use of overhead structures is minimized, reducing the cost of manufacturing, assembly, and reconfiguration of the test rig for residual strength testing. Faster testing rates have been achieved by reducing conventional whiffle tree mass, counterbalances, cables and pulleys, while allowing the underlying structure to bend and flex, as required. The example above employs levers that enable load introduction to be perpendicular to the test article surfaces during large displacements at peak loads.

ACCELERATED CYCLING

Cycling time is a significant contributor to schedule and cost for SFSTs. It is particularly important for aircraft with complex usage spectra under high loading that use fly-by-wire controls or those that fly in flight regimes that contain buffet and/or dynamic loading. In commercial aircraft, spectrum complexity is significantly reduced, the biggest challenge being the achievement of high pressurization and depressurization cycle rates to decrease the time for required cabin pressurization.

By increasing loading frequency, reduced cycle times can be realized, truncation minimized or the design

LEFT: National Fire Laboratory located in Mississippi Mills, Ontario, Canada

spectrum simplified, leading to higher fidelity between ground testing and operational service experience. Cost-wise, testing is an expensive proposition. If the fatigue test can be completed sooner, all associated test operations costs are reduced, leading to less expensive product development. Reducing cycling time requires several avenues of investigation, such as: novel techniques in control system implementation; modeling efforts, system identification and feedback control; and novel designs for load application. Being able to test at a faster rate than the loads that are being experienced in-flight has the potential to increase the fidelity of the spectrum by reducing or completely avoiding truncation, compress the test schedule, and reduce the total test costs. The main challenges to this remain avoiding test article and test rig resonance modes, and the development of robust load control schemes and/or adaptive algorithms.

REDUCING DOWNTIME

Downtime, which includes planned inspections, modifications, unplanned repairs to the test article and/or test rig reconfiguration, is the Achilles' heel of SFSTs. During new product development, the downtime can often equal the time actually spent testing.

Regarding inspections, experience has shown that almost half of a test downtime is spent doing Level 1, 2 and 3 inspections. These inspections are required to replicate maintenance and inspection programs as per the OEM *Standard Repair Manual*, which must be respected during testing for legal purposes, and is ultimately provided to the operators for maintenance. Alternatively, inspections could be triggered and damages detected on a test article by instrumentation trend monitoring. When changes to sensor readings are noted, targeted inspections can be carried out. Structural health monitoring (SHM) may be a key to ensuring SFST inspections and future fleet health. SHM is the continuous, autonomous in-service monitoring of the physical condition of a structure by means of embedded or attached sensors with minimum manual intervention, to monitor structural integrity. SHM has three different functions: usage, loads, and damage monitoring, which all have direct influence on structural performance. The last is what we commonly refer to as in-situ NDE and it is tailored for damage detection and monitoring. With proof of operation on SFST of sensors and SHM triggered inspections to detect damages, future aircraft will be equipped with dedicated SHM systems that will be one of the key technologies for assuring structural integrity and providing maintenance credits depending on the actual usage of individual aircraft, while maintaining safety.

Regarding unplanned repairs during testing, the only alternative strategy is to tolerate the damage while ensuring safety of the test article. Repairs, airworthy or not, are a main contributor to downtime and need to be mitigated using damage tolerance analysis.

The importance of replicating adverse environmental effects and in-service spectra that affect the fatigue life of aircraft structures cannot be overemphasized. Dynamic loading within the in-service spectrum is also an important consideration that has the potential to reduce uncertainty and avoid conservative safety factors imposed on testing. Structural testing remains a necessary requirement for aircraft certification, proof of concept, and life extension. Continued efforts toward optimizing test rig design, developing methodologies for accelerating testing, reducing downtime, as well as SHM technologies destined for in-service use during laboratory ground tests, should be included in the testing strategy of aircraft. Together, these can help improve fidelity and reliability while reducing the cost, time and effort of bringing aircraft structures to certification. ∎

"IF THE FATIGUE TEST CAN BE COMPLETED SOONER, ALL ASSOCIATED TEST OPERATIONS COSTS ARE REDUCED, LEADING TO LESS EXPENSIVE PRODUCT DEVELOPMENT"

Dany Paraschivoiu is program leader, aeronautical product development, NRC; and Marko Yanishevsky is team leader, structural full-scale testing, NRC

FREEDOM PRINCIPLE

A new method of PSD estimation based on instant degrees of freedom is designed to rapidly reduce estimation error at the beginning of a test and after changes in test level

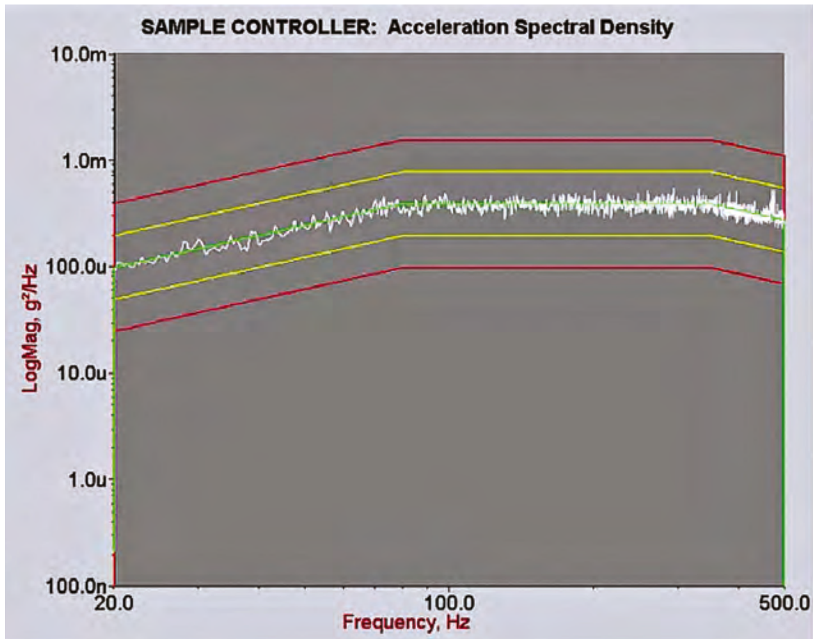
BY JACOB MAATMAN

Power spectral density (PSD) estimation is a critical tool in the vibration test engineer's toolbox. During a random vibration test, Gaussian time-domain data is transformed into frequency-domain data using the fast Fourier transform (FFT). In particular, a set of time-domain samples is transformed into a set of frequency-domain data using the FFT, and by having this frequency-domain data, the PSD can be estimated. Due to the nature of randomness, the PSD estimate generated from one set of sampled time-domain data is volatile, with high variance between estimated values and the actual PSD value.

An effective way to reduce this volatility and reduce the variance between the estimated and actual PSD is to partition the total sampling period into equally sized time periods (frames), transform the samples from each frame using the FFT, calculate the power of these FFT values, and then average the power values from each set by means of the arithmetic mean. This is generally known as Welch's method.

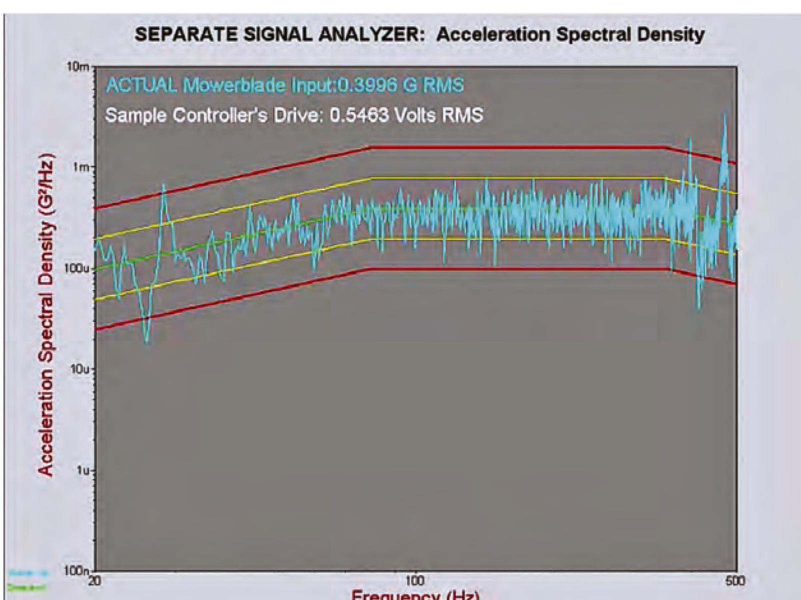
Hence, this method of FFT averaging requires a noticeable amount of time in order to gather, transform, and average the data, an amount noticeable especially to engineers who wish to know as quickly as possible whether the test and product are and will remain within tolerance limits, since failure to be within tolerance limits may indicate that the test is over-testing and perhaps damaging the product. The concern for meeting tolerance occurs with respect to changes in level, too. Methods of PSD estimation have been offered as a solution to meet tolerance after a change in level, but some methods – even a common method – lead to inaccuracies, as shown below.

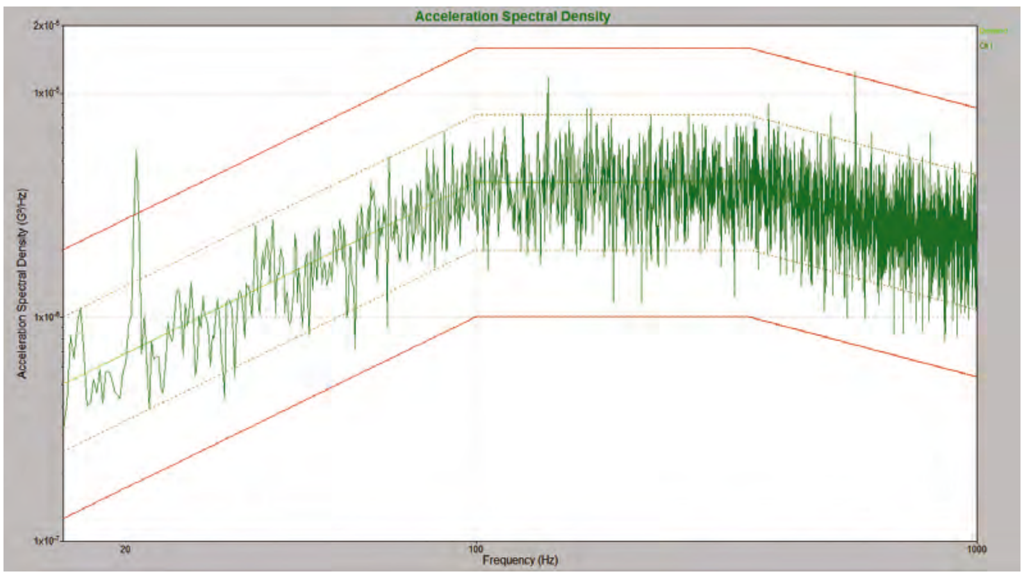
The most commonly used method of dealing with a change in level involves the multiplication of low-level data. With this method, the controller runs the test on a product at a low level (below demand) and averages the PSD estimate. At a change in level the controller uses the estimated PSD of the low-level test, multiplies that estimated PSD by the amount of the level change, and presents the data as if it had been measured at full level – using the results of one test for another. From this starting point, the method then continues averaging. This method is inaccurate, since it assumes that the ramped-up data will be a



ABOVE: PSD display using multiplication method

BELOW: PSD display using signal analyzer





ABOVE: **PSD estimation with separate signal analyzer using traditional averaging**

factor-multiple of the lower-level data, thereby assuming that the behavior of the product at high-level would exactly mimic that of the product at low-level. This is not a justifiable assumption, since during changes in level the product being tested cannot be expected to exhibit behavior exactly like that of behavior at a lower level. Resonances, for example, can shift with an increase in level. This method masks the true behavior of the product at a higher level, which undermines the very purpose of a vibration test (see images on opposite page).

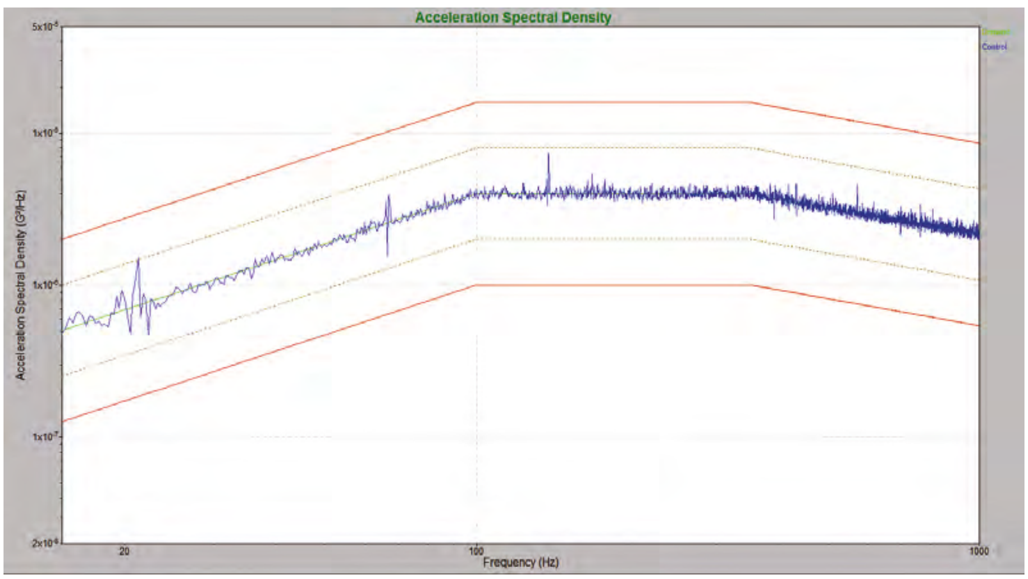
How should PSD estimation behave at a change in level? In order to achieve the goal of accurately displaying what is occurring with the product under test, it is necessary to discard the measurements taken at low level and begin averaging anew once the system has reached full level. This enables the user to see what the true vibration levels are on the product soon after the level transition, without confusing them with the measurements made at lower-amplitude levels. These initial measurements will exhibit high variance simply due to the random nature of the test and Welch's method of averaging. This behavior is inherent in PSD estimation, as the statistics of the chi-square distribution make clear. As the test proceeds, more data will be gathered and averaged into the PSD estimate, which will converge to the actual PSD of the waveform. As that convergence occurs, the estimation errors will decrease, the control errors will become apparent, and an appropriate decision may be made as to whether the test is within tolerance.

What needs to be kept in mind is that the high variance of the PSD estimation during the initial stages of the test or after averaging is reset at a change in level, or some lines exceeding the tolerance or abort lines during these times does not mean there's something wrong with the PSD estimation method, the actual signal, the test, or the product/shaker response to the drive signal. Such behavior of the PSD estimation is expected – it's estimating a random signal, and so some volatility is entirely natural, expected, and even desired as verification of the estimation method. Over time, averaging will smooth things out.

INSTANT DEGREES OF FREEDOM

Vibration Research Corporation has recently introduced iDOF – instant degrees of freedom – a method of PSD estimation designed to rapidly reduce estimation error at the beginning of a test and after changes in test level. In doing so, the PSD estimate provided by the iDOF algorithm approaches the actual value of the signal's PSD quickly, allowing for rapid verification of tolerance limits and/or faster detection of and reaction to an abort condition. The iDOF method accomplishes this significantly faster than the traditional averaging method. More importantly, unlike the multiplication method described above that attempts to rapidly display a clean PSD plot, iDOF produces a PSD estimate that accurately depicts the full-level signal PSD, without clouding the estimate with readings made at other test levels.

When it comes to error in the PSD plot (the difference between the control and demand curves), there are two sources: control error and estimation error. Control error refers to the discrepancy between the actual PSD of the data (signal) and the desired demand PSD. Estimation error refers to the discrepancy between the estimated, plotted PSD and the actual PSD of the signal. For instance, suppose one resets the PSD estimation's averaging during a test (without changing level). This doesn't affect the signal, and so the actual PSD of the data doesn't change, yet the PSD plot becomes very ragged, until enough new data has been accumulated to average out and accurately estimate the PSD. The error evident in this raggedness is estimation error, since resetting the averaging doesn't affect the actual PSD of the signal, and therefore the error between the actual PSD of the signal and the demand PSD doesn't change. This is an example where, although the data plotted on the screen has large variance, the control may be very good, with only a small amount of control error. However, consider the PSD estimation method involving the multiplication of low-level data. During a change in level, the actual PSD of the signal (in other words, the signal) undergoes a major change – including shifts in resonant frequencies – since here the signal is changing (increasing in power). Yet the inaccurate PSD



LEFT: **PSD estimation using iDOF at full level**

method doesn't indicate any changes in the PSD plot during the change in level and at the higher level.

During a change in level and at a higher level, although this method gives the appearance of minimal error on the plot, there is significant difference between the actual PSD of the signal and the estimated PSD shown on the plot. In this case, there is both large control error and large estimation error, and the estimation error offsets and masks the presence of control error.

Estimation error arises from the inherent properties of PSD estimation as described by chi-square statistics – from the fact that the PSD estimation estimates a random signal. Control error concerns the signal and arises from resonances in the signal or other noise added by the system to the signal that takes the controller work to accommodate. It is the control error that interests and most concerns the test engineer. Estimation error occurs as a matter of fact when estimating the PSD of a random signal. And estimation error is inversely proportional to the number of frames averaged – hence, largest at the beginning of a test and at changes in level when averaging is properly reset. Even if the signal was perfect, and there was no control error, there would still be estimation error present in the PSD plot, estimation error which would decrease inversely proportionally with degrees of freedom. Further, the presence of estimation error does not imply the presence of control error, since estimation error should not concern the control of the signal.

CONTROL ERROR REVEALED

However, there is a method with which estimation error can be confidently removed: iDOF. And iDOF does this in a manner that preserves control error. In other words, iDOF confidently removes estimation error, enabling the user to see control error more clearly. The iDOF method goes to work soon after test start-up and quickly after a change in level (at which change averaging is reset).

It is important to note that iDOF does not touch the control itself (evident in the fact that iDOF removes only estimation error). Nor does it affect the signal being sent from the controller to the system. But iDOF does clarify the estimation of the actual PSD of the signal. Hence the control trace – the estimation of the actual PSD of the control signal, not the control signal itself – is displayed more clearly, with less raggedness.

In a short amount of time, iDOF gives the test engineer a precise view of the signal's actual PSD, providing a clean, uncluttered picture of the true vibration. Lines which with traditional averaging might have for a time exceeded the tolerance or abort lines due to estimation error (and not to the signal itself) are quickly reined in. Yet, when spikes due to resonances or other aberrations applied to the signal by the system are present in the underlying signal's PSD (are present in the actual signal, that is), these deviations from the demand remain in the PSD estimate and are clearly manifest, as desired, allowing for an appropriate and informed decision as to whether the test is within tolerance, or if a test should be aborted to protect the product.

iDOF is an innovative PSD estimation method that rapidly reduces estimation error and as a result quickly smooths and clarifies the PSD plot, exposing actual vibrations, clearly informing the operator. ∎

Jacob Maatman is a product software engineer at Vibration Research


Over or Under Testing =
Unexpected Product Failure

ANTENNA DESIGN MADE EASY

Advances in electromagnetic simulations designed to reduce test time in the aerospace industry

BY DR C J REDDY

With today's growing communications, increasingly sophisticated antenna systems with associated electronics are being installed on board aircraft. Advances in electromagnetic (EM) simulations have improved the design process for such systems, resulting in shorter testing times and reduced costs. Altair's FEKO is an EM simulation tool, widely used in the aerospace industry for antenna design, placement and electromagnetic compatibility studies, as well as to emulate antenna measurement processes to reduce end-of-the-design testing procedures.

FEKO offers several EM solvers, including full wave and asymptotic methods. Full wave methods include method of moments (MoM); finite element method (FEM); finite difference time domain (FDTD); and multilevel fast multipole method (MLFMM). Asymptotic methods include physical optics (PO); ray launching geometrical optics (RL-GO); and uniform theory of diffraction (UTD).

FEKO's solvers are hybridized for efficient analysis of a very broad spectrum of EM problems, including: FEM-MoM/MLFMM; MoM-PO; MLFMM-PO; MOM-RL-GO; and MoM-UTD.

Applications of EM simulation using FEKO include antennas analysis, microstrip circuits and biomedical systems, placement of antennas on electrically large structures, and investigation of electromagnetic compatibility (EMC). In this article, advanced EM simulation methods are illustrated for the applications of antenna placement, nosecone radome design and the effects of electromagnetic interference

FIGURE 1: MoM simulation of the aircraft. Electric currents on the surface of the aircraft due to a monopole antenna at various frequencies

FIGURE 2: MLFMM simulation of the aircraft. Electric currents on the surface of the aircraft due to a monopole antenna at various frequencies

Method	Frequency	Unknowns	Memory	Runtime
MOM	200 MHz	5 256	0.612 GB	13.8 sec
MOM	300 MHz	10 736	2.038 GB	47.6 sec
MOM	425 MHz	22 237	8.051 GB	3.2 mins
MOM	850 MHz	89 421	113.696 GB	1.9 hours
MLFMM	850 MHz	179 514	11.545 GB	1.2 mins
MLFMM	1700 MHz	714 861	36.002 GB	4.7 mins
MLFMM	2550 MHz	1 701 258	81.204 GB	10 mins
MLFMM	3500 MHz	2 980 749	112.839 GB	34.5 mins
PO	3500 MHz	911 887	22.272 GB	2.4 mins
PO	5300 MHz	1 830 109	45.981 GB	4.0 mins
PO	7000 MHz	3 633 463	88.714 GB	10 mins
PO	7500 MHz	4 229 730	102.824 GB	12.8 mins

TABLE 1, ABOVE: Computational requirements for the aircraft model with increasing frequency and solver techniques

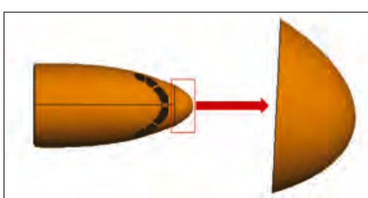


Figure 3: Nosecone of Airbus A380-800 passenger aircraft

due to lightning, and are presented in the context of the aerospace industry.

In recent years, computational electromagnetics has assisted engineers in numerically investigating various problems and reducing the need to perform actual measurements on-site. However, depending on the electrical size and complexity of the structures involved, in many cases the computational resources (memory and run time) required could make it prohibitive for EM engineers to conduct practical simulations.

Altair's cloud-based high-performance computing appliance, HyperWorks Unlimited (HWUL), provides an ideal platform to perform antenna placement studies. As a case study, a full-size fighter aircraft model is considered in FEKO. In the model setup, a monopole antenna is placed on the top of the aircraft. The aircraft has a physical length of 14.5m and a wingspan of 8.0m. At 200MHz, the length is 9.7λ and the wingspan is 5.3λ (λ is the wavelength), whereas at 10GHz, the length is 485λ and the wingspan is 265λ. The mesh should be refined accordingly with increasing frequency. Figure 1 shows current distribution on the aircraft at various frequencies up to 850MHz using MoM

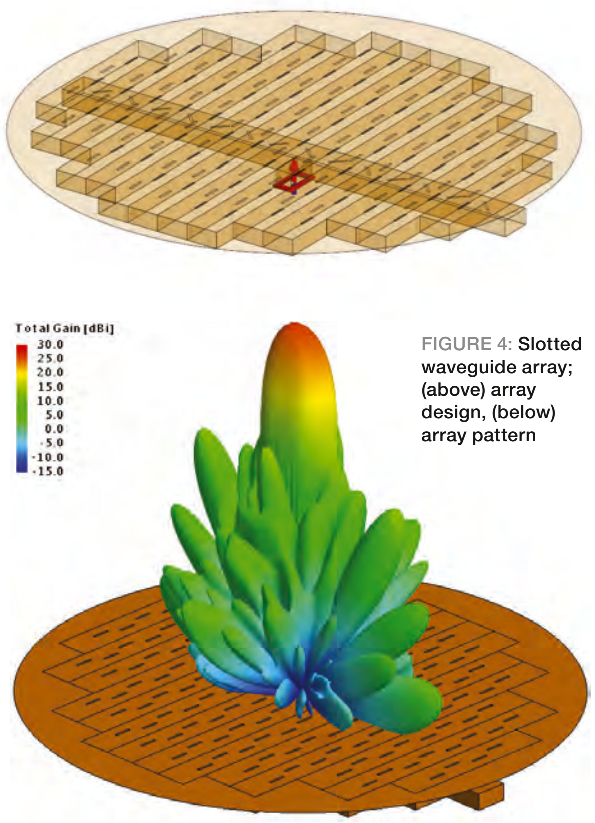


FIGURE 4: **Slotted waveguide array; (above) array design, (below) array pattern**

solver in FEKO and up to 3.5GHz using MLFMM solver in FEKO (Figure 2). Beyond 3.5GHz, we could use the asymptotic solver to establish the currents and radiation patterns all the way to 7.5GHz (Table 1).

AIRBORNE RADOMES

A radome (radar dome) is a structural, weatherproof enclosure that protects a radar system or antenna from its physical environment with minimal impact to the electrical performance of the antenna. Radomes must be radio-frequency transparent and therefore constructed of materials that minimally attenuate the electromagnetic signal transmitted or received by the antenna. Selecting a proper radome for a given antenna can improve the overall system performance through maintaining alignment by eliminating wind loading, allowing for all-weather operation, providing shelter for installation and maintenance, and so on. Applications such as satellite communications and airborne weather radar require huge radomes to protect the electrically large antennas. Figure 3 shows the nose of an Airbus A380-800 passenger aircraft, which usually covers the weather radar that operates in X-band, typically 9.4GHz.

A slotted waveguide (SWG) array, illustrated in Figure 4, is the most popular antenna for the weather radar.

The SWG array is designed in such a way that it is fed from the bottom with a single waveguide that is orthogonal to the array waveguides. The length, width and spacing of the slots is optimized for the desired pointed beam pattern.

Aircraft require nosecone radomes that can withstand extreme aerodynamic stress. For such applications, monolithic half-wave wall configurations are preferred. A radome made of a glass composite ($\varepsilon r = 4.0$, tan $\delta = 0.015$) with a thickness of 9mm is considered. The outer surface of the radome wall is coated with a 0.2mm-thick typical paint ($\varepsilon r = 3.46$, tan $\delta = 0.068$). Figure 5 shows the SWG array scanning on both sides of the aircraft. The comparison of the array pattern with and without the radomes indicates that a transmission loss of a nominal 0.7dB is introduced because of the glass composite. It can also be observed that the monolithic radome is not introducing any boresight error.

HIRF ON CABLES IN AIRCRAFT

Lightning and high-intensity radiated fields (HIRF) are major concerns to aircraft designers. Many critical systems, controlled electronically, require cables that span a large portion of the aircraft. These cables are especially vulnerable to receiving fields from lightning, broadcasting antennas and radars. Intricate solutions must address these problems with minimal shielding, to meet flexibility, weight and volume requirements.

Traditionally, significant time and financial resources were invested into measurements conducted on aircraft prototypes. The design phase could potentially iterate through several cycles if the electrical systems required modifications due to susceptibility. In contrast, computer simulations assist engineers in easily exploring various scenarios, and ensure the actual aircraft will pass the test.

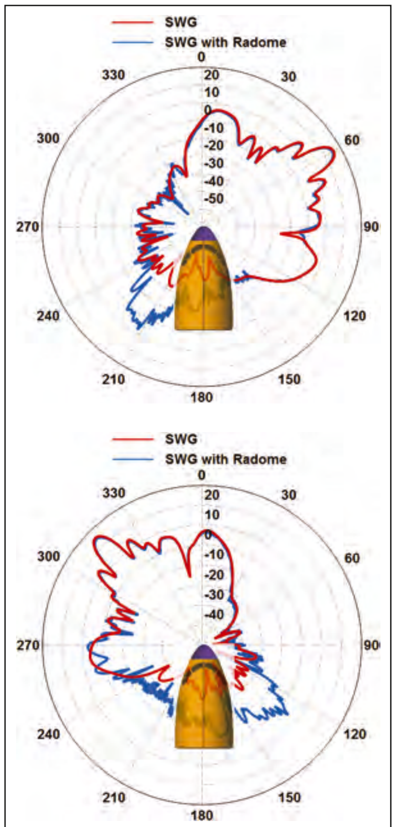


FIGURE 5: **Slotted waveguide array scanning at different angles on both sides of the aircraft, both with and without the radome**

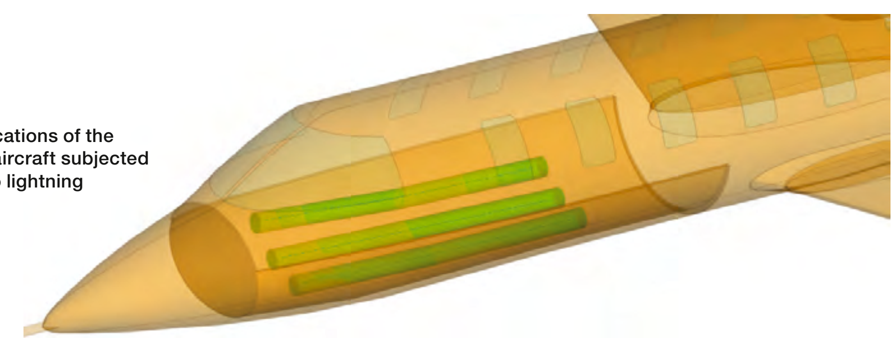


FIGURE 6: **Locations of the cables in the aircraft subjected to HIRF due to lightning**

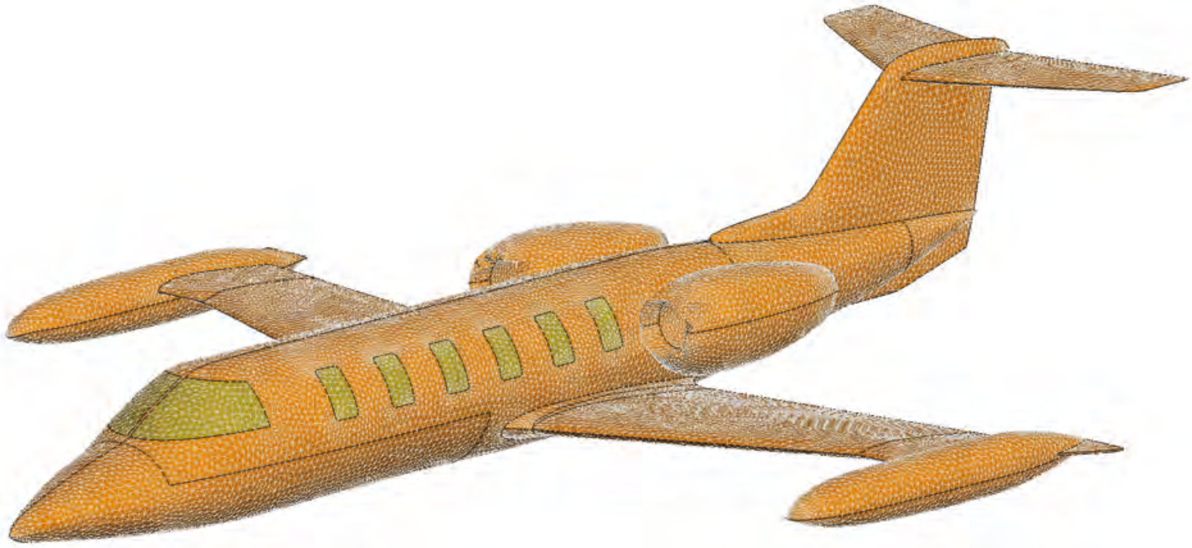


FIGURE 7: The mesh used for the HIRF simulations has 84,579 triangles

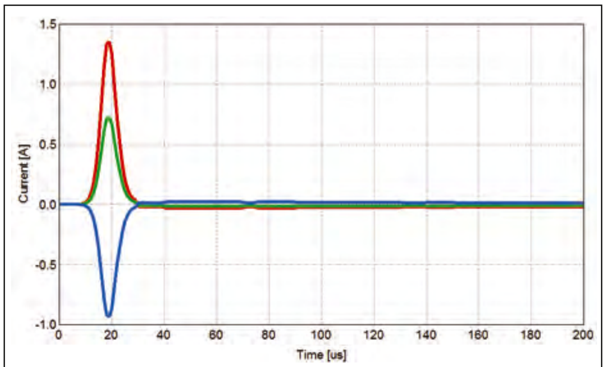


FIGURE 8: Lightning-induced currents observed at the shorted ends of the three unshielded cables

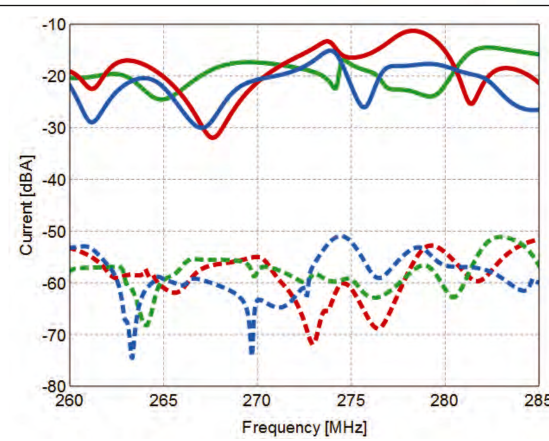


FIGURE 9: Typical example of HIRF-induced currents as a function of frequency. For clarity, not all angles of incidence have been included

As an example, consider a small jet passenger aircraft with a length of 16m and a wing span of 13.7m to study the effect of HIRF due to lightning on cables inside the aircraft. Similar to a laboratory experiment, three cables of 3m in length are placed inside the fuselage (Figure 6). The cable paths are indicated by the dotted lines, while the green tubes represent local mesh refinement operations for accuracy. The distance between any cable and the nearest metal surface is 10cm.

At frequencies of hundreds of MHz, the HIRF simulation required a much denser mesh than the lightning simulation, as illustrated in Figure 7, but two differences are to be noted. The higher frequencies facilitated sufficiently accurate simulations by meshing only the surfaces. Also, the simulation could be handled with an efficient method – MLFMM. The HIRF simulation took 16.7Gb of RAM and 1.7 hours elapsed time per frequency point using eight cores, with three incident waves impinging from the front, the side, and from 45°.

Figure 8 shows the lightning-induced currents observed for the case when one end of the cable is shorted and when no cable shielding is present. Note that the peaks are 0.7A to 1.4A, a large current spike for most systems. In the 50Ω resistors, voltage spikes of 35-70V occur. If the cables are used with digital systems, this would exceed the actual signal in the logic by an order of magnitude.

The main benefit of these simulations is that they reveal how much shielding is needed to achieve first-pass success in tests. This is important, since repeated testing is expensive, while adding too much shielding to all the cable harnesses in an aircraft adds a lot of weight and reduces the routing flexibility.

Figure 9 shows representative examples of the HIRF-induced currents in all three cables, as a function of frequency, for the case where both ends of each cable are terminated with 50Ω. The incident-field strength is 300V/m. The top three lines belong to unshielded cables, while the bottom three belong to cables with braided shields.

REDUCE TESTING TIME

This article makes clear the use of advance EM simulation methods for the application of antenna placement, nose-cone radome and electromagnetic interference, due to lightning, in the context of the aerospace industry. As illustrated, simulations play a key role in the proper design of aero systems, which in turn will reduce the final testing time and hence cut the cost of production. ∎

Dr C J Reddy is vice president of business development, electromagnetics, Americas, Altair Engineering Inc

LEAP THROUGH TESTING

Scalable, high-performance test and analysis systems lie behind the rapid response to emissions and cost challenges of aircraft engine manufacturers

BY NOEL BROWN

Airframers face stringent requirements to reduce fuel burn, environmental emissions and engine noise, drawing engine performance into central focus. The gas turbine is a highly complex machine that needs comprehensive testing and analysis during development, to understand and optimize its dynamic behavior. Brüel & Kjær's gas turbine test systems provide high performance, scalable platforms for dynamic data recording, real-time monitoring, and post-testing analysis.

Engine testing takes up considerable resources, and with huge engine test stands, data acquisition capabilities, and many staff, each test is a major operation. Getting tests right the first time has many different aspects, starting with the test setup.

REMOTE PRE-TEST PLANNING

Test planning is a complex task involving many different people defining many different sensor types and measurement aspects. A lot of up-front information needs collating, and then configuring into the test system. This is a time-consuming exercise, ripe for introducing errors.

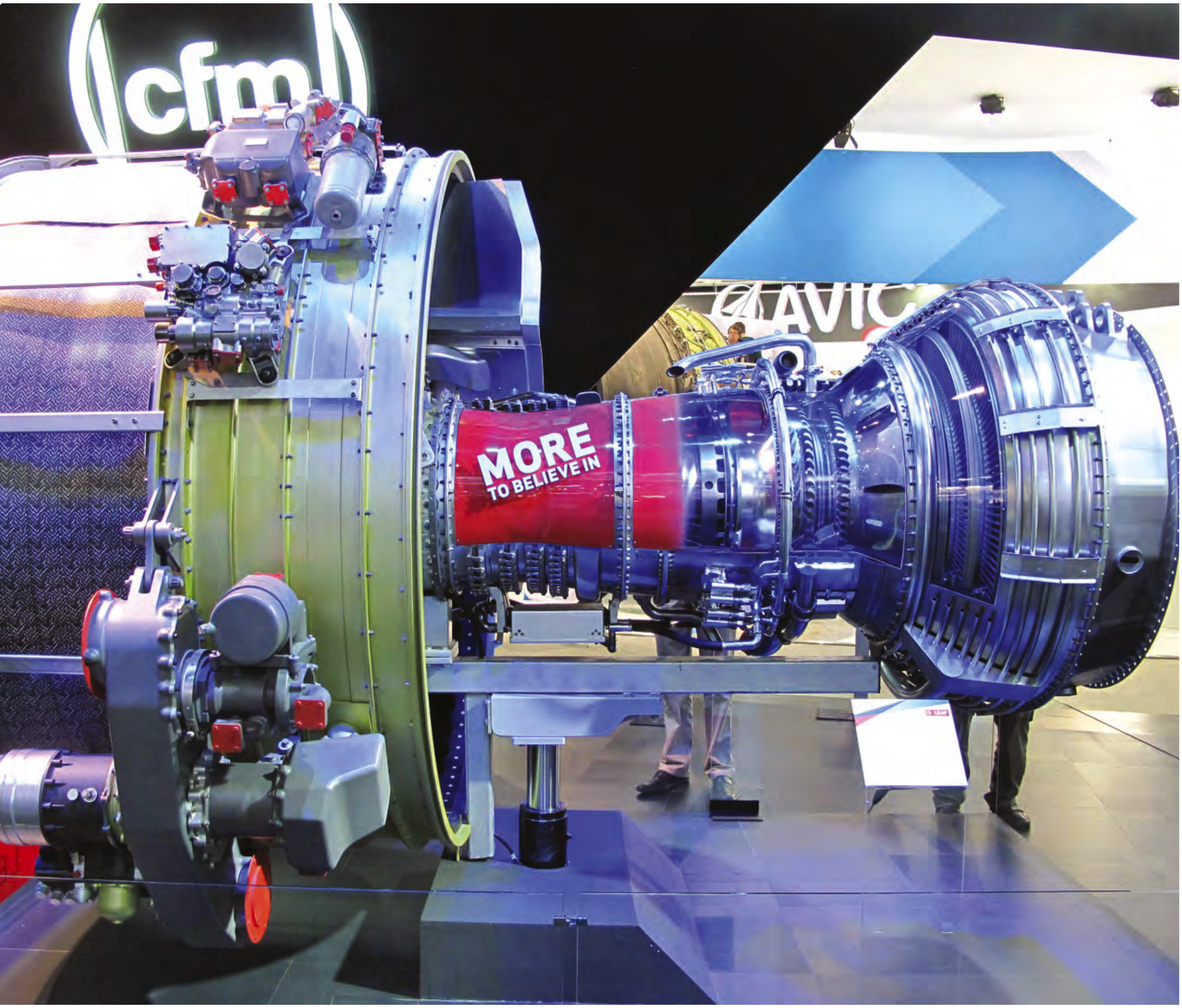
Since this data is probably in a spreadsheet, it makes sense to use this to directly configure the data acquisition system. One Microsoft Excel file with all sensor data, types, sensitivities, positions, measurement configurations, etc, can be collated during the planning phase, outside the test cell. Once ready, it can be simply loaded into the master data acquisition PC to set up the entire system. The spreadsheet input can automatically configure measurement channels, data acquisition, data monitoring displays, and ultimately the data analysis. Then, workflow-oriented software guides the user though all setup, recording and data-handling stages.

DIVERSE DATA

As engines are put through their operating envelope, test data acquisition systems must handle many hundreds of dynamic channels of diverse data types, such as strain, vibration, pressure and speed data. The

ABOVE: To speed up the tests and certification of the LEAP engine, Snecma (Safran) invested in a Brüel & Kjær gas turbine testing system

"WITH MANY HUNDREDS OF CHANNELS OF DATA RECORDING, THE DATA ACQUISITION SERVER DELIVERS HIGH-PERFORMANCE DATA HANDLING WITH MULTIPLE LAYERS OF DATA SECURITY"



Brüel & Kjær system is centered on the popular LAN-XI hardware unit, which has no channel binding; any channel can be connected to any input. This provides flexibility when configuring the system and saves time, since there is no need to designate specific sensor types to specific data acquisition types.

The same data acquisition system input plug can accept all type of transducers (charge, IEPE, differential, tacho, bridge), again easing setup, and saving customers on capital outlay by making input modules as versatile as possible. And with the LAN-XI system, no external signal conditioning is required because all conditioning is taken care of internally, reducing complexity and capital outlay.

ABOVE: **Designed to power the new generation of single-aisle aircraft, more than 9,500 LEAP engines have been ordered to date**

Since the system is scalable from a few to many hundreds of channels, some owners of Brüel & Kjær's test cell systems break their hardware down into smaller portable systems that can be transported around the world, in purpose-made transportable cases. In a test cell, larger systems can be semi-permanently mounted in a rack, and then easily split up into smaller systems that can each be transported between different test cells. With multiple systems with the same functionality, hardware and support costs are reduced, while easing the users' training and learning burden.

Setting up for the test – making sure all measurement channels are functioning, that there are no cable problems, no overloads, no noise or synchronization issues, etc – is made simple with the many indigenous LAN-XI functions. Dyn-X technology

RIGHT: The Brüel & Kjær LAN-XI family of modular data acquisition provides a versatile front end to the gas turbine test solutions

removes the need for input range-setting, and provides a huge effective dynamic range to eliminate overload worries. Smart channel integrity monitoring warns of any issues from anywhere along the entire signal path, from the transducer to the analyzer. An internal, automatic test provides daily performance control, by checking for each channel linearity and noise and frequency response. All this allows for quick system setup, removing the need for repetitive test runs. The operator can even listen to any channel to provide the final check that all is well before testing proper can begin.

HIGH-FIDELITY DATA

For engine tests on high-speed rotating blades and for fluid dynamics measurements, high-fidelity data is essential. Brüel & Kjær's system provides a measurement bandwidth of up to 100kHz, with a synchronization accuracy between channels of better than 3°. In addition, 24-bit phase-synchronous data resolution provides the highest degree of measurement accuracy.

During recording, real-time test monitoring ensures the validity of test data, to eliminate the inconvenience of re-testing. This provides instant feedback that ensures data integrity, test confidence and test safety. However, safe data capture remains imperative. So while a data acquisition server focuses on acquiring data, users at multiple monitoring stations can monitor and analyze data from each and every channel. Both during and after acquisition, clients of this real-time data stream have their own sets of channels and data analysis of interest, and have the option of selecting relevant channels and data viewing according to their own specific requirements.

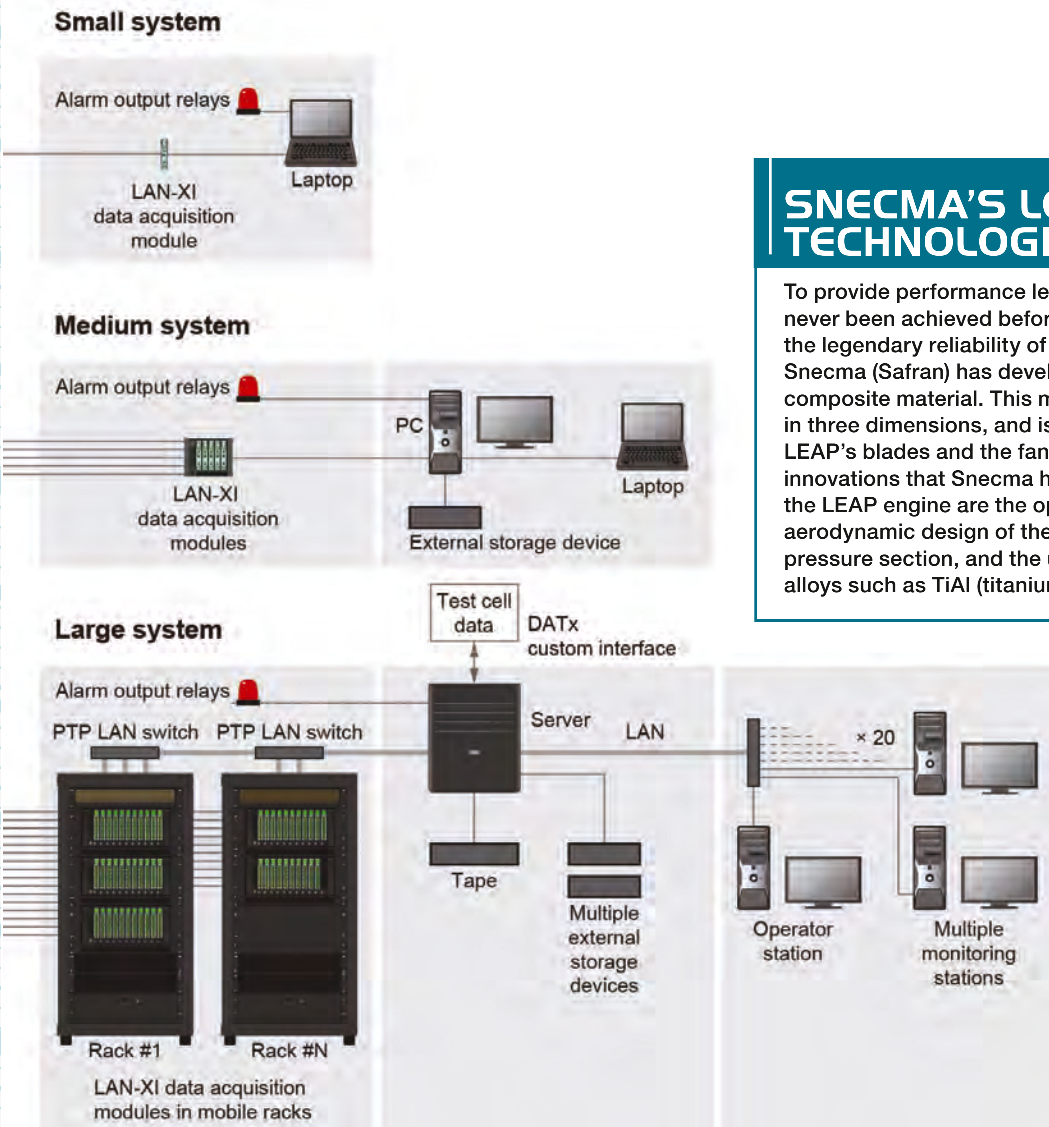
The monitoring stations have direct access to the raw time signals from selected channels, enabling them to make any type of analysis in any display format – from basic FFT and tacho, to more sophisticated 3D, Campbell, phase, order slice and tracking. Alarms can be displayed, and data can furthermore be recorded at any monitor station for back-up and local playback.

