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AEROSPACE TESTING INTERNATIONAL

SHOWCASE 2013

2013 SHOWCASE

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The strength behind new material

A report was released at the end of September 2012 by the aviation market analyst from London-based business information provider Visiongain. It says that since composites were first used within military aircraft about 40 years ago, there has been a gradual expansion in their usage, and then a sudden acceleration into new market segments (commercial aircraft, helicopters, space, etc) and alternative structures (airframes, fuselage, rotor blades). The analyst predicts that the value of the global aerospace composites market in 2012 will reach the enormous sum of US$10.3 billion. This market is set to become greater and greater.

This is why testing the material is now at the forefront of so many manufacturing companies. You might say that this is stating the obvious, as the evolution toward composites has been moving swiftly for a while, but the test processes have been playing catch-up with the carbon fiber development. Commercial aircraft companies are keen to fly the flag for composites as this looks good on their résumés. However, composite usage must be a natural progression as test practice is still in development and accidents have happened.

This is why composites are a running theme throughout this yearly showcase. It crops up again and again. Virtually every article mentions it, and several directly discuss it.

More than 50% of the next-generation A350 XWB is made of composites. On page 26 Nikon discusses the fact that Airbus has automated the A340/350/380 composite nose cowl inspection system using a revolutionary metrology system called laser radar. Incidentally, Airbus has now established its very own composite design center in Toulouse, France.

Regarding the A350 XWB, Airbus says it has increased the service intervals for the aircraft from 6 years to 12, reducing the maintenance costs and lowering the need for fatigue-related inspections of aluminum airliners, and so lessening the requirement for corrosion-related maintenance checks. On page 36 there is a discussion on the most efficient use of composites in aircraft, in applications with high fatigue loads and areas susceptible to corrosion.

The military continues to be the driving force in the use of composites. One of the prime reasons is that it has so much damage tolerance. There have been many cases of mid-air military collisions that would rip the entire wing or tail off a metal aircraft below the point of impact. Composite material impact affects only the area of collision, increasing survivability of crew and aircraft.

A contract has been signed in November 2012 with Danish company Terma A/S to even further increase the use of advanced composite components with the F-35, which is already the first mass-produced aircraft to include structural nanocomposites.

However it is hugely important to remember the importance and essential use of metals in aircraft, which is something that *Aerospace Testing International* wishes to investigate further. Despite extensive use of carbon fiber in the latest generation Boeing 777, it also has an improved aluminum alloy being used in the upper wing skin and stringers.

I am no engineer, but research does show the flexibility of metals. One type of composite construction actually consists of thin graphite epoxy skins bonded to an aluminum honeycomb core. Each metal has certain properties and characteristics that make it desirable for a particular application: soft or hard and, when needed, conductive. There are many other elements that still make metal-based construction desirable. The most obvious is testing, but there are also brittleness, flammability, de-bonding, delamination, and microbuckling, to name but a few.

However, as technology develops, problems will get ironed out faster, and test systems and infrastructures will improve. Composites are here to stay, as even now the risks are far outweighed by the benefits: weight, strength, shape, flexibility, fuel savings, parts consolidation, and durability, just for starters. Fiber is the driver!

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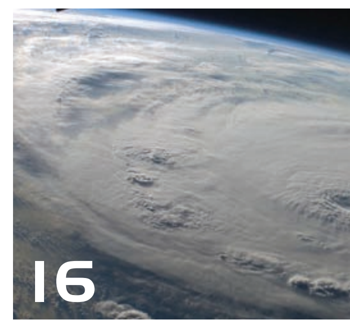
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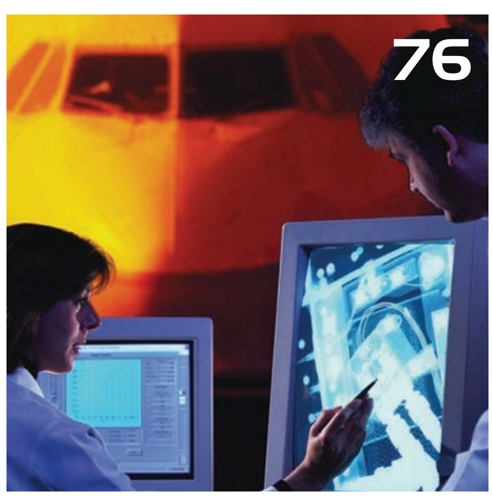
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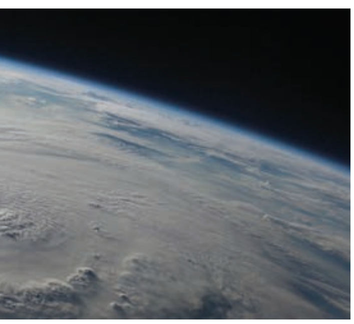


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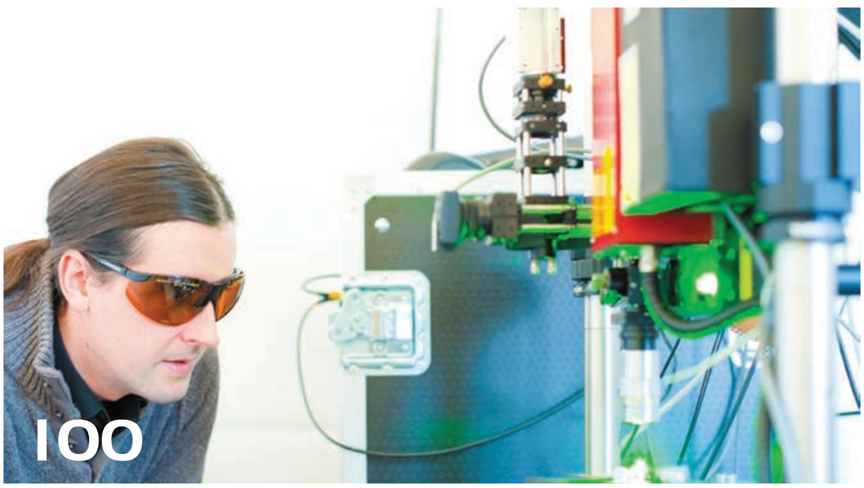
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Kraft work

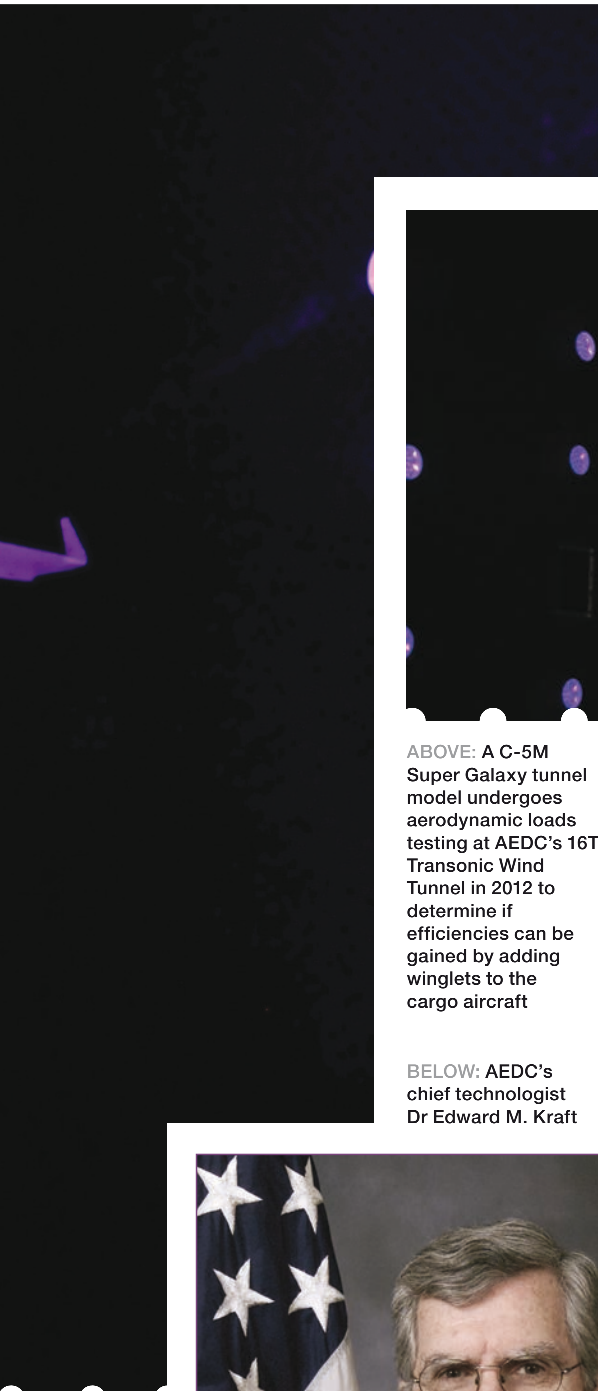
Arnold Engineering Development Complex (AEDC) is arguably the most important aerospace test facility in the world. *Aerospace Testing International* talks to its chief technologist, scientist, and visionary, Dr Edward M. Kraft

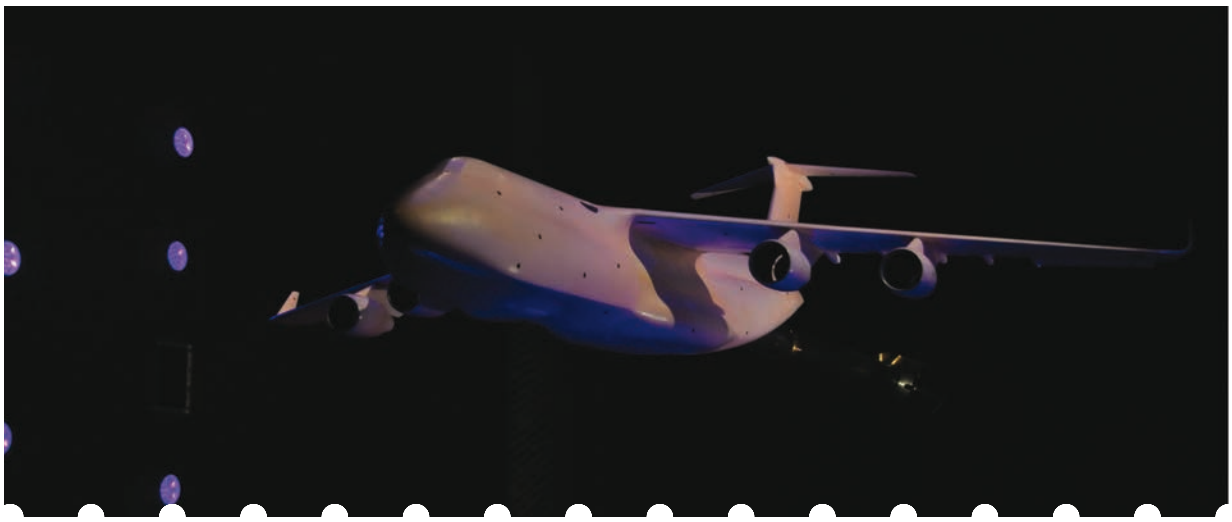
BY CHRISTOPHER HOUNSFIELD

Against all journalistic ethics I am 'cutting and pasting' straight from the factsheet of Arnold Air Force Base in Tennessee, USA. It is easier to get to the point thereafter: "Arnold Engineering Development Complex (AEDC), located at Arnold AFB, is the most advanced and largest complex of flight simulation test facilities in the world. The complex operates 43 aerodynamic and propulsion wind tunnels, rocket and turbine engine test cells, space environmental chambers, arc heaters, ballistic ranges and other specialized units. Twenty-seven of the complex's test units have capabilities unmatched elsewhere in the USA; 14 are unique in the world. Facilities can simulate flight conditions from sea level to 300 miles up and from subsonic velocities to Mach 20."

There you go, in the establishment's own words – that is why it is utterly integral to world aerospace testing. The list of aircraft, spacecraft, and missiles that began life there is very long and very impressive.

At the top of the testing tree is Dr Edward M. Kraft, chief technologist within the complex. He is unbelievably important and has influenced the modern development of aircraft more than just about anyone I have come across over the years. In his own words, he is: "Senior technical expert, technical advisor to the Air Force Test Center and AEDC commanders, US Air Force expert on aerospace ground testing, US national expert on applications of high-performance computing to test and evaluation. In my role, I provide corporate technical knowledge, history, and continuity. As a member of 'Senior Service', I am also engaged in numerous national committees related to test infrastructure, testing, and high-performance computing." All in all a pretty amazing job profile in this industry. His achievements are as impressive, but more about those later.





ABOVE: A C-5M Super Galaxy tunnel model undergoes aerodynamic loads testing at AEDC's 16T Transonic Wind Tunnel in 2012 to determine if efficiencies can be gained by adding winglets to the cargo aircraft

BELOW: AEDC's chief technologist Dr Edward M. Kraft

THE COMPLEX ITSELF

In layman's terms, AEDC is the US DoD primary ground test facility for aeronautical and space system research, development, test, and evaluation. It provides information for the early design and integration of aerospace systems. AEDC supports the entire defense acquisition process from development of new technologies, developmental testing of all DoD aeronautical systems, and sustainment of fielded systems through continuous improvement programs and support to resolve operational anomalies.