With many hundreds of channels of data recording, the data acquisition server delivers high-performance data handling with multiple layers of data security. Raid-configured hard disks, back-up storage, encrypted data, system alarms, user access control, measurement alarms, and system and event logbooks are all used to maintain data integrity.

DATA REUSE AND SHARING

With high volumes of data from complicated tests, the ability to efficiently manage test data is imperative. And with a high test throughput, the importance of good test metadata cannot be over-emphasized. Data must be cataloged, efficiently moved between company databases, backed up, converted, and sent for post-analysis.

Data acquisition and analysis are often separate functions within a test organization, and data needs to be efficiently shared, both within the test facility and off-site – frequently in a universal format that can be integrated with data from other systems. The Brüel & Kjær system can convert data to other file formats like DATx, on-the-fly, and share this data across the network in parallel with the data acquisition.



SNECMA'S LEAP TECHNOLOGIES

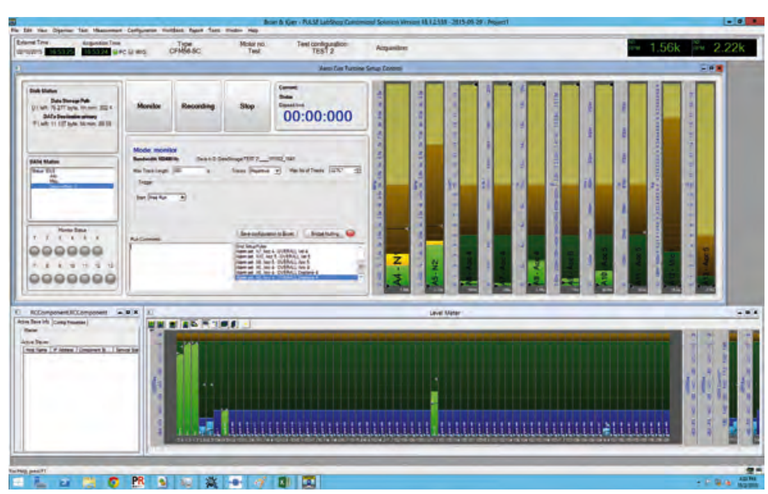
To provide performance levels that have never been achieved before, while keeping the legendary reliability of the CFM56, Snecma (Safran) has developed a new composite material. This material is weaved in three dimensions, and is used for the LEAP's blades and the fan casing. Other innovations that Snecma has integrated into the LEAP engine are the optimized aerodynamic design of the blades and high-pressure section, and the use of new metal alloys such as TiAl (titanium aluminum).

LEFT: Large systems such as Snecma's can have hundreds of channels, with selections of them visible on multiple monitoring systems

The Brüel & Kjær PULSE Reflex data processing software provides an extensive toolbox of post-analysis functions. PULSE Reflex supports a wide range of file formats for import from, and export to, native and third-party systems. Processing can be fully automated or can use batch-mode operation for sequenced or parallel analysis of multiple sets of data.

To support industry needs, test systems need to ensure the highest throughput of engine tests possible – all the way from the test plan to the final test report. Brüel & Kjær's system endeavors to help gas turbine testers at every stage, boosting test efficiency, test data integrity and test flexibility. ▮

Noel Brown is an aerospace program manager at Brüel & Kjær



ABOVE: Each viewer of the data can view channels and analyses that are limited to their relevant area of interest – while raw data is safely recorded separately

HOME FROM HOME

Wichita test labs find a perfect home in former Boeing space

BY TRACEE FRIESS

From its new location at the Air Capital Flight Line, Wichita State University's National Institute for Aviation Research (NIAR) is poised to become a leader in electromagnetic effects (EME) and environmental testing. Early this summer, the labs began relocating to space in the commercial development formerly occupied by the Boeing Company. The development consists of 324 acres of flight line, an 88-acre office park and properties that encompass 1,750,000ft^2 of hangar, warehouse, training, workshop, data center, office and other finished space. Adjacent to Spirit AeroSystems, the location is prime for rapid growth.

"Easy access to the runway is also an important advantage of the new location," explains Paul Jonas, director of NIAR Environmental Test Labs. "It will allow us to target a broader market – to expand beyond general aviation testing into the commercial transport and military aircraft markets."

NIAR's Environmental Test and EME Labs employ 17 full-time employees and nine student lab technicians. The labs perform research, testing and certification for electronic devices and other aircraft components for conditions including temperature, altitude, humidity, shock, salt fog, lightning and effects associated with exposure to radio frequency. The new facility will also accommodate the labs' training program, which includes RTCA DO-160, HIRF and specialized environmental test technician training.

"We are expanding so quickly by adding new capabilities, both in equipment and personnel, that we're running out of space in our current location," says Billy Martin, director of the EME Lab and a recognized expert in high-intensity radio frequency (HIRF) and lightning testing, design and certification, with more than 30 years of experience in the industry.

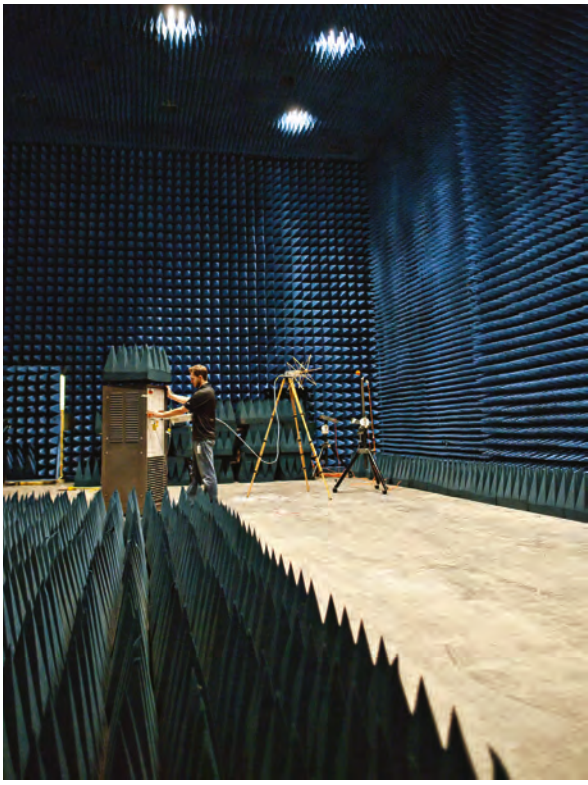
NIAR's comprehensive electromagnetic testing facility covers all aspects of testing, including component, system and full-vehicle – everything from drones to commercial aircraft. The lab can perform power quality, electromagnetic interference, RF susceptibility and direct and indirect lightning testing.

"The combination of the broad range of test capabilities, engineering design, Designated Engineering Representative (DER) and modeling services, along with the experience of our staff, makes this lab unique in the world," continues Martin. "This combination provides our customers with a distinct advantage."

FLASH FORECASTS

NIAR recently added capabilities for lightning transient analysis, HIRF and direct effects of lightning testing.

Lightning transient tests are intended to measure the actual transient levels induced into aircraft electrical wiring as a result of lightning attachment to an aircraft. This is done to ensure the transient level does not exceed the wiring's transient control levels. To measure actual transient levels, simulated lightning currents are injected into the aircraft and the resultant currents and voltages on the wiring inside the aircraft are recorded. Stated more simply, a simulated



CAPITAL ASSET

Established in 1985, Wichita State University's National Institute for Aviation Research (NIAR) is a unique research and development institute focused on providing testing and certification for airframe technologies. Working under non-disclosure agreements, NIAR laboratories provide services to federal agencies, aviation industry clients and other manufacturing industry clients. NIAR has a US$45m annual budget; a staff of 400; and 320,000ft^2 of laboratory and office space in four locations across the city of Wichita, which is known as the Air Capital of the World. As a result of NIAR's research efforts, Wichita State University ranks third among US universities in aeronautical R&D expenditures, according to the National Science Foundation. WSU ranks first in industry funding for aeronautical expenditures.

In addition to research, training and certification testing capabilities, NIAR engages in customer-driven partnerships. Today, many companies conduct R&D using what is known as the 'carry-over philosophy', in which research is geared toward refinement and optimization of existing products and technologies. Partnership with NIAR allows for an 'innovation philosophy' model of R&D, which fosters novel product configurations. These breakthroughs allow the client to pursue innovative concepts and technologies and maintain their leading position in the aerospace interiors market.

NIAR laboratories include: Advanced Coatings; Aging Aircraft; CAD/CAM; the Center of Innovation for Biomaterials in Orthopaedic Research; Composites & Advanced Materials/Mechanical Test; Computational Mechanics; Crash Dynamics; Electromagnetic Effects and Environmental Test; Full-scale Structural Test; Nondestructive Test; Reverse Engineering; Robotics and Automation; Virtual Reality; and the Walter H. Beech Wind Tunnel.

NIAR is a member of the FAA Center of Excellence for UAS Research and home to the National Center for Advanced Materials Performance, the Composite Materials Handbook-17 and the FAA Center of Excellence for Composites and Advanced Materials.

ABOVE: NIAR's Electromagnetic Effects Lab has a wide range of test equipment available to meet and exceed testing requirements

LEFT: A NIAR research engineer sets up for a radiated susceptibility test in a fully anechoic test chamber

RIGHT: A NIAR research engineer fine tunes a lightning transient generator while performing calibrations on a test aircraft

lightning strike at a reduced level is injected onto the aircraft; the field generated by the lightning strike travels the length of the aircraft, inducing voltages and currents on wiring inside the aircraft. These voltages and currents are measured and analyzed to make sure an actual lightning strike will not damage any critical equipment during flight.

With a high current generator of 200,000A, the lab is able to test all common lightning strike levels.

Direct effects lightning testing evaluates the ability of the aircraft components to resist the possible damaging effects associated with lightning attachment to the aircraft. Effects can include: melting; the development of holes at points of contact; temperature rises in metal conductors; magnetic force effects; acoustic shock effects; arcing at structural bonds, hinges, and joints; and the ignition of flammable vapors within fuel tanks.

The NIAR labs recently completed two full vehicle lightning transient tests. The first was for Garmin's supplemental type certificate on the Beechjet 400, followed by full vehicle tests for the Cirrus Vision SF50.

The lab's client portfolio includes regulatory agencies, commercial and military clients, including Spirit AeroSystems, Garmin, Cirrus Aircraft, Textron Aviation, the US Air Force, Case New Holland, Proterra, Honeywell, Williams International and B/E Aerospace.

The labs are a prime example of Wichita State's Innovation University concept, an initiative aimed at transformation through innovation, applied learning, entrepreneurship and economic impact.

"We are providing valuable incentives for companies to do business in Wichita: on-site test labs and a pipeline of experienced, career-minded graduates," says John Tomblin, WSU vice president for research and technology transfer and NIAR executive director.

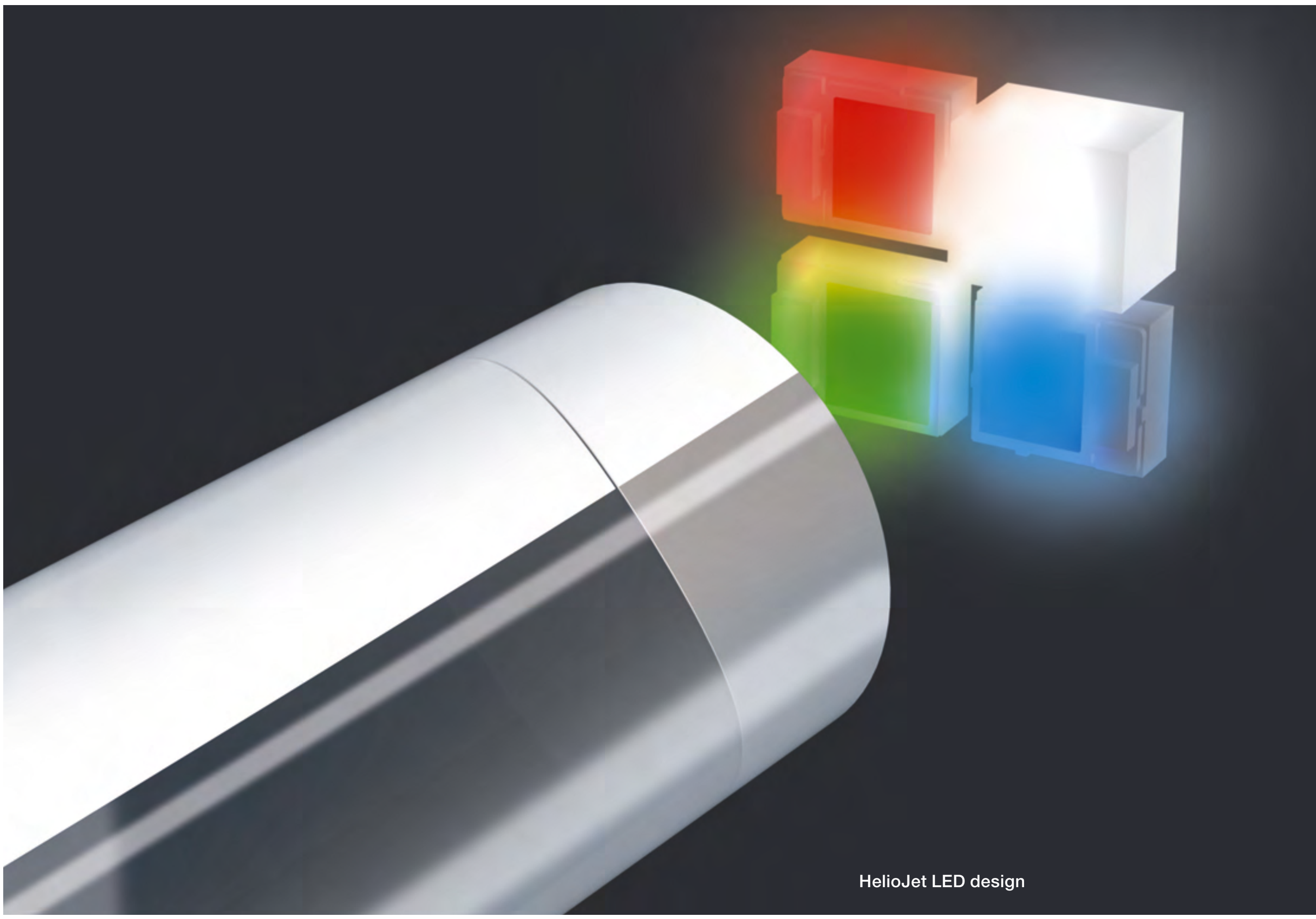
"Working in the laboratory has significantly impacted my life. Getting the opportunity to work hands-on with certified engineers provides experience that I could never have gotten in a classroom alone," says Kristyn Harpool, a graduate student and NIAR research assistant. "The testing, research and data analysis passionately drives me to keep learning and makes me proud to work in such a unique organization." ■

Tracee Friess is director of communications at NIAR

LIGHT FANTASTIC

DAUtec qualifies the next generation of LED aircraft cabin lighting through a series of electromagnetic compatibility and environmental tests

BY FREDERIK LEHNERS



HelioJet LED design

Wow! This is probably the appropriate reaction on entering a passenger cabin equipped with the new HelioJet LED aircraft cabin lighting system, developed by Schott. Two versions are available: a white system or a full-color system, called HelioJet SpectrumCC. A touchscreen control panel, as typically used with cabin management systems, enables the cabin crew to adapt lighting to the passengers' needs and comfort.

The project began approximately 10 years ago, when the initial idea was to replace dated, energy-consuming neon tube lighting with a more efficient LED alternative. It has not only led to a replacement solution, but to the development of an entire lighting system consisting of a power supply unit, an optical light converter and a control unit.

"From the very beginning, we were aiming for a solution that would optimize input as well as output parameters," remembers Klaus Portmanns, director of aviation sales at Schott. While conventional LED lighting employs lined-up LEDs, HelioJet is a little different: four individually controlled LEDs are installed at the edges of the light tube. A sensor continuously controls every LED to obtain the desired color, while the light tube itself uses a special technology to produce even lighting over its full length. This ensures a superior lighting quality over the entire lifetime of the product.

QUALIFICATION TESTING

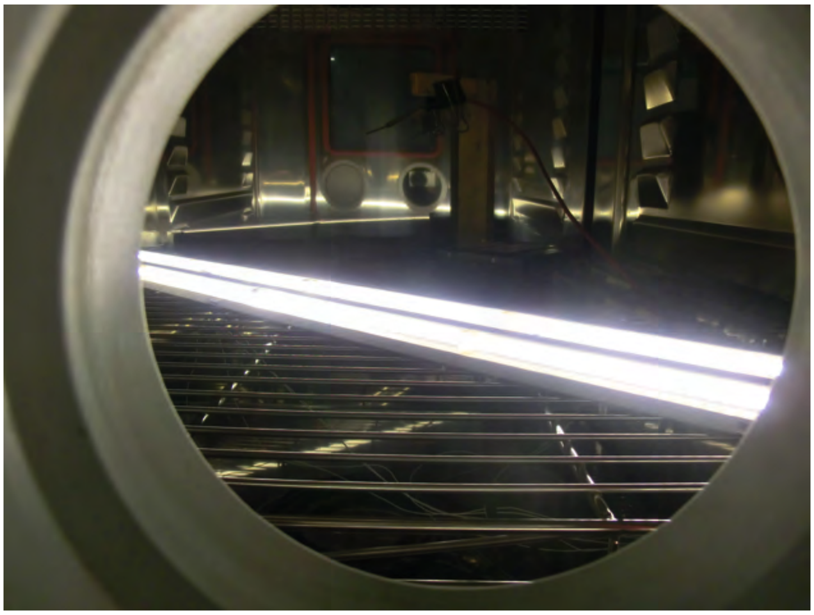
Of course, qualification is always a key milestone. When asked about the role of qualification in the development process, Oliver Keiper, project manager at Schott, replies: "DAUtec supported us through the whole process, starting with the choice and definition of the tests and continuing through their performance right up to the end of the evaluation and documentation."

Qualification comprised a series of electromagnetic compatibility and environmental tests. While problems had been anticipated during the environmental tests, especially during

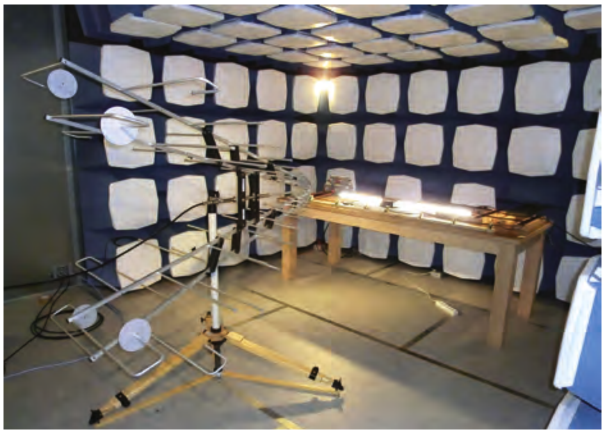
HAMBURG FACILITY

Since 2011, DAUtec has operated an EMC and environmental test laboratory in Hamburg, Germany. Three test engineers are based there, not only to operate the laboratory, but also to provide advice regarding qualification tests in the field of EMC and environmental testing. Moreover, DAUtec employs four qualification engineers, who provide its customers with a broad range of services in airworthiness, qualification and certification.

"ONE PARTICULAR ISSUE BECAME VISIBLE WHEN THE SPECIMEN WAS SUBJECTED TO THE RADIATED RF (RADIO FREQUENCY) SUSCEPTIBILITY TEST ACCORDING TO RTCA/DO-160, SECTION 20"



ABOVE: HelioJet undergoing testing in a climatic chamber



ABOVE: HelioJet RF susceptibility test

vibration tests due to the geometry of the specimen, these ran smoothly. However, one particular issue became visible when the specimen was subjected to the Radiated RF (radio frequency) susceptibility test according to RTCA/DO-160, section 20.

To ensure the equipment is capable of absorbing electromagnetic fields without becoming distorted or dysfunctional, it is subjected to such fields over a broad range of frequencies; typically from 100MHz to 8GHz, where field strength and waveform depend on the category determined for the equipment. Generally, RTCA/DO-160 suggests three waveforms: unmodulated, square wave and pulse-modulated fields.

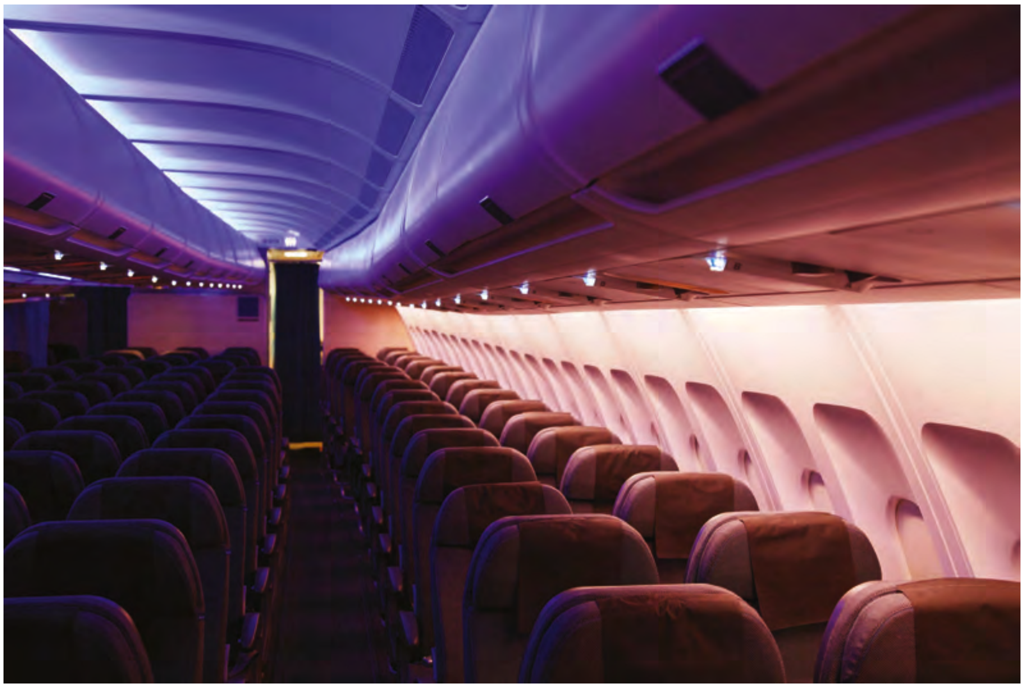
The first is a continuous waveform, with its amplitude depending on the category, while square wave is a 50% duty cycle modulated waveform with a depth of at least 90%. The final pulse-modulated waveform has a short duty cycle of 4% and a pulse repetition rate of 1kHz for test frequencies from 400MHz to 8GHz. Thus, the duty cycle equals 40µs. This pulse-modulated signal is switched on and off at a 1Hz repetition rate with a 50% duty cycle, to simulate the effects of rotational radars.

Prior to the test, the radiated field is calibrated to determine the forward power required to emit the electric field strength at every test frequency at the position of the unit under test (UUT). This calibration usually employs an unmodulated continuous waveform, while the calibration tool measures the electric field strength corresponding to the forward power applied. Both are recorded, and based on this data, the electric field strength is applied to the UUT, at test frequencies using the waveforms as required by category.

According to RTCA/DO-160, Category R was deemed to be adequate for HelioJet. This category suggests rather moderate test levels, where unmodulated and square wave modulated waveforms are applied at lower frequencies with an electric field strength of 20V/m.

At higher frequencies, only a pulse-modulated waveform with an electric field strength of 150V/m is applied.

Other categories, for example, require unmodulated and square wave modulated waveforms over the whole range of frequencies.



LEFT: HelioJet cabin lighting helps airlines apply their brand to the cabin

BELOW: HelioJet applied to a cabin in business class

What happened? Dr Otto, head of the DAUtec laboratory, explains: "After all the tests without issues, it was kind of scary at first: we installed the test setup inside the absorbing chamber after calibrating the electromagnetic field strength. Everything went smoothly and without any issues to start with. For the higher frequencies (above 1GHz), we had to exchange the antenna as usual, and as we continued testing the higher frequencies, suddenly the light tube began to flicker. Starting just before the test sequence and disappearing during test as unexpectedly as it had begun, this flicker caused some confusion among the witnesses."

Unsure of what had happened, the staff decided to delay the test and figure out what was causing this effect. "In the end, it was so obvious that no one had thought of it," admits Otto. "This effect is peculiar to test category R in RTCA/DO-160, because it suggests applying pulse-modulated waveforms to the equipment being tested."

Calibration before the test, as well as the adjustment of the forward power during the test to apply the electromagnetic field, are done in unmodulated continuous waveform mode. During the period of adjustment, the antenna continuously emits power to the UUT until the adjustment of the forward power – using a power meter coupled to a directional coupler – is finished, despite the category requiring an emission of pulse-modulated waveforms.

"If you look at the energy being absorbed by the specimen, you end up with the equipment being subjected to about 25 times more energy during the adjustment of the forward power compared with the energy being absorbed during the test itself, considering the 4% duty cycle. And the math does not take into account the 1Hz on/off modulation," adds Otto. "So, the solution we found is as simple as the problem: we allowed the unit to stabilize under pulse-modulated waveform exposure after adjustment of the test level, without taking into account what happens to the UUT during the adjustment itself."

This approach to stabilizing the specimen under test conditions after the adjustment period, which had technically caused an excessive test level, was successful. The flicker appearing during adjustment vanished shortly after the transition from radiated unmodulated signal to radiated pulse-modulated waveform energy. "This procedure is neither explicitly suggested nor proscribed by RTCA/DO-160," says Otto. "However, a stabilization period to exclude inevitable side effects seems reasonable in this instance." Consequently, official supplemental type certificate (STC) approval from the European Aviation Safety Agency was achieved, and the result of all of DAUtec's efforts is now ready for take-off. ∎

Frederik Lehners is an airworthiness qualification engineer at DAUtec

ON A GRAND SCALE

Huge test facilities such as the A350 XWB Cabin0 are used to execute integration, validation and verification measures for modern aircraft systems

BY BERND MATTNER

Huge aircraft development programs like the A350 XWB bear many risks in the development cycle for aircraft and systems. The risks are intensified by the steadily increasing number of electronic components and growing complexity. To overcome these risks, a lot of test and verification measures are executed during the entire implementation and integration process. Many of the measures are executed with test systems of different sizes and focuses. It is also a fact that the test means become bigger in size and complexity parallel to the systems under test. At the top of aircraft system integration and verification, large-scale testing facilities are necessary.

The A350 XWB Cabin0 testing factory illustrates TechSAT's ability to provide such huge test means.

Airbus Deutschland (Airbus) is responsible for the development, integration and test of the complete set of cabin systems for the new Airbus A350 XWB aircraft. The modern aircraft cabin is one of the biggest and most complex of the aircraft domains. To mitigate risks during development and integration, Airbus decided to build a complete A350 XWB Cabin0 function integration facility.

Following strict screening, Airbus selected the consortium of TechSAT, FTI Engineering Network and EADS RST to deliver the function integration benches (FIB) and integrate all test systems, simulations and configuration tools into a fully functional testing factory.

ACTIVE DEVELOPMENT PARTNERSHIP

One major reason for the selection of the TechSAT consortium was their decades of experience in the development of test systems and simulations. A number of test systems employing TechSAT's ADS2 middleware had already been successfully used in the A380 development.

This well-proven middleware was selected as the basic test system technology, with a view to improving it for use with future technology. Another advantage was that the consortium could provide employees with extensive knowledge of the test and integration environment on-site. One of the main challenges was the just-in-time delivery of the test systems parallel to the delivery of the aircraft systems. This was met by the on-site team, and through the continuous integration of test systems in the run-up to the completion of the testing factory. Even the initial integration of aircraft systems into the test systems was achieved by an integrated team supported by the consortium in an active development partnership.

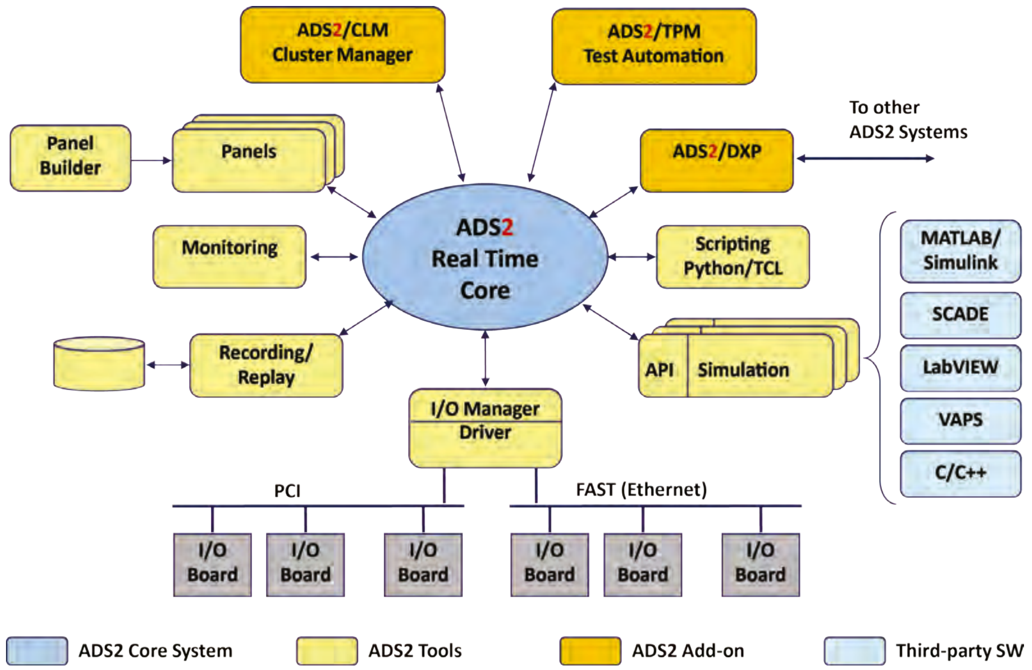
The main purpose of the A350 XWB Cabin0 testing factory is the testing and integration of cabin-related aircraft systems, with a focus on the electrical functions and configuration. The testing factory is used for initial integration and verification during the aircraft development phase, and subsequently for verification of cabin configuration variants according to the airline demands. The testing factory consists of 14 function integration benches (FIB).

The test systems installed in the testing factory cover the following ATA chapters: ATA21 air-conditioning, ATA23 communications, ATA24 electrical power, ATA26 fire protection, ATA29 hydraulic power, ATA30 ice protection, and ATA31 indication and recording system. ATA33 lights, ATA35 oxygen, ATA36 pneumatic, ATA42 integrated modular avionics, ATA44 cabin systems, ATA45 diagnostic and maintenance system, ATA46 information system, and ATA52 doors are also installed there.

All test means are used either in standalone mode or as a cluster of test systems and in connection with the Cabin0 V&V platform.

TECHNOLOGICAL CHALLENGES

Numerous top-level requirements that



ABOVE: ADS2 second-generation avionics development system

ABOVE: A350 XWB Cabin0 testing factory

were at first glance contradictory had to be solved using appropriate technological concepts. To keep costs down, it was necessary to use inexpensive COTS components wherever possible, for example an industrial PC instead of VME products. However, the short development cycles in PC technology have a negative impact on the long-term availability of components. The lifetime of even industrial PC components does not meet the usual lifecycle of aerospace test systems.

A scalable distributed computing and I/O architecture had to be provided because of the spatial distribution of the testing factory and its division into individually usable functional test benches. On the other hand, large numbers of process variables need to be processed in short cycle times. Another challenge was posed by the requirement of a comprehensive SIM/REAL concept. This would allow the integration of selected components of the aircraft systems, either as real original equipment or simulation, without changing parts of the test system.

NGTS TECHNOLOGY PLATFORM

Based on these requirements, TechSAT has designed the new generation test system (NGTS) platform. This platform is essentially based on the Avionics Development System 2nd Generation (ADS2) that was well known at Airbus and also proven over many years in the A380 program.

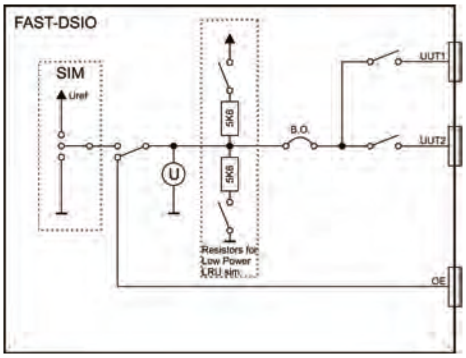
"THE MAIN PURPOSE OF THE A350 XWB CABIN 0 TESTING FACTORY IS THE TESTING AND INTEGRATION OF CABIN-RELATED AIRCRAFT SYSTEMS, WITH A FOCUS ON THE ELECTRICAL FUNCTIONS AND CONFIGURATION"

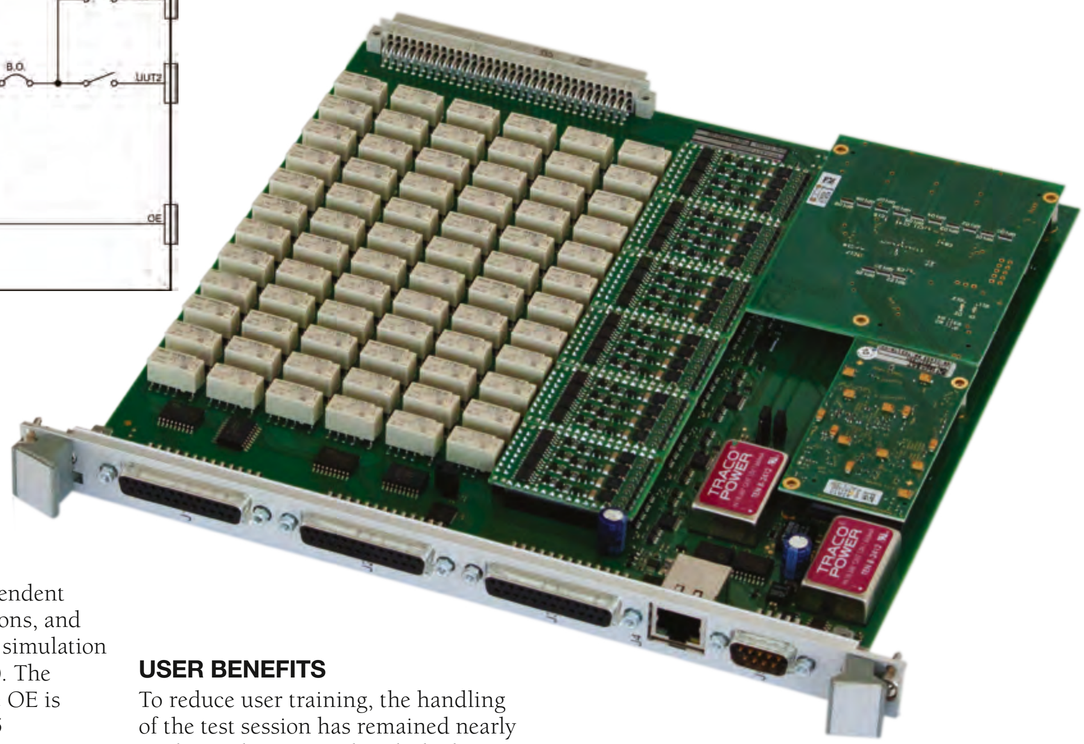
A third release of the ADS2 middleware was carried out, to support all of the required features of the NGTS platform. Major improvements include the support of distributed real-time PC-based computing and highly efficient data exchange mechanisms (for example, ADS2/DXP). The new future architecture system technology (FAST) I/O family was also developed, to complete TechSAT's concept of functional modules.

Based on the underlying ADS2 cluster concept and the use of standard Ethernet hardware, FAST allows the designing of highly scalable and flexible test systems. The concept of functional modules makes it possible that test systems remain form-, fit- and function-compatible with ongoing technological development. With this approach, single test systems as well as testing factories can be kept operational for decades.

The new FAST I/O family consists of configurable avionics interfaces with integrated standard signal conditioning capabilities and switching between simulated and real aircraft equipment.

The required SIM/REAL concept could not be reasonably implemented with COTS components, as the expected number of I/O channels was too big. Even in the testing factory, sufficient space was not available for the related wiring and switching matrices. The FAST DSIO24, for example, is a compact discrete I/O interface board featuring 24 individually configurable input or output channels with pull up/down capability, permanent monitoring,





RIGHT AND ABOVE: **FAST DSIO24 features 24 configurable input/output channels**

BELOW: **A350 XWB Cabin0 testing factory composed of several FIBs**

manual breakout, two independent switched UUT interconnections, and complete switching between simulation and original equipment (OE). The interface to the UUT and the OE is realized by separate DSUB25 connectors and a standard RJ45 Ethernet interface for connection to the I/O network. This allows smart test system design and easy maintenance over the entire lifecycle.

The avionics bus interfaces – AFDX, ARINC 429 and CAN - were realized using the existing TechSAT PMC solutions on PCI or cPCI carrier. For ARINC 429 and CAN buses, the SIM/REAL concept was realized by separate bus box devices.

To implement the SIM/REAL concept for the aircraft system AFDX connections as well, a special lab AFDX switch, the enhanced real AFDX switch (ERAS), was integrated into the ADS2 technology platform.

The generic simulation framework ADS2 GSF was enhanced to allow seamless integration of simulations created with third-party tools, such as MATLAB/Simulink, LabVIEW, or common C/C++ IDE. This allows testers to reuse many existing simulations from earlier projects.

USER BENEFITS

To reduce user training, the handling of the test session has remained nearly unchanged, compared with the known A380 ADS2 test environment. A cluster of test systems can be used in the same way as a single functional integration bench. Comprehensive simulation features allowed early A/C system integration even when the original equipment was not yet available.

In the A350 XWB Cabin0 Testing Factory, complex test scenarios with up to 1.2 million process variables in cycle times of around 50ms can be executed on the ADS2 test system cluster.

In the meantime, TechSAT has developed many additional NGTS components to fulfill the testing requirements of both small test systems and big test facilities. The next release of the ADS2 software is currently under development, to incorporate the experiences of the A350 XWB projects and to further improve performance and usability.

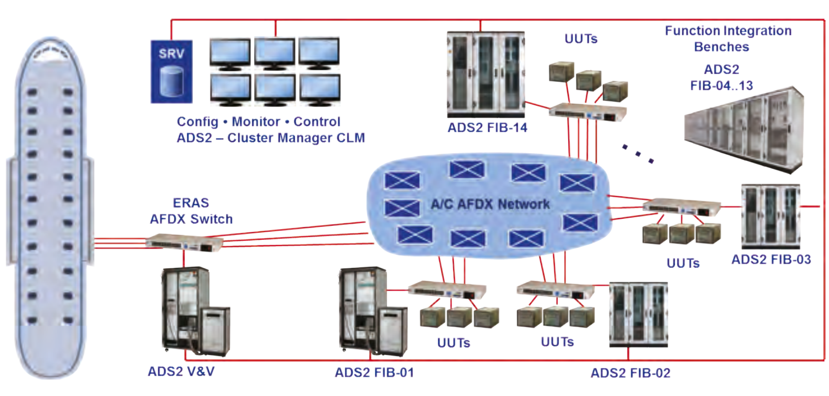
With new tools and methods (test suites, ICD tools, modeling tool integration, and so on), everything is combined into a seamless ADS2-based technology platform.

The testers' operating experience is permanently incorporated in the improvement of TechSAT ADS2 and its components. In the meantime, the value of the ADS2 NGTS technology platform has been successfully proven in several other test system projects.

The latest evolution of the TechSAT technology platform is the transfer of NGTS concepts and technology to both small test systems, such as MAYA, and integrated solutions supporting classic and model-based development.

Because of this experience, TechSAT is now able to realize integration and test means supporting all activities, from the beginning to the end of an avionics development project.

Ultimately, the size of test means is a direct consequence of the integration and verification requirements for the aircraft system. Nevertheless, it's important to rely on a smart technology platform that is scalable and flexible to meet all the integration and verification requirements over the entire product lifecycle. A test facility composed of function integration benches allows verification of defined subsystems as well as entire aircraft systems. Complementary simulations, configuration and test tools make such a testing factory extremely efficient. ∎



Bernd Mattner is a member of the operational and program management team at TechSAT GmbH, based in Germany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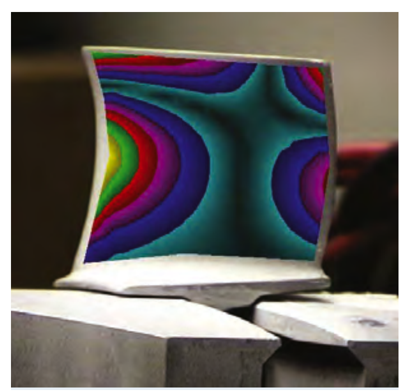
BLADE RUNNERS

Rolls-Royce is using a new vibration controller for high-frequency, high cycle fatigue (HCF) tests of low damped engine components

BY SWEN RITZMANN & SCOTT COURTNEY

The Rolls-Royce Mechanical Test Operations Centre (MTOC) in Dahlewitz, Germany, is a new, innovative test center founded in 2010 for mechanical and structural evaluation of gas turbine components during development, production and service life. The role of the MTOC vibration test team is to conduct structural dynamic investigations of these components. The main tasks performed are fatigue testing (hot and cold), frequency checking, mode shape measurement, modal analysis and dynamic strain gauge measurement.



VIBRATION TESTING AT MTOC

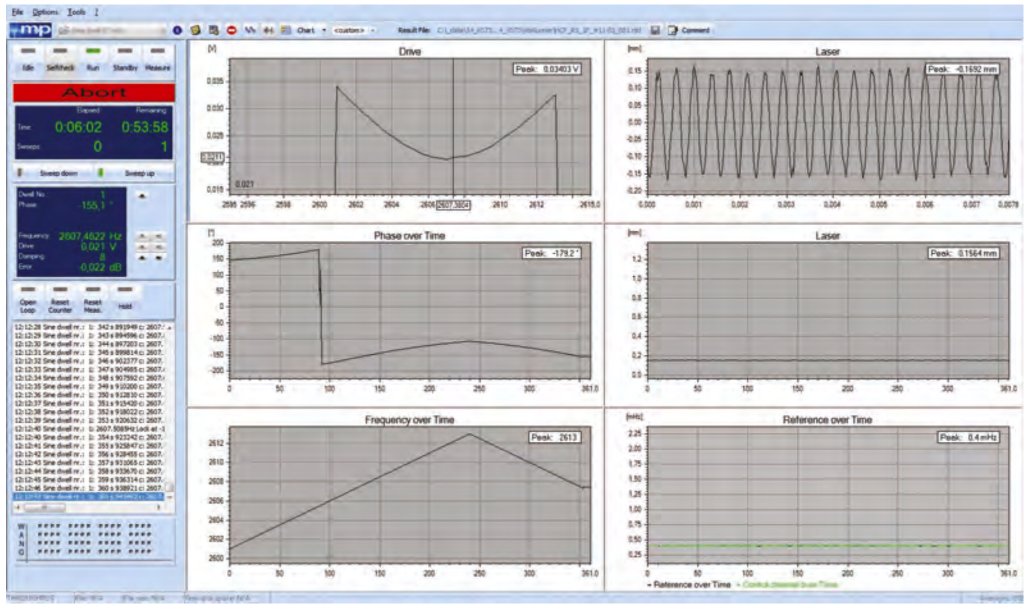
Vibration testing is a major part of the Rolls-Royce strategy to ensure the reliability of the engine components over their lifetime, and high cycle fatigue (HCF) testing of engine components at their various mode frequencies is the primary test type within this role. The Finite Element (FE) models enable prediction of eigenfrequencies and mode shapes of engine components, and also calculate stress and expected fatigue levels for the required lifetime of each component. For the validation of FE models, the analyst has to compare experimentally measured mode frequencies, mode shapes and fatigue failure levels with the FE predicted frequency, mode shape and stress calculations. This is accomplished through component testing.

The MTOC vibration testing capabilities for HCF involve the following test rigs and equipment: fatigue testing of large fan blades; hot HCF testing of turbine blades; and HCF testing of compressor blades and vanes.

For HCF testing, several technologies can be used to excite the engine parts, including: a constant airjet (flutter); chopped airjet (pulsed air); electromagnetic shaker; and piezoelectric shaker.

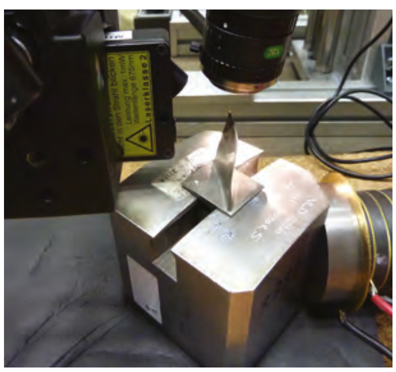
These four technologies cover the resonance frequency range of engine components up to 40kHz. For the lower frequency range, both the constant and chopped airjet systems can be used. The chopped airjet system is able to excite fan blades in the low-frequency range, as well compressor blades and vanes up to 20kHz. The electromagnetic shaker has a frequency range from low frequency up to 5kHz with a special high-frequency shaker (Unholtz-Dickie Corporation). For high frequency modes (>5kHz), the piezoelectric shaker is the only available excitation source.

For testing with higher excitation levels, the MTOC piezoelectric shaker system works as a tuned resonance system. For HCF testing, the piezo shaker excitation system must be designed with a system resonance within the expected frequency range. The shaker system behavior can be calculated as a 2DOF system. This consists of: all hardware including the clamped engine component (mass 1); the piezo disks and connecting bolt



RIGHT: Time history graphs

BELOW: Standard HCF test setup



ABOVE: Piezoelectric shaker

CENTER LEFT: Scanning Laser Doppler Vibrometer (SLDV)

BOTTOM LEFT: Hot HCF testing of turbine blades

(spring system); and the specific mass necessary to meet the required system resonance (mass 2). The new MTOC's piezoelectric shaker design and tuning technology allow for the fast setup of HCF tests (including quick change-over to a different eigenfrequency on the same component) and is the most used vibration excitation technology within MTOC.