Beyond the test facilities, however, AEDC supports problem solving for aerospace systems under development. From design and manufacturing skills to the creation of custom test hardware and test articles, to development of measurement and diagnostic tools, to leading-edge development and application of advanced physics-based modeling, to understanding how to test the most advanced systems, and to analysis skills and expertise to sort out any unusual behavior of a system under test, AEDC is a one-stop shop for support to development of systems. For more than 60 years, AEDC has been involved in essentially every aeronautical development program in the DoD. There truly is no other place worldwide that is so completely focused on aerospace testing.

LATEST PROJECTS

Recent test programs in the AEDC 16T transonic wind tunnel on the venerable large-scale B-52 and C-5 aircraft summarize the comprehensive and unique capabilities of AEDC. Both programs illustrate that the AEDC facilities support systems over their entire lifecycle. As Kraft explains: "The B-52, after over 50 years in service, is being upgraded with new armament requiring a wind tunnel weapon separation test. Because of the large size of the B-52 and the smaller sizes of today's weapons, a large-scale wind tunnel model was required for accurate representation of the small stores. The B-52 represents a tour de force of AEDC capabilities. AEDC personnel designed a 10% scale wind tunnel model that was fabricated in the AEDC machine shops. This model is the largest aerodynamic model ever tested in 16T. Computational fluid dynamics was applied to assure wall interference effects on the large model would not compromise data quality. CFD was also employed to simulate weapon separations to guide and validate test data. The 16T captive trajectory system was employed to produce weapon separation trajectories. AEDC analysts evaluated the trajectories of the stores to assure safe separation. The test results will assure safe flight testing and operation of the B-52. AEDC's 16T is the only tunnel available that could test a transonic configuration of this scale and accurately simulate weapon separation.

"Along with this, the C-5 is being upgraded to improve fuel efficiency. Various wing modifications were tested to evaluate potential drag reductions. The large scale of 16T combined with its industry standard for flow quality and data accuracy makes it one of the few test facilities in the world that could accurately resolve changes in drag coefficients needed to verify potential configuration changes. Results from these tests will lead to significant fuel

THE TEST PROCESS TO GO EVER FASTER

AEDC is central to hypersonic development and test. Dr Kraft explains: "AEDC operates the DoD's comprehensive suite of hypersonic test facilities supportive of air-breathing and boost glide hypersonic vehicles. The wind tunnels A/B/C and Tunnel 9 provide a comprehensive aerodynamic simulation capability including aerothermal and aero-optics effects. The AEDC Aerodynamic and Propulsion Test Unit (APTU) provides enthalpy matched flight conditions up to Mach 8 for development of scramjet engines. The aeroballistic range, Range G, is used to understand impact and lethality of hypervelocity systems. The AEDC Arc Heated Facilities, H1/H2/H3, provide the nation's highest pressure arc heaters for evaluating nose cone and leading-edge materials for hypersonic flight and re-entry systems. All of these test capabilities are required to develop a hypersonic weapon system. AEDC is the only place in the USA with such a comprehensive set of facilities.

"Since hypersonic systems have to be accelerated to hypersonic speeds, the transonic and supersonic facilities at AEDC also play a role in total system development. The AEDC facilities also support testing of staging and/or weapon separation from high-speed systems.

"AEDC also manages a portfolio of hypersonic T&E technology development programs for the DoD. With this front row seat at the leading-edge of test technology development, AEDC is able to translate new test technologies into practical applications in its facilities."

"OLD AIRPLANES NEVER GO AWAY – THEY JUST GET BETTER OVER TIME"

savings in the operation of the C-5 fleet... Old airplanes never go away – they just get better over time. AEDC's capabilities support the long-term sustainment of many military airframes and turbine engines," Kraft shares with enthusiasm.

TECHNICAL PROBLEMS FACED

But there are major technical and system problems that the AEDC team faces, and also the test industry itself. Kraft explains: "The major problem facing the aeronautical development and testing community is inertia. In spite of major advances in data systems producing more data per unit of time and with ever-increasing applications of physics-based modeling, the generic developmental wind tunnel test program for military aircraft has stayed constant for the last several decades. A typical tactical fighter development program requires about a 20,000-hour campaign. This has been constant since the 1980s. I believe with an aggressive approach fully leveraging accelerated test techniques, advanced physics-based modeling, and statistical engineering it is feasible to cut the standard wind tunnel campaign in half. However, risk aversion, contract impediments, and a loss of intellectual capital over the last two decades have made it extremely difficult to actively work towards this level of efficiency," Kraft notes.

BELOW: Examining the C-5 Galaxy model at AEDC family of cargo aircraft have been in the USAF inventory since 1970 and are the largest cargo aircraft flown by the service with a cargo capacity of 270,000 lb

LOOK INTO SPACE

AEDC has developed and operates a test capability for the calibration and operation of space sensors and is developing 'space threat' capability. The AEDC 7ft vacuum chamber (7V) is a thermo-vacuum chamber with NIST traceable radiation black body sources capable of simulating the low background radiation effects of deep space. The 10ft vacuum chamber (10V) is a full hardware-in-the-loop capability for space sensors capable of dynamic scene simulation of a comprehensive set of star patterns, threats, decoys, and space artifacts. It is used for pre-flight rehearsals for all MDA test flights. Kraft expands: "All of the [space] capability is backed up by expertise in cryogenic environments, plume signature measurements and modeling, as well as scene generation and space sensor test technologies.

"The space threat assessment testbed (STAT) is a result of AEDC technology developments and demonstrations of the effects of combined space environments like atomic oxygen, ultraviolet radiation, material outgassing, thruster effluents, etc., on space systems and space sensors. As established by research at AEDC in a small chamber, the effects are not additive but need to be evaluated in a combined manner. STAT builds on a long history of AEDC space system testing, particularly for space sensor development. STAT will be used to optimize space system design for survivability and operability under combined space environmental effects. STAT will also provide space operators with a real-time simulation of combined space effects on components and subsystems for development of operational tactics, techniques, and procedures. STAT is currently undergoing final construction and commissioning."

FORWARD THINKING

Kraft describes his vision of the future with absolute clarity and precision.

THE GREATEST WIND TUNNEL ASSETS

The AEDC Complex operates wind tunnels from very low speeds to more than 16 times the speed of sound. The world's largest wind tunnel, the low-speed National Full-Scale Aerodynamics Complex (NFAC), supports development of rotor craft and does unique specialty testing such as assessing loads on the large-scale decelerator for the recent Mars landing. The workhorse transonic wind tunnels support research and development of tactical military aircraft such as the F-22, F-18E/F, and F-35. The 16T is the industry standard for data quality and data productivity.