HCF TESTING PROCESS

The HCF testing of engine components can be performed as an incremental or constant sine dwell test. The dwell test can be run by manual or automatic control. However, for tests requiring large numbers of cycles and extended test times, an automatic control of the HCF test by a vibration controller is required. To control the HCF test, the displacement of the component response is measured by optical (video camera) or laser displacement sensors. The dwell test is controlled by the response displacement, and the vibration controller uses phase tracking to monitor the excitation frequency and to compensate for load-dependent frequency changes.

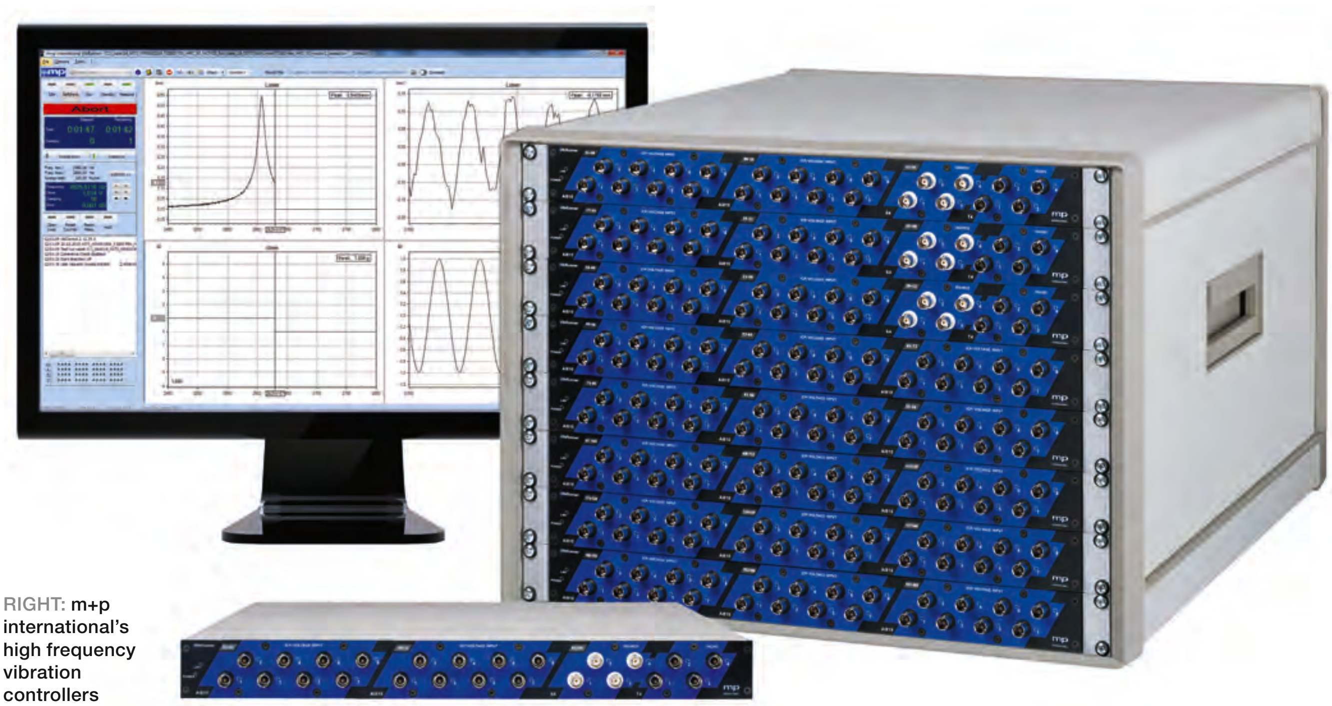
Within the Rolls-Royce group, the measure used for expressing vibration response is 'AF level' (Amplitude/Frequency), with the unit 'mHz' (meter * Hz). The AF level of a vibrating component is calculated by normalizing the response displacement by the test frequency. For example, the AF level of a compressor blade with 3mm displacement (measured at the maximum location) at 1.5kHz results in 4.5mHz. The objective of the HCF test is the validation of the predicted fatigue strength AF level versus the level at which failure occurs during vibration HCF testing.

"TO PROVIDE A VIBRATION CONTROLLER THAT CAN HANDLE THE LOW DAMPING THAT EXISTS DURING CERTAIN ENGINE COMPONENT TESTING, M+P INTERNATIONAL DEVELOPED A SPECIAL AUTO PHASE TRACKING TECHNOLOGY"

TESTING ENGINE COMPONENTS WITH LOW STRUCTURAL DAMPING

For the low damped engine parts with quality factor between 500 and 1,000 or more, a standard dwell test is not possible. Since the high quality factor results in a very small frequency bandwidth, the load dependent resonance frequency can vary within the same excitation range. A standard dwell test with low structural damping requires a vibration engineer with a lot of experience, and in addition, more time is required to tune the test setup. In order to provide a vibration controller that can handle the low damping that exists during certain engine component testing, m+p international developed a special auto phase tracking technology. To adapt to Rolls-Royce MTOC test requirements, the m+p vibration controller software was upgraded with the 'HCF' option.

Since December 2011, MTOC has been using the standard m+p vibration controller for vibration testing. The 2012 upgraded controller is optimized for HCF dwell testing with phase tracking for components with low damping. As part of a typical HCF testing flow, first a sine sweep is used to find the resonant frequency range. The following dwell test starts with a sweep within the resonance bandwidth. Once the sweep through the bandwidth is finished, the controller sweeps back to the determined resonance frequency and locks the frequency and the phase between excitation and response. The locked phase angle will be used for the



RIGHT: m+p international's high frequency vibration controllers

"WITH THIS SYSTEM, THE PHASE LOCK-IN AND PHASE TRACKING WORKS THE SAME AT 30KHZ AS THE PREVIOUS SYSTEM WORKED AT 3KHZ"

phase tracking during the remainder of the test.

MEASUREMENT AND TEST SETUP FOR HCF TESTING

The standard HCF test setup consists of: the excitation system with the clamped engine component in fixed free condition; a laser displacement sensor (LDS) for the frequency response measurement; and a video camera system to measure the maximum displacement. For the first flap or first torsion mode, the maximum displacement can't be measured by the LDS because this displacement is located at the component edge, and the sensor needs a stable measurement point that does not 'fall off' at higher amplitudes. Therefore, the measurement of the displacement sensor must be calibrated to the video camera measurement, and the sensor must be aligned to a lower but more stable measurement point.

If the frequency and phase is locked at the starting excitation level of the HCF test, the test flow follows the defined test parameters. For a constant AF level test, the test stops when defined test time or number of cycles has been reached. For an incremental HCF test, the excitation level is kept constant until the defined increment time or number of cycles is reached, and then increases to the next response AF level increment.

However, the reason for HCF testing is to measure the AF level when the component reaches failure. When the component structure loses integrity or starts to crack, the resonance frequency changes significantly. Therefore, the vibration controller's phase tracking feature must allow the excitation frequency to follow the actual resonance frequency of the component as it changes. When the defined abort level is reached (expressed as percentage of the start frequency), the vibration controller stops the excitation and aborts the testing. Typically, the abort level is defined as a 2% frequency drop, according to fatigue theory. With the saved protocol file, the test engineer can then trace the finished test according to the time history graphs shown on the previous page.

At MTOC, the m+p vibration controller VibPilot and VibRunner are in use. To achieve HCF tests for higher modes above 20kHz, the high-frequency option for the m+p VibRunner was installed. High-frequency laser measurement equipment is used as the control channel for the test. With this high-frequency setup, a resonance frequency with a small bandwidth (low damping level) is easily identified. With this system, the phase lock-in and phase tracking works the same at 30kHz as the previous system worked at 3kHz.

The installation of several high-frequency m+p international vibration controllers within the Rolls-Royce MTOC has not only helped improve the quality of HCF testing of engines blades and vanes, as well as improve overall test stability and quality, but also ensured the required setup time was considerably reduced. ∎

Scott Courtney is the vibration test team lead and Swen Ritzmann is vibration test engineer at the Rolls-Royce Mechanical Test Operations Centre in Dahlewitz, Germany

AUTOMATIC ASSURANCE

Qualifying a COTS test automation tool for DO-178C-compliant projects

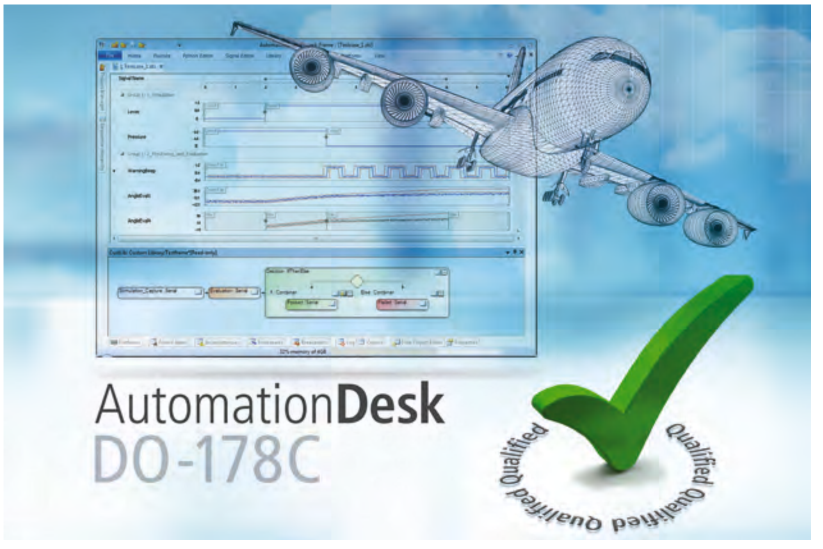
BY DR ANDREAS HIMMLER AND DR RAINER RASCHE

Developers of safety-critical systems depend on software tools to achieve their goals. This holds true for many different industries, such as the aviation, space, nuclear, automotive, railroad, medical and military industries. However, to ensure that the tools are suitable for safety-relevant applications, it is crucial to verify their output.

This specifically applies for test automation tools, used to automate certain development tasks. Test automation tools are used in order to achieve the high level of productivity required in today's development projects, as they let developers run tests on hardware-in-the-loop (HIL) test systems or in virtual validation environments, and assess test results automatically around the clock.

Users demand tools with a graphical user interface for test authoring and test automation because they can be used more efficiently. This is true especially in comparison to script-based concepts. Graphical user interfaces enable intuitive test development, for example by letting developers move signals, or segments as signal parts, via 'drag and drop' to define test steps. This lets users create and edit test routines directly in a clearly presented graphical test case. The aim of this signal-based approach is to define test descriptions as if sketching signal plots enclosed by tolerance tubes on a sheet of paper. In order to achieve this aim, a plotter-like editor is used to intuitively describe stimulus signals and reference signals for simulation variables. These signals can be defined either synthetically or by taking data from measurements in standardized file formats.

The evaluation of the monitored signals is also signal-based. For each monitored signal, users have to define just one evaluation rule. More sophisticated evaluations can be achieved by defining segments that divide a signal into several parts (based on a defined condition such as a certain velocity, for example). Thus, segments can suppress evaluation during initialization and shutdown phases, for example, or a segment can have its own individual evaluation rule, resulting in a passed or failed verdict, depending on whether the defined tolerances match (see the image at the top of the opposite page).



DO-178-SPECIFIC ACRONYMS

TQP:	Tool Qualification Plan
PSAC:	Plan for Software Aspects of Certification
TOR:	Tool Operational Requirements
TCI:	Tool Configuration Index
TOVCP:	Tool Operational Verification and Validation Cases and Procedures
TAS:	Tool Accomplishment Summary

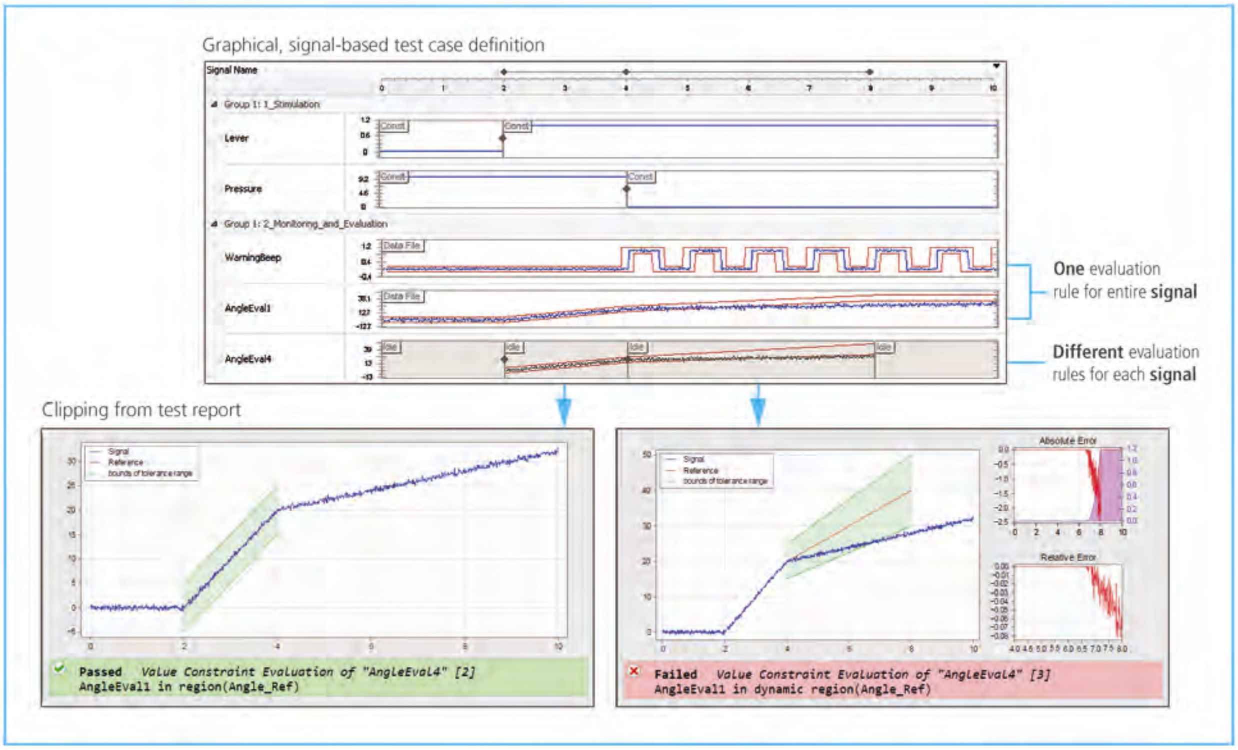
In the aviation industry, the DO-178 standard is a central pillar of software development. This standard defines tool qualification levels (TQLs) that need to be achieved based on the criticality of the software under development. The criticality of software is known as the software level, or Design Assurance Level (DAL). The DAL is determined in the safety assessment process and hazard analysis, which examine the effects of failures on the system.

With the introduction of DO-178C and its supplement, DO-330, the qualification of commercial off-the-shelf (COTS) tools has become more manageable than with the previous version DO-178B, since DO-178B provided only little advice and guidelines for the qualification of COTS tools.

This paper describes the qualification of a COTS test automation tool based on DO-178C and DO-330. The concept is based on a tool qualification kit that is developed and provided by the tool vendor, but lets the end users qualify the software tool in their own environment.

Traditional approaches of tool qualification often restrict the use of a software tool to certain conditions and environments that are predefined by the tool vendor. This can be a limiting factor, for example when only a certain operating system or even Windows versions can be used for a project.

Users can overcome these limitations with a tool qualification kit. While the functionality of the test automation tool itself is already verified by the tool vendor, the tool qualification kit lets end users verify the tool's proper operation in their own



ABOVE: Signal-based test case definition and resulting report

BELOW: Relationship between tool classification and tool qualification

software environment. A qualification kit thus gives users much more flexibility in the selection and usage of the required software tools.

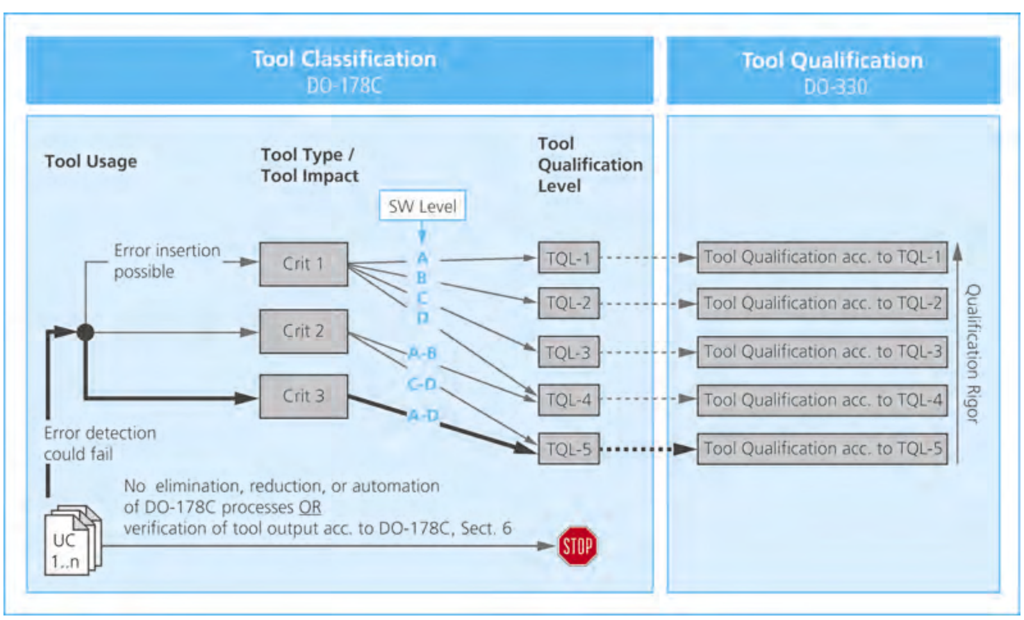
TOOL QUALIFICATION FOR AVIONICS SOFTWARE

Tool qualification is needed when processes stipulated by DO-178C are eliminated, reduced, or automated by a software tool whose output is not verified as specified in DO-178C, Sect. 6 'Software Verification Process'. The purpose of tool qualification is to ensure that the tool provides confidence at least equivalent to that of the processes that are eliminated, reduced, or automated.

The guidelines for tool qualification are: DO-178C, Sect. 12.2 'Tool Qualification' for domain-specific aspects; and DO-330 for domain-independent aspects. (For additional guidelines, refer to DO-248C: Domain-specific aspects, FAQs.)

If tool qualification is required, the impact of tool use on the software lifetime processes should be assessed to determine the TQL. Developers are recommended to use the following criteria to determine the tool impact:
Criterion 1: A tool whose output is part of the airborne software and could thus insert an error;
Criterion 2: A tool that automates verification processes and could thus fail to detect an error, and whose output is used to justify the elimination or reduction of verification processes; and
Criterion 3: A tool that, within the scope of its intended use, could fail to detect an error.

The TQL depends on the tool category and software level of the application. This paper assumes that the COTS tool to qualify is a Criterion 3 tool – i.e. a tool that could fail to detect an error. Thus, TQL-5 has to be applied, regardless of the DO-178C software level.

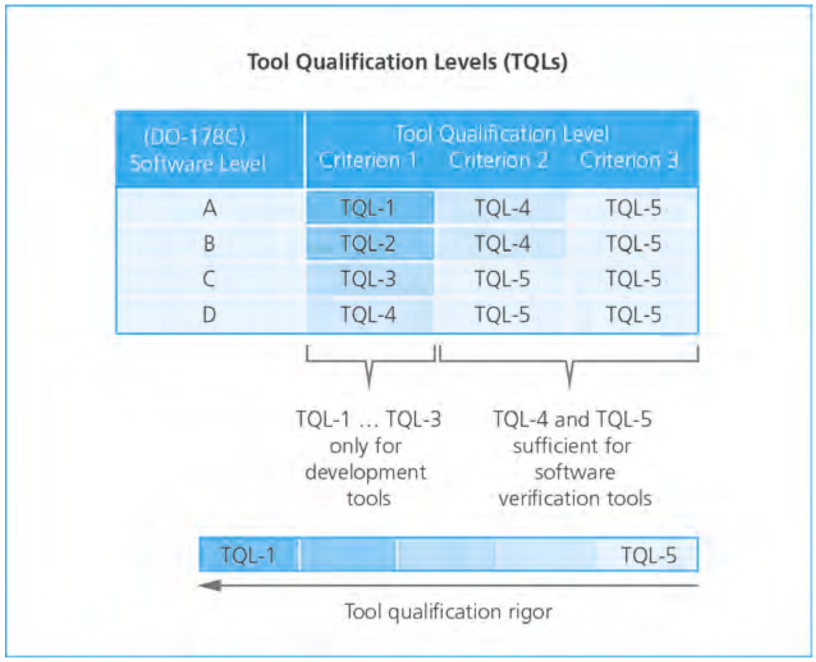


TOOL QUALIFICATION KIT FOR A COTS TEST AUTOMATION TOOL

The image at the bottom of the page, overleaf, visualizes the workflow that is applied to qualify the COTS test automation tool, AutomationDesk. The workflow consists of three consecutive phases: tool development and verification; tool qualification; and avionics software development and verification. The documents resulting in the three different phases of the workflow are also displayed. Dotted lines around these documents indicate when these documents are created. All documents in the left box that start with 'Dev' are created

RIGHT: Relation between software level, criteria and tool qualification levels

BELOW: Workflow and documents for DO-178 projects for the COTS test automation tool AutomationDesk



while the tool is being developed. This is done by the tool developer; and it is done independently of the environment the tool is used in. The box on the right-hand side contains all documents that are created during the qualification of the tool in the avionics software developer's environment. These documents are based on the documents that were prepared by the tool developer.

The content of the documents provided by dSPACE, their relation to each other, and how they are used for the qualification of a COTS test automation tool for DO-178C-compliant projects, are described as follows: the Dev-TQP includes a description of the tool verification environment, a functional overview of the tool, its interfaces, and its architecture.

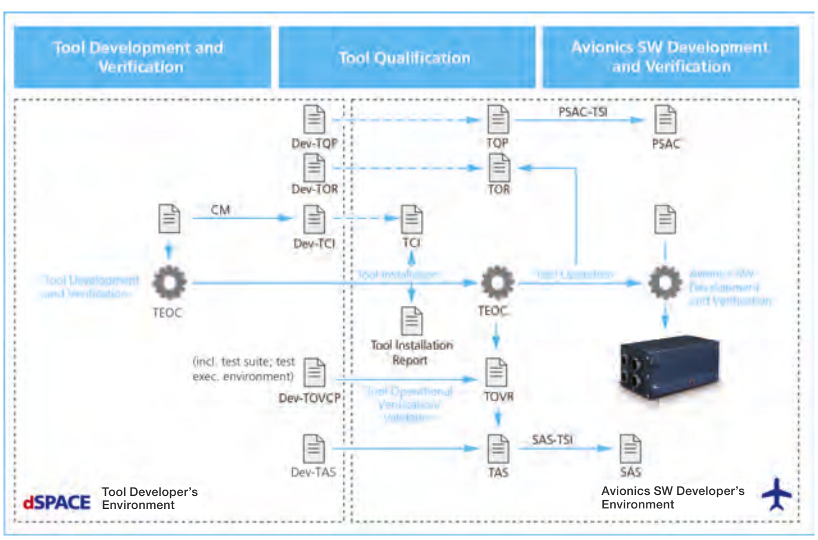
The Dev-TOR, provided by dSPACE, are used in the DO-178C/DO-330 tool qualification process for AutomationDesk. The Dev-TOR communicate the functionality and intended use of the automation functions to the user. The user then takes the Dev-TOR to determine whether AutomationDesk meets the software lifetime requirements. Based on the Dev-TOR, the user creates Tool Operational Requirements for the operational use of the tool.

The Dev-TOVCP, provided by dSPACE, detail how the tool operational verification and validation process activities for the automation functions are performed. The Dev-TOVCP are based on the Dev-TOR. The Dev-TOVCP comprise test cases, test procedures, and – if needed – additional review and analysis procedures. The tool user carries out the Dev-TOVCP in the installed environment to create the Tool Operational Verification and Validation Results (TOVR). The TOVR provide pass/fail information for each test case, analysis and review. They also include the actual results of the tests, reviews and analyses, as well as records of all discrepancies found (if applicable).

The Dev-TOVR, provided by dSPACE, were produced when dSPACE executed the Dev-TOVCP in a reference environment using the VEOS platform. Dev-TOVR contain the actual results of all defined tests. The users can take the Dev-TOVR as a reference for what the actual results produced in the installed environment should look like.

The TAS is a primary data item for showing compliance with the TQP and includes, for example, a summary of the actual tool lifetime or any differences from the tool overview proposed in TQP.

As a summary, dSPACE provides a DO-178C qualification kit for AutomationDesk, a COTS test automation tool that uses a signal-based approach to define test descriptions as if sketching signal plots enclosed by tolerance tubes on a sheet of paper. This qualification kit focuses on the functionality of the signal-based testing feature of AutomationDesk, which gives the user intuitive graphical test authoring and test execution including meaningful reports generated during test execution. ∎



Dr Andreas Himmler is business development manager aerospace, senior product manager hardware-in-the-loop testing systems at dSPACE; and Dr Rainer Rasche is group leader, software development at dSPACE

TUNNEL VISION

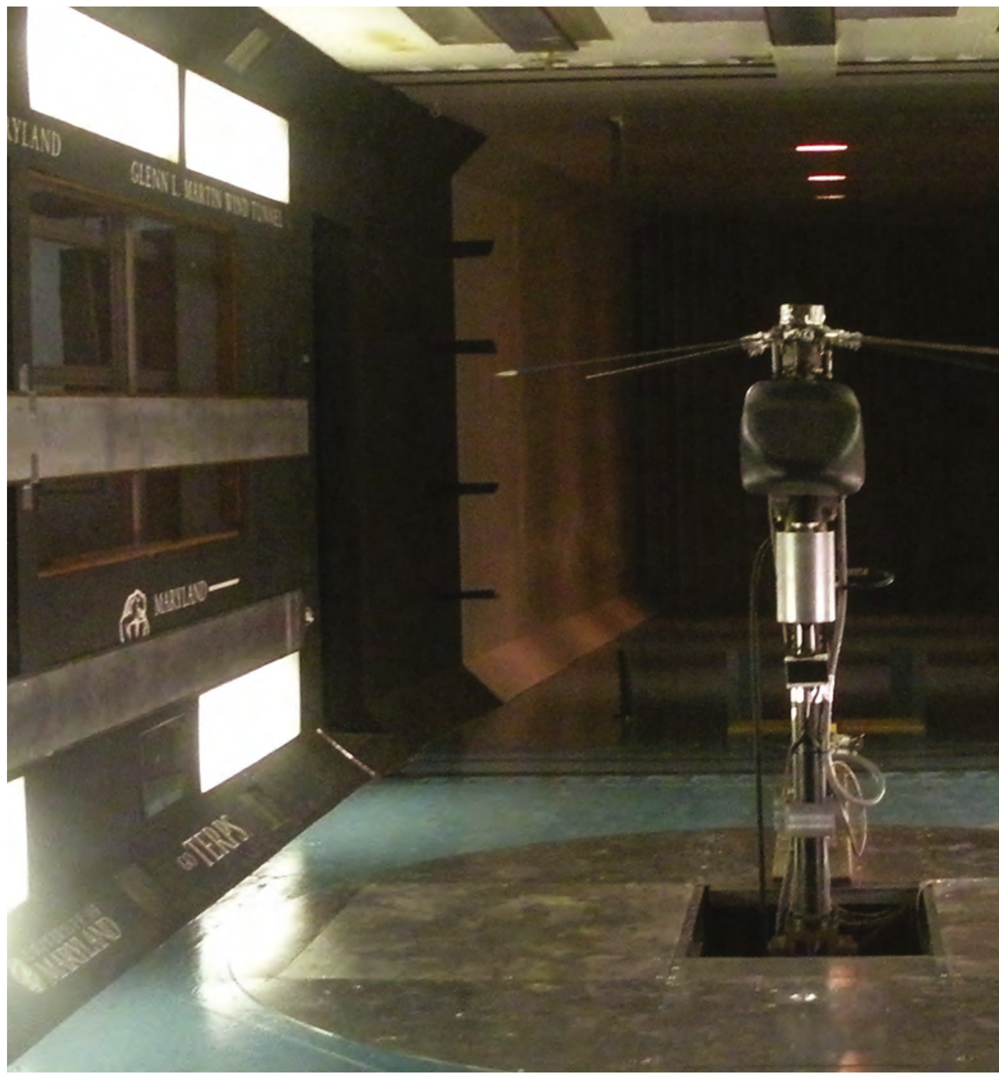
University of Maryland's Glenn L Martin Wind Tunnel features a unique balance system that allows a wider range of testing subjects

BY DR JEWEL B BARLOW

The Glenn L Martin Wind Tunnel (GLMWT) at the University of Maryland is a subsonic tunnel with a design maximum speed of 300mph (134mps) with test section dimensions 7-9ft high and 11ft wide (2.36 x 3.35m). The GLMWT was a joint development of the University of Maryland and the Martin Aircraft Company following World War II, with the first test taking place in December 1949. It has been continuously engaged in research and development tests encompassing a wide range of applications since that time. Airplane-design-related experiments have always been a part of the test program with the particular areas of focus changing as the industry has advanced from primarily conventional fixed-wing subsonic operations to higher speeds, vertical and short take-off configurations, and now a wide range of small- to medium-sized potentially autonomous craft.

PLANE SAILING

Devices and vehicles tested in the GLMWT have come from many areas other than flying vehicles. GLMWT test #1 was a parachute for ordnance deployment. Further parachute tests followed over many years. One of the most extensive test programs ever conducted on Class 8 truck aerodynamics was carried out in 1953-54, and many more truck aerodynamics tests have been done, right up to the first quarter of 2015. Automobile shape development has been a prominent area, beginning in the 1950s and continuing to the present, with sponsors including major manufacturers, a number of startup companies, and racing teams. Tests for marine applications have included both aerodynamic and hydrodynamic characteristics for military and commercial surface vessels, drag and hydro-acoustic studies for submarines, America's Cup yacht keel-bulb systems, and ocean racing sail suites. Architectural elements of buildings and other structures exposed to atmospheric winds are frequent subjects of experimental studies. The aerodynamic effects on various sports



ABOVE: Helicopter rotor rig mounted on external balance, with a rotor balance incorporated in the rig
LEFT: The 19ft fan and nacelle enclosing the 2,250hp drive system of the GLMWT
RIGHT: The US Olympic bobsled team used the GLMWT to optimize tuck positions

"THE GLMWT BALANCE IS UNUSUAL IN THAT IT IS A YOKE DESIGN RATHER THAN THE MORE COMMON PYRAMID DESIGN"

ABOVE: A special mounting system to minimize interference of the support system on the skin friction drag of a trimaran

LEFT: 2D wing test arrangement attaches to the external balance at both ceiling and floor

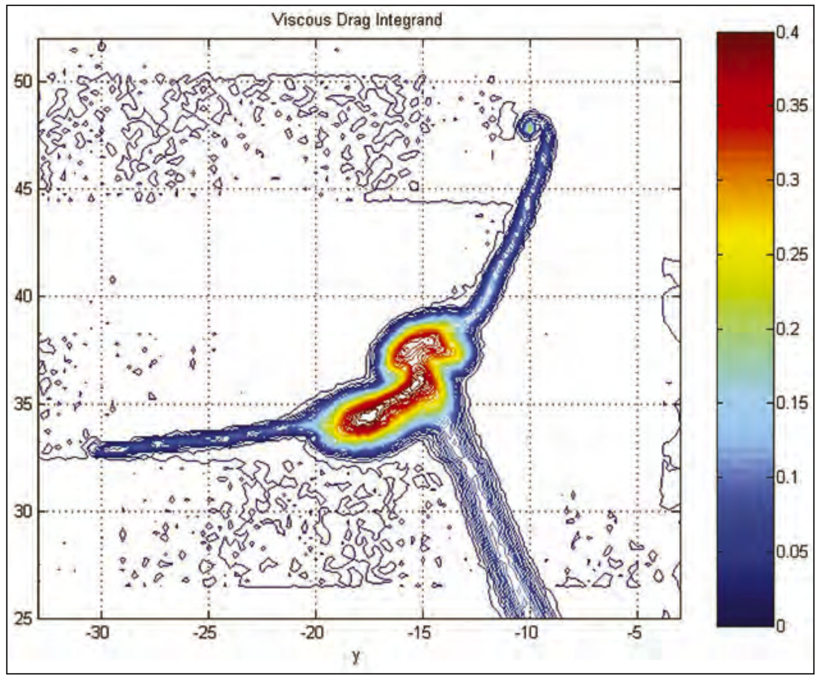
activities have been studied from time to time. Javelins, bobsleds, and speed skating equipment have been evaluated along with the aerodynamics of spinning balls. The list of applications is surprisingly long. It is often said that almost anything that moves in air or water, or is exposed to flowing air or water, has been the subject of testing at the GLMWT.

MEASUREMENTS

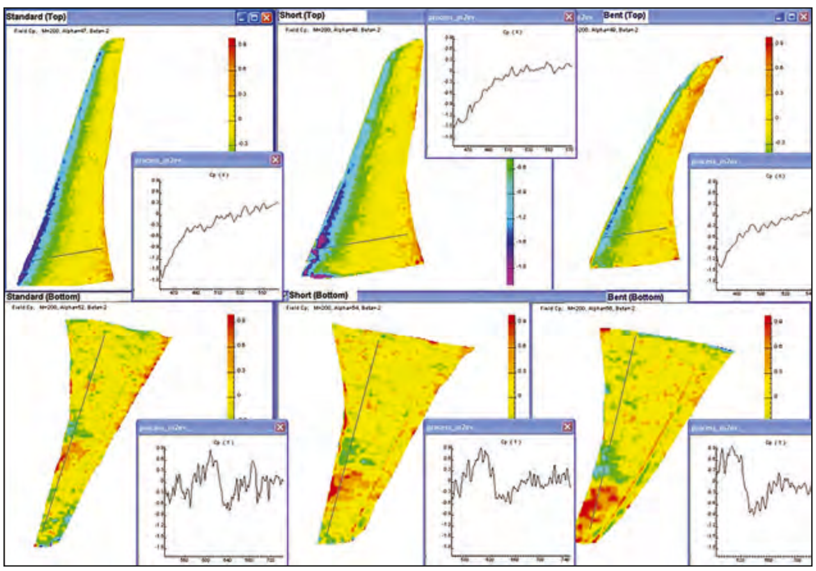
The most frequently used instrument, by far, is the external balance. The GLMWT balance is unusual in that it is a yoke design rather than the more common pyramid design. An advantage of the yoke design is that it leaves a large volume directly below the center of the test section that is not occupied by balance structure. This allows large subfloor systems to be part of model installations without impinging into the airstream, and without negative effects on the force-and-moment measurements. It is also easy to provide balance attachment points above and on the sides of the test section, which provide flexibility in model support that is difficult to obtain with more common pyramid balances. The mechanical design of the balance has stood the test of time. The output elements have been modified several times as technology has advanced. The current configuration is considered a fourth-generation system. It has output elements with 1 part in 320,000 resolution. There are embedded check weights so that 'dead weight' runs can be done at any time.

Accompanying figures show several applications that make use of exceptional capabilities of the GLMWT balance system. The four-man US bobsled and its complete team can be installed on the balance so that the minimum drag tuck positions can be discovered. The total weight of the bobsled and team is nearly a ton. The balance can easily handle this weight and at the same time can measure drag increments of the order of a few grams. An installation for a 2D airfoil test is shown, above. The upper end of the wing as well as the lower end is directly attached to the balance. This arrangement avoids the well-known

BELOW: Flow through model of AD150 VTOL aircraft on single strut support (top); and battle-damaged F18 on single strut support (bottom)



ABOVE: A data set from a wake survey of a yacht keel winglet system showing the viscous drag distribution



ABOVE: Pressure sensitive paint applied to yacht keel winglets

problems introduced by '2D inserts', which have often failed to produce results commensurate with the accuracy necessary for evaluating airfoil properties. A model representing the mirrored underwater portion of a trimaran is shown suspended on three flying wires (see previous page), which are attached to the balance below and above the test section. This test required the absolute minimum interference on the surface flows as the objective was to measure just the variation of the viscous drag associated with changes in the location of the outriggers. A similar mounting arrangement is possible for suspending a person in a flight suit. Two more common aircraft mounting cases using a single post are illustrated above. One is a flow-through model of the fuselage of the Advanced Dynamics Flight Systems AD150 VTOL design (top left). The other is an F-18 model with simulated battle damage (top left lower), which was part of a test program to support development of an automated reconfiguration of the flight control system.

The GLMWT also works with the University of Maryland's Center for Rotorcraft Education and Research to conduct helicopter rotor tests. An example of a rotor test that explored very high advance ratios is shown on page 70.

Pressure measurements are the second most common data sets. The GLMWT is currently incorporating the very latest modular pressure transducers into its custom data system. The system provides a high count of ports and is expandable to a very large number, should there be a need. Pressure-sensitive paint has been used in experiments at the GLMWT. A result of an application to a winglet of a yacht keel-bulb system is shown, left. The pressure system is also used to acquire data from a wake survey system using 1/8in diameter seven-hole probes. This system has associated software, which can calculate drag decomposed into viscous and vortex contributions. The image above shows a data set for the viscous drag of a keel-bulb system with winglets.

Surface-flow visualization using various oils is frequently used in cases where details of separation regions are sought. A recent project concerned the flow on a fighter wing and an exploration of the changes that occur over a small change in angle of attack.

ANTICIPATED DEVELOPMENTS

The GLMWT is fortunate to be located at the University of Maryland, at which there are many other laboratories with faculty staff and students studying aerodynamics over a wide range of applications. Collectively they are making use of almost every available type of experimental device. It is an ongoing challenge for the staff at the GLMWT to track the most promising of these, as they gain the potential to be useful and economically feasible in the larger facility applied to development testing for clients. ∎

Dr Jewel B Barlow, director, Glenn L Martin Wind Tunnel, University of Maryland

MULTIPLE CHOICE

Improving dynamic environmental tests with multiple-input, multiple-output technology

BY ALEX CARELLA

Dynamic environmental testing is applied every day in the laboratories of many industries the world over: from qualification tests for consumer products, to acceptance for space hardware and worthiness tests for military equipment, most engineering products have to meet specific vibration excitation levels to ensure their design or functioning is compatible with the operational environment.

This science began in the 1940s and has continuously evolved ever since. Not only has the understanding of the vibratory environment and its effects shed more light on the subject, but the equipment to perform these tests has evolved a great deal over the past seven decades, especially due to increased computer power and electronic miniaturization. We have probably reached the point where hardware and software technologies have outpaced the evolution of vibration-test specifications.

Nowadays there exists commercial off-the-shelf hydraulic (for example, hexapod) or electrodynamic (for example, DongLing multi-axis vibration test) exciters that enable us to excite multiple axes simultaneously. Although multi-axis shakers might have been available earlier, only recent advances in computer power have enabled controllers to provide the necessary robustness and quality for multiple-input, multiple-output (MIMO) tests. Yet despite the introduction of standard methods such as the Method 527 (multi-exciter) in the US Military Standard (MIL-STD-810G), we are still at the dawn of MIMO testing and there are quite a few questions that remain.

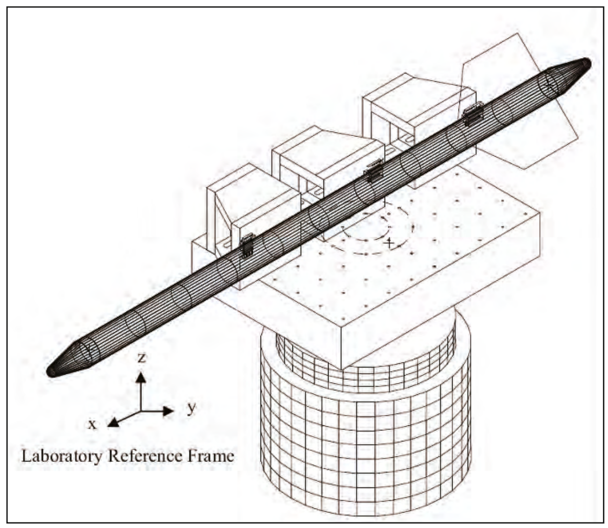


FIGURE 1A (LEFT): Single shaker test with a complex fixture

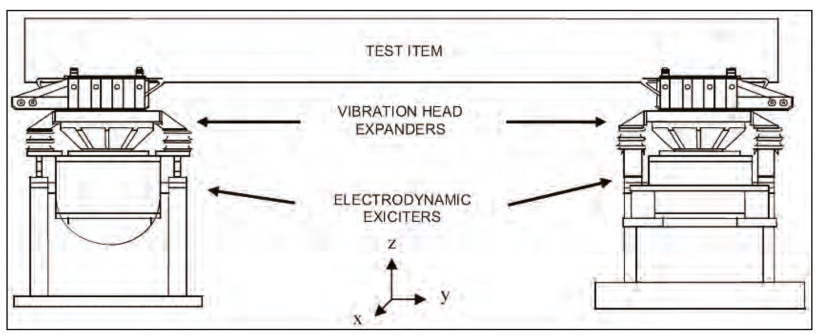


FIGURE 1B (ABOVE): Twin-shaker test: two shakers at both ends of the test object are independently controlled

MIMO TESTING

Today's MIMO control algorithms have reached the maturity necessary for industrial application. At the same time, COTS hardware and software have evolved; commercial acquisition systems enable us to acquire data anytime and anywhere in operational conditions to perform complex signal processing (once the domain of specialized technical experts). In this new scenario, researchers have been able to propose a novel technique that can potentially change the way tests are conducted: quicker test times by exciting all three axes simultaneously and smaller/less-costly lab setups without the need for large shaker installations. But most importantly, the excitation loads and vibration levels injected into the test item are more representative of those seen in actual operation. Vibration testing has advanced a long way since it began and more improvements will follow… it's dynamic after all!

This article describes an application of MIMO testing to the broader engineering community that is not yet found in standard testing methodologies. In fact, this test methodology has been proposed by researchers at the UK's University of Bristol. The work carried out by Prof. David Ewins with Dr Phil Daborn and their colleagues is groundbreaking on at least three counts: it demonstrates the effectiveness of MIMO testing in reproducing effective operation loads in the laboratory; it avoids the over/under testing that is an inherent part of single-axis tests; and it shows that effective testing is not linked to the power or size of the shakers, but to their number and distribution.

In the traditional test setup we would see the structure attached to a cumbersome fixture and excited by a large, single-axis shaker with the reference profile controlled at the connection points of the structure to the shaker table, as schematically represented in Figure 1(a). More advanced setups would use the twin-shaker setup, in which a long structure is attached to two shakers that are independently controlled based on two control accelerometers on each shaker, represented in Figure 1(b).

The method developed by Daborn et al. is the Impedance Matched Multi-Axis Testing (IMMAT) and is based on the analysis of vibration data measured in operational conditions at several points of the structure, and the definition of these measured levels as excitation levels or reference profiles at multiple points along the test item. In fact, by imposing the vibration levels in the form of autopower spectral densities (ASDs) and cross power spectral densities (CSDs) measured in operations as targets at the same locations in the laboratory test, this new approach represents a significant departure from the current practice of enveloping a number of measured power spectral densities (PSDs) to define the most severe case and impose (or control) this at the input (or base).

To illustrate the benefit of the MIMO approach of IMMAT, a mock-up structure (Figure 2), was set up and similar hardware (modal shakers) and the same control systems (LMS SCADAS hardware and LMS Test.Lab MIMO Random software) employed by the research team in Bristol were used.

The MIL-STD-810G contains some detailed annexes to Method 527 in which MIMO control strategies are discussed and the selection of parameters is proposed. This article does not seek to discuss the theoretical formulation of MIMO control nor the benefits of the different methods, but focuses more on the engineering aspects of the methodology.

To accomplish this goal, it is appropriate to describe the definition of the reference target in a MIMO context and the difference with single-axis tests. In the latter type of vibration test, there is only one reference profile. In these tests there is one single-input-single-output (SISO) or multiple single-input, multiple-output (SIMO) control sensors, but these are averaged and compared to the reference. In a MIMO setup, there are multiple shakers and control accelerometers. The control

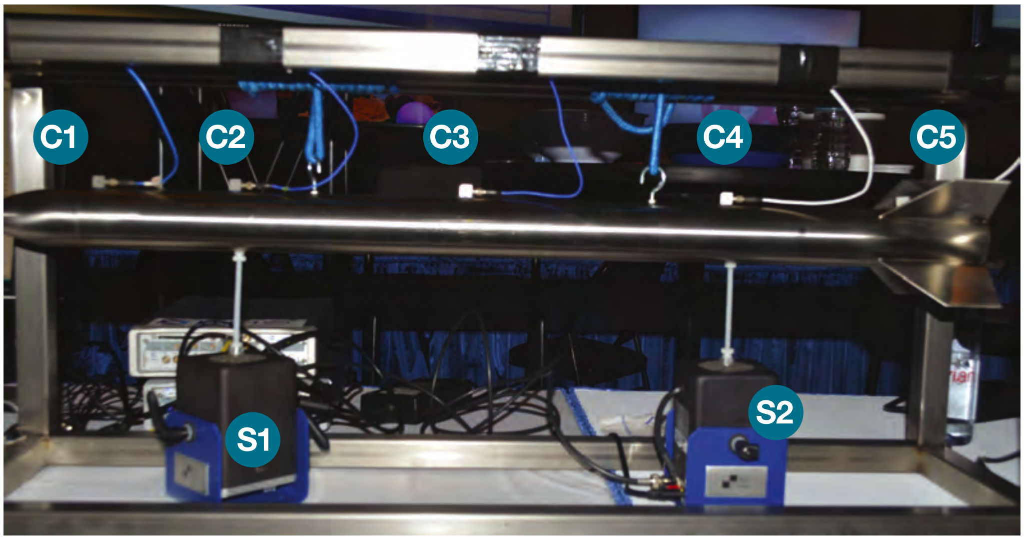


FIGURE 2 (ABOVE): **Demonstration setup with two modal shakers and five control accelerometers**

algorithms require that the number of control points is equal (square-control) to or larger (rectangular-control) than the number of exciters. For this reason, the control target in a MIMO test is a matrix as opposed to the vector of a SISO/SIMO test. The image in Figure 3 is a screenshot of a target matrix (which refers to the MIMO setup shown in Figure 2).

The diagonal elements of this target matrix are the autopower spectral densities: these specify the vibration levels that must be met to qualify the test item. In a SIMO test, there is only one ASD that is used as reference. The off-diagonal terms are the cross-spectral densities. Although the coherence establishes a direct relationship between the amplitude of the ASD and CSD, there is less focus on the role of the phase of these spectral quantities. There are a number of theories that address the definition of the amplitude and phase of the CSD to be assigned in a MIMO test setup; for example, the work of Smallwood.

One of the fundamental novelties in the IMMAT method is the use of operational data to define the target matrix. In fact, the method is based on measuring the data in operational conditions and processing the measured time traces to generate both ASDs at the control points, as well as the CSDs between each of them. In the laboratory, these vibrations can be reproduced by using a number of smaller shakers distributed along the test item and using a MIMO control algorithm to control these shakers.

In the attempt to quantify the advantages of using such advanced testing methods, we have endeavored to replicate the experiments.

First, using only the front shaker (S1) in Figure 2, the structure was excited with a white noise. This was to simulate generic random excitation levels in terms of root-mean-square acceleration (G_{rms}) and is not relevant for the purpose of this exercise.

The raw time data was post-processed with the signal processing toolbox offered by COTS software (LMS Test.Lab) to derive the auto spectral densities at the five control points (C1-C5 in Figure 2) and all the cross-spectral densities between each of these points. Following the data processing stage, it is possible to perform vibration tests in which

FIGURE 3 (RIGHT): **Reference target matrix**

	Point ID	nose:+Z	front:+Z	mid:+Z	rear:+Z	tail:+Z
1	nose:+Z	0.0437 g	0.98	0.98	0.98	0.98
2	front:+Z		0.0941 g	0.98	0.98	0.98
3	mid:+Z			0.127 g	0.98	0.98
4	rear:+Z				0.116 g	0.98
5	tail:+Z					0.103 g

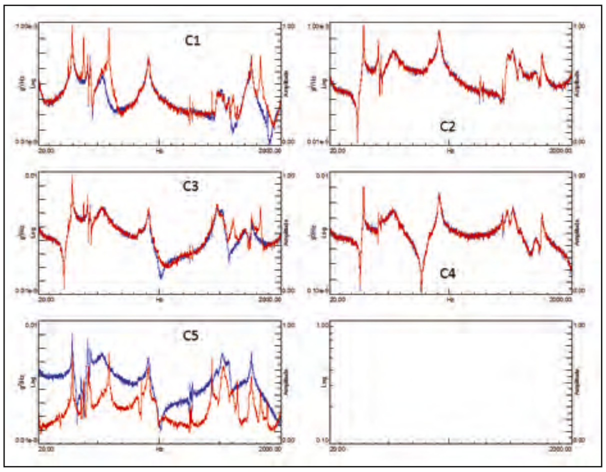


FIGURE 4 (ABOVE): **Comparison between target (blue) and measured (red) PSD with the twin shaker (two control points) setup. The control point (C2 and C4) is on target, but the other points show ranges of under/over testing**

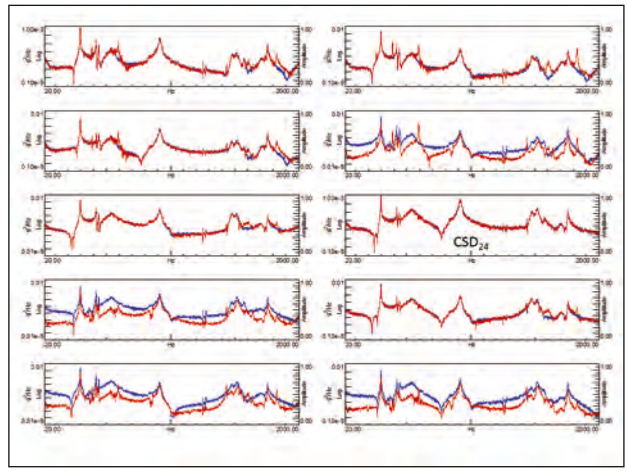


FIGURE 5 (ABOVE): **Comparison of the target (blue) and measured (red) CSDs on the twin shaker (two control points) setup. Only the C2/C4 CSD is equal to the target**

multiple shakers are independently controlled to impose that vibration spectra and levels on the different points of the structure (MIMO random control).

To assess the efficiency of this test strategy and the improvements of the MIMO setup, two different tests were conducted: one with two control locations and a second with five control points.

The first test was performed using the ASD as the target in the locations corresponding to the shaker attachments (points C2 and C4 in Figure 2) and the CSD between these two points. The comparison between the target (blue) and controlled ASD (red) is shown in Figure 4.

Similarly, by comparing the target and measured CSDs, only the one measured between C2 and C4 will coincide with the target one, while the others will follow what the dynamics of the structure will allow.

When we include all the ASD and CSD measured on five points (C1-C5) in the target matrix, the pictures change considerably. As shown in Figure 6, by controlling more points (five) along the structure, both PSD and CSD are matched to the target, which means that the test is replicating the dynamics the structure (frequencies and modes) experiences in operational conditions. This clearly avoids any under/over testing.

It is noteworthy that in order to test at the operational vibration level, there is no need for large and costly shakers. In fact, by using a number of distributed modal (smaller) shakers, it is possible to inject energy into the system in a more realistic and efficient way. In the paper *Qualification test of an aircraft piccolo tube using multiple-input, multiple-output control technology*, which was presented at the 28th Aerospace Testing Seminar in Los Angeles, California, USA, in 2014, we describe how the de-icing system of a commercial aircraft (a slender structure more than 4m long) was qualified using a MIMO test setup and five distributed modal shakers. ■

Alex Carella is responsible for dynamic environmental testing with a special focus on the space and defense industry in the Siemens PL STS (former LMS) organization. He is also a board member of the Belgian Society for Testing and Environmental Engineering (BSTEE) and the Aerospace Testing Seminar (ATS)

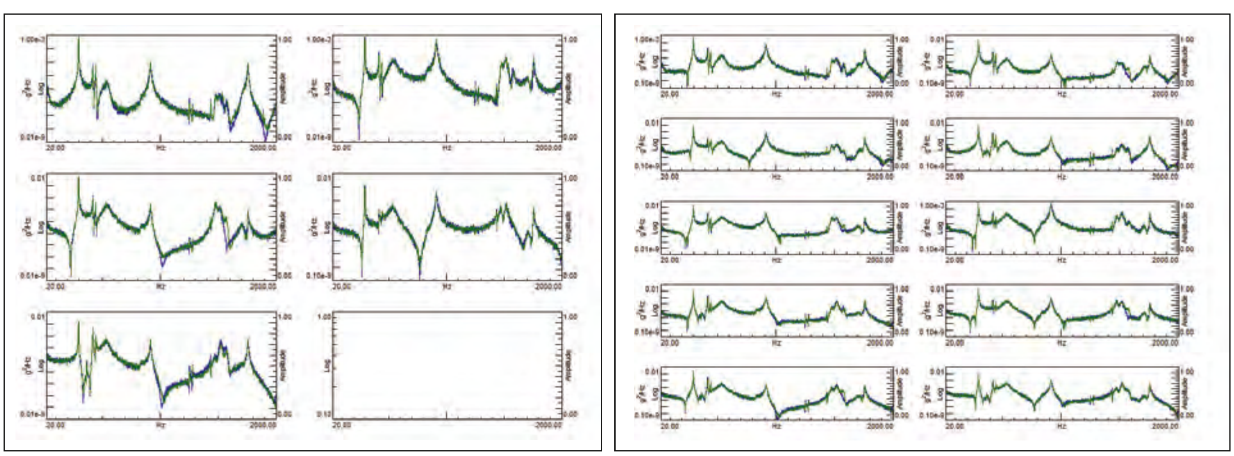


FIGURE 6 (ABOVE): **Comparison between target (blue) and measured (green) spectra: (left) PSD and (right) CSD**

LIFT OFF!

The inside story on the new measurement hardware behind the success of the recent Atlas V launch

BY RAIMUND TRUMMER

On July 15, 2015, at Cape Canaveral, an Atlas V rocket was successfully launched, with all of its systems monitored and recorded using measurement hardware developed by Dewetron. The Atlas V is United Launch Alliance's (ULA) vehicle for launching GPS satellites into space with a predicted signal accuracy two times greater than heritage satellites. Dewetron provided data acquisition hardware for the launch pad of the Atlas V rocket. With its Trion modules, the company supplied the key element to achieving the needed accuracy and to coping with the high data volumes in the small physical space at the launch site.

"We are thrilled that our hardware was part of this launch today," said Oskar Dohrau, CEO of the Dewetron Group, speaking at the time of the Atlas V launch. "We are proud that despite a challenging time schedule, our team developed and delivered the hardware in time and according to all standards and requirements stipulated by our customer."

EFFICIENCY AND ACCURACY

So why was Dewetron chosen? Dewetron Trion series input modules, which plug into DEWE2 series instruments, offer a typical precision of 99.98%. They also combine a separate 24bit ADC for each channel with the signal conditioning all in one – these specifications are comprehensive and do not have to be added up with a separate A/D card or other electronics in order to find the 'real' accuracy numbers. The modules are available for a wide range of sensors: temperature, low and high voltage, current, vibration, charge, acceleration, microphone, strain gauge, resistance, etc. The rugged modules have sampling rates up to 2MS/s, and high channel density. High accuracy is guaranteed and comprehensive: the self-test function ensures confidence before important measurements.

Cabling needs to be correct to realize the full potential of many sensors and the required signal conditioning electronics. Trion modules are available with most popular signal/sensor connectors, such as LEMO connectors, which enable the highest quality cabling and interconnections. The front panels of these modules are easily adaptable to any connectors up to a certain size to provide cost-efficient and quick customization. Other popular connectors including BNC and SMB are also available, but very important for mobile use are the rugged and lockable connection plugs. With this approach, the modification of existing sensors or the fabrication of adaptors can be avoided. In large sensor systems, like at the launch pad, this can save a tremendous amount of time and money.

Within this ULA project, Trion-Multi modules are used for all analog inputs. These multifunction modules offer galvanic isolation and accept a variety of sensors such as strain gauges, IEPE accelerometers, potentiometers and temperature sensors, as well as any voltage signals up to 100V. Due to large distances between sensors and signal inputs, there are special requirements to the sensor excitation, which are all considered on the module's power circuits. To ensure the highest signal quality, the module uses a combination of an analog and a digital filter in addition to the ADC's native anti-aliasing filter. The digital filter is fully programmable and calculated directly

ABOVE: Dewetron's measurement technology has supported space shuttle launches since 2005

ABOVE: Trion modules exchange

in the FPGA of the module – releasing the host system from significant computing tasks and enabling the application of 8th order filters to thousands of channels online, for example. Whenever the user selects sample rates and filters, the Trion module automatically configures the ADC's anti-aliasing filter, and the analog filter, and calculates the digital IIR filter. The advantage of digital IIR filters in comparison with analog filters is that they do not have any component-related tolerances. So even for high-filter orders, there is absolutely no signal delay or phase shift between the channels.

Using a single type of analog input module was crucial to ensure the same signal propagation time for all signals. This also has an economic advantage as just one type of spare part needs to be prepared for potential malfunction cases.

For digital signals, the Trion-DI64 modules were integrated. These modules also feature galvanic isolation for each channel and have been adapted to the existing connectors.

Using just two types of Trion modules was sufficient to cover this complex application. But there are many more modules available with different sampling speeds, or for different signal types like high voltage, synchronous counter or encoders, and bus interfaces like CAN, ARINC, 1553, etc.

The plug-and-play feature of the modules enables the user to freely combine and exchange them, which is crucial for flexible instrumentation with changing requirements. The hardware can be reconfigured for different tests in moments. This flexibility saves priceless test setup time. Even more time will be saved after the test, when all the data can be reviewed in a single system, in perfect synchronization, due to Dewetron's Sync-Clock technology. This synchronization is obligatory because several thousand sensors on ground support equipment were connected with the Atlas V rocket itself.

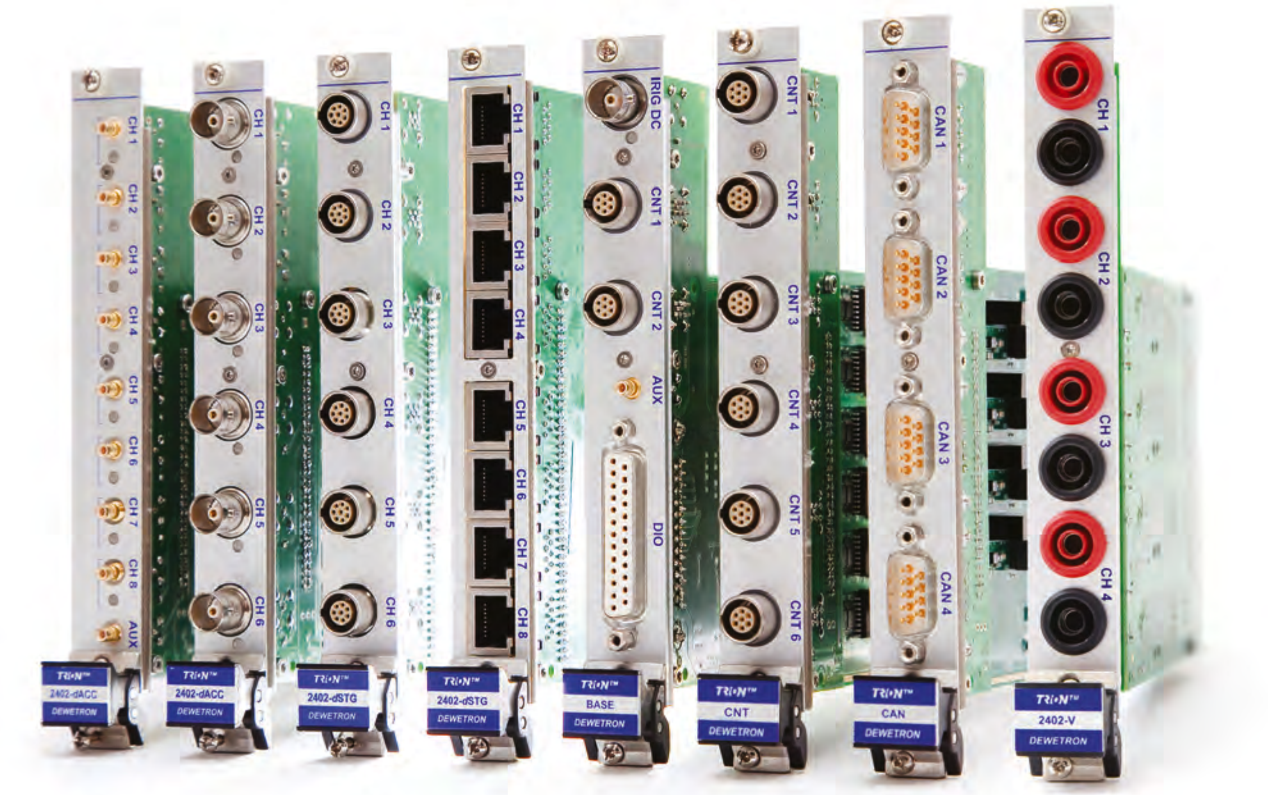
SYNCHRONIZATION OF INPUTS

Dewetron's Sync-Clock provides the timing structure that enables all different data types to be recorded in perfect synchronization – with each other and in relation to an absolute time reference.

Within the data acquisition system, a precise high-speed Sync-Clock is generated and divided into multiple phase-synchronous slower clocks for analog inputs, bus data and video pictures. Sync-Clock can be hardware synchronized to an external time reference – either the highly precise PPS signal from GPS, or one of the popular IRIG time codes. Sync-Clock makes it possible for a single system to be used to record analog and digital signals, all at potentially different rates, plus ARINC, plus MIL-STD-1553, video, audio, and even PCM data – in perfect unison and by a single instrument.

Without this technology, engineers would be forced to use multiple separate instruments and would have to learn different user interfaces, and the data streams would not be directly synchronized with each other. But with Sync-Clock, several major advantages are realized, such as a smaller file size, lower power consumption, lower overall cost, and the requirement to deal with only one

"WITHOUT THIS TECHNOLOGY, ENGINEERS WOULD BE FORCED TO USE MULTIPLE SEPARATE INSTRUMENTS AND WOULD HAVE TO LEARN DIFFERENT USER INTERFACES, AND THE DATA STREAMS WOULD NOT BE DIRECTLY SYNCHRONIZED WITH EACH OTHER"



ABOVE: Trion series modules

user interface. Efficiency during the tests themselves, when test engineers are very busy, is streamlined by putting everything onto a single flexible display.

LINUX-BASED SOFTWARE

While the hardware for United Launch Alliance's recently installed new LIS Data Acquisition System (LIS DAS) comes from Dewetron, the software has been provided by Amergint Technologies from Colorado. The LIS DAS is a critical data collection and processing system used during assembly, checkout and launch operations, and it connects to several thousand sensors on ground support equipment and the Atlas V itself. Sampling each sensor, the system provides an aggregate telemetry stream to the voting computers that control the launch. It was key to run the whole LIS DAS on Linux, which was achieved by combining Amergint's softFEP software platform with Dewetron's Trion hardware. The LIS DAS showcases the softFEP product's ability to sample, process and display such a diverse set of sensor data, all in real time.

For the past two years, Dewetron has also offered new Open Systems with an extended range of software options, including driver libraries for the well-known graphical development tools NI LabVIEW or DASYLab. Text-based programming languages such as C#, C++, Visual Basic, Java, Delphi and others are also supported. It was this Open Systems product strategy that enabled Amergint to easily integrate Dewetron's measurement technology into its softFEP software platform.

KEY STATS

There are more than 300,000 analog Dewetron measuring channels in use worldwide across the aerospace, automotive, energy and power analysis, and transportation sectors. The company's customers come from the public and private sector and include the biggest names in their field. The list includes Airbus, Boeing, NASA, Mercedes-Benz, Toyota, Volkswagen, Johnson & Johnson, Hyundai, Siemens, Bombardier, New York Subway, US Air Force, US Navy, and many others.

FIRST THE SPACE SHUTTLE, NOW THE ATLAS V

The new measurement technology was Dewetron's first supply contract with the ULA, the joint venture by Boeing and Lockheed providing spacecraft launch services to the US government. However, the space shuttle launches from 2005 until the end of the program were also monitored by Dewetron's measurement technology. Replacing the previous system after 10 years, ULA used the new LIS DAS system for the Atlas launch for the first time on July 15, 2015. The Dewetron/Amergint systems will support the Atlas launches to be used to put more than 100 satellites into orbit.

Beyond the space sector, any supply contract in the aerospace industry demands the highest standards and requirements. Customers in other sectors profit from the company's expertise that is approved by the most demanding industry of all.

Dewetron's great strengths are found not only in its ability to supply complete DEWE2 series instruments that are immediately ready-to-use, but also its ability, through the use of a modular approach with easily changeable Trion modules, to create high-quality, customized solutions and a high channel density in a very short time. ▮

Raimund Trummer is chief operating officer at Dewetron

MINI MARVELS

The miniaturization of pressure measurement

BY NICK BROADLEY

The world of pressure scanning has, like most technology, advanced significantly in recent years. The requirement for many channels of pressure measurement came about with the advent of complex wind tunnel models, but now pressure scanning is used by a variety of industries – mostly in the sphere of aerodynamics, but also covering aerospace, gas turbine development, motor racing, building research, road and rail vehicles, and more. Increasingly, other disciplines are finding a need for high-accuracy, high-speed pressure measurement in a small package.

ABOVE: Many MicroDaqs can be combined into a large pressure scanning system just by networking the outputs together

LEFT: The FlightDaq is available with 32 or 64 channels

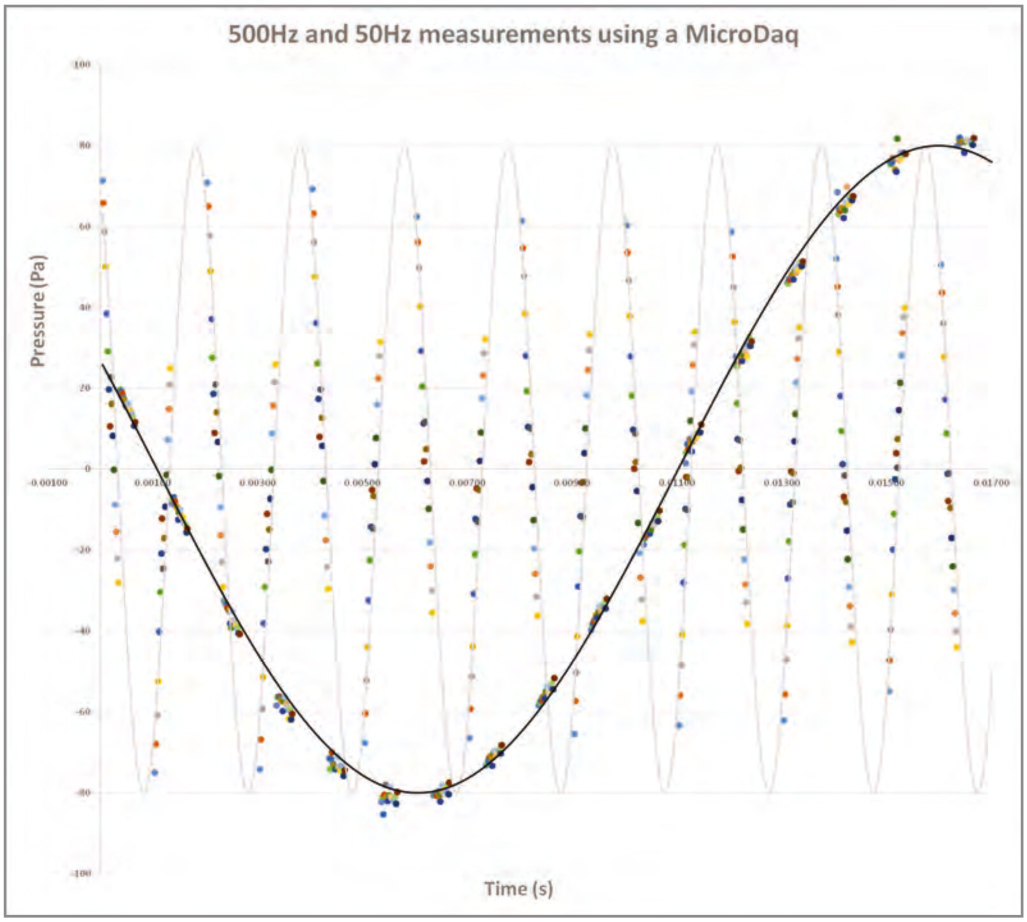
Mechanical scanners were the original solution, but these were replaced by the invention of the miniature electronic pressure scanner by Pressure Systems Inc (now TE Connectivity Inc) in the 1970s. This high-density scanner, which has been a market leader for more than 30 years, was significantly improved in 1996 by the introduction of the ESP DTC (digital thermal compensation) scanner.

This technology, which is unique to TE, has revolutionized the world of pressure scanning. It was originally conceived to provide an improvement in accuracy and to reduce the requirement for online calibration, but for the majority of applications, it has removed the need for in situ calibration altogether and now miniature pressure scanners can be treated in the same way as a large, discrete transducer and calibrated only once every 6 or 12 months, while at the same time giving unparalleled measurement density and quality.

DISTRIBUTED DIGITAL SCANNERS

DTC technology has enabled Chell (as the UK distributor for these products) to pioneer the manufacture of a series of miniature, self-contained, distributed digital pressure scanners, starting with the CANdaq in 2001 and moving onto the MicroDaq in 2008 and now the latest MicroDaq2 and nanoDaq, which were released this summer. These devices handle the interface with the scanner and provide a high-speed, engineering unit output via Ethernet, CAN and EtherCAT.

A distributed scanner architecture has a number of advantages, the first of which is convenience. Both MicroDaq and nanoDaq output a series of 16-bit integers for every channel, where 0 bit equates to -full scale and 65536 equates to +full scale. All the user has to do is read this incoming stream and use the full scale to convert to floating point engineering units (although software is provided to log the incoming data from a number of units). No calibration or manipulation of the data is required. MicroDaq2 and nanoDaq also use an embedded web server for configuration of the units, which enables them to be reconfigured in situ using the Ethernet interface. Implementation of the pressure scanner can be made even less complicated by adopting the EtherCAT variant – the MicroCAT – which can be added to any existing EtherCAT interface in a matter of minutes.



The number of scanners available to the instrumentation engineer is not governed by the size of an interface or card, which means the pressure tapping plan can evolve rather than being fixed at the design stage. There is also the obvious performance advantage of bringing digital signals through the model or vehicle that are then easily networked together.

The distributed architecture brings with it a speed advantage because the pressure scanning system is no longer limited by a fixed number of analog-to-digital converters or processors because every scanner has its own dedicated set. As a result, the small-sized distributed system can produce data at up to 5kHz per channel. The addition of time stamping in the form of IEEE 1588 PTPV2 and EtherCAT also means the data from a number of sources can be time aligned to microsecond resolution.

These higher speeds, often coupled with increased sensitivity, are now bringing pressure scanning into the world of transient measurements. The graph at the top of this page shows data from a 32-channel MicroDaq in which 16 channels are used to measure a 50Hz pressure wave and 16 channels are used to measure a 500Hz pressure wave.

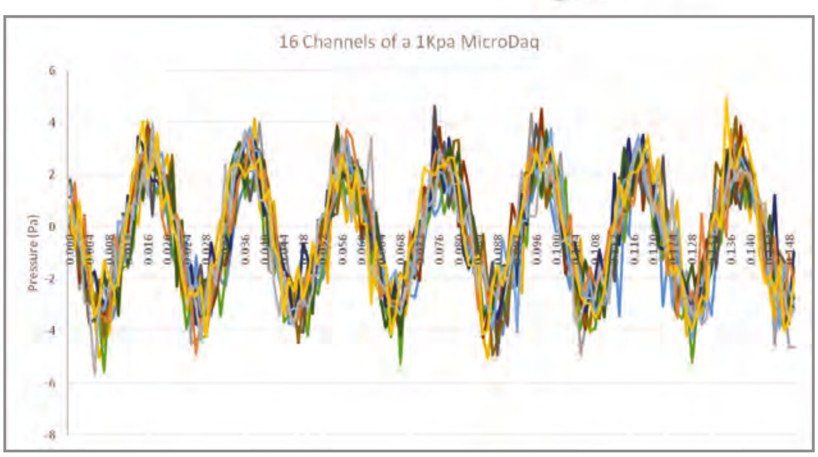
These measurements were taken with a MicroDaq that contained a 1kPa (4in water) ESP DTC scanner, so all the signals measured here are below 10% of the full scale of the scanner. This sensitivity can be further enhanced by the sensitive or derange feature within the DTC scanners. This reduces the full scale range of the scanner by a factor of three. The graph at the bottom of this page shows a non-averaged 50Hz pressure wave with a magnitude of ±4Pa, which equates to 0.4% of the full scale range of the scanner.

Where applications do not require very high speeds, the MicroDaq and nanoDaq can be configured to average the samples together to improve the data quality further.

The MicroDaq and nanoDaq both make use of the DTC technology within the scanner to constantly measure the temperature of each of the pressure sensing elements. There is one pressure measurement and one temperature measurement for every channel of the scanner. These measurements are then combined using an algorithm, which enables the MicroDaq or nanoDaq to constantly compensate zero and span for temperature. This process is continuous and happens seamlessly in the background of the pressure acquisition.

ABOVE: 32-channel MicroDaq data, where 16 channels are measuring a 50Hz pressure wave and 16 channels are measuring a 500Hz pressure wave

ABOVE: The MicroDaq series is now available with an EtherCAT interface



LEFT: Graph showing non-averaged 50Hz pressure wave

ABOVE: The new nanoDaq measures only 70 x 33 x 15mm and is a fully compensated digital unit

ABOVE: The nanoDaq can be configured for a variety of pneumatic interfaces

FURTHER INNOVATIONS

Chell has packaged the same technology used in the current MicroDaq2 into a rugged flight package, known as FlightDaq. High-speed, high-accuracy data is available with time stamping in a temperature-controlled package suitable for environments between -67°F (-55°C) and 176°F (80°C). Data is available over Ethernet, CAN or EtherCAT interfaces and this interface also gives control of the scanner purge and re-zero facility.

Meanwhile, the new nanoDaq is another step forward for Chell and is based on the new TE microscanner. TE has re-engineered the scanner into a smaller 16-channel package and removed the non-essential calibration valve because the microscanner uses DTC technology.

Requirements for an array of applications have called for the smallest package possible but with the ability to acquire fast, accurate data – therefore giving the opportunity to measure transient events. Another common requirement is to have the option of outputting absolute pressure data so there is no need to pipe up and measure the reference pressures to the differential scanners.

Chell and TE have worked together to meet these requirements. The result is the nanoDaq, which gives a digital, engineering unit interface to the analog microscanner in the same way as the MicroDaq did for the ESP DTC scanner. Like the MicroDaq, the nanoDaq features Ethernet and CAN interfaces with IEEE 1588 PTPV2 time stamping (a hardware implementation). An EtherCAT version will be available soon.

The nanoDaq contains two 16-channel microscanners, giving a total of 32. The scanners can be removed and reconfigured. Having two scanners also means that two distinct ranges can be used. The reference lines from both scanners are routed through to an onboard barometric sensor, which enables the user to select between differential or absolute measurements.

The nanoDaq, like the MicroScanner, is packaged to minimize both its own volume and the pneumatic volume in the measurement channel. To that end, it is available with a number of configurable pneumatic interfaces: It can be interfaced directly to the TE QDCM quick disconnect, use conventional bulged tubulations or interface directly with the measurement structure. The latter option reduces the pneumatic volume still further and removes the uncertainty associated with a large quantity of flexible tubes.

A 32-channel nanoDaq now measures only 70 x 33 x 15mm, but provides engineering unit time-stamped data. The advances made in the microscanner enable improvements in overall performance in terms of accuracy and speed.

Overall, the nanoDaq represents the smallest intelligent pressure scanning solution. Its size and performance make it suited to model applications, but it is also built to be rugged enough for on-vehicle applications – a big advantage when corroborating real-world with wind tunnel or CFD data.

The reduction in size not only opens up new locations for measurement, but also enables the scanner to be located as close as possible to the measurement point. This, together with the increase in speed and sensitivity (and coupled with time stamping) now makes nanoDaq suitable for quasi-dynamic measurements.

Pressure scanning technology is a good example of more and more requirements being placed on a smaller and smaller package size. The nanoDaq delivers both of these and brings the advantages to existing scanner users and an ever-increasing array of applications, both within and outside of the aerospace industry. ■

Nick Broadley is managing director of Chell Instruments Limited

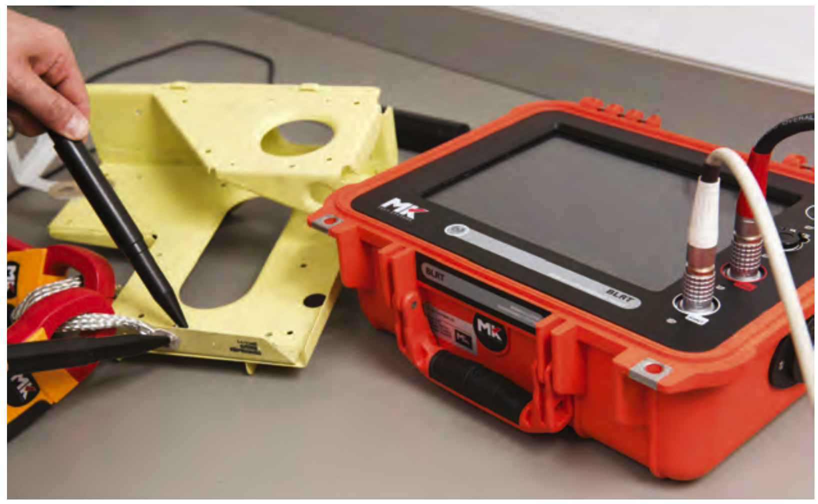
SHOCK THERAPY

How do you ensure that every bond, loop and joint will perform as needed when lightning strikes?

BY JASON EVANS

If you regularly travel by air it's likely that whilst in a thunderstorm your plane has been struck by lightning. A lightning strike is a safety critical event, happening so frequently that it is almost inevitable – about once every 3,000 hours for commercial aircraft.

A 200kA strike can cause massive currents to pass from the aircraft fuselage to the wiring and aircraft systems. Lightning strikes also result in electromagnetic fields and short term transient voltages being induced into aircraft systems. Other unwanted and uncontrolled electrical events can be caused by stray currents resulting from faulty equipment, and high intensity radiated fields (HIRF) generated by various radio frequency emissions such as high power radio and radar, particularly military radar. Radiated fields can cause voltage transients which in turn can result in malfunction of flight systems. If not routed effectively to ground, these currents are potentially catastrophic. An effective ground circuit is essential in protecting the aircraft from the damage of these electrical events.



ABOVE: MK Test Systems' Bond Loop and Resistance Test (B-LRT) system

LEFT: Loop testing

An ineffective ground circuit can result from incorrect assembly and/or material defect at manufacture, and degradation of material and joints through the lifetime of the aircraft.

Cable shielding, bonding straps, mounting brackets, pipework, current return circuits, and aircraft structure are all used to create the ground circuit. The growing use of composites means that the electrical bond between metallic elements is increasingly important. It is critical that all the jointing elements provide a low-resistance pathway. High resistance results in an increase of energy at that joint causing an increase in temperature, so causing a further increase in resistance – a vicious cycle that is a known cause of fires on aircraft. A Boeing study showed that between November 1992 and June 2000 over two thirds of the inflight fires on Boeing planes were electrical.

Accurate, controlled and correct testing of the ground circuit bonding is vital. The simplest device for bond testing is the Kelvin 4 wire resistance meter, used to measure resistance of the conductive path between two elements. The resistance measurement is accurate to fractions of a milliohm.

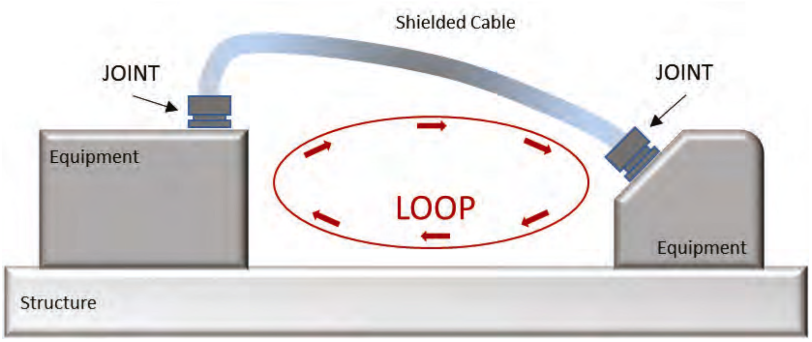
Testing an electrical grounding loop can be more difficult. A loop is a series of conductive components with one or more parallel resistance paths. Standard ohmmeter test methods should not be used to test loop or joint resistance, as they will give a false value.

Using the Kelvin bond test meter to measure the resistance between components in a loop will not give true resistance results. The existence of parallel resistance paths means that this method of testing can mask a high resistance fault, and can result in a high resistance bond being passed as good during testing.

Methods have been developed to accurately measure resistance of grounding loops and parallel resistance paths. Here, current clamps induce and monitor an alternating current flowing in the loop; the drive voltage required to induce the flow is known; the two values are resolved to deduce the total resistance of the loop.

Joint testing involves measuring the resistance of each joint within a loop. With the loop current flowing, the AC volt drop across each joint is measured. A series of mathematical adjustments are made to convert the measured impedance to a resistance value. Joint testing allows the detection of individual, marginal, high-resistance joints within a loop, and in the event of a loop failure allows the diagnosis of exactly which joint is responsible.

To effectively validate the ground circuit requires the bond test, loop test, and joint test. MK Test Systems' B-LRT test system uniquely addresses all three.



With integrated computer and MK's test management software, test requirements are downloaded to the system. Test flows and operator guidance are created automatically, and test results are stored against operator, test item, test ID, time and date. Result diagnostics and comparison against allowed tolerances is automatic.

In OEMs, the B-LRT is used to ensure that the complete grounding circuit is implemented and within resistance limits. In MRO, tests are carried out to gauge the degradation of the ground circuit elements between aircraft checks. The B-LRT offers through-life traceability and the ability to quickly compare resistance values of each bonding element over time.

A single-aisle aircraft requires around 800 ground circuit measurements in each wing. An aircraft engine requires around 400. The total tests per aircraft runs into thousands. Using a computer-controlled automatic system during manufacture and maintenance drives up efficiencies, guarantees accurate, repeatable, traceable results, and ensures that every bond, loop and joint will perform as needed when lightning strikes. ∎

Jason Evans is a director at MK Test Systems Limited

ABOVE: Loop showing parallel current path

RIGHT: A commercial aircraft is hit by lightning about once every 3,000 hours

COMFORT ZONE

A flexible CAN control box that functions as an intelligent test and simulation module is helping to make the testing of seat electronics more efficient

BY OLIVER FELS AND ARNE BREHMER

CANister is user configurable, which enables flexible use in production or in development for driving outputs and testing

Boeing and Airbus are forecasting a need for 32,000 to 38,000 new aircraft in the next 20 years due to high demand for mobility. For the lucrative long-distance market in particular, the manufacturers are forecasting around 8,500 new aircraft. Large, established and premium airlines have long recognized that they can survive only if they can offer their paying customers a flight experience that goes well beyond that of just transportation and focuses on the flight passenger – by means of exceptionally good comfort and service.

To improve the profitability of long-distance flights, airlines such as Lufthansa and American Airlines began to modify their class weighting toward more business class and premium class offerings. Introduction of the Economy Plus class – which is positioned between economy and business – also enables a comfort upgrade in the lower price segments.

Along with onboard multimedia offerings and services, passenger seats continue to assume greater significance. Often the functionality, space and layout of the seats are important decision-making criteria in choosing an airline. This has led to a high level of customization and many types of business and first class seats. Each airline insists on its own custom seat configuration and unique seat layout. To remain competitive, airlines need to update their cabin layouts and seat configurations at continually shorter time intervals and must increase their functionality and sophistication. An entire cabin configuration is completely updated every eight years on average, substantial upgrades are performed every four years, and sometimes the seats are replaced every one to two years. Seat manufacturers and suppliers benefit from the high demand, but they must also be able to handle the large range and variability of products. These challenges cannot be overcome without efficient methods and tools in development and integration tests.

TEST BENCHES FOR ACTUATOR CONTROL

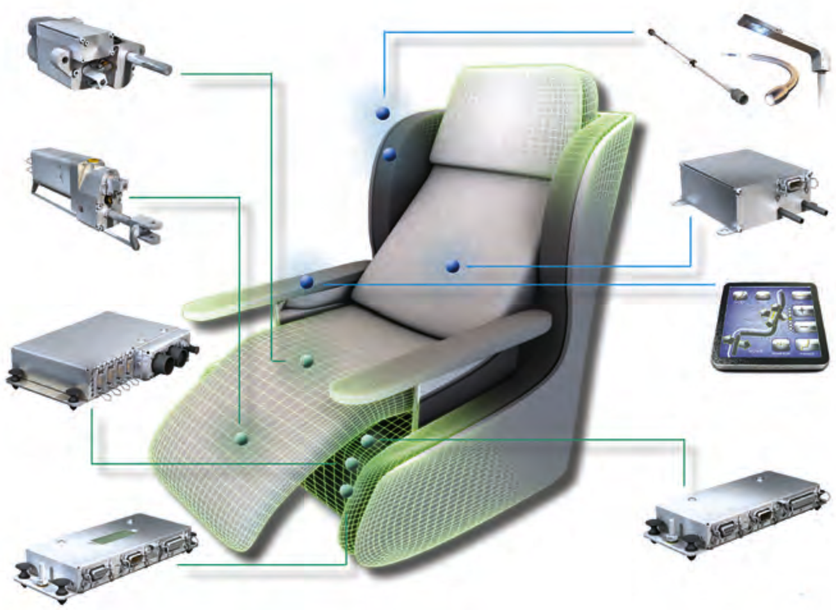
The company Dornier Technologie Systems – which has headquarters in Uhldingen-Mühlhofen, Germany, on Lake Constance – is a leading supplier of components and modules for passenger seats with very high comfort standards. The company develops and produces seat actuators, cabin lighting applications, pneumatic comfort functions, user control panels for passengers, and modules for power supply. The individual components are integrated into an overall system to fulfill specific requirements for a premium class seat for an airline and the specific seat manufacturer. Not only do the seats need to fulfill the test requirements of DO-160G (Environmental Conditions and Test Procedures for Airborne Equipment) and DO-178B (Software Considerations in Airborne Systems and Equipment Certification), they must also take other constraints such as low weight, quick and easy maintenance, low noise operation and flexible configuration into consideration.

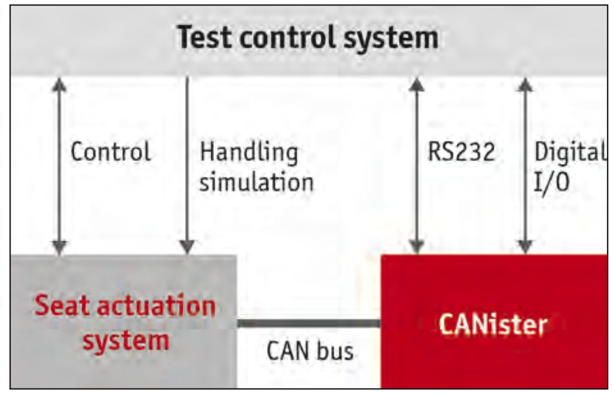
Because airlines place high value on brand recognition, there are many custom seat specifications. At Dornier, they result in an enormous number of variants in testing.

To fulfill specific functions, a business class seat is extended to include a number of additional electronic components such as: two to six linear and rotary actuators, power supply, digital control of lighting, pneumatic pump systems for massage functions, passenger control panel, controller for discrete control and seat interface, and maintenance interfaces.

In order to assure the required quality and reliability despite the large number of variants, Dornier uses tools such as Vector's CANister, which serves as a universal, handheld test device for development, final assembly and field use. As an intelligent CAN node, the device controls CAN-networked aircraft components such as control units, sensors and actuators, and it can simultaneously analyze response messages if the user desires. The mobile control box offers 16 user-assignable buttons and 20 user-assignable LEDs with which the engineer can make inputs and receive notifications. System reactions can be tested at the push of a button, for example actuating aircraft seats into the best possible position for shipping. Application cases range from a universal control panel to an intelligent tester or simulation module.

During development, CANister is also used to simulate passenger control units (PCUs). Since the PCUs are individually customized for the specific seat manufacturer and the end customer, they must frequently be procured as extra, separate devices





from a supplier. Dornier has reduced these procurement costs by simulating the PCU with CANister. In addition, tests and remaining bus simulations can be started earlier in development without needing to have the final versions of the PCUs on hand.

In final assembly, the finished and installed components are subjected to a final functional test to verify the functional integrity of each individual device before it leaves the company. CANister is used here to stimulate the devices with CAN messages in a semi-automated test procedure. In this procedure, CAN messages are sent periodically, and the responses of the CAN components are checked and visualized on the CANister device. In addition, individual components such as the pneumatic pumps for massage functions undergo a specific test.

CANister has proven its worth in the field based on its compact design. Here, Dornier uses it as a tester to check the functionality of the finished installation in the airplane. CANister's compact design and ease of

ABOVE: **Line-replaceable units of a seat actuating system**

ABOVE RIGHT: **Schematic for the use of CANister in automated test runs**

BELOW: **CANister is used for functional testing during final assembly**

reprogramming makes it relatively easy to change to different test scenarios and devices – and this offers savings when there is a need for different test revision levels and hardware that would otherwise have to be retrofitted with great effort.

The seat actuator systems are used at different airplane seat manufacturers, which is why both high-speed CAN and low-speed CAN are needed on the physical bus level. Both applications are covered by a single CANister device, which saves on costs. The version used is equipped with one high-speed and one low-speed channel, and they may be used simultaneously.

It is also conceivable to use the CANister in automated test runs (see diagram, top right). The CANister will be connected to the test control system via an RS232 interface or digital inputs/outputs. Because the control box has many integrated inputs and outputs, it offers optimal communication and control options. In addition to its RS232 interface, the tester also has eight digital inputs and eight digital outputs, four analog inputs, and – depending on the variant – two Hall sensor inputs or two PWM outputs. This lets users connect conventional sensors and actuators without a bus interface.

CONVENIENT CONFIGURATION

Dornier uses the CANister Configurator to configure and program the CAN control box. In this Windows software, the engineer can easily define which individual actions the device should execute, and how it should react to events, for example by sending messages or turning LEDs or outputs on or off. Simple signal checks are possible with the Configurator, while special C programs are used for extensive evaluations of individual control unit messages and for sending the required responses. A function library makes the entire CANister functionality available to such individual programs and enables complex evaluations and test flows. In this process, Dornier is able to access existing models of the CANbus that were created in software development using the Vector analysis tool CANalyzer.

The Configurator is used to load finished configurations into CANister as a hex file. Requirements and constraints often change in development and testing, making program maintenance necessary. The combination of high-performance control box hardware with flexible configuration software can handle these situations ideally and enables quick reactions to them. A maximum of 16 different configurations may be stored in the device.

Airplane manufacturers must respond to increasing demands by airlines for customized cabin equipment with many different variants. For suppliers of passenger seats such as Dornier, this trend – which is expected to grow in upcoming years – means increased complexity in development and higher demands in testing. The described test layout with Vector's CANister implemented at Dornier is one of many applications in which CANister serves as a flexible tool for communicating with a network in development, production or in the field testing. ∎

Oliver Fels is head of software development at Dornier Technologie Systems, and Dr Arne Brehmer is head of aerospace business at Vector Informatik

CLICK THINKING

Airborne applications demand compact, high-speed cameras that can also offer standardized communications and data formatting

BY STEPHAN TROST

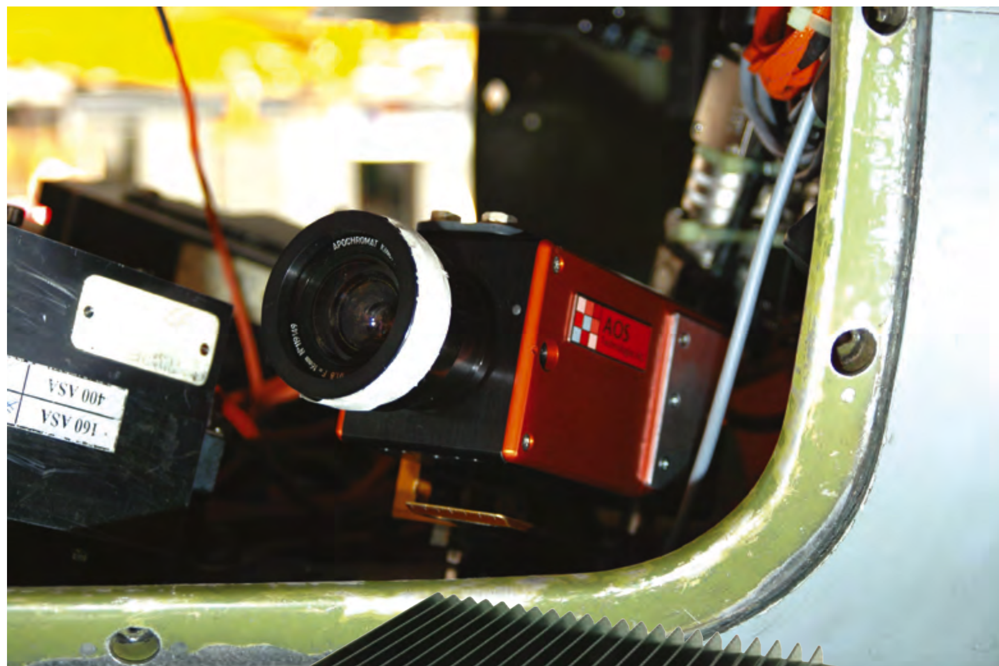
High-speed cameras recording store separation or other events during test flights are commonly used measurement systems of current development processes. The data collected by these camera systems delivers important feedback to design and test engineers for improvement or validation of systems.