It also has a number of specialized test capabilities for military aircraft such as store separation, airframe/inlet integration, and nozzle/afterbody integration, and is capable of testing integrated live propulsions systems. The smaller 4ft transonic tunnel 4T provides a cost-effective capability for smaller missile aerodynamic testing as well as weapon separation on tactical aircraft. The supersonic/hypersonic tunnels A/B/C are the world's only moderate-scale continuous flow tunnels covering the flight regime from low supersonic to Mach 10. They are heavily used for missile development as well as development of systems such as the Space Shuttle. Tunnel 9 can simulate flight to Mach 14 and provides a unique capability of high Mach numbers and a large-scale Reynolds number. It is particularly useful for aerodynamic, aero-optic, and aerothermal analyses. Tunnel 9 has played a significant role in understanding the aerodynamics of the X-51.

AEDC also operates the most comprehensive set of turbine engine test cells in the world, including four altitude test cells that can simulate flight up to 100,000ft and 100,000 lb of thrust. AEDC also has three sea-level cells, two with ram-air capability, well suited for accelerated mission testing of military turbine engines. These turbine engine cells are also supported with some of the most advanced instrumentation and diagnostic tools, including optical and IR probes that can map light-off characteristics of augmenters.

"Aerospace ground testing will be critical for system development for the foreseeable future. Although physics-based modeling will augment aerodynamic testing in the future, the wind tunnel facilities are still the best source for high-volume, high-quality, cost-effective data over an extensive flight envelope. Turbine engine test cells will be required to not only provide engine performance data, but also operability and durability. Modeling will never be able to replicate long-duration testing cycles for durability and accelerated mission testing of turbine engines.

"Two important developments are on the near horizon for aeronautical systems: First, physics-based, scalable, high-performance computing will revolutionize the entire design, integration, and test process. Multiphysics, multidisciplined, highly scalable approaches to modeling complex flight systems are currently under development in a DoD program referred to as the Computational Research Engineering Acquisition Tools Environment (CREATE). Scaling computer models to efficiently use thousands of processors is making modeling highly detailed maneuvering aircraft with movable controls surfaces, structural response, integrated propulsions system models, and weapon separation a practical engineering tool.

"CREATE will transform testing, not by trying to replace wind tunnel test points with computed test points, but by leverage testing and modeling to revolutionize the requirements setting, design, and quantification of margins and uncertainties in design.

"Second, the development and application of innovative test techniques like pressure sensitive paint combined with off-body measurements such as laser Doppler velocimetry, planar laser induced fluorescence, etc., will provide more comprehensive understanding and improvement of fundamental aerodynamic phenomena such as vortex structure management and drag reduction."

"AEROSPACE GROUND TESTING WILL BE CRITICAL FOR SYSTEM DEVELOPMENT FOR THE FORESEEABLE FUTURE"

PERSONAL CONTRIBUTION

When asked what as a scientist Kraft feels he has contributed most at AEDC, he reveals: "My most lasting contribution to the aeronautical development test process is the creation and implementation of a visionary approach to integrating testing with high-fidelity physics modeling to improve the quality and efficiency of the output. This approach was first demonstrated for weapon separation from the F-15E in 1988. The integrated technique had a profound impact on the cost of weapons integration on the F-22 and F-35. The integrated T&E approach has been applied to all tactical aircraft and bombers since 1988 without any flight test incidents.

"In recent years, I have extended this vision to the entire defense acquisition process. Through collaborative efforts I have been able to mobilize the air force, army, and navy to develop the CREATE tools and to begin to implement them with better design, integration, and testing processes from early analysis of alternatives, to engineering development, and to sustainment," Kraft concludes. I mentioned I would go back to his achievements, and as discussed, his impact has been great.

MARK CARPENTER

LIYUN LAO

The new ice age

The essential study into icing in aircraft fuel systems – from laboratory testing toward improved icing management

BY LIYUN LAO, MARK CARPENTER & HOI YEUNG

The presence of water in jet aircraft fuel has been a topic of concern for the aviation industry for decades. However, this issue has been under much closer scrutiny since BA Flight 38 came down just short of the runway at London Heathrow Airport on January 17, 2008.

The post-accident investigation and fuel system tests established that the accident was due to restriction of fuel supply to both engines, probably caused by ice blockage in the fuel feed system. The cause of this ice is trace water contamination in jet fuel, which may freeze during long flights at high altitudes. The resulting ice particles may be entrained in the fuel supply system and, if present in sufficient quantity, block fuel filters or other restrictions in the supply system, thereby interfering with the steady flow of fuel to the engines and creating a safety hazard.

The quantity of absorbed water in an aviation fuel will depend on the ambient conditions such as temperature and humidity, and the fuel composition – mainly the aromatic constituents. Fuels are carefully filtered to remove dirt and most of the free water as part of the aircraft fuelling process. However, filtering cannot remove dissolved water or water vapor that enters via the fuel tank vent system while the aircraft is in flight. The fuel will tend to precipitate any excess dissolved water when it is cooled to the temperatures prevailing at high altitudes.

Excess water may then appear in the form of fine water droplets (typically less than 10µm across) or as ice crystals. The larger water droplets will gradually settle to the bottom of the fuel tank under gravity. However, the detailed mechanism of water shedding, droplet formation, and the formation of ice both from entrained water droplets and slugs of water, is not well understood as there is a complex interaction between water shedding, nucleation, and growth of water droplets, ice nucleation, and growth, and the influence of fuel composition and fuel additives on all these phenomena.

SYSTEMS IN PLACE

Most large aircraft are fitted with fuel system heat exchangers, which mostly use waste heat from engine oil to preheat the fuel.

These systems are generally satisfactory, but there are occasional circumstances when insufficient heat is generated to warm the fuel in the low pressure feed system if it is presented with a large quantity of ice. To avoid this potential issue, one measure is to limit the continuous duration of flight at very low temperatures; for example, after every two hours of high-altitude flight, the airplane is required to reduce altitude. However, this strategy leads to an increase in fuel consumption over the course of a flight. Another method is to use a fuel system icing inhibitor; this is used extensively for military aircraft and certain small civilian jet aircraft, but is not added to fuels for general civil aviation. While the fuel system icing inhibitor has some advantages, there

In January 2008 flight BA58 crashed short of the runway at Heathrow. Accident investigation put it down to ice crystals in the fuel, clogging the fuel-oil heat exchanger of each engine

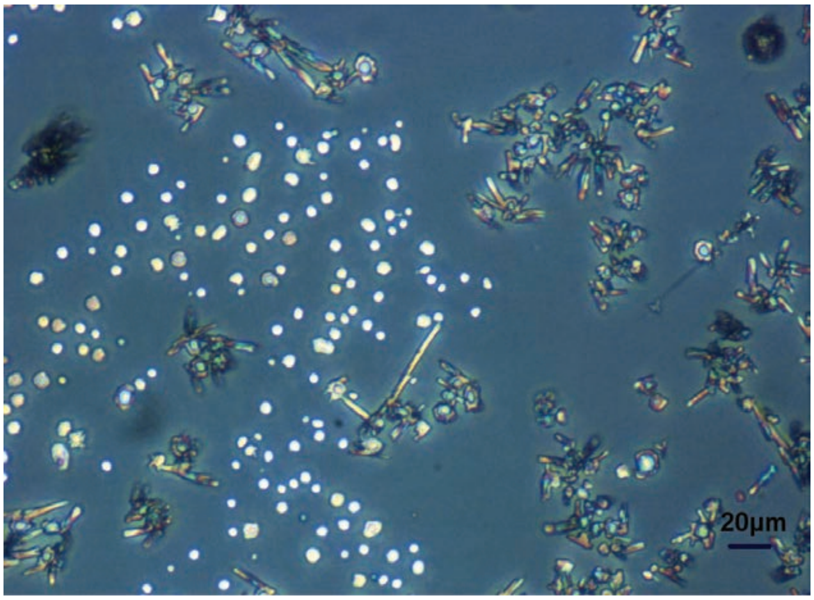
ABOVE: Bottom cooling mode. Cloudiness developed from the bottom of the fuel tank, since heat transfer is dominated by conduction, which leads to a stratified regime

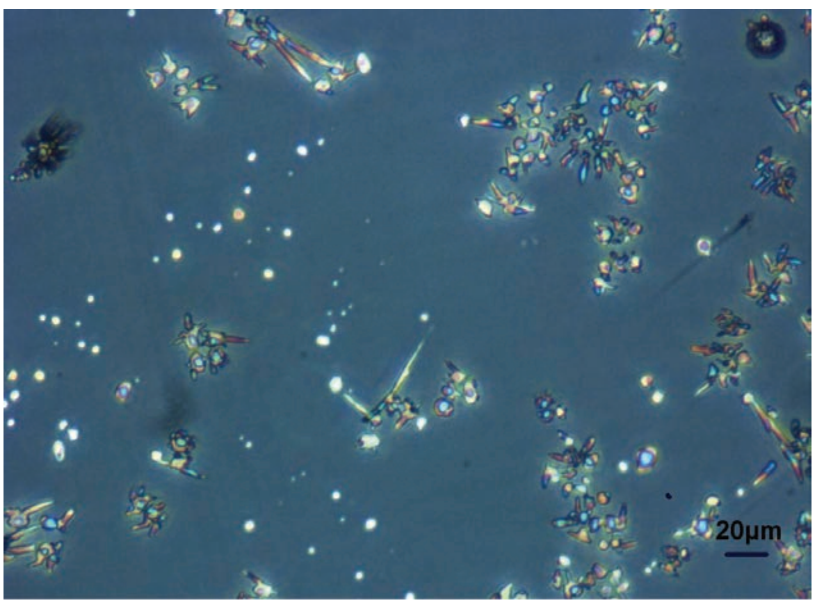
LEFT: Top cooling mode. Cloudiness in the fuel was homogeneous since heat transfer is dominated by convection which enhances mixing in the tank

"EASA IS PLANNING TO FUND ANOTHER RESEARCH PROJECT – ICE ACCRETION AND RELEASE IN FUEL SYSTEMS"

are concerns about degradation of coatings used in fuel tanks, potential for accelerated corrosion of fuel tanks, environmental issues, and safety concerns about its handling.

In order to achieve an improved solution to water management in aircraft fuel systems, an understanding of ice formation, accretion, release, transportation, and re-deposition in aviation fuel systems is required. Following the safety recommendations in the Air Accidents Investigation Branch (AAIB) report into the accident to BA Flight 38 at Heathrow Airport, the European Aviation Safety Agency (EASA) funded a research project called Water in Aviation Fuel Under Cold Temperature Conditions (WAFCOLT) (see http://www.easa.europa.eu/procurement/closed-calls-for-tenders.php for more information). This project examined the formation of ice crystals in jet fuel and the influence of several key parameters including water concentration, fuel temperature





WATER, WATER EVERYWHERE…

Visualization of water deposition on a sub-cooled horizontal aluminum surface was carried out. Preliminary results from the study suggested there were at least two different types of deposition on the sub-cooled surface when the fuel was cooled. One was ice crystals of hexagonal habit, growing in areas with sharp surface aberrations from the dissolved water phase, when the fuel temperature was lower than -10°C. Another was spherical water droplets or ice particles, believed to be of cubic habit, deposited on the surface directly from the dissolved water phase. Under near-static conditions, it was also observed that ice accreted on a sub-cooled surface was loosely adherent and would be expected to have poor mechanical properties.

In parallel, a study of ice crystal formation in fuels and model hydrocarbons was carried out by the CSFE Group at Cranfield University, using a Leica DM LM optical microscope fitted with a phase contrast system and Linkam THMS600 cold stage. The cold stage includes a micro-heating element and automated liquid nitrogen cooling system to give accurate thermal control over a wide range of temperatures. The test program compared the behavior of three model hydrocarbons (simulated constituents of jet fuel) with three different jet fuels (all supplied to the Jet A-1 specification). Each of the samples was conditioned to achieve the maximum dissolved water content at 25°C; behavior of the samples was observed in the cold stage system when subjected to pre-programmed cooling and heating cycles.

range, and cooling rate. The type and related mechanical properties of ice crystals formed in fuel were also highlighted in this project. EASA is planning to fund another research project – Ice Accretion and Release in Fuel Systems – which will investigate the accumulation and shedding of ice in a gas turbine engine fuel system by using a fuel supply system test rig representative of a large aircraft. Recently, a more comprehensive and ambitious three-year project was launched with EU Framework 7 funding; the project is known as SAFUEL (the safer fuel system).