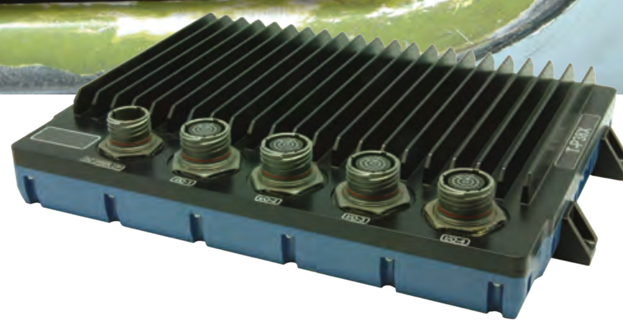
Recent developments have aimed to standardize the communication and data format, in order to simplify data exchange when performing analyses. Beyond that, space is getting tighter and tighter, and as a result, the need has arisen for smaller and more compact cameras. Customers' needs for electrical, mechanical and operational fit-the-aircraft cameras are encouraging camera designers to take on a flexible approach.

CAMERA DESIGN

To begin with image data acquisition, a solid camera is a prerequisite. In some applications the tasks demand that the camera contains integrated non-volatile memory to record short sequences and store in the camera for subsequent downloading. Some other tasks require a long-time recording system with high framing speed to cover even the most 'unexpected' events with recording capacities of minutes or even hours. In a complex system such as a fighter aircraft, it is paramount that the camera adapts to the aircraft and not the other way around. In one application, the camera design may be required to have connectors straight out of the back. Other mounting positions require having the connectors coming out sideways for a 90° view. Some positions may result in recessed lens mounting due to space restrictions in the mounting area. All designs must meet the environmental and EMI specifications to be aircraft-ready. In addition, it is sometimes desirable to have aircraft-specific connectors on the cameras for ease of integration.

Camera designers have to integrate all these requests. One approach is to have a semi-customizable camera platform where functionality, optical parameters, and identical operation of each camera are assured. Such cameras must perform reliably under any given environmental conditions and must be commercially attractive. To reach these goals, designers must first attain a high degree of flexibility in terms of electronic design. Such modules satisfy the highest possible adaptation to a custom-specific mechanical design, making the camera ready to fit in the space required. Interface parts must be easily adapted to connectors and power requirements of particular aircraft. Such camera designs can be a headache to designers, but are highly beneficial for users.





ABOVE: AOS S-EM camera in an instrumentation pod

RIGHT: Airborne controller for connection of high-speed and streaming cameras

NETWORKING AND COMMUNICATION STANDARD

It is important to standardize the communication of cameras, if they are intended for use in a network environment. A very novel idea in flight video data capturing is to network cameras via a central control unit. In such cases, the captured sequences are downloaded to a control unit and new commands are sent to the camera for subsequent takes. The GigE Vision standard is an easy-to-implement and versatile communication protocol for this approach. This standard is now extended by the IRIG committee to even better suit inflight applications for both high-speed cameras, as well as high-speed streaming cameras. The protocol allows enhancement of video data collection during flight. For instance, during certain periods, a live stream with a standard 30 frames/sec is recorded directly in the control unit. Once 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

ABOVE: Q-MIZE 180° with extra MIL connectors on the back (left); and Q-MIZE 90° FH (FlatHead) with recessed lens and connectors on the side (right)

non-volatile camera memory. These memory portions can be accessed later either on the ground or in flight through the control unit if requested via the network.

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 standard nowadays. Until recently, users had to cope with various data formats, sometimes in manufacturers' proprietary formats, complicating the exchange of data. The newly established data format under IRIG-106 Chapter 10 seems to be a viable basis for all data gathering and subsequent analysis. This common data format eases the use of analysis tools; a secure correlation of measurements, taking into account different sensors and cameras, is achieved. Standard interface technology and a common data format are very economical ways of producing results and gaining insight information and – maybe of even higher importance – allowing simple comparisons between measurement data.

Flight test video instrumentation has made substantial improvements by establishing two standards: a common interface standard based on GigE Vision, and a specific common data format under IRIG-106 Chapter 10.

By specifying the camera location and having semi-customized cameras that fit in this compartment, as a result, the technical and economical aspect of such projects are well balanced. This brings inflight video instrumentation to the next level, where data capturing and the comparison of analyzed data under generally accepted formats is becoming standard procedure. ∎

Stephan Trost is managing director at AOS Technologies

DRAG AND DROP

Politecnico di Milano's large wind tunnel has been used to assess the drag performance of a heavy-duty helicopter as part of a European project that aims to deliver cleaner skies

BY DR GIUSEPPE GIBERTINI

The use of helicopters for civil purposes continues to increase, with such growth a cause for concern with regard to its potential impact on the environment. In response, an important part of the European Clean Sky program (funded by the European Union) was the Green RotorCraft (GRC) project, which aimed to study and devise new solutions to mitigate the pollution produced by rotorcraft. Within the framework of this project, GRC2 hoped to unearth solutions for the reduction of aerodynamic drag – as less drag means less power is required, leading to a fall in pollution. Among the different platforms considered for these studies, the case of a heavy-class helicopter was consistently examined during GRC2.

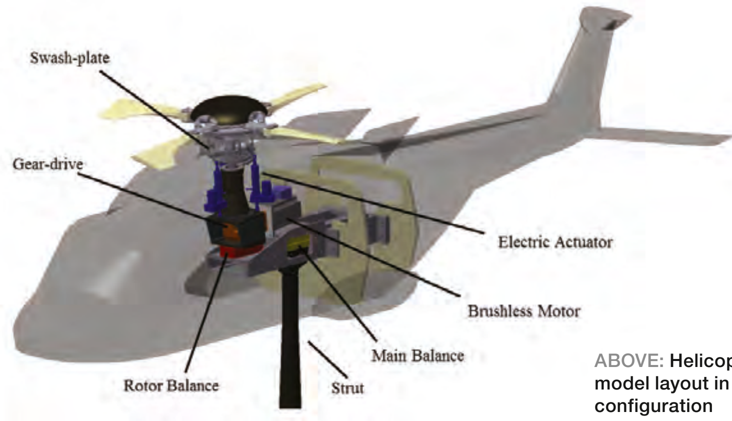
Several solutions concerning different helicopter components (rotor hub cap, engine cowling, gear sponsons, horizontal tail plane, back door ramp and blade root fairing) were investigated by means of CFD and alternative geometries were developed via optimization procedures. The application of these solutions to the considered platform promised to produce a consistent reduction of drag. Nevertheless, the complexity of the aerodynamic flow around a helicopter is still quite challenging for numerical simulation, hence an experimental assessment was considered necessary.

The tests were carried out in the large wind tunnel at Politecnico di Milano (LGV) with a ¼ scale model, more than 4m long. The helicopter fuselage model employed was basically the same as that employed in wind tunnel tests during the 'GOAHEAD' (Generation of Advanced Helicopter Experimental Aerodynamic Database for CFD code validation) project funded by the European Union's Sixth Framework Program for Research (FP6). However, for the present experimental campaign the model's internal structure, motorized horizontal stabilizer and swash-plate were purposely redesigned and built. In the configuration adopted for GRC2 tests, the model used was a typical 'drag model' – that is, it did not include the complete main rotor, only the rotor hub with the blade stabs (first 30% of the rotor radius). Three electric actuators acting on the swash-plate were used to set the collective and cyclic pitch of the blade stabs. The rotor was driven by a 2.5kW brushless servo-motor with a 5:1 gear-drive. The 1/rev of the master blade was measured using a Hall effect sensor mounted on the rotor shaft.

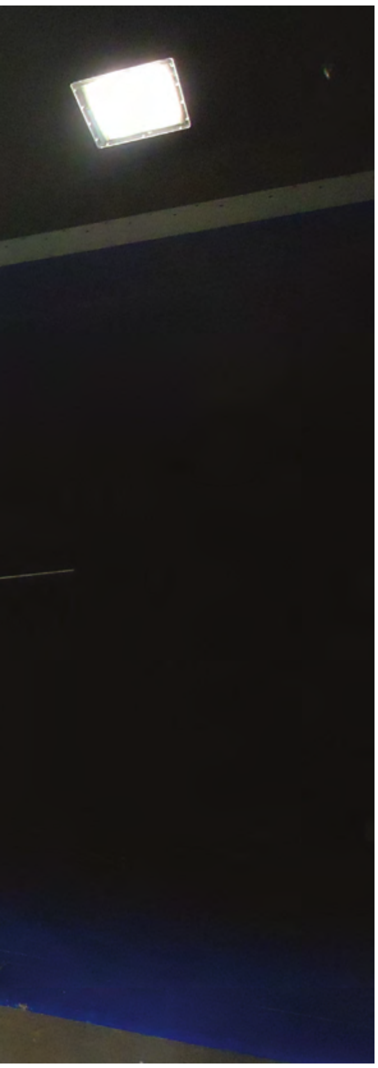
The model was fixed to the GVPM vertical strut. The head of the strut was controlled by a hydraulic system that allowed the angle of attack of the model to be set. The model sideslip was set via a turning-table positioned on the test section floor. Two ways of model mounting were arranged: one with the model upright; and one with the model upside-down. The upside-down mounting was necessary to evaluate the strut effect with the use of a 'dummy strut', but was also considered more appropriate for the study of the optimized solutions involving the lower part of the fuselage, that, in this way, was not disturbed by the supporting strut.

COMPARATIVE TESTING

As the main target of the project was the validation of the computed optimized shapes in terms of their drag reduction,



ABOVE: Helicopter model layout in upright configuration



ABOVE: The helicopter model in the LGV test section

ABOVE RIGHT: Stereo PIV measurement on the model in upside-down configuration

the main goal of the experiment was to measure helicopter total drag. With this aim, both the original helicopter configuration and the optimized version were tested to assess the optimization effectiveness by comparison. An accurate estimation of the aerodynamic performance was performed by adding all the optimized components, from the original to the final optimized configuration. In addition to the global aerodynamic loads measurement, two partial balances for rotor hub and horizontal tail plane were used during testing. Moreover, as a more detailed study of the flow can help the physical interpretation of the results and also allows for a deeper evaluation of CFD reliability, the comprehensive wind tunnel campaigns included pressure and velocity surveys. In particular, more than 300 pressure taps of the model were connected to a pressure scanner system as well as 20 Kulite-supplied fast-response transducers for unsteady pressure measurements.

Furthermore, stereo PIV surveys were carried out in the close wake to investigate the effects of the proposed solutions on the three-dimensional flow field. A particular setup of the PIV instrumentation was studied for the present activity. The cameras and the laser were mounted on slides with high accuracy in position to survey several longitudinal measurement planes. This technique enabled the reconstruction of the three-dimensional flow field over a measurement volume of interest positioned, in particular, over the back-ramp and in the region ahead of the helicopter fin.

The wind tunnel confirmed the effectiveness of the CFD-based optimized components, showing an overall drag reduction of about 6% at cruise attitude. The rotor hub of the helicopter-optimized configuration was equipped with a new hub-cap and a set of fairings for the blade attachments. In particular, the PIV surveys enabled the evaluation of the pattern of the rotor-hub wake, which when combined with the unsteady pressure measurements on the fin, proved useful for further investigation of the performance of the different optimized hub-caps, as well as for possible 'tail-shake' effects.

Moreover, an array of vortex generators positioned on the fuselage back-ramp area enabled performance improvements in terms of drag reduction. In fact, their action enabled the avoidance of the recirculating region at the junction with the tail boom typical of the pronounced upsweep of the after-body shape characterizing the blunt fuselages that yields to penalties on helicopter drag. The drag reduction due to the vortex generators is in the region of 2% – a useful result as it produces the benefit of a considerable reduction in fuel consumption with a very simple intervention on existing helicopters.

The wind tunnel campaign is the result of a very successful cooperation between a number of European universities, aeronautical research centers and rotorcraft manufacturers, providing a clear example of how such research efforts could help deliver a new generation of rotorcraft vehicles that lead to a cleaner sky.

Dr Giuseppe Gibertini is professor of Helicopter Aerodynamics at the Department of Aerospace Science and Technology, Politecnico di Milano

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GROUND CONTROL

A new generation of dynamic strain sensors has been developed for ground vibration testing

BY BOB METZ

Ground vibration testing (GVT) is a measurement campaign performed in the development process of an aircraft, with the objective of obtaining experimental data of the aircraft to validate and update the structural dynamic models, which in turn is required to predict important behavior, such as flutter. These measurements are usually carried out using piezoelectric accelerometers and help identify displacement mode shapes. However, the use of new dynamic strain sensors in vibration and modal analysis related applications has recently gained popularity, due to some advantages, such as sensor size and the fact that strain relates directly to stress.

Ground vibration testing of aircraft, or modal analysis, is a very important step in the aircraft design, being most useful for identifying the structural dynamics of the aircraft. The data is then used for correlation and updating of numerical models in use by design engineers. This in turn leads to better and more accurate models of the aircraft, improving the design efficiency and reducing the overall design cycle time.

Modal analysis has traditionally been associated with the use of accelerometers. The use of strain sensors in modal analysis has received increased interest from both industry and academia. They can be used to assess structural integrity on prototype stages, but can also give a better insight to determine higher levels of stress within a complex structure.

Another application for dynamic strain sensors is the measurement of strain-displacement relationships, or, more specifically, load predictions. In many aerospace applications, size and weight are restricted, and any sensor placed on the outside of an aircraft should minimize interference with its aerodynamic properties. PCB's piezoelectric strain gauges make for an attractive solution for inflight measurements.

The piezoelectric strain gauge has a large voltage output of ±5V at 100 micro-strain, and its dynamic performance is characterized by a 100kHz upper frequency response.

For applications where low strain levels occur, a piezoelectric strain gauge is useful because of its sensitivity, generating an output nearly 10,000 times larger than the output of resistive strain gauge. Frequency response measurements are accurate when the wave length in the unit under test is large compared with the length of the sensor. Wavelength can be determined by the formula:

$\lambda = c/f$, where c is the speed of sound and f is frequency.

A good rule of thumb to follow is that the wavelength should be 10 times the length of the sensor, so that the upper frequency limit is determined by the equation:

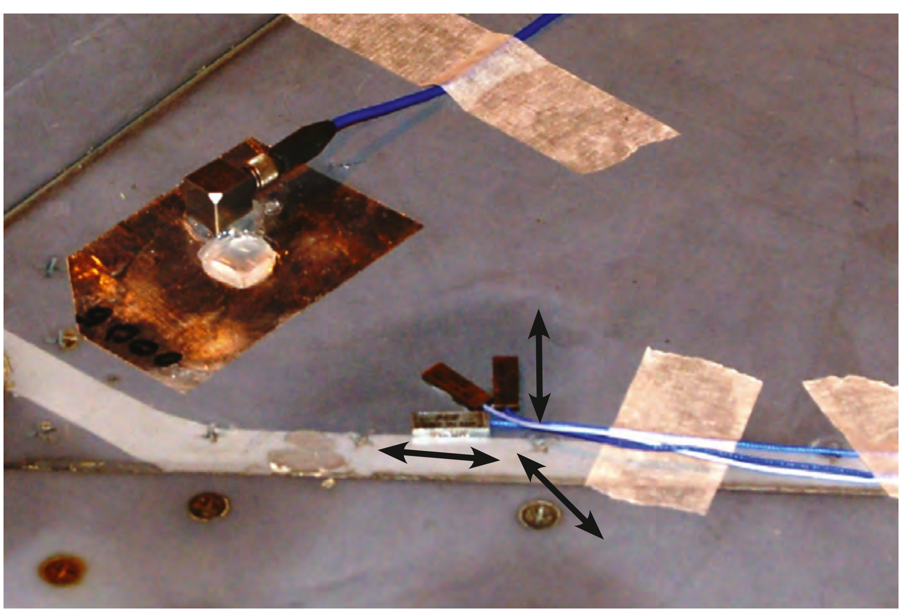
$f_{max} = 0.1c/L$, where L is the length of the sensor.

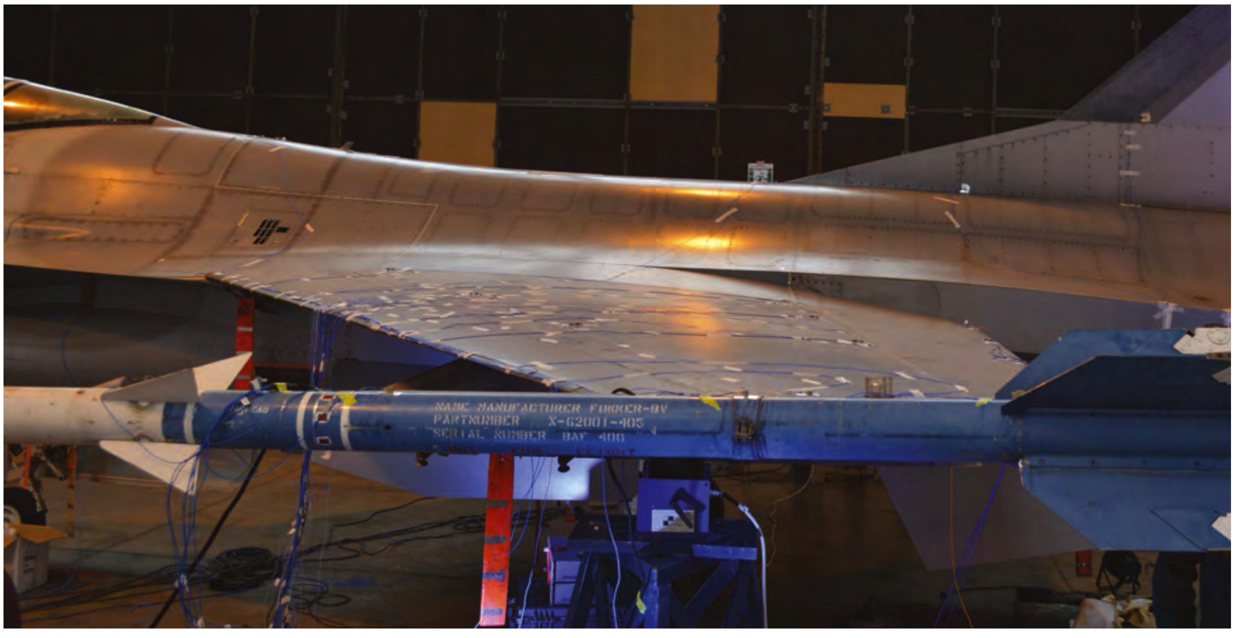
Based on this calculation for steel and aluminum, the maximum frequency would be close to 50kHz.

DIFFERENT APPROACH

PCB's Model 740B02 dynamic strain sensors differ from resistive strain gauges in two ways. Firstly, they can be mounted and reused using a quick-bonding cyanoacrylate gel, which makes the bonding procedure much faster, and more compatible with the instrumentation timings and efforts required for a GVT test campaign. Nonetheless, proper mounting is critical to good sensor performance, as

BELOW: **PCB Model 740A02 piezoelectric strain sensor and accelerometer mounting on F-16 wing (arrows indicate sensitive direction) (Photo: Siemens Industry Software)**





ABOVE: F-16 left wing strain sensor array (Photo courtesy of Siemens Industry Software

BELOW: Cantilever beam calibration device for Model 740B02

"JUST LIKE THEIR MODAL ACCELEROMETER COUNTERPARTS, PIEZOELECTRIC STRAIN GAUGES HAVE DISTINCT ADVANTAGES OF BEING QUICKLY MOUNTED AND REUSABLE. THEY ALSO BENEFIT TEST ENGINEERS BY HAVING A WIDE FREQUENCY RESPONSE AND A HIGH VOLTAGE OUTPUT SIGNAL COMPARED WITH FOIL RESISTIVE GAUGES"

with the traditional strain gauges, all surfaces must be clean, dry, and free of oils before applying adhesive. Since the 740B02 strain sensor can be re-applied multiple times, the lifetime cost and labor cost for installation are dramatically reduced.

The second difference compared with resistive strain gauges is that the 740B02 piezoelectric strain sensor combines a quartz sensing element and a built-in microelectronic ICP signal amplifier within a titanium housing of outer dimensions 0.2 x 0.6 x 0.07in (5.1 x 15.2 x 1.8mm). This is the same ICP signal conditioning used for modal accelerometers. The sensor measures in-plane normal strain along the length of the sensor (see images on previous page). The sensor is designed for minimum sensitivity to transverse strain, and because the sensing element is quartz, it is inherently insensitive to pyroelectric (thermal) disturbances. An overall view of an array of the strain gauges mounted on the wing of an F-16 is seen, above.

The calibration of the strain sensor is not performed on-site like foil gauges; rather it is performed in a controlled metrology lab, where the sensors are dynamically calibrated using a steel cantilever beam (see image, right). The beam has an added end mass such that the first resonant mode is approximately 5.7Hz. Each Model 740B02 sensor is mounted to the beam with a cyanoacrylate adhesive and the sensitivity is computed using resistive foil reference gauges. Alternative beam materials could be used to correlate the sensitivity of the piezoelectric gauges to that being tested in any practical application. For example, the sensitivity on steel may be 50mV/ micro-strain; however, if we replace the material with aluminum, the sensitivity drops to 41mV/ micro-strain. However, with 10,000 times the output of a bonded foil resistive gauge, a small drop in sensitivity is acceptable.

Just like their modal accelerometer counterparts, piezoelectric strain gauges have distinct advantages of being quickly mounted and reusable. They also benefit test engineers by having a wide frequency response and a high voltage output signal compared

with foil resistive gauges. They have low transverse sensitivity and thermal error, along with the ability to be calibrated in a controlled metrology environment. The use of ICP strain sensors that complement ICP accelerometer measurements in GVT applications becomes a practical and economical way to determine stress patterns. ∎

Bob Metz is director of aerospace and defense at PCB Piezotronics Inc

SMALL WONDER

Finding the right data acquisition system for flight testing often comes down to four important factors: space constraints, power requirements, environmental ratings and recording time

BY MIKE BECKAGE

The challenges facing today's flight test engineers are more complex than ever. Historically, data acquisition systems (DASs) used for flight testing have been large, rack-mounted configurations that rely on aircraft power to operate. While larger vehicles may not face space or power limitations, setup often requires complicated sensor cable runs, which can affect data fidelity. Long cable lengths often result in unintended consequences including under-powering the transducers, signal drop between the transducer and the data acquisition system, noise from cable motion, and even electrical interference. These complex setups can also be time-consuming and often require some ingenuity to mount the DAS and sensors. Sensors placed external to the vehicle, such as the landing gear or wings, require additional provisions that are far from trivial.

Today's requirements are multifaceted and demand innovative solutions. Placing the DAS as close as possible to the area of interest is highly desirable, but not always easy. Smaller aircraft, including UAVs, require a compact DAS with low mass that does not alter the balance and structural dynamics. Access to onboard power is often limited or unavailable, so in-situ placement requires system autonomy – in other words, the DAS needs to operate standalone without a tethered PC or controlling device, either inside or outside of the aircraft. Plus, more test instrumentation is being placed inside the aircraft in an effort to maximize test schedules and expenses, which in turn also often means higher channel counts and longer flight durations.

ABOVE: SLICE data recorders onboard NASA's low density supersonic decelerator (LDSD) in the stratosphere collecting critical strain data on the parachute risers

RIGHT: Rated to MIL-STD-810E, SLICE is engineered to operate in temperatures from -40°C to +60°C and at altitudes up to 15,240m, and is shock-rated to 500*g*

Diversified Technical Systems' highly portable, rugged, miniature SLICE data recorders make gathering flight data easier. Small enough to embed near the sensors, yet with negligible impact on test dynamics, they can record hours of high-speed data (up to 500,000 sps/channel) to 16Gb flash memory using true simultaneous sampling.

A complete standalone system, SLICE MICRO's 42 x 42mm footprint and excellent thermal characteristics

ABOVE: SLICE standalone data acquisition systems are designed for embedded applications in rugged test environments with challenging space and power limitations

allow a user to 'embed it and forget it'. The modular architecture includes a base with the microprocessor and memory, and sensor-input layers that stack on top and connect to external sensors. Each layer weighs about 28g (less than an ounce), making SLICE an option for even small drones. Unlike other small data recorders, SLICE includes built-in signal conditioning, gain, offset, trigger, anti-alias filtering and sensor excitation. SLICE also supports a variety of sensor types including bridge, IEPE, pressure, strain and thermocouples. Each SLICE stack records 3 to 24 channels and can be daisy-chained for high channel-count tests. A simple interface provides power, trigger and communication signals for full onboard autonomy.

Because SLICE is easily powered using standard battery packs, access to main aircraft power is not needed. With a 9-15V DC input range and extremely low power draw, SLICE is a top pick for many applications including electronic pod, nacelle and flight testing that may last for hours or even days.

SLICE data recorders are autonomous and small enough to be mounted directly on driveshafts, rotors and landing gear, eliminating the need for slip rings or telemetry for measurements on rotating devices.

For applications that have no access to the DAS after installation in the test article, SLICE can be configured to start recording immediately without fear of running out of record time, even if take-off is hours away. Alternatively, SLICE can be set to trigger at a specified event threshold. System setup is easy using a PC and the SLICEWare software interface.

Since both DTS and SLICE have their roots in automotive crash and blast testing, neither are strangers to extreme test environments where failure is not an option. Onboard equipment must repeatedly deliver reliable and accurate data. SLICE MICRO, and its even smaller counterpart SLICE NANO, meet the rigors of MIL-STD-810E, which certifies a broad range of environmental conditions including low pressure for altitude testing up to 15,240m, exposure to low and high temperatures (-40°C to 60°C), and vibration. Packaged in a rugged aluminum enclosure, SLICE is shock-rated up to 500g (SLICE NANO can be supplied rated to 5,000g or more).

Also well-suited for flight and impact testing is the SLICE PRO DAS, which functions in much the same way as MICRO and NANO, but with higher channel density, software switchable bridge and IEPE sensor support on each channel, and an internal rechargeable battery that provides up to one hour of primary power when fully armed.

With the growing demands of space exploration, regulations and R&D, tests often require innovative solutions to solve long-standing challenges. Customers including NASA, FAA, SpaceX, Boeing, Airbus, Raytheon, AV AeroVironment and the US Navy rely on SLICE DAS on the ground, in the air, and even in the outer stratosphere, for critical one-chance tests.

For more than 25 years, DTS data recorders and sensors have been used worldwide in crash, blast and biomechanics testing by auto makers, aerospace and leading research facilities.

Headquartered in Seal Beach, California, USA, DTS has technical centers in North America, Asia-Pacific and Europe, with worldwide on-site support available. ▮

"SMALLER AIRCRAFT, INCLUDING UAVs, REQUIRE A COMPACT DAS WITH LOW MASS THAT DOES NOT ALTER THE BALANCE AND STRUCTURAL DYNAMICS"

Mike Beckage is chief technology officer at DTS, based in Seal Beach, California, USA

MIND THE GAP

A new generation of portable non-contact electronic gap tools are replacing feeler gauge measurement methods in aircraft assembly applications at major OEMs

BY ROBERT FOSTER AND BRYAN MANNING

In the past few years, there has been a growing demand for new gap measurement applications on assemblies with a heavy use of composite CFRP to CFRP gaps, and difficult-to-access gaps, along with heightened interest in measuring large-area shim locations requiring multiple sensor configurations.

Additional trends in the commercial aircraft market have driven the need to change to more efficient gap measurement solutions. The rapid growth in the use of composite materials in aircraft that lighten the aircraft weight, while reducing fuel and maintenance cost, is now a well-established practice.

A more recent trend is the steep increase in aircraft demand, leading to a heavy backlog of orders and requiring both Airbus and Boeing to build 40 units per month of the most popular A320 and 737 models. New gap measurement tools are now in place that result in significantly faster production rates in critical applications such as main wing manufacture.

One of these new tools is Capacitec's Gapman Gen3 portable non-contact electronic gap tool, which has replaced feeler gauge measurement methods in aircraft assembly applications at Airbus, Boeing, Bombardier, Embraer, and military aircraft such as JSF.

To date, the Gapman has achieved a gap measurement/shimming operation build rate improvement that is five times faster than manual feeler gauges. Benefits include ease of operation, enhanced structural integrity of aircraft component join locations, and a shim gap database to assist users in continuous process improvements.

Datalogged gap values can now also be communicated wirelessly from the Gapman to customer-driven template data programs for direct control of the gap shimming manufacturing process.

SENSOR SELECTION

The capacitive gap sensor wand model selection is application driven and chosen in reference to the following factors: minimum gap; gap range; target material combinations (metal/metal, metal/CFRP, CFRP/CFRP); difficulty of access to targets; and large surface gap areas. There are dozens of standard models of both flexible wands and spring contact sabers, along with the option of developing multiple sensor array models according to customer needs. Sensor positioning tools are also available to accurately place gap sensors into difficult measurement locations, greatly improving the results of gauge R&R testing.

Kapton flexible wands are typically used to measure the thinnest gaps and where the flexibility of the wand improves accessibility to the target (see image below). The thinnest gap measurement available can be found in Model GPD- (3X1) I-A-225, which offers a range from 0.15mm (0.006in) to 1.0mm (0.0394in). The popular Model GPD-4.5 (.0075)-A-250 has a range of 0.20mm (0.0079in) to 3.0mm (0.118in). Other models can be specified to have a range up to 10mm (0.394in).

Flexible wands account for the majority of aircraft gap measurement and shimming processes. Examples of typical applications are the joining of several fuselage skin subassemblies such as frame gaps and wing skins to stringers and ribs and VTP assembly. The Gapman typically measures a combination between CFRP and primer-painted metal surfaces.

SPRING CONTACT WANDS

Spring contact wands are typically used in applications where: one or both targets are non-conductive; a target width is <5mm (0.2in); or the surface or shape of the target is irregular. These are also the most popular choice for CFRP/CFRP applications, where the minimum gap is >0.64mm (0.025in). The spring contact wand Model GPD-5 (0.22)-A-150 has a range of 0.64mm (0.025in) to 3.0mm (0.118in), while the range of the GPD-10 (0.034)-A-350 is 0.86mm (0.034in) to 10.0mm (0.394in).

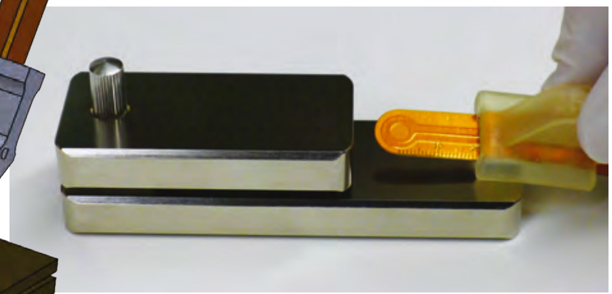
The horizontal stabilizer join areas typically use a design shim, which requires measuring gaps up to 5mm (0.2in). In one application, a non-contact or spring contact wand is built onto a 15mm-wide shim with a GPD10 sensor at the core.

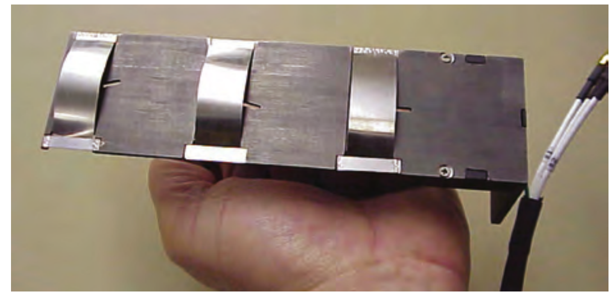
Spring contact wands can also be used to measure gaps between large mating surfaces such as wing tie plates, hatches, doors and windows, as well as for cargo door alignment.

GAP WAND POSITIONING

In some cases, airframe assemblers have thin gap applications where the target gaps are difficult to access. These areas can be above, below or in difficult horizontal access locations.

LEFT: **Flexible wands are ideal for measuring the thinnest gaps and hard-to-reach targets**





This makes it challenging for operators to be able to position flexible wands parallel to the measurement surfaces. When using non-contact capacitive gap sensor wands, best practice is to align the top and bottom sensors parallel to the two measurement surfaces. The central image above shows an example of a handheld positioning fixture constructed with a flexible urethane wand positioner to guide the sensors parallel to their target surfaces.

Tightly controlled composite subassembly applications sometimes have limited entry access to critical gap measurements. In response, Capacitec has developed a dedicated hand-positioning tool designed to enable the sensors to repeatedly gain access, parallel to the gap targets, helped by a 60° holder for tactile positioning (see image above, left).

ABOVE FROM LEFT: **Hand-positioning tool with a 60° holder for tactile positioning (left); a handheld positioning fixture constructed with a flexible urethane wand positioner (center); and a three-sensor contact wand array built into a positioning fixture**

MULTIPLE SENSOR CONFIGURATIONS

In applications such as main fuselage section joins, and starboard and port wings to fuselage assembly, aircraft manufacturers have been searching for novel multiple gap sensor measurement solutions. The photo above shows an example of a three-sensor contact wand array built into a positioning fixture. The resulting benefit is ideal sensor positioning in critical join locations with much faster and higher quality inspection rates.

Looking to the future, Capacitec is developing arrays with up to 16 sensors for even wider area gap measurements. ∎

Robert Foster is president and Bryan Manning is director of marketing and business development at Capacitec

TRIPLE WHAMMY

What are the major hardware and software trends in data acquisition, and what implications do they have for the true cost of such systems?

BY DR FRED BLÖNNIGEN

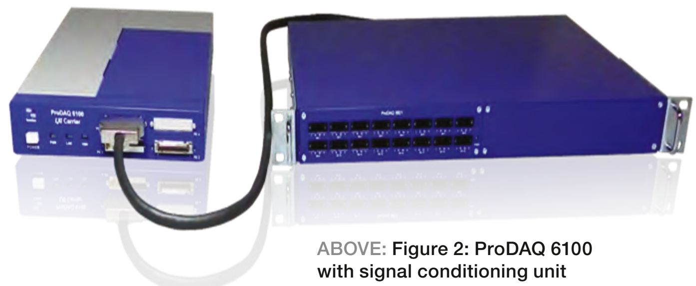
ABOVE: Figure 1a: ProDAQ 6100 LXI carrier

Beyond the need for measurement accuracy, purchasers of data acquisition systems must consider their price – according to three particular aspects. The first is the pure purchase of the system, the second is the setup of the system and the third aspect is the operation of the system. Users should also consider longevity and available support for a system. All these aspects together form the true cost of a system and should be taken into account.

HARDWARE ASPECTS

For purchasers, the first and most important question is, Which system architecture should I use? The answer is not as easy as it seems and depends on your requirements. Most users will want to apply their system to a range of future requirements. If this is the case, one should stay away from proprietary solutions, as the vendor of choice may not have modules for your next requirement. Buyers would also be advised to choose a system that is covered by an IEEE standard and where you have a good number of different vendors. Bustec's architecture is based on LXI (LAN eXtension for Instrumentation). More than 50 vendors produce different measurement devices. As the name suggests, it is based on Ethernet. This standard has been in existence now for 38 years and will remain in use for decades to come. Other serial buses such as USB are changing too fast and are controlled by a single vendor. This is also true for most PC-based buses where rapid changes in the PC world exclude any real chance of longevity. It also applies to PC-derived buses, such as PXI and PXI express. Any change of PC technology is followed by a change in these derived buses with users left struggling with an obsolete infrastructure.

A further two questions then follow. The first one concerns real time and how to handle this with Ethernet; the second is how to synchronize the different channels over Ethernet. Remember Ethernet is non-deterministic. Both are very valid questions. Take the question of real time. Bustec offers LXI carriers of different sizes where you fit in the different input and output cards. In addition, these carriers hold one or several processors. Real-time loops are handled with these processors, which control the input and output cards fitted into these LXI carriers (see Figures 1a and 1b). With regard to synchronization, the user is interested in the time correlation of all input channels and their synchronization to exactly the same clock. This should be independent of the measurement speed of the different channels. Bustec uses the IEEE1588 time synchronization protocol. The synchronization accuracy achieved is 20nsec FWHM. This synchronization is maintained for all channels, even running at different acquisition speeds. Avoid solutions that only offer the ability to synchronize same-speed channels but have no time relation between channels running at a different acquisition speed. It should be stressed that multiplexing ADCs is ill advised as the lack of time information makes the interpretation of data very difficult. This is true even for 'slow' channels such as temperature.



ABOVE: Figure 2: ProDAQ 6100 with signal conditioning unit ProDAQ 5720

ABOVE: Figure 1b: ProDAQ 6100 LXI carrier opened

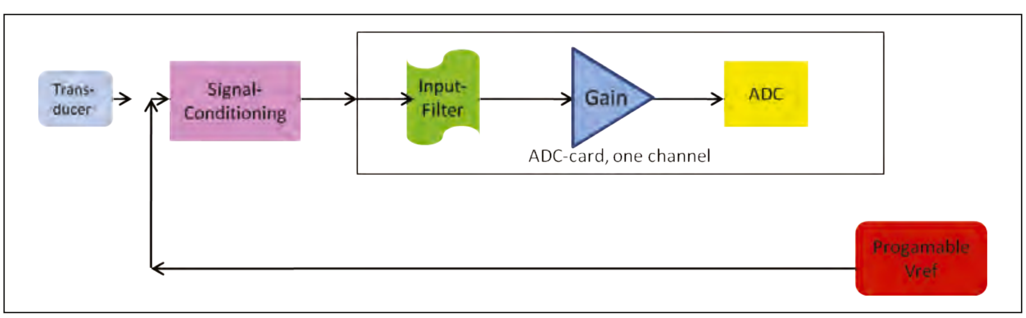
MEASUREMENT QUALITY

Consider the different input and output cards. Here, the most important factor is the measurement quality of the data acquisition cards. Today's technology sees cards with one 24-bit Σ-Δ ADC per channel. Older successive approximation ADCs are limited to 18-bit and have the inherent problem of requiring programmable filters per channel for the different frequencies to be used. If you don't use programmable filters, you will have alias frequency problems. These filters increase the cost at least by a factor of two compared with the new Σ-Δ ADCs.

To achieve good measurement accuracy, users also need a good calibration procedure. In response, Bustec has introduced a unique 'on the fly' calibration method with an onboard programmable voltage source. This source will set the calibration points to +/-90% of full scale and to 0V, independent of the gain selected. The whole calibration sequence (including the signal conditioning units) will take less than a second, even when there are thousands of channels to calibrate. The calibration source has a very low temperature coefficient with less than 1.5ppm/°C. The user is now able to calibrate even against temperature swings related to day and night temperature differences. The time saving in calibration represents an enormous cost saving for test operation. The programmable calibration source can additionally be monitored with a DMM, if required for NIST purposes.

If signal conditioning is required, the programmable voltage calibration source is brought to the SCU via shielded twisted pair cables. This is the same cable that connects the SCU with the data-acquisition card (Figure 2). There, it is switched in the input of each SCU channel into the signal path (Figure 3). With this calibration facility, Bustec, using a broad range of different acquisition cards, reports an absolute measurement accuracy of up to 0.0012%.

BELOW: Figure 3: bloc diagram of calibration mechanism



SOFTWARE CONSIDERATIONS

Software package requirements vary from test to test. This is the reason why some companies try to solve this requirement with a graphical programming language. If you have very different requirements for each test, this is a reasonable approach. But it requires knowledge about programming, either by having an in-house group or by using consultants. This again increases the cost. In a lot of cases, the requirements don't change drastically between different tests. Here a good 'out of the box' package does the job, so long as different mathematical data treatments are possible in real time. But in such cases, what should the user request from a vendor?

It is sensible to allow for distributed intelligence. This enables you to grow your system over time, without facing a bottleneck in data-throughput, calculating power and storage capabilities.

Furthermore, system setup for large systems should be fast, with the possibility to configure multiple channels in a single action, so long as these channels have the same parameters.

In addition, the system should have an auto configuration mode, to enable the user to see what resources are available in his or her test.

Last but not least, the software should be intuitive, to allow users to handle their tests without the need for excessive training in how to operate the software.

To summarize, users should not just consider the purchase of the system, but also the time for each test setup, including calibration and overall ease of use, with regard to both their hardware and software. ∎

Dr. Fred Blönnigen is CEO at Bustec Production

FAST RESPONSE UNIT

Advanced fatigue testing systems for aerospace fasteners

BY LAURIE CRONIN

Aerospace fasteners are comparatively small but extremely critical airframe structural components. Bolts, studs, screws and rivets must withstand the demands of repeated pressure and temperature cycles, variations in dynamic loads, and high vibration levels. Testing machines must be able to duplicate these in-service conditions to verify that the parts meet specifications.

Magnetic resonance testing machines, also known as high-frequency pulsators or vibrophores, are specifically designed for rigid metal or ceramic specimens, and can induce low-amplitude stress cycles at loads similar to those experienced in aircraft applications. Operating at high test frequencies, vibrophores can perform a high-cycle fatigue (HCF) test in a short period of time, enabling increased specimen throughput.

The vibrophore functions like a driven oscillator, where a large mass on the end of a spring is subjected to an external, time-dependent force. When installed in the testing machine, the specimen functions as the spring, and is oscillated by the excitation mass via the resonance drive. A proportional-integral-derivative (PID) controller provides a feedback loop based on mean force (or stress), frequency and displacement, and tunes the force exerted by the resonance drive to the natural frequency of the testing system.

HIGH-CYCLE FATIGUE TESTING DEVELOPMENTS

Zwick/Roell has recently introduced a new generation of vibrophore systems, available in capacities from 50kN to 1,000kN and offering a frequency range of 30-300Hz. These new products are the result of decades of HCF testing experience with Zwick's Amsler line of high-frequency pulsators. But with the demands of modern materials testing challenging the existing technology, Zwick decided to design an integrated load frame, electronics and software package, according to Markus Semrau, product manager for vibrophores at Zwick: "Today's vibrophore systems are controlled by the fully digital testControl II measurement and control electronics," he says. The control frequency of 10kHz provides rapid response to events during tests. Taken in combination with a high measured-value acquisition-rate and 24bit resolution, the system's control frequency enables very precise measurements.

Cycle times for testing, and the total cost of testing, are important factors in selecting fastener testing equipment. The new vibrophore systems offer ways for lab managers to optimize testing programs, enabling manufacturers to realize productivity gains that lead to market advantages.

As well as functioning as dynamic testing machines that reduce the time required for HCF testing, the new vibrophores can, for the first time, be used as fully fledged static materials testing machines – with test loads of up to 1,000kN. "This makes them an attractive proposition for laboratories primarily concerned with static tests, as well as for those that mainly perform dynamic tests, with only the occasional static test," continues Semrau. "Some of our customers use the vibrophore in the day shift as a static testing machine. At the end of the shift, they then use it as a dynamic testing machine, as these tests, while fast and efficient, can run several hours if testing over multiple cycles is required. So basically they get two machines for the price of one. When they come back the next morning, the vibrophore is done with the dynamic test and will be again used as a static machine."

The stiff four-column load frame of the new Zwick vibrophore supports excellent alignment, which is a critical factor when testing fasteners. The one-piece frame and integral weight

> "A HIGH-QUALITY REMOTE-CONTROL UNIT WITH DISPLAY SIMPLIFIES THE SETUP PROCEDURE AND ENABLES ACCURATE POSITIONING OF THE CROSSHEAD WITHOUT DIRECT USE OF THE PC"

set also allow for easy adjustment of the test frequency.

Additional improvements focus on the ergonomics of the testing process. "When designing this new line of systems, we made sure that the day-to-day work with the vibrophores will be easier and more comfortable," explains Semrau. "A high-quality remote-control unit with display simplifies the setup procedure and enables accurate positioning of the crosshead without direct use of the PC. This greatly enhances operator convenience, particularly when the PC and the testing machine are installed separately, for example in an acoustic booth. Also, the software comes with a number of features that will make completion of common tasks easier and testing more efficient."

From a cost-of-ownership perspective, magnetic resonance systems can be installed in most labs without infrastructure modifications and consume only 2% of the power of a comparable servohydraulic test system. Operation of the vibrophore is straightforward, requiring minimal training. Furthermore, with few parts subject to mechanical wear and tear, vibrophores are reliable and low-maintenance machines. The new vibrophores have been well received: "Our customers especially favor the new design," reports Semrau. "During the design stage of the vibrophore, we focused on the ergonomic aspects of working with and setting up the machine, especially with regard to the height of the clamping table."

For aerospace manufacturers who rely on fast, accurate fastener testing, the new vibrophore combines proven technology with updated control methodology and enhanced ergonomics, in a system designed to meet current and future testing needs. ∎

LEFT: Zwick remote-controlled Vibrophore 100 system provides ergonomic testing in a compact footprint

Laurie Cronin is metals industry specialist at Zwick USA

INSTRUMENT CHECK

With aircraft now flying with smaller vertical separations, it is more important than ever that altimeters and air data computers maintain the highest accuracy

BY NANDU BALSAVER

Every aircraft is equipped with instruments that monitor two parameters that are essential to flight: altitude and airspeed. A third parameter, vertical speed (rate of climb or descent), is derived from the altitude parameter. Most jet aircraft monitor a fourth parameter – Mach number – which is derived from both altitude and airspeed.

To determine the altitude and vertical speed, the instruments measure the ambient air pressure (static pressure). The higher the aircraft is flying, the lower the pressure. To determine airspeed, the instruments measure the difference between the ram air pressure (pitot pressure) and the ambient air pressure. The faster the aircraft is flying, the higher the ram air pressure. Since these instruments are providing data based on air pressure, they are known as air data (or pitot-static) instruments or air data computers. The entire air data system on the aircraft is typically known as the pitot-static system.