The core aim is to develop a new generation aircraft fuel system, by investigating and minimizing fuel

ABOVE TOP: **Toluene, on slow cooling to 44°C, showing finger-like ice crystals and 2 – 12µm spherical water/ice droplets on the bottom of the sample container**

ABOVE BELOW: **Toluene, on slow reheating to 11°C, showing disappearance of droplets suggesting that water droplets are being redissolved**

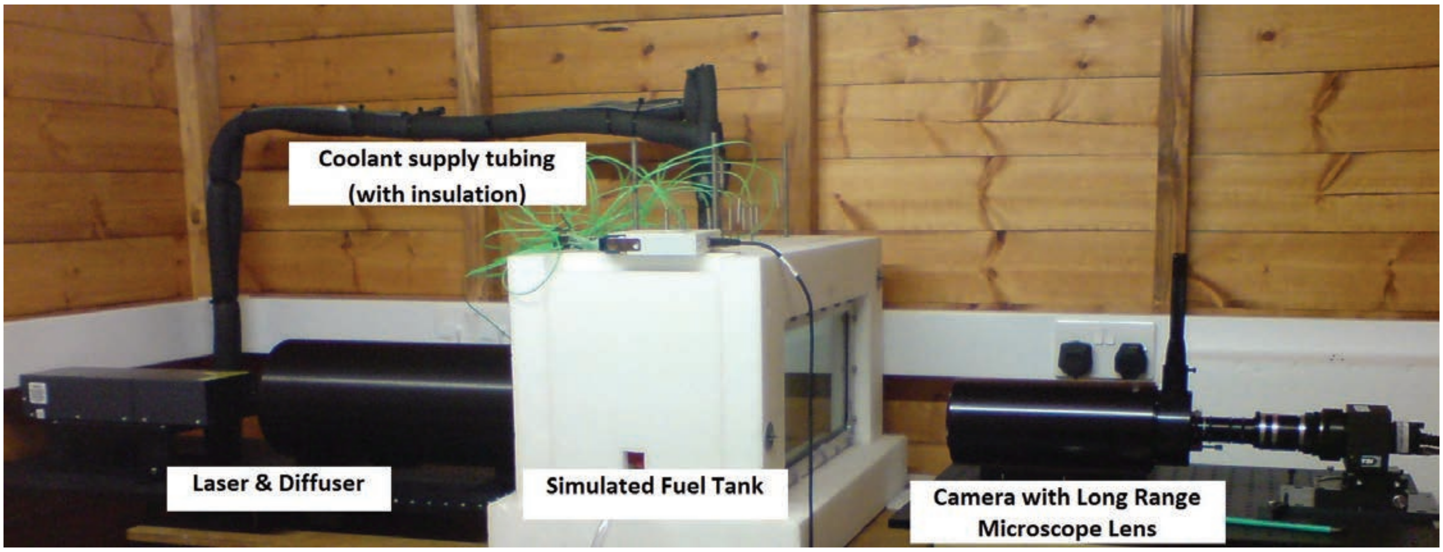
system hazards related to fire, ice, and system failures. Cranfield University in the UK had an important role in WAFCOLT working with Airbus UK, and will be a major contributor to SAFUEL in collaboration with 11 industry and academic partners.

ICE GROWTH IN FUELS

In order to understand the characteristics of accreted ice in fuel systems, knowledge of ice growth is crucially important. The Process System Engineering Group at Cranfield University conducted experimental simulation of the freezing phenomena experienced in aircraft fuel tanks under very cold atmospheric conditions.

A 20-liter simulated fuel tank, fitted with a long-range microscopic imaging system, was constructed. The fuel tank is equipped with top and bottom cooling plates, which were used to simulate the heat transfer process across the upper and lower surfaces of a wing tank. The imaging system enables non-intrusive monitoring of the water/ice precipitation and accretion behavior while the tank is subjected to various thermal regimes. It comprises a laser source for the illumination of the fluid in the simulated fuel tank, a CCD camera with a Questar QM100 long-range microscope lens, and computer control.

The experimental investigation in the simulated fuel tank revealed several interesting phenomena that



ABOVE: Simulated fuel tank fitted with a long-range microscopic imaging system for investigation of icing in aviation fuel

"ON REHEATING TOLUENE, THE WATER DROPLETS BEGAN TO DISAPPEAR, LEAVING THE ICE CRYSTALS LARGELY INTACT"

may be experienced in a real aircraft fuel system. For example, cloudiness was observed in the fuel body when it was cooled. The pattern of the cloudiness formed depended on the whether the top cooling or bottom cooling was used. It is thought that the observed cloudiness phenomena in the fuel tank was due to the excess dissolved water precipitating out as a fine dispersion of water droplets as the temperature was lowered.

The top cooling mode provided a homogeneous cloudiness distribution since cooling was dominated by convection, which enhances mixing in fuel. The bottom cooling mode, which is representative of a fuel tank with a head space or ullage, produced a stratified cloudiness layer since cooling was dominated by conduction.

ZERO DEGREES

In the three Jet A-1 fuels and two of the model hydrocarbons that were used for these tests, there was no evidence of the water droplets in the fuels developing crystalline ice formations even though the temperature was lowered to -44°C. This contrasts with the water in the aromatic hydrocarbon, toluene, which formed ice crystals when cooled to -44°C.

On reheating toluene, the water droplets began to disappear, leaving the ice crystals largely intact. The ice crystals melted at around 0°C. An explanation for the formation of ice crystals in toluene, and not in the fuels or other hydrocarbons, is that it can hold a much higher concentration of dissolved water at 25°C compared with the fuels and other hydrocarbons. The interaction and interchange of water between the dissolved state, supercooled water droplets, and ice crystals is complex and requires further investigation.

FURTHER STUDIES

The ultimate objective of studying icing behavior in aviation fuels is to understand the boundary parameters of ice formation and improve the design of existing aircraft fuels systems to eliminate the chance of ice blockage occurring. In order to achieve this aim, different scales of test and evaluation will be required.

At the smallest scale is laboratory test work focusing on the basic issues related to icing in a fuel system. This includes: determining the icing-related basic properties of different aviation fuels, with or without additives; and determining the characteristic parameters that affect ice accretion and release from surfaces in fuel, for example, due to surface properties, degree of sub-cooling, and/or fluid dynamics.

At this scale, the factors influencing icing processes would, as far as possible, be studied independently.

Segmentation studies of different aspects of icing behavior need to be balanced with an understanding of the effects from coupled or synergistic behavior from those same factors on icing. Therefore, middle-scale testing, which involves pilot-scale models of aircraft fuel pipelines, fabricated using typical geometries and typical fuel system components, would be necessary. At this scale, the icing process will be simultaneously influenced by those factors investigated in laboratory scale tests. The largest and most expensive form of testing which, in a sense, could be seen as represented by full-scale trials, not only provides information about scaling-up of systems, but can also be used as verification of the basic knowledge obtained from the earlier tests. ∎

Liyun Lao is the senior research fellow in multiphase fluid system, Process Systems Engineering Group, Cranfield University. Mark Carpenter is a research fellow in Fuels Technology Research, Chemical Safety, Fuels and Environment Group, Cranfield University. Hoi Yeung, professor of Flow and Process Assurance, and head of the Process Systems Engineering Group, Cranfield University, all in the UK

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RICHARD S. STANSBURY

MASSOOD TOWHIDNEJAD

Gale force: into the storm

One particular unmanned aircraft system development has shown great potential as a platform for collecting in-situ measurements within a tropical cyclone

BY RICHARD S. STANSBURY & MASSOOD TOWHIDNEJAD

Tropical cyclones are destructive forces of nature that threaten people, properties, infrastructures, communities, and economies. While scientists have developed many models to predict the paths and intensifications of these storms, there is still a tremendous number of unknowns. In order to enhance these models, it is necessary to develop new data collection techniques to fill the knowledge gaps.

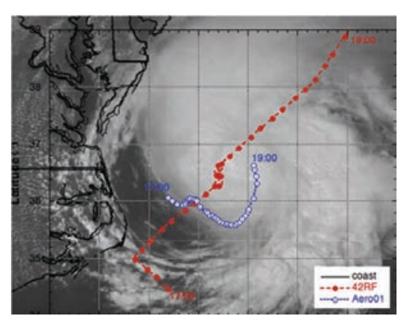
Unmanned aircraft systems (UAS) provide a new and powerful means for collecting additional in-situ data from tropical cyclones. In recent years, unmanned aircraft (UA) have been used to complement some of the traditional methods of hurricane data collection.

For scientists to dramatically improve their understanding of rarely observed regions of the storm (i.e. conditions from surface to approximately 5,000ft), detailed and continuous observations must be obtained. To this end, an aggressive effort to use low-altitude unmanned aircraft designed to penetrate and sample the hurricane environment will help fill this critical data gap.

THE UAS DEVELOPMENT

A new approach has now been developed and is undergoing tests to collect in-situ meteorological measurements from a tropical cyclone using a UAS. The UA will be equipped with a MIST Sonde scientific payload. This new UA will be dropped from one of the National Oceanic and Atmospheric Administration's (NOAA) WP-3G Orion hurricane hunting aircraft (known as a P-3) directly into the eye of the tropical cyclone. The UA is packaged in a cylindrical sleeve that is dropped via a sonobuoy chute. Once exiting the aircraft, a parachute will deploy, slowing down the UA and separating it from its sleeve. Next, the wings deploy and the aircraft enters its pre-planned flight regime.

Data is wirelessly broadcast back to a control station on the P-3 and/or ground control station (GCS). The UAS known as Gale is under development and going through a test program by a team of scientists and engineers from Embry-Riddle Aeronautical University (ERAU) and NOAA. Funded through NOAA's UAS program, the project is supported by the Hurricane Research Division (HRD), which identifies the science mission requirements, and directly use the data collected. NOAA's Aircraft Operations Center (AOC) provides support for deployment of the UAS into the storm from one of NOAA's P-3s. The AOC will also support clear air flight tests within restricted airspace.



ABOVE: light path of NOAA/NASA Aerosonde UAS flight demonstration into Tropical Storm Ophelia in 2005

UAS REQUIREMENTS & DESIGN

Science data is collected from two sources onboard the aircraft. First, a MIST Sonde sensor board has been

ABOVE: Hurricane Lili, captured during the Expedition Five mission, shows the compact storm system and the structure of its estimated 15 nautical mile wide eye (picture: NASA)

BACKGROUND TO THE GALE

The Department of Electrical, Computer, Software, and Systems Engineering (ECSSE) at ERAU has conducted unmanned systems research and student projects for almost a decade. During the 2005-2006 academic year, students in the senior design course developed a UAS for aerial surveillance. A team of students founded a student-lead UAS design team, Team Blackbird, to compete annually at the Association of Unmanned Vehicle Systems International's Student Unmanned Aircraft Systems competition. Team Blackbird was awarded 2nd place in 2009 and 3rd place in 2010 at this competition, and will compete again in June 2013.

Team Blackbird and ERAU faculty began collaboration with a local UAS design and development company, DynaWerks Technologies, LLC (DWT). Within the partnership, ERAU students and staff assisted in the integration of avionics, tuned flight control systems, and performed limited flight tests. It was from this that DWT was identified to assist in the design of the Gale UAS airframe. Collaboration between ERAU and NOAA began in the summer of 2008 with a discussion of ERAU's UAS capabilities and a visit to the Kennedy Space Center. The goal of this initial meeting was to determine areas to support UAS operations off Florida's coast to support NOAA's existing UAS program. The initial meeting ultimately led the creation of an expendable UAS that could be deployed from the P-3 into the tropical cyclone eliminating the ingress/egress of the UAS to/from the storm.

GALE UAS SPECIFICATIONS

Wingspan	50in
Length	34.5in
Dry weight	8.5 lb
Gross weight	8.5 lb
Propellant type	Battery, Lithium-Ion Polymer
Payload capacity	1.0 lb
Payload type	Mist Sonde sensor card
Max speed	60kts
Cruise speed	42kts
Stall speed	25kts
Endurance	60 minutes

> "THE DATA IS BROADCAST TO THE P-3, WHERE IT IS RECEIVED AND PROCESSED BY THE AIRBORNE VERTICAL ATMOSPHERIC PROFILING SYSTEM"

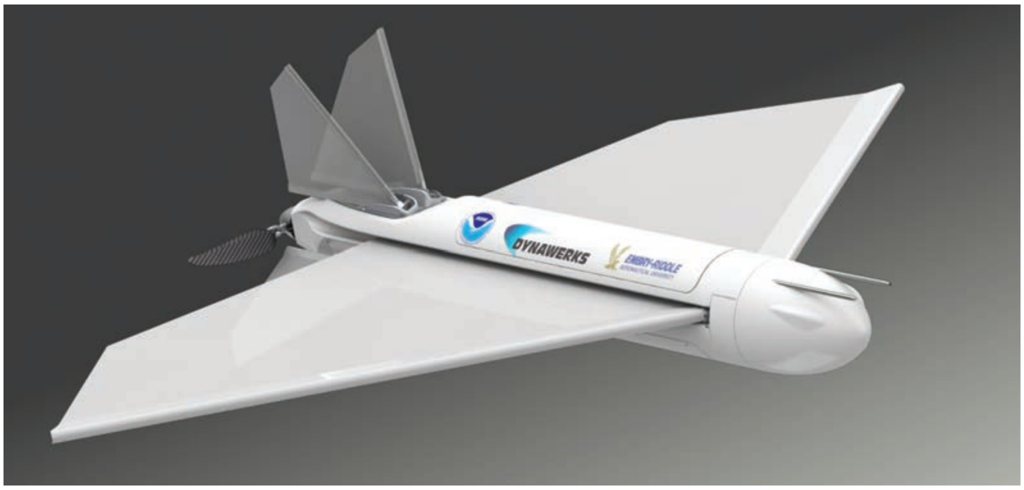
integrated onboard the aircraft. The MIST Sonde sensor must be integrated within the airframe such that airflow over the sensor is approximately 6-10mph (roughly, 2.68-4.47m/s) so that it can sense the temperature, humidity, and barometric pressure without the risk of the probe becoming wet from precipitation.