ABOVE: Laversab 6200 – an automated pitot static tester for helicopters

LEAK CHECKS

The air data instruments/computers in an aircraft need to be checked regularly for the accuracy of their measurements. The entire pitot-static system also needs to be checked for pressure leaks – checks are performed by an air data tester (or pitot-static tester), at first when the aircraft is built, and thereafter as part of the aircraft's normal maintenance process.

While the aircraft is in the hangar, the air data tester's pitot and static outputs are pneumatically connected to the aircraft's pitot-static system through the aircraft's pitot tubes and static ports, using hoses and aircraft-specific adapters. A leak check is performed to ensure that the leaks in the entire system are within permissible limits. The tester is then used to accurately generate the pitot and static air pressures that are equivalent to specific airspeeds and altitudes. At each airspeed and altitude, the aircraft's air data instruments/computers are checked to determine if they are indicating these parameters within the permissible tolerance. Aircraft instruments/computers that are out of tolerance are replaced.

These basic air data checks are performed on all aircraft, including helicopters and UAVs. Other tasks that involve using air data testers include: transponder checks; TCAS tests; auto-pilot testing; cabin pressure controller checks; outflow valve checks; and checking EPR (engine pressure ratio) indicators.

Laversab has supplied systems to customers in both the commercial and military (right) aviation sectors

RVSM

Prior to 1997, aircraft that were flying between altitudes of 29,000ft and 41,000ft were required to maintain a minimum vertical separation of 2,000ft from other aircraft in the area. Since 1997, this minimum required vertical separation has been reduced to 1,000ft, thereby allowing more aircraft to fly in a given airspace. The mandate for reducing the vertical separation is known as RVSM (reduced vertical separation minima). The mandate applies only to altitudes between 29,000ft and 41,000ft (flight levels 290 to 410) and therefore does not apply to helicopters and those aircraft that do not fly between these altitudes.

Since aircraft are now flying with smaller vertical separations, it is important that the altimeters and air data computers in the aircraft maintain a better accuracy than before. The air data testers that are used to check these instruments need to be at least four times as accurate as the instruments. So, if a high-accuracy, RVSM-compliant altimeter has a

ABOVE: Model 6580-HA – an automated air data test set

ABOVE: The model 6600 is a high-accuracy, automated pressure controller, designed for controlling air data parameters such as altitude, airspeed, Mach and climb

maximum tolerance of ±60ft at 41,000ft, the air data tester must have an accuracy of ±15ft or less. This translates roughly to a pressure accuracy of about ±0.003 inHg (±0.1 mbar). Therefore, the de-facto requirement for an air data tester to be RVSM-compliant is a pressure accuracy of ±0.003 inHg (±0.1mbar) on its static output, when generating pressures equivalent to altitudes between 29,000ft and 41,000ft.

Since the RVSM mandate does not pertain to airspeed, there is no specific accuracy requirement on the pitot output of the air data tester for RVSM-compliance.

AOA AND AOS

Traditionally, the angle of attack (AOA) of an aircraft is measured by the position (angle) of a vane located on the side of the aircraft nose. Lately, there are several aircraft that have eliminated the vane and instead determine the AOA using air data as measured by integrated probes, which sense pitot, static, Alpha1 and Alpha2 pressures. The air data testers required to test these aircraft need to have three independent pressure outputs – pitot, static-1 and static-2. Both the static outputs need to be RVSM-compliant.

There are some aircraft that also monitor the angle of sideslip (AOS). This parameter too can be checked by using an air data tester with three outputs. It is conceivable that future aircraft may include more sophisticated air data computers that require both AOA and AOS to be generated simultaneously. This would require a four-output tester.

LOW AIRSPEEDS

Helicopters and UAVs (drones) are equipped with airspeed indicators that need to be checked for accuracy at very low airspeeds, sometimes as low as 10kts. This requires an air data tester with a very high accuracy on its pitot output. Special variants of air data testers are available that are ideally suited for this purpose.

Over the past few years, the market has been flooded with air data testers from several manufacturers. Testers have generally become smaller, lighter and less expensive. However, since air data testers do not require certification from any governing body (such as the FAA or EASA), there is a tendency to overstate performance specifications in order to meet RVSM-compliance and other aircraft-specific requirements. Unfortunately, many buyers of air data testers do not take the time to verify the tester's specifications and end up making a purchase based solely on price.

To maintain RVSM compliance, air data testers typically need to be calibrated every 12 months. Buyers should keep in mind that a long turnaround time for this annual calibration could constrain their operations. Other factors that should be considered while selecting the right air data tester are repair charges, turnaround time for repairs, options for upgrading a two-output tester to a three-output tester, proximity of service and calibration centers, and availability of on-site training.

Facilities that maintain helicopters should consider testers with internal batteries, which can be operated for several hours without external power. The same holds true for airlines that perform line maintenance. Users in cold climates should opt for testers that can be operated at temperatures at least as low as -20°C.

ACCESSORIES FOR AIR DATA TESTING

Adapters that fit onto the aircraft's pitot probes and static ports, and inter-connecting hoses, are accessories essential to air data testing. Even high-quality hoses and adapter seals tend to wear out over time and need to be replaced when necessary. Neglecting to do so invariably results in a lot of time being wasted in tracing leaks in the hoses and adapters, instead of checking for leaks on the aircraft's pitot-static system.

When an air data instrument/computer does not meet required tolerances and is removed from the aircraft, it is usually repaired and/or recalibrated in an instrument repair facility. These repair-facilities as well as manufacturers of air data instruments/computers, generally use a high-accuracy air data tester – packaged in a rack-mount or bench-top configuration – during testing and calibration. Rack-mount air data testers are also used in automated test equipment systems for the same purpose. The rack-mount/bench-top versions are available either with or without internal pumps.

RVSM compliance has pushed air data testers to become more accurate. The advent of measuring AOA and AOS through air data has helped create three-output testers. As air data computers become even more sophisticated, air data testers will surely have to follow suit. ∎

Nandu Balsaver is president of Laversab Inc

SOUND INVESTMENT

Ultrasonic probes help ensure flawless integration of aerospace components, with manufacturers increasingly inventive in their design and application

BY NICK TYLER

Necessity, they say, is the mother of invention. And that is certainly the case when it comes to the NDT of aerospace components. For many years, ultrasonic NDT has shown itself to be an essential technique for the proving of new and in-service aerospace components.

The traditional spot-checks for corrosion and cracking are, of course, the mainstay of metal airframes and engine components. But across the aerospace industry, single-element ultrasonic inspections are being replaced by phased array inspection methods, which can be applied to almost any composite component.

Every inspection requirement presents its own unique challenges. And most inspection procedures start by defining the material type, the defect size and orientation being searched for, and the access to the inspection surface. These considerations usually require specific transducers for different inspections, and a wide range of ultrasonic frequencies and form factors will be called for across the industry.

The typical defect types that can be inspected by ultrasonic phase arrays include ply dis-bonds caused by poor penetration of the adhesive, the inclusion of foreign matter in the lay-up, wrinkles or ply folds, porosity, and de-laminations caused by handing damage or post-cure machining such as hole drilling or edge trimming.

ABOVE: **Sonatest WP2 wheel probe is ideal for large-area inspections**

RIGHT: **The Dryscan 410D is used in the inspection of attenuative materials such as GRP and honeycomb core parts**

FIT FOR PURPOSE

In one common application, the NDT inspection will be required to look for barely visible impact damage (in service), or poor lay-up of the fibers (in manufacturing) of a large flat area such as a flying surface. Wheel probes such as the Sonatest WP2 are designed to meet these needs, providing an array of up to 100mm width in a choice of ultrasonic frequencies and housed in a water-filled roller, with an ergonomic handle and a built-in encoder. The unique, patented tire material of the Sonatest wheel probes means that the operator only needs to fill the wheel with water, and the application of a light spray of water on the inspection surface is sufficient to give high-quality UT data.

For these large-area inspections, data gathered from multiple passes of the wheel have to be 'stitched together', so the alignment of the wheel between each stripe has to be carefully maintained. The addition of a laser pointer to guide the inspector makes this possible. Furthermore, the ultrasonic coupling between the wheel and the surface has to be kept consistent, so guide rollers are designed into the wheel probe, which can be changed to match the form factor of the inspection surface.

Finally, the operator may be working at a distance of 10m or more from the data-capture equipment, and benefits from the visual feedback of a remote display fitted to the wheel, guaranteeing good-quality data on every pass of the transducer.

Other typical inspections require that the bond between surfaces and stringers are checked along their length, and stringer probes are purpose-designed to achieve this. In a recent development, Sonatest has been developing a concave array and immersion tank stand-off for a procedure specific to an airframe manufacturer in the Far East.

Furthermore, fiber/epoxy composites have unique ultrasonic properties that demand the highest quality UT instruments. The ultrasonic attenuation in these materials is much

> **"EFFECTIVE AT SENSING DIS-BONDS BETWEEN THE HONEYCOMB AND THE SKIN, BRIDGING, AND INTUMESCENT FOAM, THE DRYSCAN METHOD HAS PROVED INVALUABLE IN A WIDE VARIETY OF APPLICATIONS THAT CANNOT BE INSPECTED BY CONVENTIONAL ULTRASONIC MEANS"**

greater than in most metals. To obtain reasonably consistent results, a wide dynamic range and time-controlled gain is usually required. The structures are also small in ultrasonic terms (of the order of a few millimeters), which means the sampling resolution of the instrument has to be in the region of a few nanoseconds. The Sonatest Prisma and Veo PA instruments were designed to exceed the needs of the aerospace industry, and the Sonatest Rapidscan 2 is the fastest large-area scanner of its type in the world.

HONEYCOMB STRUCTURES

Beyond the standard fiber/epoxy composites, there are some materials with ultrasonic properties that make them almost impossible to test using conventional techniques. Honeycombs and foam sandwiches are notoriously difficult to inspect, but Sonatest has, for some years now, offered a little known and under-utilized technique known as the Dryscan, which uses a pair of low-frequency (<1MHz) transducers in through-transmission mode to offer go/no-go testing for many of these honeycomb structures. Effective at sensing dis-bonds between the honeycomb and the skin, bridging, and intumescent foam, the Dryscan method has proved invaluable in a wide variety of applications that cannot be inspected by conventional ultrasonic means.

Most recently with the advent of additive manufacturing for aerospace components, the need for new quality assurance and in-service inspection is continuing to grow and challenge the boundaries of equipment and operators alike.

Sonatest's transducer and equipment solutions are designed to meet all of these challenges, with the aim always to ensure the user achieves flawless results every time. ∎

Nick Tyler is product manager at Sonatest

POCKET PRECISION

A new ultra-portable dynamics measurement unit: compact, lightweight, power-efficient and simple to use

BY DR JIM HONE

HGL Dynamics has been delivering high-performance dynamic measurement systems to industry leaders (Rolls-Royce, Snecma, Siemens) and independent test houses in Europe, the USA and the Far East for more than 15 years. Almost without exception, these systems have been modular, network-connected, medium-to-large-scale (128 channels or greater) systems for use predominantly with gas turbine development test cells.

HGL was one of the first vendors to provide completely modular, PC-based systems using an Ethernet 'backplane' – and the company continues to embrace new standards and technology. Innovations by CPU and ADC manufacturers led to HGL developing one of the market's most compact, power efficient, yet functionally capable product portfolios, allowing it to provide its clients with infrastructure cost reductions and efficient inventory utilization.

In recent years, however, it became apparent that one area of the marketplace had failed to advance – the ultra-portable device sector, which predominantly comprises one- to eight-channel, usually handheld, measurement systems. These have generally remained bulky, with large batteries but short operating durations, poor measurement specifications, and an inability to flexibly meet multiple application needs. HGL undertook extensive research among its customers and distributors, which led to the discovery that even basic requirements were mostly unfulfilled due to the very limited capabilities of existing 'ultra-portable' equipment.

ABOVE: **Pegasus is an ultra-portable complete dynamics measurement unit**

COCKPIT NOISE CASE STUDY

An existing customer had a requirement to measure the cockpit noise experienced by fast jet pilots, to assess hearing protection and communications efficiency. The client's existing solution relied on a pair of IEPE microphones mounted to the pilot's helmet; these were fed to an individual IEPE power supply box measuring 4 x 4 x 10cm. The signals were directed from the IEPE units to a separate two-channel recorder unit (4 x 6 x 8cm), which recorded WAV files onto a built-in SD memory card. Each unit in the solution included batteries, which last between six and eight hours. It was a cumbersome yet fragile and easily damaged system, with considerable interconnecting wiring. However, what the client wished for was a rugged, single box solution that can fit inside a flight suit pocket (approximately 12 x 18 x 3cm) with a minimum continuous operation of eight hours.

GAS TURBINE CASE STUDY

HGL receives many requests regarding the remote noise measurement of gas turbines, both fixed and in-flight. Another key area is rail and automotive noise measurement, predominantly in remote locations where power and network access is restricted. Most current solutions providing power/storage for up to 300 hours' autonomous operation are the size of a small suitcase; they are difficult to mount and very conspicuous. In all cases local storage is required, with wi-fi or GSM transmission of data/events being an optional (often power hungry) but useful item.

AXLE BEARING CASE STUDY

On-vehicle measurements (rail, automotive or aero) often require one to four channels of high-speed measurements to be provided alongside unit positional and/or environmental sensing. One example was a railway axle bearing measurement system on a train, where the four dynamic channels were

ABOVE: Pegasus features micro SD card storage to at least 128Gb

used for the bearing measurements but actual location (GPS), and vehicle motion (three-axis accels and three-axis gyros) were also required.

In all these (and many other cases), no one solution existed on the open market that provided the required functionality. Ironically, the closest potential solution was utilizing a smartphone bolted onto an existing dynamics system. Cell phones are a great example of ultra-portable technology where physical sizes have reduced radically, while functionality and battery life have increased.

The HGL design team wondered whether the best parts of its existing Dragonfly acquisition card and the concepts demonstrated by smartphone evolution could be combined to provide a new ultra-portable measurement solution, which could support all of the requirements identified in the case studies.

After two years of development, HGL has chosen the 2016 Showcase edition of *Aerospace Testing International* to launch the resultant platform, Pegasus, into the marketplace.

WHAT IS PEGASUS?

Pegasus is a truly ultra-portable complete dynamics measurement unit; it is pocket-sized, lightweight, extremely low power, and simple to use.

Measuring 13 x 7.5 x 3cm, and weighing only 300g, Pegasus's compact milled aluminum chassis packs in two to five dynamic input channels for voltage/IEPE sources; a six-axis MEMS accelerometer/gyro device; a MEMS pressure transducer for altitude measurement; micro SD card storage to at least 128GB; a 3.5in LCD touchscreen; USB port for tethered operation/battery charging; and four AA alkaline/NiMH batteries for 12-hour continuous recording.

The front end includes two to five simultaneously sampled 16bit analog-to-digital converters (ADCs) capable of sample rates to 250kHz (100kHz bandwidth), with a signal-to-noise ratio (SNR) of close to 96dB – unheard of in a handheld device of this class. The front end also features built-in AC/DC coupling, six voltage ranges from 0.2Vp-p to 20Vp-p, and a 4mA IEPE current source – all programmable on a per-channel basis. In mid-2016, HGL will provide a 24bit version of the Pegasus, which will increase the SNR to approximately 110dB.

The processing power comes from onboard ARM processor and FPGA combinations, which are externally programmable via the USB link. HGL has developed multiple apps, including Basic Recorder, Rotating Machinery, Route Measurement, and Trim Balance. The API will be published, and this will allow third-party apps to be developed as required.

In addition to the headline ADC channels, the Pegasus also includes a six-axis MEMS accelerometer/gyro device, which allows the movement of the unit to be measured in any Cartesian and/or rotational axis at rates up to 100Hz, and a pressure/altitude sensor. The data from these sensors can be recorded along with the main ADCs and/or can be used to trigger data recording or event marking.

On the model shown, a 3.5in capacitive touch LCD display is used for all primary control/status functions. Configuration and acquisition can be achieved using simple touch gestures. The 320x240 pixel display means rich monitoring displays can be used during acquisition (oscilloscopes, bar graphs, FFTs and polar plots) at refresh rates of up to 10Hz.

Pegasus is powered via the onboard AA-sized batteries or the USB when operating in tethered mode. A set of standard alkaline batteries will allow operation for approximately six hours, while the use of NiMH rechargeable cells will allow for extended operation, up to 12 hours. There is a built-in charging facility for NiMH batteries, which is activated when the USB is connected to a suitable host; a full charge takes approximately four hours. If recharging the batteries in situ during long tests is not practical, it's the work of moments to fit fresh batteries. The unit may also be connected to a small (4W) solar panel and/or a small wind vane to charge in the field.

When operating in tethered mode, data can be stored on the micro SD card or streamed directly to the host PC across the USB. HGL has a simple recording application available for tethered operation and can provide an API/Windows DLL so that custom applications can be created.

Natively recorded data formats (on the SD card) will include the HGL data format, WAV, and MATLAB; where tethered operation is concerned, an almost endless variety of data formats can be used.

Over the next few months, a number of different Pegasus models and options will be made available, including GPS, 3G, wi-fi, and other conditioning types, among them strain gauge. In addition, an Ethernet and sync option is being developed, which will allow connection to existing HGL systems as another acquisition module, further increasing its flexibility. ■

" WHAT THE CLIENT WISHED FOR WAS A RUGGED, SINGLE BOX SOLUTION THAT CAN FIT INSIDE A FLIGHT SUIT POCKET (APPROXIMATELY 12 X 18 X 3CM) WITH A MINIMUM CONTINUOUS OPERATION OF EIGHT HOURS"

Dr Jim Hone is managing director of HGL Dynamics Limited

AUTOMATING NDT INSPECTION

Non-destructive testing will play a major role in the design and maintenance of the next generation of composites-intensive aircraft

BY SAM H SERHAN

Automated non-destructive testing (NDT) is generally used to perform quality control, root-cause failure analysis, or component design optimization, particularly with regard to composite materials in next-generation aircraft. NDT is needed for the purpose of validating critical and complex components; this requires automated NDT systems with advanced inspection features. These NDT systems are required to perform tridimensional component testing, to input the component's CAD drawing to produce both reliable and repeatable testing results. These requirements for a reliable NDT of complex and composite aerospace components has driven the development of an automated NDT solution using high-precision ultrasonic scanners and advanced software tools, for full 3D contour following capabilities.

Ultrasonic testing of composites using automated systems is frequently used for aircraft components. However, for critical aircraft components such as engine blades or engine cases, ultrasonic testing requirements are more demanding in terms of inspection reliability, resolution and repeatability. These factors are usually considered more important than the overall inspection bottleneck. The solution is a multi-axis scanner where position of the axis is guaranteed with high-precision – reliable performances of the scanner are obtained from good metrological alignment conditions, offering excellent positional accuracy and repeatability. The scanner has enough axes to reach any inspection point in 3D space and follow the inspected part curvature. It is also fully controlled via a centralized system control station with advanced 3D motion control, data acquisition, data reporting and data analysis modules, making automated NDT inspections more reliable and easy to perform.

MOTION CONTROL

Motion control for automated NDT solutions is designed for very specific inspection tasks and needs; such as the control and synchronization of two independent manipulators with different configurations in order to inspect parts in through-transmission mode. The motion control system also needs to be coordinated with the data acquisition process to perform real-time inspections. The inspection of curved composite parts adds an extra complexity to the system motion control process.

TecView 3D allows arbitrary motions, and performs the necessary path planning in order to follow any contoured shape. Such a capability is among the most complex and demanding in terms of both electronics and software development efforts. TecView 3D also allows users to import CAD files of the inspected parts, teach and learn the parts, perform full 3D inspections, as well as generate accurate inspection C-scan images for analysis and interpretation.

The control system must respect several parameters in very precise ways. One important requirement for reliable automated 3D ultrasonic testing is to maintain a constant probe angle during the entire inspection time. The distance between the probe and the tested part also needs to be controlled. In brief, the way the software ensures this is by using inverse kinematics. In robotics, the robot uses this concept to provide a desired position known as motion planning. It is capable of mapping out the angle and distance the probe should be based on its distance and orientation throughout the curved piece. A common challenge for testing of composite materials is the variation of wave attenuation, a parameter used to characterize problems in the material. Such variation naturally occurs due to the part shape, thickness and material composition, which adds extra complexity to data analysis.

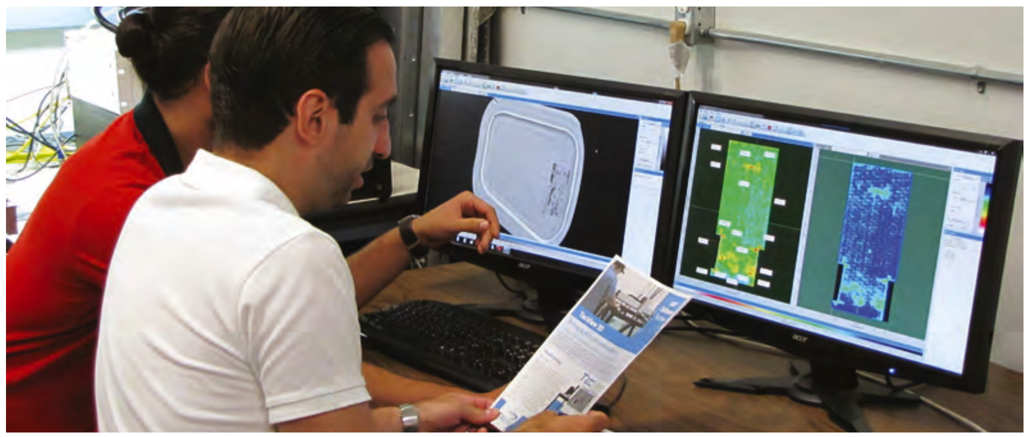
DATA MANIPULATION AND INTERPRETATION

Data manipulation and display modules need to be optimized for multiple computer processors and designed to handle large amounts of data (by accessing computer memory more effectively). Due to the precision of the scanning, by its very nature the data will be large, with many results in accordance with the scan.

The data interpretation requires an advanced set of tools to achieve proper interpretation in terms of defect identification and sizing. It also needs to adapt to part variations in order to perform an overall analysis of the results, as well as pinpoint flaws. This can either be done by performing analysis relative to some calibrated samples similar to the inspected parts in order to perform localized analysis, or by using of more advanced signal processing tools which consider these variations to perform a global analysis. Maintaining a proper signal-to-noise ratio during the automated inspection is also one of many challenges due to the composition and/or complexity of the part geometry.

NDT technologies must evolve in parallel with the advances made in the conception and fabrication of aircraft. The advances of new materials such as woven composites combined with complex shapes will act as a driving force in the development of new and advanced NDT solutions and scanners. ∎

Sam H Serhan is president of TecScan



LIFE ON THE OCEAN WAVE

The Swedish Defence Materiel Administration reports on recent sea trials of the A109LUHS helicopter on an amphibious transport ship of the Royal Netherlands Navy

BY JONAS LINDE & KJELL PETTERSSON

The test and evaluation (T&E) directorate at the Swedish Defence Materiel Administration (FMV) currently operates two T&E flight test sites. The first, FMV T&E Flight Test Centre (FTC), is located in Linköping and is a fully equipped and experienced FTC with fixed- and rotary-wing aircraft, experimental test pilots, and flight test engineers. The main task for FMV FTC is developmental test and evaluation (DT&E) and verification and validation (V&V) of all the different aircraft that are operated by the Swedish Armed Forces, including: fighter program JAS39; helicopters such as NH90, A109 and Black Hawk; UAVs; and tactical transport and airborne early warning and control aircraft, such as C-130, Sabreliner and Saab 340. The second flight test site, FMV T&E Vidsel Test Range, is Europe's largest overland test and training range and is well known for its potent capability to host live firing trials and large-scale exercises.

SEA TRIALS

FMV FTC in Linköping has recently performed an interesting project – the Ship Helicopter Operational Limitations (SHOL) flight test campaign, which was performed in cooperation with the Royal Netherlands Navy (RNLN).

Sweden has a long history of participation in different international operations and during spring 2015 the Swedish Armed Forces participated in the EU operation Atalanta. The Swedish contribution was a helicopter component (two aircraft) that was to be embarked on a RNLN amphibious transport ship (LPD2) named Zr.Ms Johan de Witt. The very short preparation time mandated that vital parts of the DT&E effort had to be performed en route to the area of operation outside the coast of Somalia.

While the aircraft itself is always limited to operations within its service release envelope, and may be cleared for ships (in general), each unique ship-helicopter combination needs to be explored in an appropriate manner. For this reason, sea trials are required for each particular helicopter-ship combination.

EMBARKATION GROUND TESTS

FMV FTC was tasked to perform First of Class Flight Trials (FOCFT) with an A109LUHS on LPD2. The tests were performed with a ground test campaign before leaving Dutch harbor, followed by a SHOL flight test campaign during transit to mission area. The following test objectives were assessed: parking on deck; parking in hangar; moving with towing truck on ship; refueling/defueling; and dry air supply.

FLIGHT AND RANGING TESTS

The SHOL trials were then performed by FMV FTC authorizing a Dutch test plan. FMV FTC was responsible for authorizing the flights, while the Dutch flight test department was responsible for test execution, data gathering and data analysis. The main objective was to validate the published Cross-Ops envelope and provide limitations for ranging the A109LUHS on LPD2.

More specifically, the following objectives had to be achieved during the sea trials: validate the Cross-Ops envelope (only port take-off and landings) and determine an operational flight envelope for take-off and landing in a 45° angle with the ship's centerline (oblique), as well as starboard procedures; determine an operational envelope for ranging; perform remaining operational test and evaluation (OT&E) items for safe flight operations on board the ship; and present the test results so that they can be used by operational crew.

The purpose of the sea trials in particular, is to establish aircraft flight characteristics, for example power margins, aircraft attitude and controllability limits in an omnidirectional relative wind envelope expressed in indicated wind by the anemometers mounted on the ship. The flight test data obtained should indicate within the low speed hover envelope where regions exist where safety margins between available and required aircraft rejection criteria are marginal or even exceeded. This is required for safety reasons as limitations are likely to be exceeded during shipboard operations by operational aircrew in these regions.

CHALLENGES

The verification had several challenges that had to be overcome. This was the first time that FMV FTC had performed FOCFT on board a foreign ship. The testing (FOCFT) was also performed in transit to the mission area, requiring an evaluation report to be drafted and authorized in a very short time. And if that wasn't enough of a challenge, the test campaign was performed by two test organizations from different countries and with different national rules, regulations and cultures. This was reflected by the two nations' test crew in the helicopter, as both used slightly different test methods.

> “THE JOINT FLIGHT TEST EFFORT RESULTED IN SIX HOURS OF FLIGHT TESTS THAT WERE FLOWN DURING SEVEN DAYS AT SEA, OPENING SHOL ENVELOPES FOR DAY AND NIGHT OPERATIONS AT THE AFT LANDING SPOT”

LEFT: Ship Helicopter Operational Limitations (SHOL) flight testing lasted for six hours

RIGHT: Zr.Ms Johan de Witt of the RNLN

JUST IN TIME

The joint flight test effort resulted in six hours of flight tests that were flown during seven days at sea, opening SHOL envelopes for day and night operations at the aft landing spot. A joint effort in analyzing flight test data and drafting a joint flight test report resulted in releasing a recommended SHOL envelope to the Swedish Air Force (SWAF) within five days after finalizing the campaign.

The challenges faced during these sea trials were overcome as a result of the competence and determination of the Swedish and Dutch flight test teams. A major factor for success was FMV FTC’s excellent knowledge of the A109LUHS system and SHOL testing. Another key factor was the Dutch experience of performing FOCFT with another nation’s helicopters on board its naval vessels.

The positive test crew coordination and joint view about how to perform flight testing formed the basis for the campaign. The critical factor for achieving this is a common training base, which is a result of attending recognized flight test schools.

However, the best measurement of the success was that the campaign

enabled SWAF to conduct a large number of missions from LPD2 in Operation Atalanta during spring 2015. ∎

Jonas Linde is director marketing and sales and senior flight test engineer at FMV T&E; and Kjell Pettersson is project manager and senior test engineer at FMV T&E, Swedish Defence Materiel Administration

FIT TO FLY?

The aviation industry typically undergoes gradual evolution, however a paradigm shift is taking place in the MRO sector with regard to borescope measurement technologies

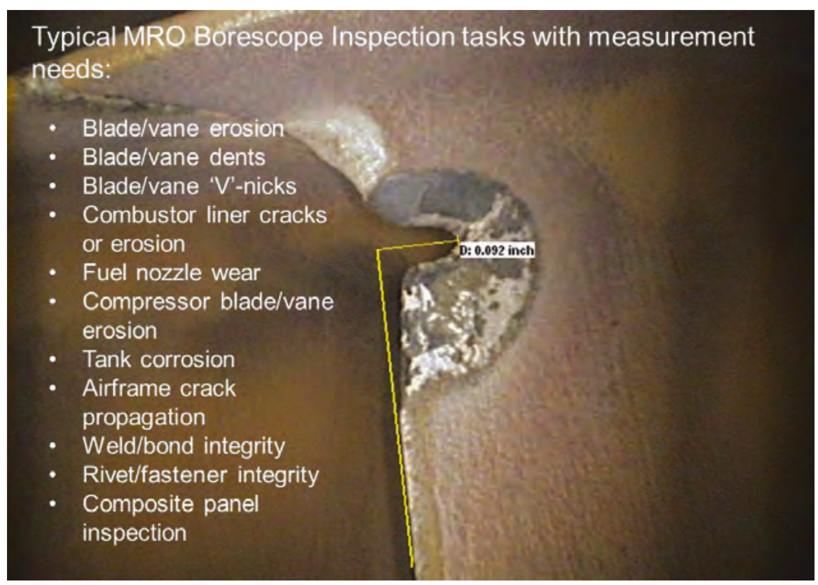
BY KLAUS HAMMERL

More than ever, operational uptime of turbines and aircraft is absolutely key. Inevitably, this has placed emphasis on faster turnaround times in MRO shops. From an engine perspective, maximization of 'on-wing' time is now viewed as the key objective for stakeholders such as airline operators, lessors, MRO service providers and turbine OEMs.

In this context, borescope inspection solutions are increasingly used to support safety, performance and quality control of turbines and other airframe structural parts, to detect and evaluate defects or imperfections without costly disassembly or removal. In this microcosm of the aviation industry, a concurrent paradigm shift is also occurring as borescope inspection is no longer simply about performing a visual inspection.

Defects increasingly have a requirement to be measured to enable firstly a go/no go decision, but also subsequent measurements to monitor the defect for propagation or further damage. Increasingly, modern engines and airframes have significant damage tolerances, allowing continued operation as long as the damage is closely monitored with proven technology. Accurate measurement can enable failures to be predicted and for appropriate maintenance to be scheduled at a convenient time.

ABOVE: The Techno Pack T LED offers a powerful LED light source, a 15in monitor, high measurement accuracy and a newly developed software with user-friendly interface



SHADOW AND STEREO MEASUREMENT

Today, trained aircraft technicians can select from a number of video-endoscopic measurement technologies. Essentially, shadow measurement and stereo measurement are the most established technologies, but increasingly have become problematic for the modern MRO sector as they fail to meet the levels of accuracy and repeatability expected due to certain restrictions and application complexity. However, the fundamental flaw with both shadow and stereo is that the tip of the probe has to be changed from a viewing tip to a measurement tip, adding time to the inspection process and therefore cost.

Shadow measurement requires the use of shadow measurement tips, which project a shadow onto a target. To measure the target, the videoscope processor uses triangulation based on the shadow's location. Shadow measurements can only be taken on a frozen image or on a recalled image that was saved in measurement mode.

Stereo measurement technology uses a prism to split images, allowing the camera to capture left and right views with a precise angle of separation. The reporting technology then analyzes the position of user-placed cursors, applies a triangulation geometry calculation, and returns a measurement value.

LASER MEASUREMENT

In 2007 Karl Storz launched its proprietary laser-based measurement Multipoint technology, which allows fast measurement results and a full-scale view without the need to change measurement tips, leading to

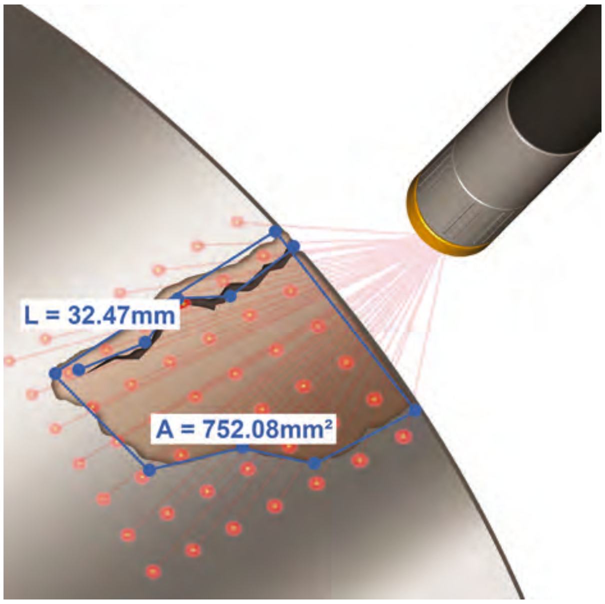
"IT'S LIKE POINT AND GO – ONE IDENTIFIES THE DAMAGE, SETS THE LASERS TO MEASURE, THE MULTIPOINT GRID INDICATES GREEN, ONE TAKES THE IMAGE, MEASURES, SAVES THE IMAGE, AND THEN CONTINUES ON WITH THE INSPECTION"

significant workflow improvement. Multipoint uses a 3D laser system with 49 laser points that allows the camera, in cooperation with the software, to detect the surface structure of the subject surface. The laser-based Multipoint measurement system ensures very precise certified measurement in universal positions and on different surfaces.

BORESCOPE CONSIDERATIONS

3D phase measurement as a surface scan technology principle is well known and applicable in the automotive industry. But what are the variables that determine aviation borescope success and failure, and what needs to be considered when selecting borescope solutions with measurement functionality?

A precondition for an effective inspection process is the high visual performance of a system. So the borescope system needs to provide precise probe articulation, and high-quality image sensor processing paired with fully adjustable light intensity, to guarantee a bright and sharp image for effective and precise defect detection and assessment. The size and scale of the live screen image is a strong factor that impacts on visual fatigue, ergonomics and inspection effectiveness and worthiness. Many systems use an integrated 4-7in display, but this display size is often too small to ensure sufficient visual comfort and also to visually detect small but critical defects. Operators using systems with stereo measurement face the issue that the screen live image is split into two stereo images during the measurement process and they have no full-scale view. This reduces vision and operational comfort significantly and operators have to change the probe tips during the inspection multiple times.



BELOW: The Karl Storz Multipoint laser measurement system uses a 3D laser system with 49 laser points, which allows the camera, in cooperation with the software, to detect the surface structure of the subject surface

"When using stereo measurement, I often have to do the inspection twice," says Terry Lewis, director at Team Europe, an EASA Part-145 and FAA repair station specializing in aircraft engine maintenance. "First I inspect the turbine with the standard tip to detect defects. Then I have to do the inspection again with a mounted stereo measurement tip. Many times I have difficulties relocating the defect and then the split image is too small to conduct the measurement precisely with visual ease," continues Lewis. "Since using the Techno Pack T LED from Karl Storz, we have found the measurement capabilities far superior to any other systems we have used in the past. It's like point and go – one identifies the damage, sets the lasers to measure, the Multipoint grid indicates green, one takes the image, measures, saves the image, and then continues on with the inspection. I believe we have reduced our downtime using the Karl Storz system by 60-70%."

Both Multipoint and 3D phase measurement have the strong benefit that the user has a full-scale view and requires no tip change and instant measurement when a defect is recognized. An additional factor that drives workflow and usability is the capability of the technology to cope with 'parallax error' – essentially, the ability to measure precisely in appendicular tip positions, even when the probe tip is not ideally positioned, or is working in an environment that suffers vibration.

All established systems have a validation system to ensure measurement accuracy. For its Multipoint software, Karl Storz provides a scientifically proven calibration certificate indicating the true accuracy of the system. Nevertheless, many measurement errors or inaccuracies are due to infrequent use of the system by the operator, so when choosing a videoscope provider, it is important to check the aftersales support provided.

Overall, the user needs to be well aware of limitations of the different measurement technologies and understand with adequate training the pre-conditions for conducting an accurate measurement. For instance, Multipoint measurement is excellent for linear measurements; whereas 3D phase measurement is good for topographical depth analysis. But according to key users' experiences, it seems that for selective tasks, 3D phase is more prone to parallax errors when compared with Multipoint, stereo and shadow measurement.

All solution providers strive to minimize the required process steps to more intuitively derive meaningful measurement data in minimal time. "The new Multipoint software has very much improved the experience, leading to a smooth, straightforward workflow, ultimately adding value to our organization with regard to supporting our customer," concludes Team Europe's Lewis.

Currently, no measurement technology solution exists that is suitable for every kind of measurement task and application. However, Karl Storz, together with leading global application experts, continues to develop and refine its technology. Ultimately, in light of the increasing emphasis on on-condition monitoring and the huge responsibility of making the decision to either fix or fly, it is the company's belief that engineers should have the most accurate information possible, in the fastest time possible. ▮

Klaus Hammerl is director of product management and marketing at Karl Storz Industrial Group

CLOSE TO THE ACTION

Small, remote and connected: new approaches to flight test instrumentation

BY DAVID BUCKLEY

Flight test instrumentation (FTI) engineers face a number of challenges when instrumenting aircraft, including an increasing push to reduce weight of equipment and wiring, gather more and more data, and the need to meet demanding time schedules while ensuring no data is lost during flight test.

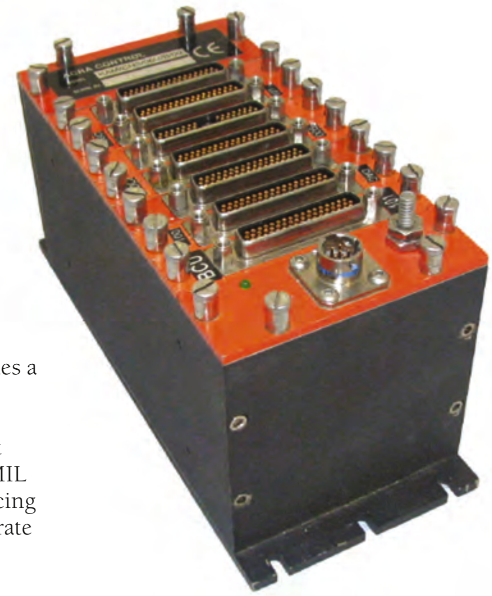
To reduce weight and save on installation time, there is a trend to move data acquisition closer to the sensors. To meet the needs of the FTI engineer, these remote data-acquisition chassis must be reliable, miniature, modular, flexible, and easy to configure and manage.

A modular chassis is a better alternative than using custom-designed, dedicated acquisition units, as it eliminates the need to develop a unique box for the individual aircraft zone, each of which would typically require a different number and different types of measurements.

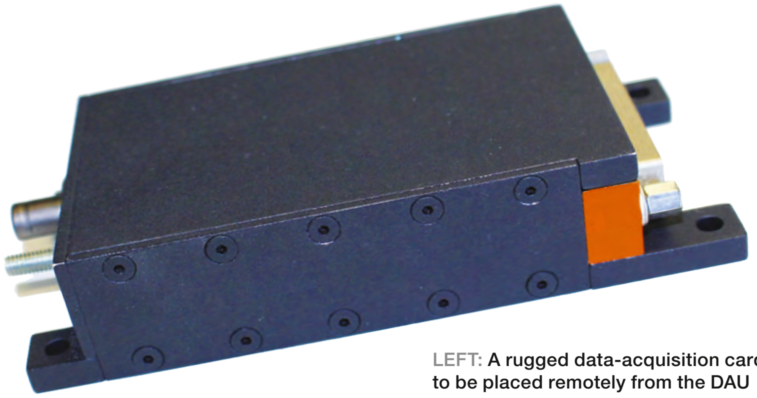
Designing the modular chassis with maximum flexibility enables the flight test instrumentation engineer to tailor the data-acquisition solution to closely match the requirements of the test campaign. A solid chassis can easily be sized to hold the precise number of acquisition cards required for a particular zone. Furthermore, a solid chassis can be adapted to allow the acquisition cards to be placed in any orientation, so that the chassis can be manipulated to fit in any location.

Further flexibility can be gained by allowing the acquisition cards to be housed remotely from the chassis. The most compact modular DAU comprises an acquisition card, a transmitter and a power supply. What we've found is that as the data acquisition chassis gets smaller, the power supply becomes a larger percentage of the volume. That's because any equipment connected to aircraft power must comply with standards such as MIL STD 704 to ensure safety. By placing an acquisition card inside a separate housing and connecting the card directly to the backplane of the chassis, the need for a separate power supply and transmitter is removed. The remote acquisition card will send acquired data back to the chassis via a serial cable from which it would also be powered. The acquisition card can thus fit into a space just marginally larger than its own dimensions. Multiple remote cards can be connected to a single chassis, enabling a network of miniature acquisition units to be placed in most space-constrained locations.

A truly modular chassis means any combination of acquisition cards can be housed together in the chassis. However there is a continuing trend of increasing bandwidth of avionics buses and sensors. A backplane with a high speed dedicated to link to each user slot is ideal for ensuring that the acquisition chassis is capable of handling the increasing bandwidth requirements into the future. This ensures that the existing stock of cards can be used with any new designs for many years to come.



ABOVE: Curtiss-Wright's Acra KAM-500 is a COTS-based data-acquisition unit (DAU) designed for FTI applications



LEFT: A rugged data-acquisition card able to be placed remotely from the DAU chassis in space-constrained locations

Faster system configuration and preflight checks can be performed using a single software suite to set up DAUs, Ethernet switches, recorders and third party systems. This is becoming possible with the adoption of metadata standards. DAUs with onboard processors can facilitate a fast system check through the use of built-in web servers to report status while in-box compilation and in-service firmware upgrading mean faster programing and modifications.

Reliability is another key requirement for a data-acquisition chassis. It has been shown that designing using FPGA-based state machines produces extremely reliable data-acquisition products. Even if the system gets into an unforeseen state due to power dips during flight, it will cycle out of that state within one acquisition cycle and begin operating normally again.

Modern chassis need to operate in heterogeneous networks. To ensure interoperability with third-party equipment, the chassis needs to be a full network node that supports open standards, including the soon-to-be-published INET standards. To connect multiple miniature nodes to the network, it would be a significant advantage if the chassis had the built-in capability to daisy-chain other network nodes without needing a separate module.

One example of a location for a remote DAU is the aircraft's engine casing. Placing the chassis in a high temperature zone can cause electronic components to reach temperatures outside of their specification. This can be a particular problem for miniature chassis, where many electronic components are co-located in a small box. In cases such as this, one option is to add a large heat sink to the chassis to improve the cooling, but this is likely to reduce the number of potential locations in which the system can be installed.

The solution? Locating many of the data-acquisition cards remotely from the chassis makes it possible to significantly reduce the heat generated in the chassis.

The remote data-acquisition chassis is playing an increasingly more important role in flight test configurations. In order to allow the flight test engineer to acquire more measurements in a shorter campaign, the remote DAU needs to be miniature, modular, flexible, reliable and easy to configure and manage. ∎

David Buckley is chief architect at the Acra business unit of Curtiss-Wright Defense Solutions

ABOVE: Miniature DAU chassis designed to enable closer location to an aircraft's sensors for FTI

SHAKE MAKER

An innovative shaker offers some impressive performance statistics for vibration and shock testing

BY MICHAEL GAROFALO

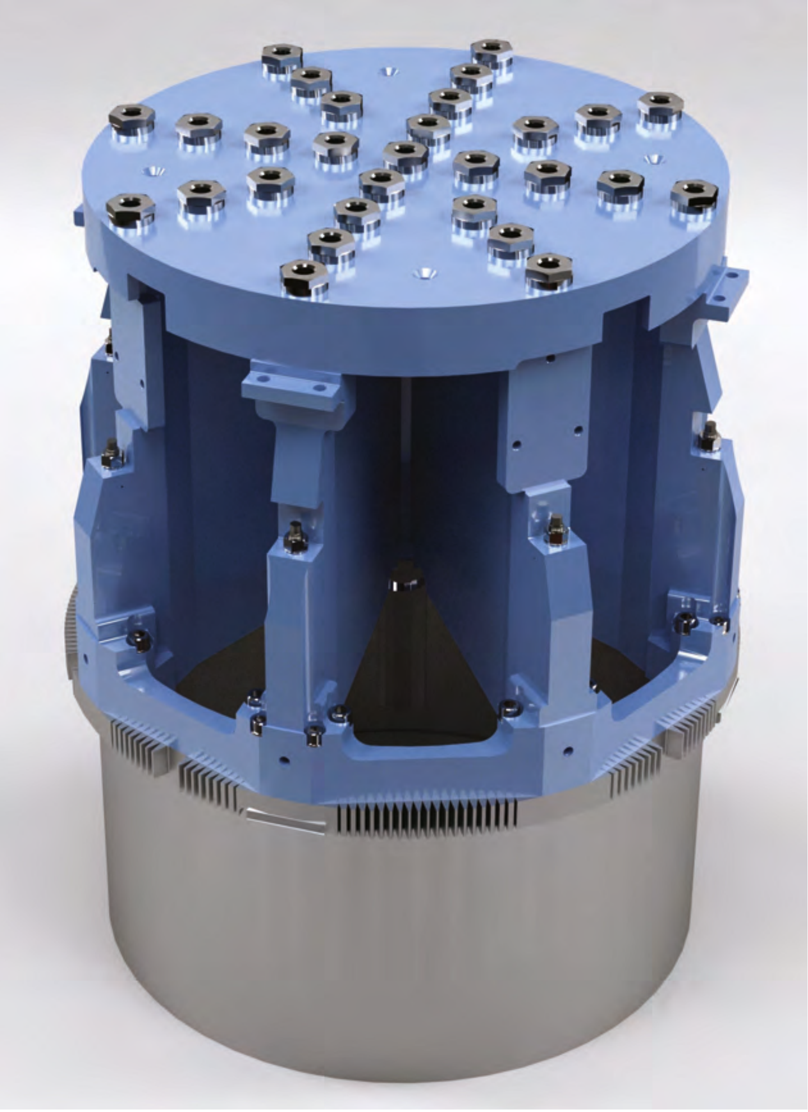
With 3in (76mm) peak to peak stroke, the Model T2000 shaker is an ideal solution for high-level vibration and shock testing. In combination with available power amplifiers rated up to 720kVA output, the 3in stroke T2000 produces high-acceleration and high-velocity output. Specific breakthrough performance examples include 154g RMS random on a 16 lb (7kg) load, 100g peak sine on a 140 lb (64kg) load, 100g peak/11ms half-sine shock pulse on a 900 lb (409kg) load, and up to 295in/s (7.4m/s) intermittent velocity.

Why haven't numbers like these been available before? What improved technical design component has made this huge increase in vibration and shock ratings possible? The answer can be found by looking closely at the T2000 shaker armature – known as the 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: an epoxied multi-turn (water cooled) driver coil; a flexing AC current lead that has to carry 1,000A or more; and 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 coupled direct 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 ability to deliver hundreds of kilovolt amps of power-amplifier output to the moving armature's driver coil, without the need for a flexing current lead, is a key advantage. Taking this current lead out of the picture creates a step change in armature reliability.

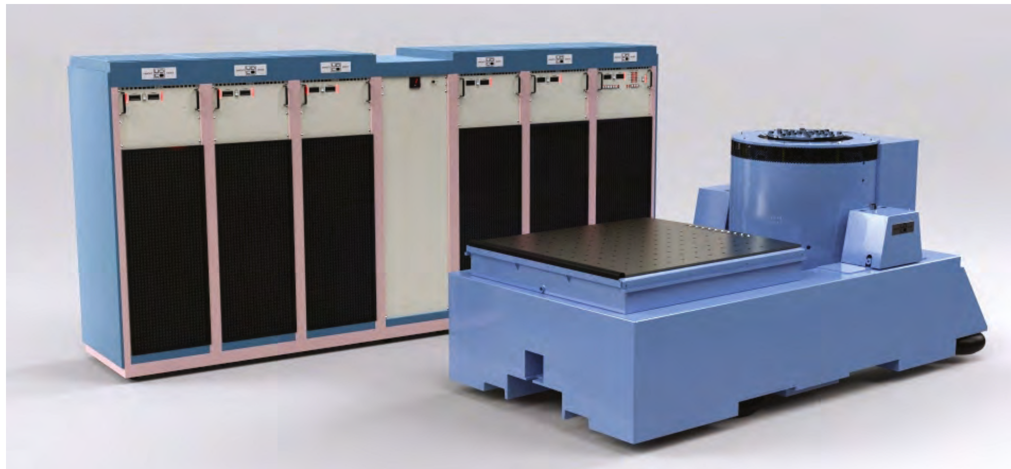


ABOVE: **T2000 shaker's armature is air cooled and constructed of solid metal**

AIR COOLING

Another inherent benefit of the Induct-A-Ring design is the ability to air cool the driver coil, thus 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.

Anyone working in vibration testing will be familiar with one 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 then fail further until the coil may 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 loose driver coil often reveals itself as an elongated helix dangling from the armature frame – the 'slinky effect'. The T2000 Induct-A-Ring armature is immune to this condition by virtue of its solid metal construction with no windings or epoxy joints employed in the force-generating driver coil.



ABOVE: **UD Model 2XSAI360-T2000-3**

Michael Garofalo is applications engineer at Unholtz-Dickie Corporation

WATCH THIS SPACE

Satellites require exceptional materials testing solutions to ensure they are able to withstand the harsh environment of space

BY DR ERNEST WOLFF

Precision dimensional stability and thermal conductivity material testing for the range of conditions experienced by aerospace vehicles, structures and payloads is essential in helping national laboratories and contractors for space programs assess various material properties. These include thermal conductivity, coefficients of thermal expansion (CTE) and of moisture expansion (CME), microyield strength, microcreep, and predisposition to microcracking.

Materials used in early satellites expanded and contracted considerably due to temperature variation as the satellite moved in and out of Earth's shadow. Space material temperatures can cycle through hundreds of degrees Celsius: 160°C to -175°C and back every one to two hours during low-earth orbit; drop as low as -235°C in geosynchronous orbit; and exceed 1,500°C in re-entry.

Contraction due to loss of moisture content occurs in organic materials in space. Testing for CME often takes months in the laboratory since moisture desorption is a slow process, continuing for years during a material's tenure in space. Stresses and strains from the forces applied to space materials during launch and re-entry impact material properties. Some material changes are permanent; others temporary. Some structures in space are kept under stress to maintain their shape, causing their materials to deform permanently over time (creep).

Contraction and expansion of materials may result in functional failures. For example, for antennae in low-Earth orbit, a material CTE of over a few microinches per inch per °C may result in unacceptable misalignment. Significantly lower thermal expansion coefficients are required in space mirrors, to avoid optical distortion. Mismatches in thermal expansion between adjoining materials and connecting adhesives, as temperature varies, may result in microcracking and joint integrity problems. During storage, creep may loosen fasteners, which may then fail when subjected to vibrational forces during launch.

ABOVE: Custom horizontal thermal-cycling chamber (24in diameter by 72in long; 120°C to -235°C at 15°C/minute)

New materials have been developed and continue to be developed with extremely low CTE and other desired properties. Since the 1960s, strong heat- and cold-tolerant fiber-reinforced composite materials have been developed, with near-zero CTE over the operable temperature range. The advent of reusable rockets in the 1970s required materials able to withstand repeated thermal, moisture and stress cycles. Today, development of new materials continues, with demands for self-healing and smart materials.

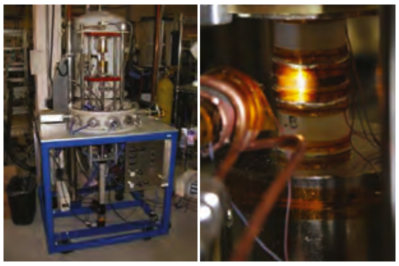
A manufacturer's material specification sheet is not reliable for characterization of a material's properties when deployed in space. Material properties vary due to manufacturing variation, storage conditions, and previous exposure. Testing is typically done on samples of the material to be deployed.

Since thermal cycling can permanently alter a material's properties, for example through microcracking, space materials are often preconditioned with thermal cycling. The thermal-cycled material may be examined for cracks and other structural changes after thermal cycling. Testing preconditioned material more accurately forecasts the space material's properties.

In response, PMIC has designed and built thermal cycling chambers of varying sizes with liquid nitrogen and helium environments for space materials. A 6ft-long, 2ft-wide cylindrical chamber to thermal cycle components of an aerospace structure is shown, left. The chamber housed stands on which 200 components were mounted, including a variety of structural components with hybrid composites containing adhesive joints. Minimizing the thermal mass of the chamber enabled a fast thermal ramp rate of 15°C per minute, allowing 500 thermal cycles from 120°C to -235°C and back to be completed in just a month.

Depending on the shape of the structure deployed in space, testing simple, regular-shaped material samples may not accurately assess the change in geometry of the structure in response to environmental changes. PMIC has tested the creep of materials used in the solar shield boom and optics bus assemblies for the James Webb Space Telescope at elevated temperatures and loads.

ABOVE: Elevated temperature creep fixture (for GFRP laminate at 172 lb load) using a dual path interferometer with a resolution and 40-day stability of 3.0E-8 inches (top view with specimen, top); and end view on optics table (below)



LEFT: ASTM E-1225 thermal conductivity measurement system (front view, left); and specimen installed in system (right)

PMIC has designed an interferometer system using a dual-path (optical) Michelson interferometer to monitor the length change of a 19 x 1 x 0.02in test specimen and a reference arm as an applied load of 172 lb was applied to the specimen. Elevated temperatures shorten the time it takes for the material to elongate, thereby shortening end-of-life testing time. By using an interferometer and mirrors, the elongation could be measured in an area where the load concentrations were uniform. The length changes of the specimens were monitored for 42 days with a precision resolved to 3.0E-8 inches. This approach for measuring creep is a generalization the ASTM E289 method employed at PMIC to measure CTE using laser interferometry.

Thermal conductivity of space materials is relevant to how well insulated manned capsules are, and how quickly heat in a satellite's processing unit can be transported to its exterior and radiated into space.

A national laboratory needed a method for determining the effective thermal conductivity of compressible foams. PMIC modified the ASTM E-1225 thermal conductivity measurement system and created a test plan to measure the heat transfer characteristics of the specimen at both hot and cold temperatures, while monitoring and controlling the thickness and/or compression pressure of the specimen. Thickness was measured using a camera and image-processing software. Loading was monitored and controlled using positioning stages and load cells.

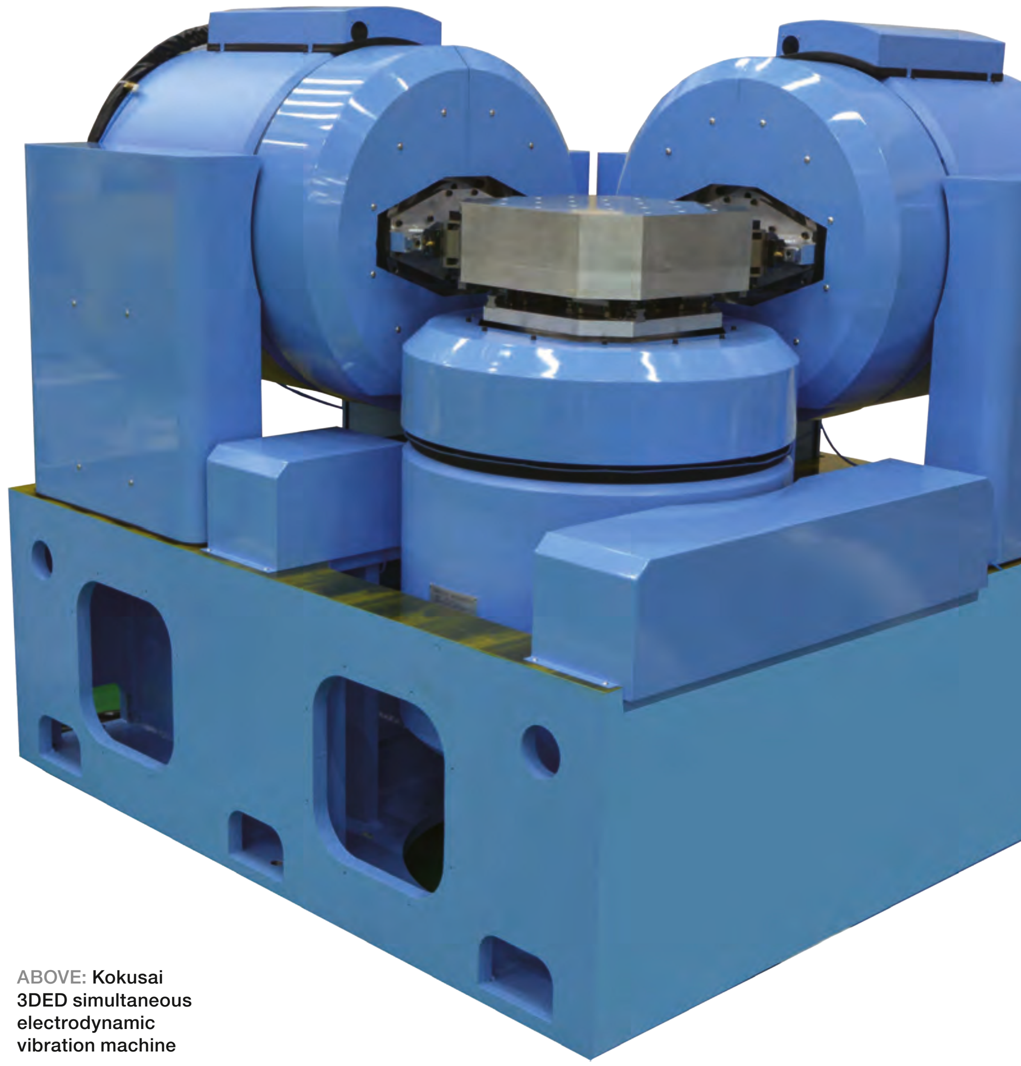
The power of this method is that the specimen thickness could be carefully maintained to compensate for the thermal expansion of the specimen and apparatus. ∎

Dr Ernest Wolff is the founder and CEO of PMIC Lab

SHAKE, RATTLE AND ROLL

A new three-axis electrodynamic shaker meets MIL-STD-810 standards, simplifying and improving vibration testing

BY JOHN K FUNCHEON



ABOVE: Kokusai 3DED simultaneous electrodynamic vibration machine

Vibration can destroy any product unless adequate design and testing have been performed. The requirements for effective product, package and transportation testing continue to grow quickly as consumer expectations in these areas increase. Accurate simulation of product use and the packaging abuse that occurs during shipment and handling is crucial to understanding what the real world is actually doing to your products. A wide range of aerospace components are subject to varying degrees of vibration and shock. Having products arrive to the market only to fail later due to vibration is extremely expensive and unacceptable to the customer.

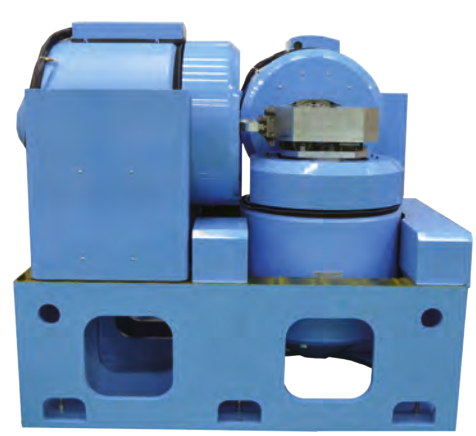
Many years ago, Kokusai, an international supplier of vibration measurement equipment, introduced its Quake line of vibration testing equipment. Quake is a series of independent, simultaneous, multi-axis, electric servo-controlled 'shakers'. Standard models ranged from vibration frequencies between 0.01Hz and 200Hz, and even up to 300Hz in some vibration profiles, such as ASTM D4169 Air Transportation. While their accuracy and reproducibility were of the highest standard, some applications required even higher frequencies – up to 2,000Hz – while demanding a similar high level of performance.

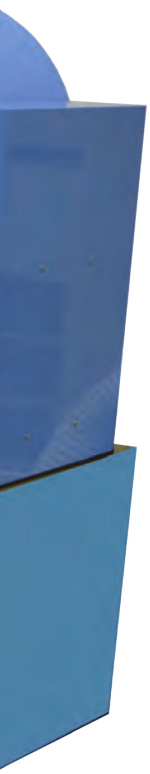
Basic specifications for MIL-STD-810 standards were released in 1962. These standards were provided as the general technical terms and requirements for procuring various parts and equipment to be used by the US military. Subsequently they have been extensively applied to non-government products. In the aerospace industry, some manufacturers have tried to apply them to their technical requirements for multi-axis vibration tests, but found it difficult to realize results because of the limitations of existing test equipment.

In response, Kokusai has introduced a three-axis electrodynamic shaker that meets MIL-STD-810 standards. The Kokusai 3DED simultaneous electrodynamic vibration machine has a range of 5-2,000Hz, and by borrowing some of the patented technology from the Quake and with an additional five years of R&D effort, the 3DED continues to maintain key measurables at higher frequencies.

SUPPORT BEARING SYSTEM

One of the goals throughout the system's development was the introduction of a unique patented multi-axis guide and structural support and alignment system. Compared with hydrostatic support bearing systems, which can be expensive to purchase and to maintain or replace, the 3DED uses a new support bearing system. It consists of





> **“THIS THREE-AXIS INDEPENDENT SIMULTANEOUS SLIDE SYSTEM ALLOWS FOR FULL MOTION WITH MINIMAL CROSSOVER EFFECT. ADDITIONALLY, THE HORIZONTAL AND VERTICAL GUIDE SYSTEM LIMITS UNWANTED AXIS MOVEMENT AND INCREASES ‘PART UNDER TEST’ CAPACITY”**

the slide system used on the Quake series, and a completely new guide system that maintains structural integrity on the axis identified through the entire range of motions. Extensive testing and analysis of the characteristics of causes and influences of inaccuracy and crossover effects were taken in all three axes simultaneously – and in particular in the high frequency range. The slide system is lightweight and highly accurate without having to deal with hydraulic fluids and seals. This three-axis independent simultaneous slide system allows for full motion with minimal crossover effect. Additionally, the horizontal and vertical guide system limits unwanted axis movement and increases ‘part under test’ capacity. With both isolation techniques, the entire system limits any crossover, eliminating the need for an isolation pad.

Figure 1 shows an actual random test demonstrating that the excitation motion of every axis is mechanically constrained by the linear motion guide system. Compared with other systems with different bearing structures that allow for unpredictable and uncontrollable motion, the test result shown demonstrates that the drive input control can be accurately calculated to maintain exceptional control results. Without appropriate linear control, results such as these are difficult, if not impossible, to achieve at higher frequencies. Because every axis is mechanically constrained, the accuracy of random is ±3dB and the accuracy of sine/sine sweep is ±10%. This test was $1G_{rms}$ from 50-2,000Hz.

Figure 2 shows an actual MIL-STD-810G Method 514.6 ANNEX E Category 24 test result, clearly showing the tight control achieved by the 3DED guide and support system.

Kokusai produces a wide range of vibration-related test devices, including balance and uniformity test equipment for the automotive and tire industries, flat belt testers (including dynamometers), horizontal impact, drop, biaxial material tensile, tensile and compression and torsion testers. The company was founded in 1969 and its world headquarters are located in Tokyo, Japan, with manufacturing facilities in Japan, China, Korea and the USA. ∎

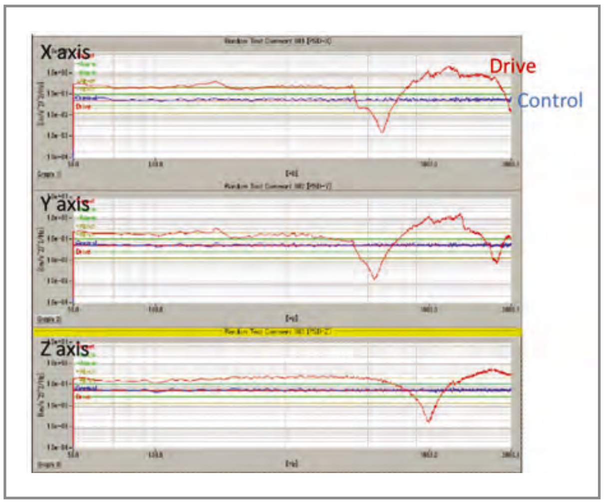
John K Funcheon is vice president and general manager at Kokusai

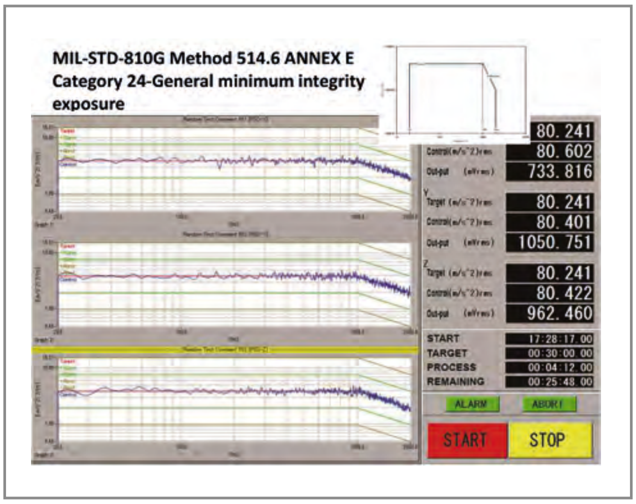
KEY AREAS OF DEVELOPMENT

• New slide structure
A special slide mechanism using extremely tight clearances on the contact surfaces has been developed in conjunction with a major guide manufacturer (patent nos. 2014-0049122-A1 and EU 2713487). This guide system maintains a uniform condition on the sliding surfaces throughout the entire working range, ensuring high rigidity and accuracy even under three-axis motion with a high frequency range.

• Vibration isolation on every axis
To eliminate vibratory influences from any axis, a unique vibration isolating system has been designed such that the force generator applies only to the axis intended, without allowing any force transmission or ‘noise’ to any other axis. Extremely low cross-talk and high accuracy for every independent axis are maintained when compared with traditional isolation designs. This system eliminates the need for a separate isolation pad.

• No-contact/high-rigidity guide system
The addition of retainer devices in the motion guide unit has eliminated contact with the sliding motion under some testing conditions. The 3DED guide system reduces heat and noise. Limiting tipping moment with the test object ensures high linearity of motion and accurate results, while avoiding overheating.





FAR LEFT: Figure 1, demonstrating that the excitation motion of each axis is mechanically constrained by the linear motion guide system

LEFT: Figure 2, MIL-STD-810G Method 514.6 ANNEX E Category 24 test result

SELF-CONTROL

Airbus Helicopters has upgraded its component test cells with a new test automation and control system

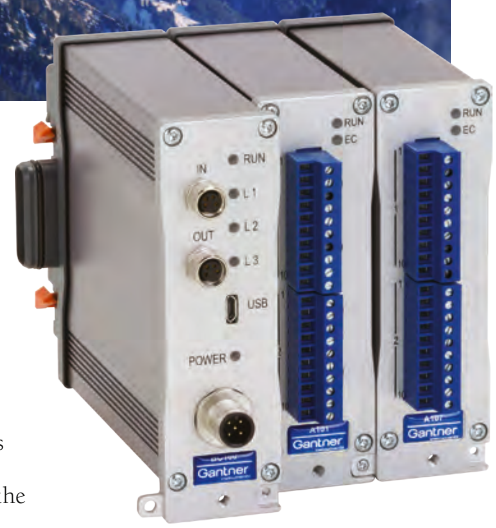
BY ANNETTE C KEHRER

Airbus Helicopters (formerly Eurocopter Group) is a global helicopter manufacturing and support company. It is the largest in the industry in terms of revenues and turbine helicopter deliveries. With the growth and advancement of its product offering, Airbus Helicopters saw the need to upgrade its fatigue test benches in its newly refurbished manufacturing location in Donauwörth, Germany.

The legacy General Measurement and Control System (GeMCoS) to be replaced at Airbus Helicopters is a comprehensive and proprietary concept that is used across all of the company's component test benches. It is a far-reaching and well-considered design – but one that is also highly customized and 'closed', making it difficult to expand and fairly inflexible to future requirements. The design of the new system had to be able to provide the functionality that Airbus Helicopters had become used to, while also using modern and flexible technology that could easily be expanded going forward.

Well-known test automation technology suppliers from around the world presented their ideas and displayed their expertise in the areas of precise measurement and control technologies specifically required for Airbus Helicopters. After a long and intensive evaluation considering all technical and commercial aspects of the project, Gantner Instruments was selected to provide the total solution for Airbus Helicopters. In the words of the Airbus Helicopters' testing specialists, "We chose the best, most modern and most flexible concept for our next-generation test automation and control system."

To provide the total solution that the customer required for this project, Gantner teamed up with long-time software partner Stiegele Datantechnik and long-time automation and control integration partner Optimeas. Together, the three companies founded a new working consortium known as GSO (Gantner Stiegele Optimeas), focused on total data acquisition and control solutions specifically for Airbus Helicopters.



ABOVE: Airbus Helicopters EC145 in service with Swiss operator Rega

RIGHT: The Q.bloxx EC family is mounted in a 19in rack mount

SYSTEM COMPONENTS

The heart of the new system is the Q.bloxx EC family of products, mounted in a 19in rack mount packaging. The Q.bloxx-EC provides the highest in performance and flexibility – meeting and exceeding the most demanding test, measurement and control applications found at Airbus Helicopters.

A critical part of the system is Q.bloxx A106 EC – a universal two-channel measurement module. This module provides for flexible and uncompromising strain gauge bridge measurement, using two galvanically isolated analog input channels for strain gauge half- and full-bridges and linear variable differential transformers (LVDTs). The sensor connection is made via a six-wire circuit, including sense cables to compensate cable influences.

The transducer excitation can be individually configured depending on the application and ambient conditions per channel. For example, DC voltage for dynamic measurements, large cable lengths, and high-impedance transducers can be handled. Or the system can handle 600Hz carrier frequency for slow measurements with excellent stability, low disturbance sensitivity to interference and also large cable lengths and high-impedance transducers; or 4.8kHz carrier frequency for dynamic, interference resistance, and also for inductive transducers.

Other features are: measuring ranges of 1.25mV/V to 1,000mV/V, two analog outputs, one digital input and one digital output per channel, fast signal conditioning such as high-pass and low-pass, linearization, min, max, arithmetic and alarm.

Furthermore, Airbus Helicopters uses the compact, eight-channel measurement module, Q.bloxx A116

"THE NEW SYSTEM HAD TO PROVIDE THE FUNCTIONALITY THAT AIRBUS HELICOPTERS HAD BECOME USED TO, WHILE USING MODERN AND FLEXIBLE TECHNOLOGY THAT COULD EASILY BE EXPANDED GOING FORWARD"

EC. This provides for flexible strain gauge bridge measurement with eight real parallel input channels for the universal connection of strain gauge quarter-, half- and full-bridges with DC voltage supply.

The connection of the bridges is carried out with sense wires to compensate cable influences. But even when connecting single strain gauges in quarter-bridge circuit of the cable, the influence of long cables is compensated by a reference measurement. The transducer excitation can be set to 2V DC or 4V DC.

For bridge completion, resistors of 120Ω or 350Ω with a temperature coefficient of 0.05ppm/K are used (0.0025%/K). Temperature fluctuations have thus only a very small influence. Meanwhile, the input ranges 2,000µm/m and 20,000µm/m cover all applications.

The module has eight parallel A/D converters with 24bit resolution for a sampling rate of 10kHz per channel. The maximum jitter between the measured values is up to 500 channels less than 1µs.

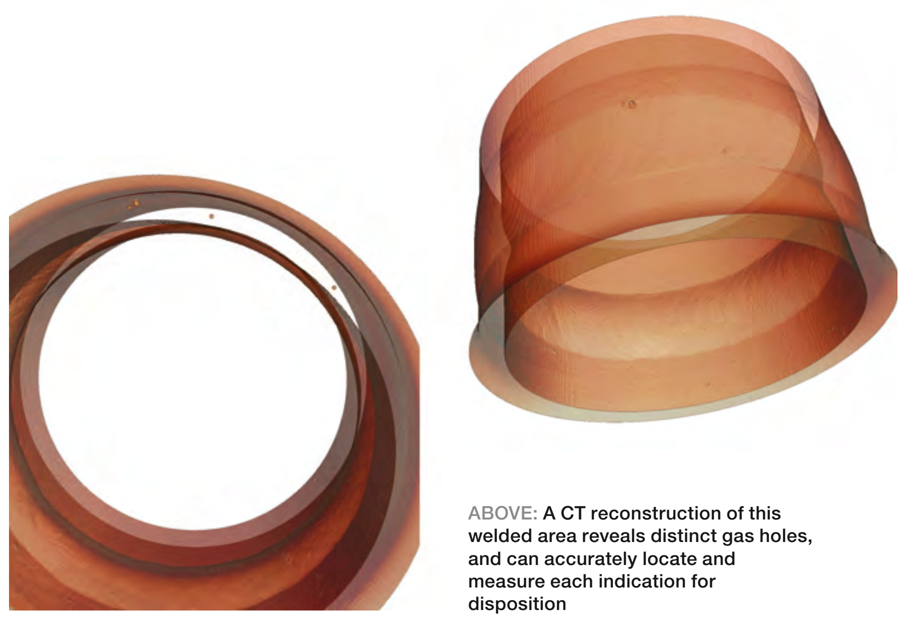
Other features include shunt calibration, digital filter fourth order, min/max storage, arithmetic, alarm, and an accuracy class of 0.05. Finally, the user-friendly software allows customers to configure each channel according to the specific application required. ∎

Annette C Kehrer is marketing director at Gantner Instruments

ANOTHER DIMENSION

Would using 3D imaging change aerospace acceptance criteria?

BY PATRICK R CARLSON



ABOVE: A CT reconstruction of this welded area reveals distinct gas holes, and can accurately locate and measure each indication for disposition

Have you had products rejected with access to only one dimension of data? Could a new understanding of true indication sizing, visualization of edges and spacing distances change how acceptance criteria are devised and interpreted for the future?

When designing and building production hardware, indications of a certain size need to be allowed, but avoiding component failure is a must. Many things built in the past were much heavier but performed for much longer. Consider a casting. In times past, increasing wall thickness could help with producing an acceptable product, but the trade-off was weight. The specific indication size in question would have additional material stock surrounding it with a reduced failure mode. Today the industry has changed gears with a goal of producing parts with less material and reduced weight, while in many situations, using the same, or even more restrictive acceptance criteria. Focusing on radiography and understanding the differences between film, digital 2D and the newer technology of computed tomography (CT), will enable users to quantify size, spacing and the real orientation of indications in your product.

For aerospace, parts were designed and created with certain test methods available. The destructive methods of bending, shearing, cutting samples and pulling test objects apart to test tensile strength all created data used in the design of parts. In non-destructive testing, inspection methods such as liquid penetrant, film radiography, eddy current, magnetic particle and ultrasound, depending on material and part application, were used. The majority of the criteria used with these inspection methods were 2D, and the decision to accept or reject was based on a diameter, a length, or a width.

The robust radiographic film technology has served the industry as a great tool. We were able to adjust contrast and sensitivity to specific applications and different parts. A few of the drawbacks with film were low speed, overall cost, and the ability to only see indications in the 2D perspective. This was especially true if a rotated 90° view was not practical or achievable. With the focus of this article being acceptance criteria, the film-generated, two-dimensional picture of a component gives less than 100% useful quantitative data. If a round indication in a tube wall is being interpreted, is it truly round? What's the true depth of the indication? What's the true spacing of indication to indication, and what is their orientation relative to an edge or feature? If an accurate answer could be given to all of these questions, some acceptance criteria could be relaxed. This could lead to a higher acceptance rate of certain hardware.

DIGITAL RADIOGRAPHY

Advancing into digital radiography and having the ability to remove film as the imaging medium proves positive. With the emerging digital detector array (flat panel detector) as the imaging medium, the drawbacks of film have now been eliminated. In the digital era, we now have significant choices, both in terms of x-ray tubes and detectors. You may choose a system with lower spatial resolution with the minimum magnification required to allow for maximum part coverage. You also have a choice of higher resolution with less part coverage per image, or a system with multiple tubes or detectors for both. When tubing welds were reviewed on film, they were the same size (1:1) if in contact with the film. This made review slow to interpret due to their size and the need for an optical magnifier.

With digital radiography (DR), geometric magnification is used to enlarge the tube weld image, and increase spatial resolution to find small indications. This speeds interpretation, making the correct 'accept or reject' decision easier. Unfortunately, digital radiography still has the same hurdles to overcome as film images when we review the issue of indications in the 2D perspective. With a 2D image we have the same viewpoint, and we're only able to measure the lengths, widths, or diameters. We need a 3D perspective to truly and accurately know all aspects of the indication and its orientation within a product.

COMPUTED TOMOGRAPHY

CT enables you to see the true indication and its location. With film and DR this typically required many assumptions to be made, resulting in 'judgment calls' from personnel. CT is simply a collection of 2D radiographs made while rotating the part, normally 360°. These radiographs are merged with software, resulting in a reconstructed 3D volumetric view of a product. In the 2D digital perspective

RIGHT: Aluminum casting with indications of porosity and shrinkage – locating the true size and volume of the indication enables the supplier to correctly accept or reject the product

"CREATING A POLYGONAL MESH TO EXTRACT THE SURFACE INFORMATION AND THE ABILITY TO DEFINE SURFACE ITEMS SUCH AS GAS POROSITY WITHIN A WELD INCREASES MEASUREMENT ABILITY AND ACCURACY"

we talked about the image in relation to the pixels capturing data. When referring to CT we tend to speak in three-dimensional voxel data. The array of pixels collects data, but the resulting CT volume is a collection of voxels displaying the data. Using CT as a tool enables image visualization in the volume, as well as the ability to view 2D clipping planes to take measurements and view a specific slice plane or multiple planes at one time.

Another dynamic feature of CT is the ability to create a surface rendering of the component. Creating a polygonal mesh to extract the surface information and the ability to define surface items such as gas porosity within a weld increases measurement ability and accuracy. With products like tube welds or castings, where the material is relatively homogeneous, surface extraction can be very simple. In the case of our tubing weld, the porosity indications have a surface created around them, allowing post-processing software to measure these features or create a porosity report based on threshold size settings for minimum and maximum indications. At this stage the interpreter now has the full capability of reviewing the data in 3D. We can measure the indication, review spacing and orientation, and make decisions on part quality with data we have not had before.

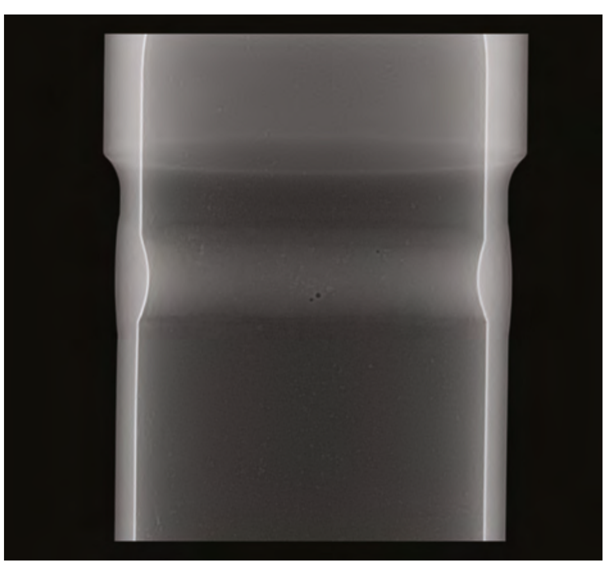
Advances in CT, such as North Star Imaging's SubpiX or super resolution scanning, provide a new tool for increased resolution in many applications. When performing a scan on an aluminum aerospace casting for 3D indication sizing, often an x-ray tube's focal spot will limit the geometric magnification that can be generated due to geometric unsharpness. With this limitation, SubpiX can offer the ability to create a smaller voxel size to ensure multiple voxels of data represent even the smaller indications of concern.

If 200 micron detection is required, a 3D scan at 100 micron puts 8 voxels (2x2x2 pixels) of data across the indication. Probability of detection is on the low end but possible. If super resolution or SubpiX is used, now you can achieve 64 voxels (4x4x4 pixels) of data in your area of interest, increasing the probability of detection. This technology still provides all the 3D viewing capabilities – visualization, measurement and surface rendering – with added confidence and increased probability of detection.

The majority of all design work today is performed in 3D; 3D CAD drawings are made and 3D finite element analysis is performed. However, because of the limitations of 2D inspection methods, engineers have had to employ 2D acceptance criteria in their 3D objects. This acceptance criteria may need to become more restrictive when the inspection method cannot provide an indication's true shape, size and orientation. Without this information, some worst-case assumptions may have to be made regarding the indication. This can drive more conservative acceptance limitations to protect the integrity of the product. The advanced tools in CT now enable design and quality engineers to analyze their hardware with the same 3D approach they used in creating its design. Also, for hardware hinging on a reject condition from a 2D inspection method, a CT scan may provide further detailed information, which could promote the acceptance of the hardware. Will CT have an impact on how acceptance criteria is created and applied for future products? We believe it has a high potential to do just that. ▮

Patrick R Carlson is applications and training specialist in digital radiography at North Star Imaging and is certified NAS 410 and ASNT NDT Level III in radiography

BELOW: In standard film imaging, a 1:1 image size is collected, making interpreting small indications more difficult (image created in 2D to replicate film)



LEFT: Using digital radiography, magnification can be used to enlarge the part size to make defect detection more accurate

AUTO PILOT

Test stand software continues to evolve to better meet the requirements of the component maintenance manual

BY MARK DALLAS

During the 1970s, the aerospace industry started pressing toward automated test stands. During these early years of automation, the test stand industry was forced to develop homegrown operating systems, as there was no viable commercial software available.

Once the software industry started to introduce products for this market, the test industry started to offer these systems as an option to their customer base, which preferred a commercial off-the-shelf (COTS) solution. However using COTS software, which was designed to support much larger process and factory automation industries, made it difficult to accurately validate that the tests were being conducted in strict adherence to the component maintenance manual (CMM) due to the background operating systems.

As such, Testek, a leading supplier of semi-/fully automated test stands, made a decision to proceed in both directions: continue to enhance its developed test executive product, TestEx; and support customers that wanted a COTS platform-based solution.

One of the major advantages that OEM and MRO users started to see with the TestEx solution was the ability to meet the regulatory authorities' (FAA, EASA, etc) requirements for documenting and verifying that any software controlled test meets the CMM requirements.

TestEx is a software engine that uses application datasets to exercise units under test (UUTs) on modern data acquisition and control systems. The product is configurable to portable electronic consoles and large multi-unit mega-stands. TestEx contains no UUT-specific processes, remaining generic to support the widest possible range of components and applications. It hosts the application datasets on the test computer environment, adapting them to the operating system, utility software tools and measurement/control device interfaces.

ABOVE: Main test screen

TestEx has been in service for over 39 years, steadily maturing over time, providing increased functionality and utility as the computer and software industries expanded. Capabilities for on-screen reports, sophisticated alarm/hazard monitoring and graphical plotting/analysis were implemented to provide better visibility and control of the testing process.

TestEx manages the equipment in which it resides by providing resources for calibrating parameters, troubleshooting devices, adjusting user accounts, and logging important events. Additionally it may be used at run-time to provide visibility of internal processes, for example closed-loop/control set-point acquisition and many more. Authorized users have the tools to verify the operation of their systems and can quickly isolate and confirm discrepancies before they become problems.

Testek maintains an extensive inventory of legacy application datasets that support many different kinds of UUTs. These datasets are supplied in three formats: test-lines, macros and spreadsheets. The lowest level, test-lines, describes the most critical operational sequences, for example start-up, shut-down, high-speed tests, etc. These sequences tailor the UUT to the test stand, configuring measurement and control devices to appropriate circuits. Macros encapsulate commonly used command sequences that are easy to run and can be changed when necessary. Lastly, spreadsheets sequence setups of simultaneously controlled parameters and provide the most visible means of manually interacting with the UUT.

BELOW: Semi-/fully automatic drop-down test menu

Running in conjunction with application datasets, TestEx provides authorized users with three modes of testing: manual, semi-automatic and fully automatic.

Manual mode uses gauges to display the current value of test parameters as various conditions are set up using either macros or spreadsheets.

In semi-automatic testing, tests are selected from pre-programmed pull-down menus. The software takes responsibility for starting, stopping and controlling the equipment, and monitoring critical conditions in support of the selected tests (operations not performed in manual mode).

Fully automatic testing runs predefined tests in their configured test order. Evaluation and reporting of test results is done automatically. The only required operator interaction is to answer questions about the UUT (has a hose been connected, etc) or to record leakages or other observations.

Meanwhile, Testek has formed an alliance with National Instruments. TestEx software has been reconfigured in National Instruments' LabVIEW and renamed TestEx-LV. This takes advantage of current technology improvements including deterministic real-time control/monitoring/sampling using detached embedded processors, distributed computing, connection with open-source tools for generating reports, efficient SQL databases and seamless support for more modern hardware devices. ▮

Mark Dallas is a senior proposal engineer at Testek

RIGHT: Automated test report and main operator test screen

TIME CRITICAL

Doreen Clark, product manager at Vision Research, says companies need to be more aware of the workflow issues surrounding the use of high-speed cameras

BY ANTHONY JAMES

ABOVE: Phantom v2512 delivers a speed of over 25,000 frames per second

WHAT EXPERIENCE DOES VISION RESEARCH HAVE WITH REGARD TO THE AEROSPACE TESTING INDUSTRY?

Vision Research has sold digital high-speed cameras into aerospace applications since the company was launched, more than 15 years ago. The applications are very broad, covering everything from stores separation to 'splarge' (bird strike) tests on aircraft windshields. We have cameras studying the impacts of bird strikes on turbines in airflow tests using particle image velocimetry (PIV) techniques.

WHAT MISTAKES DO CUSTOMERS MAKE WHEN CHOOSING HIGH-SPEED CAMERA EQUIPMENT?

Customers can focus solely on the key specs of a camera system: resolution, maximum frame rate, minimum exposure and light sensitivity. And, while these are all critical features and must be considered in camera selection, there are other considerations that should be studied. For example, what is the workflow required to maximize the utilization of the camera and deal with the images acquired during an experiment or test?

Often the cameras are deployed and used in environments that are very expensive to run. A wind tunnel, a jet engine test or a bird strike test, for example. When an experiment is expensive, you need to get the maximum amount of usable footage in the shortest possible time. One way to do this is to have a large amount of memory in the camera, segment that memory for multiple shots, and then take imagery 'back-to-back' as quickly as possible. This imposes a need for large amounts of internal memory in the camera, and ways to get that imagery out of that memory quickly to a secure storage location.

We have introduced cameras that can hold as much as 288Gb of memory – about 4-5 times today's maximum for most high-end cameras. That memory can be segmented into as many as 63 segments (segment sizing depends on the resolution, frame rate and record time needed). Assuming an experiment allows the memory to be segmented into 12 or 16 segments, that means that 12-16 different experiments can be run back-to-back with no downtime associated with offloading data from memory prior to the next test/experiment. This dramatically increases the camera utilization and decreases the time and cost associated with a set of experiments.

Our CineMag IV enables the user to then offload that 288Gb of memory into a 1TB or 2TB non-volatile storage medium in a few minutes. Without this feature, it could take hours to download the data – a time during which the data is at risk if not stored in non-volatile memory. Once saved to a CineMag IV, the data can be retrieved from the camera or from the media mounted on a docking station (our CineStation IV), both of which support 10Gb Ethernet for very fast downloads.

So the amount of memory a camera supports, the ability to segment memory to enable back-to-back experiments, and to quickly save imagery in that memory to a safe, non-volatile medium, as well as to later quickly access and download the results, are all key to maximizing camera utilization, reducing test costs, and recognizing a shorter ROI on the camera purchase.

SO MEMORY IS KEY?

Memory is very important in a digital high-speed camera, especially at ultra-high frame rates. Adequate memory can be key to 'getting the shot', especially on asynchronous and unpredictable events. And memory can be critical to ROI/payback on a camera investment. For example, wind tunnel time is very, very expensive. If a camera can take a dozen shots back-to-back in a short period of time, immediately saving the results into non-volatile memory for later retrieval, the test will be less costly than having to download each shot after it is taken, possibly consuming many extra hours of test time.

ANY MORE CONSIDERATIONS?

The 'big three' are always important: speed, resolution and light sensitivity. There are engineering trade-offs between these. And we have a broad range of cameras that optimize these trade-offs differently for different environments and applications. So it is important to understand the subject(s) to be studied. What is their size? How far away are they? How fast are they moving? What field of view is needed? Will magnification be used? Are you

LEFT: Phantom CineStation IV can be connected to a PC using Gb Ethernet

just viewing the slow-motion movies for qualitative analysis? Or will you also do quantitative analysis? Answers to these questions (and others) will help you decide on the resolution, frame-rate and exposure times required, for example. And those answers will lead you to the appropriate camera. Our technical team is glad to help with these analyses.

HOW ARE THE NEEDS OF THE TESTING INDUSTRY CHANGING?

We see cameras being used more often and in more applications than in the past. As camera performance improves and costs come down, they become a more valuable and accessible tool. A high-speed camera not only provides a qualitative analysis tool with the slow-motion video that enables us to see phenomena that cannot be seen by the naked eye, but also provides pixel-level data that can be quantitatively analyzed by motion analysis software and particle image velocimetry (PIV) and digital image correlation (DIC) systems. ∎

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

BELOW: CineMag inserted in the back of the v2512 camera

FEEL THE HEAT

Signal conditioning for high-temperature gas turbine engine tests

BY DOUGLAS R FIRTH

Designers of measurement systems for gas turbine engine testing have to deal with a complex set of challenging environmental conditions. Hundreds of sensors and lead wires collect data on pressure, strain, vibration and temperature, while interacting with the extremes of these conditions. The test environment is further complicated by hot gases, magnetic fields and noise pick-up. A systems approach that combines world-class signal conditioning with fast, rigorous self-testing separates critical data from the noise and ensures the data is valid.

Precision Filters' 28000 system offers a suite of signal conditioning and amplifier cards to meet these testing challenges. Testing is expensive and time-consuming – signal conditioning systems must provide the highest level of confidence in the validity of their test data, while reducing setup and troubleshooting time.

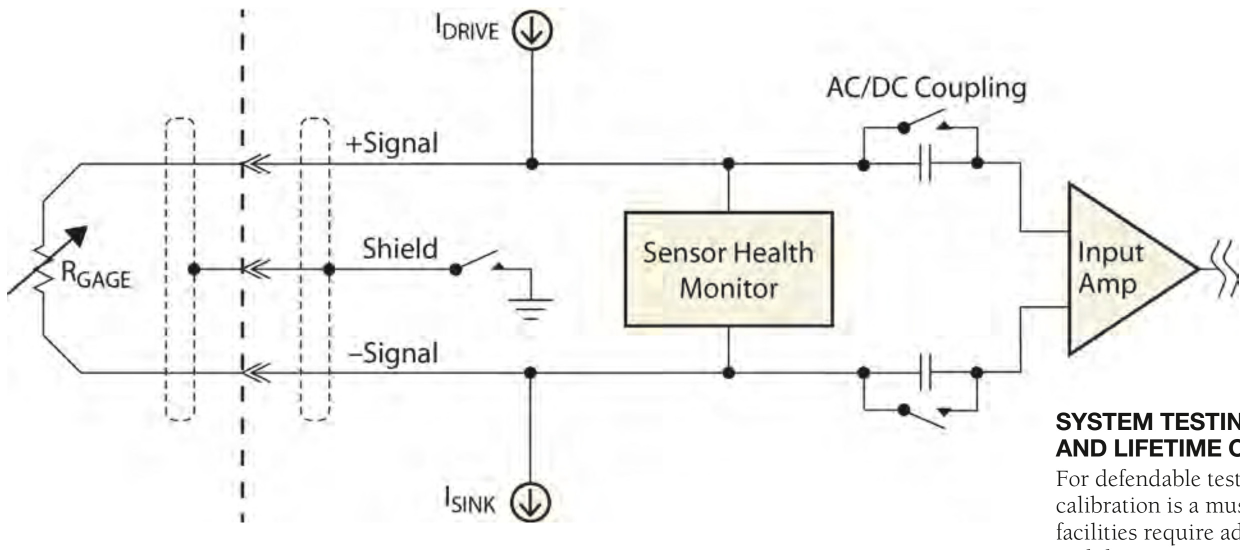
MEASURING STATIC AND DYNAMIC STRAIN

Strain gauges are commonly used in R&D testing on gas turbine engines. These gauges measure strain on both the rotor and the stator, often at extreme temperatures and in noisy environments. The Precision 28144 quad-channel conditioner provides a universal transducer conditioning solution for high-temperature static and dynamic strain gauges.

Strain gauges subjected to very high temperatures while measuring dynamic strain require high-temperature alloys for leads. The temperature change after engine startup results in sensor lead resistance changes of tens or even hundreds of ohms. On the engine's rotating side, leads pass through a slipring, where there is a high potential for noise coupling. In a high-temperature environment, a gauge's substrate can break down, causing leakage. Furthermore, the environment may contain high electrostatic and magnetic fields that couple into the cables.

Precision Filters has developed balanced constant current technology to enable the wide dynamic range measurement of strain in harsh environments using only a two-wire connection to the gauge. The circuit is insensitive to temperature-induced changes in lead resistance. As a result of the circuit being balanced, the differential input amplifier rejects noise pick-up in the leads. Also, the circuit continues to measure strain if a gauge terminal shorts to the test article.

Balanced constant current technology is available on the Precision 28144 and the 28458 high-density dynamic strain conditioner. (For more information on PFI's balanced constant current technology, see *Balanced constant current excitation for dynamic strain measurements*, available for download at www.pfinc.com.)



A basic strain gauge cannot distinguish between strain imposed by the mechanical process and expansion of the test material due to its temperature coefficient of expansion. This reporting of strain due to thermal expansion is often called apparent strain.

At moderate temperatures (below 250°C), temperature-compensated strain gauges can minimize apparent strain. Typically, a three-wire Wheatstone bridge configuration connects the gauge to the bridge completion inside the signal conditioner. This three-wire connection, however, can suffer from variable lead-wire resistance, causing measurement uncertainty due to gauge desensitization and possible DC output from the bridge. In a noisy environment, electrical imbalance and poor electrostatic noise rejection make it impossible to get simultaneous static and dynamic readings from the same gauge.

At temperatures above 250°C, a second gauge is arranged in a half-bridge configuration with the measurement gauge. The compensating gauge should be placed in the same thermal environment as the measurement gauge, while avoiding strain caused by the mechanical process. Because both gauges exhibit the same response to apparent strain, the apparent strain readings cancel in the half-bridge configuration. A three-wire connection may be used to condition the half bridge; however, this configuration is susceptible to gauge factor desensitization and DC errors caused by resistance changes in the extension wires.

With both voltage and balanced constant current excitation, Precision's 28144 has the flexibility to address virtually any high-temperature static or dynamic strain measurement problem.

ABOVE: **Balanced constant current connection for dynamic strain measurement**

LEFT: **Precision Filters 28000 signal conditioning system for rotating machinery**

ACCELEROMETER CONDITIONING

As a gas turbine gets hotter, measuring vibration gets harder. High-temperature accelerometers can perform at temperatures in excess of 750°C. At such temperatures, accelerometers often have extremely low insulation resistance across the piezoelectric sensing element. Using a general-purpose charge amplifier could result in low-frequency gain peaking as high as 20-30dB – causing excessive low-frequency noise, gain errors, or even total saturation of the charge amplifier.

Precision's vibration amplifiers are compatible with the highest-temperature accelerometers on the market and exhibit minimal peaking – even with accelerometer shunt resistance as low as 10kΩ.

VERIFYING CABLE AND SENSOR HEALTH

The best signal conditioner is of little value if the measurement system fails during a test. Discovering a faulty gauge or a defective cable after the test is too late. Lost data can never be recovered, and often it is impossible or too costly to repeat a test. A simple, failsafe protocol for verifying the health of all gauges, lead wires, and cabling is essential to any successful measurement system.

The Precision Filters 28000 signal conditioning system has built-in hardware and software that allow the measurement team to quickly and easily run a series of automated sensor, circuit, and cable run checks. Precision Filters systems feature signal conditioning cards that facilitate real-time monitoring of sensor and cable health, measure and report cable roll-off, and detect insulation leakage.

SYSTEM TESTING, CALIBRATION, AND LIFETIME COSTS

For defendable test data, yearly calibration is a must. Most research facilities require additional validation and documentation of performance specifications. Continual setup and teardown take a toll on sensitive circuitry and demand a rigorous approach to system verification. Yet verification protocols are seldom followed if inconvenience and cost outweigh the perceived benefits. The Precision 28000 self-test subsystem conducts comprehensive yearly calibrations and on-site pre-test go/no-go diagnostics at the push of a button – without removing the system from the equipment rack.

The lifetime cost of a test measurement system is the total cost of ownership. This includes the purchase price of the components; installation; time required for setup, teardown and reconfiguration; acceptance testing; maintenance; and calibration. Operation and maintenance costs, notably staff time, generally exceed acquisition costs, particularly with poor-quality equipment. Often overlooked is the cost of bad data, or no data – a high price to pay for failing to conduct adequate pre-test verifications. The cost of a failed test, even one gas turbine engine trial, can be immense.

The Precision Filters 28000 system significantly reduces lifetime costs and provides automated self-diagnostic and calibration capabilities that can reduce or eliminate component or system failures.

A systems approach to designing a signal conditioning system helps to ensure accurate measurements in the challenging environment of gas turbine engine testing. The Precision Filters 28000 system's innovative signal conditioning techniques, combined with automated go/no-go testing and simple annual calibration, give you confidence in your data – while reducing lifetime and ownership costs. ∎

Douglas R Firth is president of Precision Filters Inc.

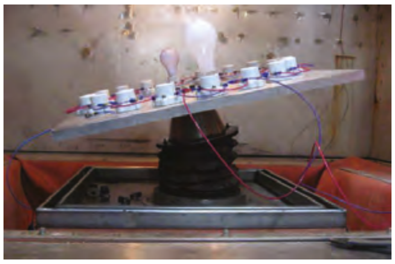
RAPID RESPONSE

Accelerated stress testing provides vital evaluation data to help determine product life and reliability

BY BRAD BURCH

Aerospace manufacturers are increasingly using accelerated stress testing (AST) to contain costs and move projects forward with greater confidence. AST is focused on determining failure modes based on a small group of samples when subjected to different levels (nominal to very high) of multiple, simultaneously applied, stress sources. It looks for areas of potential design improvement to create a more reliable product. This method is also highly useful for comparison testing – for example, comparing materials and designs.

AST simulates the real-life conditions, as well as additional and elevated conditions, that products can experience to provide evaluation data that helps to ensure a product's life, functionality and reliability. Through this type of evaluation, AST can save time and money in various applications without making test setups and executions complex. Two of the most common AST tests are HALT and FMVT.



ABOVE AND RIGHT: Accelerated stress testing of light bulbs

HIGHLY ACCELERATED LIFE TEST (HALT)

A HALT is structured to provide context to failure modes relative to the service conditions and to the operational and destruct limits of a product. In the HALT process, a product is subjected to increasing levels of stress, including temperature and vibration (independently and in combination), rapid thermal transitions, and others specifically related to the operation of a product. It looks at how far beyond service conditions a product can go before it stops working or is destroyed.

Questions HALT can answer include what will fail, what caused the failure, and how the failure ranks against specifications.

FAILURE MODE VERIFICATION TESTING (FMVT)

Structured to provide context to the failure modes relative to the maturity of the design or in comparison with similar designs, FMVT is a patented process designed to reveal design weaknesses first predicted by an FMEA (failure mode and effects analysis) process. By exposing even early samples or prototypes of a design to a combined set of amplified environments and/or stresses, multiple unique failure modes (and their sequence and distribution) can be produced.

FMVT brings together disciplines of design and reliability engineering, as well as computer modeling and failure analysis, and addresses questions such as what will fail, what caused the failure, and how the failure ranks against other failures. Additionally, FMVT can often be done on a single sample if it is a repairable system. So if you are working with an expensive prototype, multiple weak links can be found faster and more cheaply.

HALT and FMVT are key in the discovery and verification of a product's failure modes, the identification of which is the point of AST, and also provide critical context and cause-and-effect analysis about how failure modes affect the product and its systems overall.

HALT procedures include applied stresses, such as six-axis vibration, thermal extremes with rapid transitions, and voltage changes, using equipment such as repetitive shock HALT chambers and more. In HALT, increasing stress surveys are applied one at a time to determine the product's failure limits, and then a combined stress test is performed. The goal of HALT is to determine the operating limits, destruct limits and failure modes of a product to the applied stresses. It is employed early in the development process to iterate a design and is often used for printed circuit boards.

FMVT procedures see the applied stresses of six-axis vibration, high and low temperatures, fast thermal ramping, voltage changes, contaminants, humidity changes,

> **"WITH A TYPICAL TESTING TIME OF THREE TO FIVE DAYS, FMVT EMPLOYS HIGHLY ACCELERATED TEST METHODS TO DETERMINE MULTIPLE FAILURE MODES AND ROOT CAUSES"**

impacts, operating speeds and other stresses that can break the part. The stresses are applied simultaneously, individually and are randomized, as the objective is to expose the product to a high number of increasing stress combinations. The ultimate goal is to determine a product's failure modes as a function of stress levels and time to failure and to rank those failure modes relative to each other to determine opportunities for improvement or the maturity of the design.

With a typical testing time of three to five days, FMVT employs highly accelerated test methods to determine multiple failure modes and root causes. It uses 'time to' and 'number of' failures to measure the opportunity for improvement or maturity of a product relative to the technological limit. This method can typically handle a large number of stress sources more easily, and although it was developed specifically for mechanical and electromechanical products, it can be applied to any product given the correct equipment.

Clearly there is much more to AST than this article can cover, so manufacturers are advised to work with experts in the subject, such as a third-party test lab, to define a test plan that will cover all aspects of the operating range and the information needed to be measured. ∎

Brad Burch is a sales engineer based at Intertek, Grand Rapids, Michigan, USA

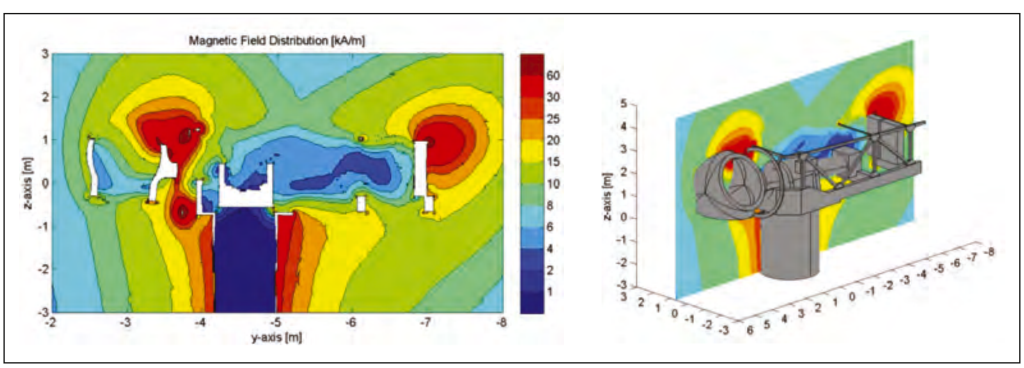
WIND FACTOR

What can the aerospace industry learn from the wind turbine industry when it comes to lightning protection?

BY SØREN FIND MADSEN

Lightning protection of avionics has been a field of interest and research throughout the last century. Especially since the late 1980s, when SAE and EUROCAE committees started working closely together, the airworthiness requirements, standards and certification test methods have been globally accepted.

Since wind turbines entered the market for renewable energy on a larger and more commercial basis back in the 1990s, lightning performance of these power plants has gone through a tremendous development. With the implementation of design principles, tools and methodologies adapted from the aircraft industry, wind turbines and the associated verification testing were greatly improved. The first HV attachment tests were conducted in accordance with the MIL-STD-1757A, whereas later blade tests followed the guidelines in the avionics test standards SAE ARP 5416A and EUROCAE ED-105A. In 2010, all the experience was compiled into the first IEC standard on lightning protection of wind turbines – the IEC 61400-24 Ed1.0.



ABOVE: Full-scale test on a nacelle and hub system where the drivetrain is rotating with nominal speed during the test

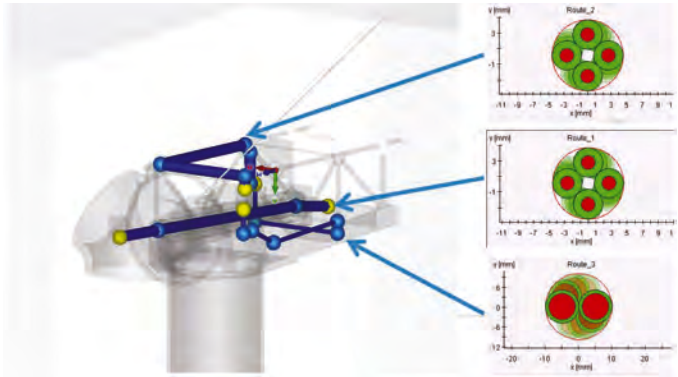
LEFT: Magnetic fields associated with lightning current flowing through the wind turbine nacelle structure

Now a further five years have passed, turbines exceed 200m in height, blade lengths exceed 80m and are made of CFC and GFRP materials, and the environment used for lightning performance evaluation of wind turbines is well defined. Global Lightning Protection Services (GLPS), which is AS/EN 9100 certified, has been heavily involved in the evolution of wind turbine lightning protection, and it is now time for the wind turbine industry to pay back this knowledge to the aircraft industry.

DIRECT EFFECTS

Lightning performance of avionics starts by realizing where the lightning strikes, and the consequence associated with the strike. The likely strike points are defined by applying the Lightning Zoning Concept described in SAE ARP 5414A/EUROCAE ED-91, to identify the exposure of the different parts of the structure. Secondly, the attachment process is explored experimentally by scale-model tests of complete aircraft or by subcomponent testing of wing tips, antennas, nose radomes, etc, in the high-voltage laboratory.

In the wind turbine industry, the attachment process is also dealt with by: numerical modeling of the lightning environment; considering the real 3D geometry of the turbine; the background electric field preceding the strike; and the development of the connecting leader incepted from the turbine. These models can be applied on aircraft as well; the physics involved



ABOVE: **Indirect effects modeling of wind turbine nacelle installations**

is similar and the boundary conditions can easily be adapted. The outcome is a more specific risk exposure assessment of the likely strike points and the associated amplitudes of the strikes.

Once the aircraft has intercepted the strike, the second step is to ensure that the lightning current is conducted safely through the fuselage of the aircraft. Here, modeling of the thin skin behavior, anisotropic material properties (CFC), and current density versus arc root dispersion becomes important. The design of protection measures is an iterative process involving modeling of material and subcomponent characteristics, and repeated high current testing. The specific waveforms used are described in SAE ARP 5412B /EUROCAE ED-84A.

INDIRECT EFFECTS

Indirect effects covers influence on the wiring and control system, originally imposed by the direct effects lightning current flowing through the fuselage. These effects are very important, since the control logic and communication between individual subsystems may be subject to errors and damages for even limited magnitude of current and voltage surges. The magnitude of the stroke current is expressed in kiloamperes, has a median value of approx. 30kA and is driven by a voltage in the mega volt range. The induced currents and voltages causing damages to electronics may be only tens of volts or tens of amperes.

Aircraft manufacturers and lightning consultants have developed many tools for assessing the indirect effects in an early phase of the design. Most of such tools involve constraints and limitations concerning materials and geometries, so lately GLPS has explored the use of commercially developed numerical tools for indirect effects modeling. Software packages for time domain simulations dedicated for indirect effects are now available, and by carefully implementing the 3D geometry of the structure involved, the wiring schematics, the cross-section and surge impedances of cable bundles, and the impedances of loads and sensors, etc, a thorough description of the lightning indirect effects environment is available. GLPS uses such software in the early design phase of wind turbine nacelles, where indirect effects can be assessed and mitigated before prototyping and more complex full-scale test evaluation.

FINAL VERIFICATION

The final verification of wind turbines, as well as aerospace structures, will be lightning testing following relevant standards and guidelines. A successfully completed and well-documented test sequence is the key to obtaining the certification to lightning standards, and more importantly to ensuring safe operation throughout the lifetime of the equipment. Tests to represent the realistic lightning environment are also performed in a large variety of combinations involving combined high-voltage and high-current testing, current distribution assessments in larger structures, material properties and non-linear components, etc.

Tests are typically conducted on a material and subcomponent level to get in-depth understanding and knowledge of subassembly properties and behavior, whereas tests on system levels bring insight into the context of larger interactions. The final verification is a full-scale test of complete blades of 60m+ and entire nacelles in operation, which finally documents compliance with the lightning environment. By injecting full-scale current into entire structures, it is ensured that non-linear components as surge protection devices behave as realistically as they would in real field applications. The typical full vehicle tests on aircraft where low current levels are injected into the entire structure require a detailed knowledge of and insight into the design to evaluate the impact and scale the magnitude of the exposure to the subsystem tests (pin injection, cable bundle, etc).

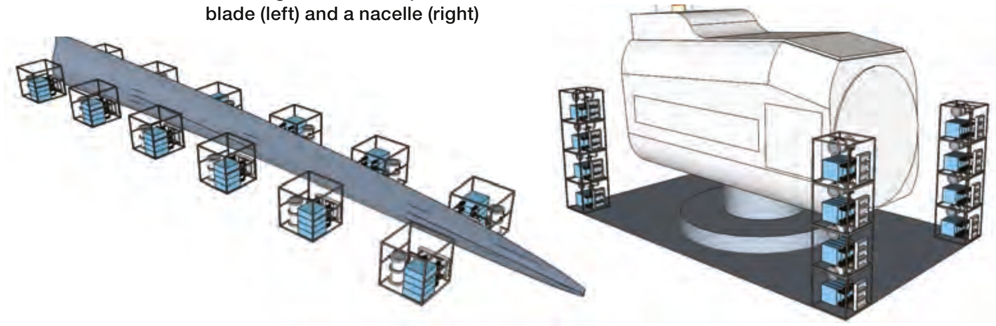
FUTURE TESTING CAPABILITY

In the wind turbine industry, the latest trend is requesting more full vehicle tests. The benefits of considering the multifactor impact and all non-linear components without the need for discussing scaling with the certifier are substantial. The structure is tested with the full lightning current in a realistic configuration, all systems are in operation, and the performance is easily documented.

In a cooperation between GLPS and the Technical University of Denmark, an even larger impulse current generator is currently being designed. The generator being commissioned late 2017 can be configured in various ways, and will be capable of injecting IEC level stroke currents into complete structures as 100m blades and 10MW nacelles. The output voltage, output capacitance and current waveform parameters can be adjusted carefully to accommodate different test items. ∎

Søren Find Madsen is chief technology officer at Global Lightning Protection Services

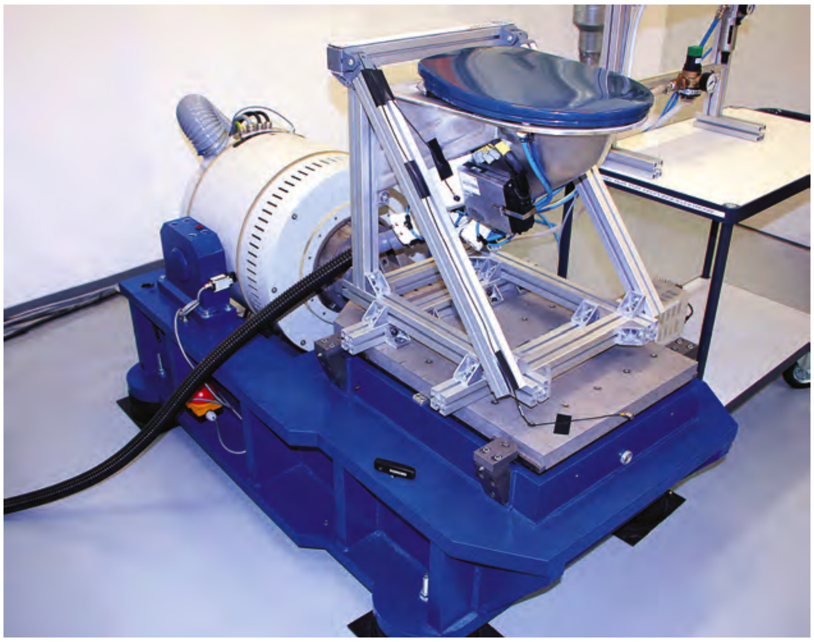
Test setup involving the modular impulse current generator set up for a wind turbine blade (left) and a nacelle (right)



MONUMENTAL CHANGE

Treo's environmental simulation laboratory and the Institute of Product Development of the Hamburg University of Technology are working together on new 'windmilling' tests for entire aircraft monuments

BY HANNO FRÖMMING, DIETER KRAUSE AND OLAF RASMUSSEN



LEFT: Lavatory on electrodynamic exciter

For all jet aircraft components, the sustained engine imbalance (SEI) load case is an important design criterion. Also known as 'windmilling', SEI describes a situation in which one or more turbine fan blades are lost during flight because of fatigue or sudden damage, for example from a bird strike. Of course the engine is shut down immediately, but continues to revolve due to the airflow. The resulting imbalance induces severe vibrations into the aircraft body. Ongoing development on aircraft engines is resulting in bigger fan diameters (such as in the Airbus A320neo), which causes higher vibrational loads. Therefore, the SEI load case with its stationary low-frequency vibrations is becoming increasingly critical.

Every part of the aircraft has to endure these vibrations for a defined period to enable the aircraft to safely land on the nearest available runway. For intercontinental flights, this can be more than three hours. Not only must the primary structure of the aircraft stay intact, but all interior parts have to be able to withstand these vibrations as well, staying either fully functional (critical parts) or at least in a state that will not harm any passenger or the aircraft structure. Depending on the aircraft type and the position of the engine, the vibrational loads can easily go beyond 1g. Therefore the SEI load case is an important part of the qualification process for new aircraft interior components.

BELOW: Galley G2 on hexapod test rig

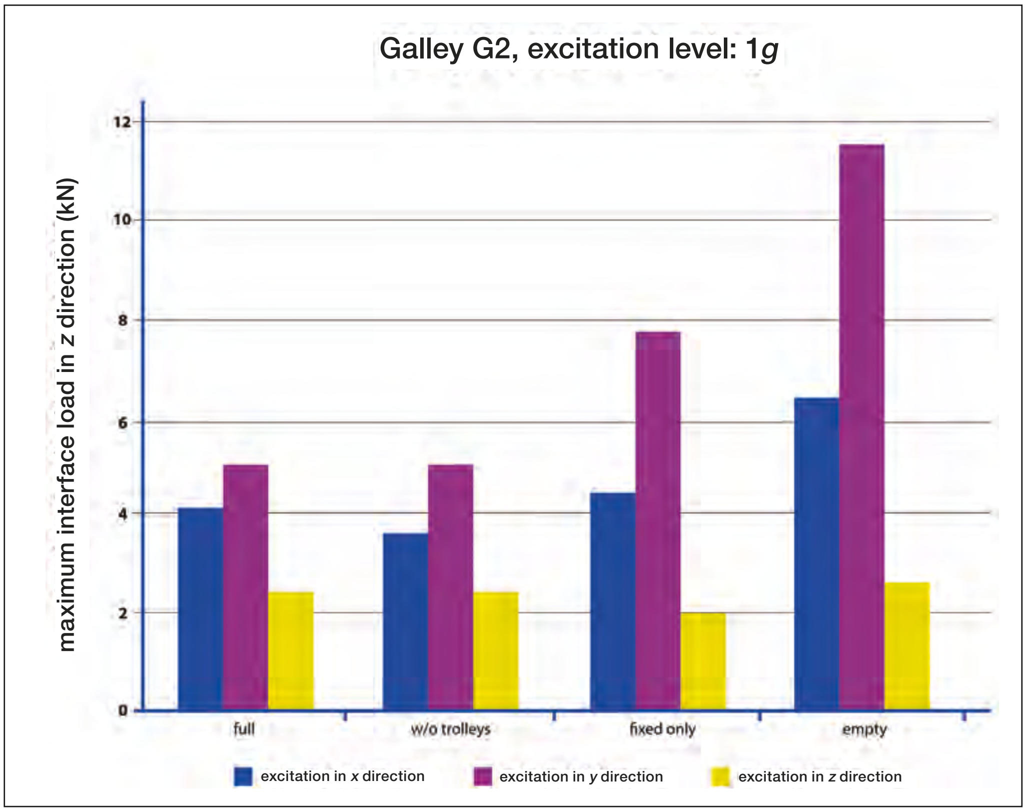
However, these tests were often relegated to static tests in the past. To compensate for the huge uncertainties in the transformation from real multi-axial dynamic loads to single-axis testing loads, and further still to only static loads, for the qualification tests, huge safety factors are necessary that prevent the full potential of lightweight design. Therefore, the trend in certification of aircraft interior components is toward (single-axis) dynamic testing as a remedy to the use of excessive safety factors necessary when using static tests.

Treo is an accredited service provider for product and component testing in the areas of environmental simulation and EMC. The company has many years of experience in single-axis vibration tests of aircraft components using electrodynamic exciters, and operates special test equipment to fulfill even higher test requirements such as large vibration amplitudes. The Institute of Product Development (PKT) of the Hamburg University of Technology (TUHH) has been doing research in the area of aircraft interior components using both numerical simulations and real tests for more than five years, including several projects with the aircraft industry.

ACADEMIC COOPERATION

Treo's environmental simulation laboratory and PKT have joined forces to implement ISO 17025-compliant windmilling tests of entire aircraft monuments.

For testing large aircraft interior components such as galleys and lavatories, they use the TUHH hexapod test rig, which was funded by the German Research Foundation (DFG). This unique machine (see Figure 2) enables excitation in all six degrees of freedom. Each axis can be controlled separately or in combination to create realistic loads for a huge number of test scenarios. The six hydraulic cylinders create forces of up to 500kN and move the platform at 1.3m/s or vibrate it at up to 30Hz. With its diameter of 2.3m (plus extensions, if required), the platform can hold an entire aircraft



RIGHT: Interface loads in the *z* direction at different loading and excitation conditions

BELOW: Finite element model of galley G2 with interfaces (blue circles)

galley and subject it – and its loading – to SEI testing in all directions without the need for modifications for each direction.

In addition to this work in testing, PKT is involved in the field of virtual testing to reduce the number of full-scale real-world tests, using a combination of numerical simulations and pre-tests on a smaller scale. Using suitable numerical models such as the one shown below, sensor positions and critical load cases can be determined prior to the real tests, thereby reducing the time on the test rig.

Despite the trend to shift effort from real-world testing toward numerical simulation, some parameters, for example damping, still have to be determined on the test rig. Complex structures show non-linear dynamic behavior caused by such effects as slip zones, which cannot be fully described even by very detailed numerical models.

EMPTY MONUMENTS: CRITICAL LOAD CASE

Test campaigns in the past have shown, for example, that the damping ratio of aircraft interior components depends strongly on the loading conditions. Contrary to prior assumptions, the tests on galley G2 produced the results shown above. The galley was mounted on the hexapod test rig using a special fixture. The loads at all interfaces (see image, below left), as well as several accelerations, were recorded during the tests, which consisted of sine sweeps from 3-25Hz to determine the dynamic behavior of the specimen. On the lower attachments, three-dimensional load cells were used to measure the *x*, *y* and *z* directions at the same time. The upper attachments (tie rods) can only transmit loads in the *x* direction, so one-dimensional load cells were used there. Accelerations were also recorded in all three directions. The resulting interface loads in the *z* direction at an excitation level of 1g are shown in the graph above.

Clearly, excitation in the *y* direction produces by far the strongest reaction forces in the interfaces. Therefore the effect of loading-dependent interface loads is quite visible here. Where the interface load from the fully loaded galley peaks at approximately 5kN, it rises to about 11.5kN when the galley is completely empty. One could say that this situation would not happen in reality because fixed galley inserts such as beverage makers or ovens are not removed during flight. But even then, the galley with those fixed items reaches almost 8kN, which is an increase of about 60% compared with the fully loaded galley.

The empty galley results in the biggest interface loads due to the low damping, whereas the fully loaded galley is definitely not the worst load case, which it was deemed to be before the tests because of the much higher gross weight (up to 800kg loaded versus 150kg empty). The huge amount of energy dissipation in the gaps and joints damp the resonance behavior enough for the effect of the mass increase to be more than compensated.

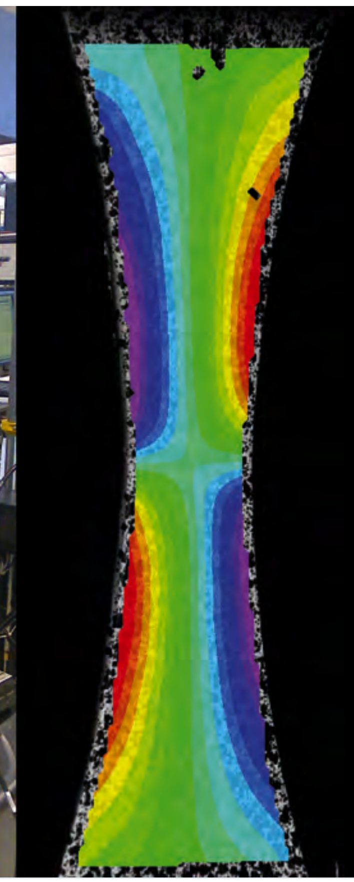
The latest results and experience from testing show the importance of physical tests. These tests should already be implemented in the early stage of product development to save costs of late modifications or failures in qualification tests. The cooperation of Treo and PKT provides full assistance and service during all stages of product development, from specification to qualification. ∎

Hanno Frömming is managing director of Treo – Labor für Umweltsimulation GmbH, Hamburg, Germany; Prof. Dieter Krause is head of Institute PKT at Hamburg University of Technology, Hamburg, Germany; and Olaf Rasmussen is research assistant at PKT at Hamburg University of Technology, Hamburg, Germany

TEAM PLAYER

Fabrice Bernard, test engineer at Testia France, explains his company's recent collaboration with Airbus ESV to provide a full package of mechanical testing, NDT and test monitoring services

BY ANTHONY JAMES



TELL US ABOUT TESTIA'S RECENT COLLABORATION WITH AIRBUS – AND HOW DO CUSTOMERS BENEFIT?

With its knowledge, background and capabilities in the field of mechanical testing, Airbus took the decision earlier this year to begin offering its full range of expertise to external customers, in addition to its internal clients.

These capabilities include static, dynamic, fatigue, fracture, stress, bending and tensile tests. Test equipment and facilities include uniaxial and multi-axial test machines up to 6,300kN, which can accept specimens up to 5.6m in length.

Since it was founded in 1994, Testia France has provided Airbus with a non-destructive testing (NDT) inspection service during mechanical test (before, during, and after), including ultrasonic (UT), eddy current (ET) and thermography (IRT) tests, as well as high-speed camera and digital image correlation services since 2007.

It seemed only natural then for Airbus and Testia France to combine their expertise and provide a full package of testing services to customers. Under the arrangement, Testia France is responsible for marketing this new service, as well as for customer relations and for the technical performance of each entity's respective area.

Customers are drawn not only from the aerospace sector, but also the automotive, shipbuilding, energy and railway industries, as well as any other sector interested in outsourcing its mechanical tests.

WHAT INVESTMENTS HAS TESTIA MADE TO ENSURE IT REMAINS AT THE CUTTING EDGE OF NDT AND OTHER ASPECTS OF MECHANICAL TESTING?

We're investing heavily in NDT hardware and software: approximately €500,000 a year, with several millions of euros invested in NDT equipment over the past 20 years.

For example, we've been investing in the latest radiography testing equipment, acquiring two new facilities to boost our capacity of x-ray inspections – a $15m^3$ x-ray chamber with a 255kV source, and an x-cube, which can be upgraded for tomography.

For UT, a 1.6 x 2.3m immersion tank has been put into service at the engineering laboratory for prototyping special UT measurements and the two immersion tanks of our training department have been retrofitted with new motors, controllers and software developed in-house. Also for UT transmission measurements, the product department has designed and integrated a C-frame into an eight-axis robot at our Nantes site.

Meanwhile, for mechanical testing, we have invested in high-speed cameras and two systems for digital image correlation. We can also provide structural health monitoring measurement with our fiber Bragg grating equipment for temperature and strain monitoring, where conventional electrical strain gauges cannot be used.

BEYOND YOUR COLLABORATION WITH AIRBUS, WHAT OTHER RECENT PROJECTS HAS TESTIA BEEN INVOLVED WITH?

Testia France has recently delivered a turnkey solution to the Duqueine Group that controls the 80 references of the A350's composite fuselage frames. This facility requires only a non-certified operator to put the frame inside the machine and then remove it after the control process. The frame, which is Z-shaped and measures up to 7m, is scanned by eight phased-array probes. The resulting cartography is then automatically analyzed to detect any flaws and a report is produced with a pre-check (pass, fail). A level 2 operator needs only to check and

LEFT: Testia France continues to invest heavily in the latest NDT hardware and software

approve the report. The thickness is also measured at different points of the frame during the process, with an automatic report once again produced. The full process takes less than 10 minutes for the longest frame. Testia France has also helped Duqueine to qualify the system against Airbus Industries Test Methods requirements.

Other important projects include the next version of our UT and ET testing instrument – the Smart NDT Tool – and its customization to specific customer requirements. For example, we have recently delivered a dedicated application to control by ET the blade of the Puma A330 for Airbus Helicopters.

We have also recently delivered an IRT machine that includes an infrared camera and dedicated image analysis software to control composite parts for A400M aircraft.

WHICH NDT TESTING METHODS OFFER THE GREATEST POTENTIAL FOR AEROSPACE APPLICATIONS NOW, AND IN THE FUTURE?

All are complementary. Nevertheless, with the increase of carbon fiber-reinforced polymer parts on primary structures, the use of UT and IRT methods should increase even more. We think that for complex parts (especially engine parts), computed tomography will be essential in the future. For less complicated parts (structure) and for maintenance, the industry will gain in productivity with fully automated inspection or assistance systems that are not required to have a certified operator and give 'pass/fail' or go/no go automatic sanctions. ∎

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

SEEN TO BE SAFE

How a new automatic x-ray inspection system will help maintain the next generation of engine turbine blades

BY GINA NAUJOKAT

It all began with the development of titanium aluminide (TiAl). In the future, this new material is expected to replace a portion of the conventional, highly stressed, low-pressure jet engine turbine blades made of nickel-based superalloys. Material experts at MTU Aero Engines, and its partners, have created a breakthrough for the aviation industry using this new lightweight construction material. Titanium aluminide has a high melting point and a sufficiently high stability, while simultaneously offering a substantially lower density than Inconel. And that is precisely the point – weight reduction is gaining ever-greater importance, especially in aviation. Reduced weight means less fuel consumption, and consequently lower CO_2 emissions.

Until now, the greatest difficulty in employing titanium aluminide was machinability. The material combines the properties of ceramics and metal, and cannot be cast in its final contour – it must be forged and milled. MTU research partners at Montanuniversität Leoben, a university for science and engineering in Austria, ultimately found out through thermodynamic calculations which temperature range and phase configuration type would make it possible to reshape this material via forging, being mindful of its brittleness.

The first use of titanium aluminide occurred as early as September 2014 for new blades in the high-speed, low-pressure turbine made by MTU for the geared turbofan engine in the A320neo. The propulsion system received certification in December 2014. Titanium aluminide is going into series production at MTU, and MTU has brought in partners for this large-scale project.

ABOVE: Daniel Genke, an NDT technician at Atlas Air Service, prepares for series inspection of the TiAl turbine blades using the fully automatic Y.MU56 TB x-ray system

PROJECT PARTNERSHIP

Präwest Präzisionswerkstätten Dr Jung is a German firm specializing in high-tech machining, and considered a pioneer in the field of machine milling. In 2009, Präwest had already concluded a strategic partnership with MTU and currently carries out the machining work on the TiAl turbine blades. Atlas Air Service, an aircraft maintenance specialist, is meeting the major challenge of implementing quality inspections for the blades with x-ray. Atlas Air Service brought in Yxlon International, the renowned provider of industrial x-ray inspection systems, to accomplish this. Nicolas von Mende, member of the management board at Atlas Air Service, states, "It rapidly became apparent to us that Yxlon is the perfect partner to have at our side for this project. Yxlon has decades of experience with robotic systems and profound know-how in the areas of digital radiography and automated defect recognition. What's more, major players in the aviation sector, such as Boeing or Airbus, have long been among the clientele of Yxlon. MTU also has several Yxlon systems working in successful operation."

Having joined forces, efforts turned to developing an inspection system specific to the client that would be able to fulfill the precise specifications at MTU with certainty. In light of a planned unit volume of several tens of thousands of turbine blades per year, manual inspection by an operator is not economical. The only way to make the exact positioning of the inspection item within the x-ray beam enactable and repeatable is with the assistance of an extremely precise robot. As a result of automated defect recognition (ADR), the inspection findings remain consistently accurate and objective.

The Yxlon MU56 TB X-ray system has been adapted precisely to meet the requirements at Atlas Air Service, including a Variofocus x-ray tube, a flat-panel detector and the fully automatic imaging and control software PXV5000, making it ideal for series inspection, specifically for components that are made of lightweight metals.

"The biggest challenge with this new application was detecting tiny flaws up to 0.15mm," explains Hans Decker, software development engineer at Yxlon. "In this case, the Yxlon Variofocus x-ray tube was the only option." With its variable focal spot ranging from 250µm at 290W to 800µm at 1,600W, the tube forms a bridge between microfocus and conventional x-ray tubes. When using the small focal spot at 250µm for inspecting TiAl turbine blades, enough power still exists to clearly depict these kinds of minimal defects with a sufficient resolution.

The homogeneous microstructure and low density of the TiAl alloy had an optimal influence with respect to this application because the alloy is easily radiolucent and, due to its homogeneity, tends less toward segregations than is the case with conventional nickel alloys. Nonetheless, for fully automated defect recognition it is necessary that defects in the image are highlighted distinctly and precisely. "On the basis of PXV5000, we have programmed a proven imaging and control software using a mathematical method that displays only the defects while suppressing the surrounding structures in the original image," continues Decker. Thus the unambiguous evaluation of parts by the system was ensured.

The TiAl blades are x-rayed in multiple inspection positions during each inspection run. Equipped with a gripper manufactured to precisely match the blades' geometry, the robot grips the blades one by one from a specially designed pallet, manipulates them in programmed sequence to the different positions, returns them to their initial starting point, and then repeats the process with the next blade. If a blade is defective, it is directly sorted out by the robot and brought to a separate storage point.

ABOVE: **The robot manipulates the turbine blades to the different inspection positions between the x-ray tube and detector**

All inspection items are clearly identified on the basis of serial numbers using an integrated scanner. The results are saved in the DICONDE format, constantly retrievable, including the inspection parameters, and equally deployable in other systems when needed.

The MU56 TB system conforms to ASTM in accordance with state-of-the-art technology. Among other factors, this means the system carries out automatic system tests in compliance with ASTM E2737, which verifies its constant quality of inspection.

The MU56 TB was installed at the Atlas Air Service facility in Ganderkesee, Germany, in February 2015, and was saluted with a festive welcome. Atlas Air Service takes pride in being the pioneer of this inspection service by offering this x-ray system. Plans for the future involve retooling the x-ray system to include other, similarly sized inspection items, and expanding the range of services offered. The Yxlon system is already geared up for automatic feeding and discharging of inspection items, which will further facilitate series inspections and increase inspection time. For Atlas Air Service, this new mainstay signifies a key diversification in the market and, as a result, a safeguarding of the current roughly 250 jobs at its five locations in Germany. ∎

"THE FIRST USE OF TITANIUM ALUMINIDE OCCURRED AS EARLY AS SEPTEMBER 2014 FOR NEW BLADES IN THE HIGH-SPEED, LOW-PRESSURE TURBINE MADE BY MTU FOR THE GEARED TURBOFAN ENGINE IN THE A320NEO"

Gina Naujokat is marketing communications manager at Yxlon

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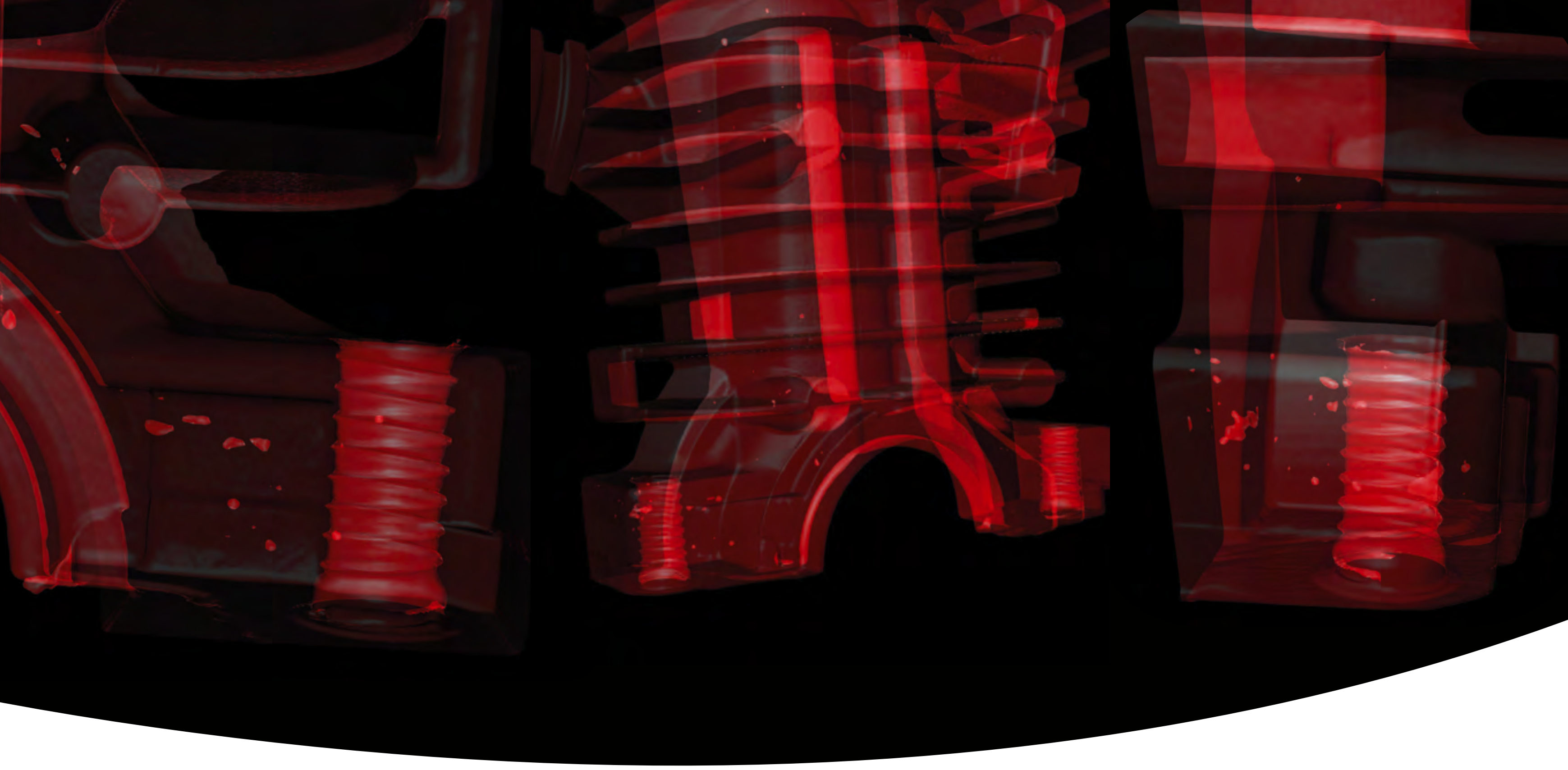

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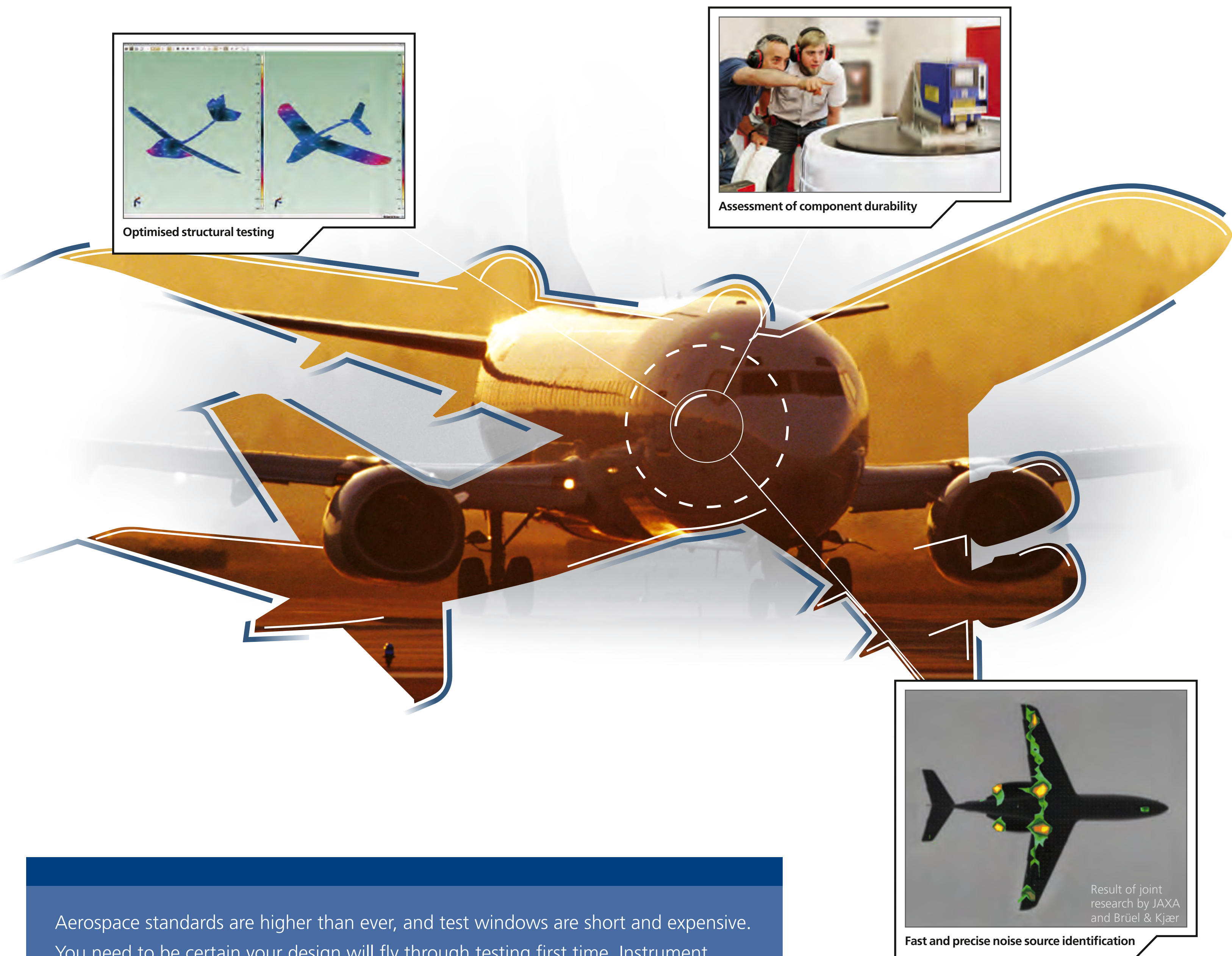

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