Additionally, the board will be equipped with a GPS to determine the vehicle's position and velocity vector. This data is broadcast to the P-3, where it is received and processed by the Airborne Vertical Atmospheric Profiling System (AVAPS) chassis and laptop. The second data source is the Gale UAS's autopilot – the Piccolo. The Piccolo SL's air data, GPS position, velocity vector, true heading, and derived wind speed measurements will all be collected. This data will be transmitted via an Iridium data link to the GCS located at ERAU.

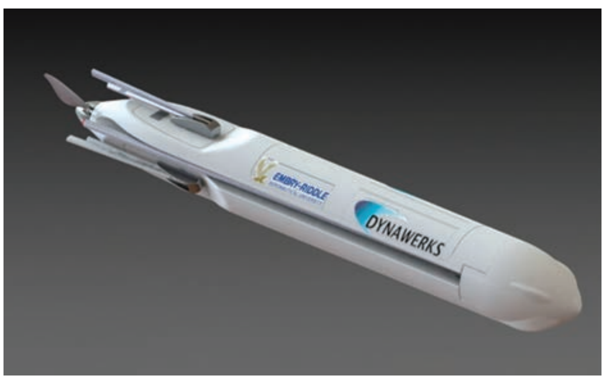
The Gale UAS design must be capable of operating within sustained hurricane force winds and testing is imperative to this. The system is designed to operate for 60 minutes in flight after a drop from the P-3. Once it loses power, it will terminate in the ocean. The current airframe specifications of the Gale UAS are shown in the table on the left.

FLIGHT TESTING

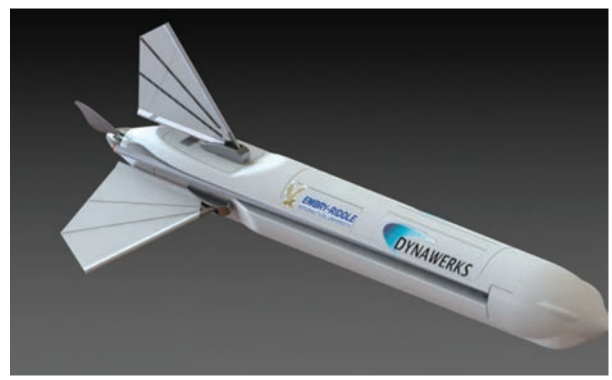
Evaluation of a platform such as Gale is 'non-trivial' given the current regulatory environment. In August 2013, the Gale UAS was permitted to operate in restricted airspace over the AVON MOA restricted airspace in benign 'clear air' conditions. For the flight, a number of success criteria were identified including: successful separation from the P-3; separation of the outer sleeve from the aircraft; deployment of tail surfaces; deployment of wing surfaces;



"THE TAIL WINGS DYNAMICALLY DEPLOY, FOLLOWED BY MECHANICAL DEPLOYMENT OF THE SIDE WINGS"



The images here show the Gale UAS transition from deployment (left) to freefall (right) to flight configurations (above)



successful flight; and recovery. For the flight, the team was required to deploy at 3,000ft rather than 10,000ft in order to maintain visual line-of-sight at all time by the safety pilot.

From this first flight test, the results were only a partial success. The aircraft was successfully launched and its surfaces deployed. It was, however, unable to make a full transition into flight mode. The aircraft was leveling off when it approached the surface, and hit the tree line near the ground control station. The impact ruptured the batteries on board resulting in a loss of aircraft. An analysis of the vehicle debris provided additional engineering insights that were used to revise the design for the next flight test. The figure on the following page shows a successful flight of the airframe in an earlier R/C flight test.

TEST AIMS AND CONCEPT OF OPERATIONS

There are two hurricane flight concept of operations (CONOPs) considered for the Gale UAS test prototype. Both missions also result in the UA's flight being terminated in the ocean.

First is the 'vertical profile of tropical cyclone eye' – over a mature hurricane, the P-3 will fly into the eye of the cyclone. Ahead of entry, the following activities are performed: the UAS will be prepared; the storm characteristics including eye radius, vector of eye motion, and the geodetic coordinates of the eye's center will be determined; given the storm characteristics, the flight regime's path will be generated and uploaded to the autopilot; and LOS communication is established between the onboard control station and the autopilot. The aircraft will be located within a sleeve with an attached drogue parachute. At time of launch, the sonobuoy tube of the P-3 will be opened and the aircraft (in sleeve) will be dropped. The altitude at time of launch is anticipated to be near 10,000ft.

One aim of the program is to test the following: as the aircraft falls from the P-3, the parachute will be deployed, which will pull the outer sleeve away from and off the aircraft. The tail wings dynamically deploy, followed by mechanical deployment of the side wings to ensure the aircraft enters stable flight from freefall. The aircraft is anticipated to enter its flight regime at 5,000ft.

The aircraft and payload aims to collect and transmit data continuously. From 5,000ft to 1,000ft, the aircraft will follow a step-descent pattern in which it will hold and maintain an altitude for three minutes, and then descend 1,000ft to the next hold altitude. Once the aircraft reaches 1,000ft, the process shall continue, but with a 100ft descent between each altitude. Near the end of the UA's endurance (approximately 60 minutes), at 200ft, the aircraft will discontinue its step-descent, and will be flown into the eye-wall. Once inside the eye-wall, the aircraft will fly into the winds of the eye, maintaining altitude for the remainder of its operating life.

Second is the 'vertical profile of tropical cyclone eye-wall' – the second CONOP is identical to the first until it reaches its flight regime. Once at 5,000ft, a gradual descent is performed until the aircraft reaches 2,500ft. At 2,500ft, it will be directed to breach the eye-wall. Once inside the hurricane's eye-wall, the aircraft will perform a

> "THE GALE UAS COULD BE EXPANDED TO SUPPORT A VARIETY OF ATMOSPHERIC MEASUREMENT AND OCEANOGRAPHIC STUDIES"

GO GET THE DATA

A custom software application called PyVAPS will merge two data sets into a single data set based upon the GPS timestamp. The scientific constraints requires the following accuracy for each of the following: air pressure data must be collected with an accuracy of ±0.5mb; air temperature data must be collected with an accuracy of ± 2°C; the relative humidity must be received with an accuracy of ±10%; GPS position of the aircraft can be received from the MIST Sonde or the Piccolo SL must have the accuracy of <10m, and finally the 3-axis GPS velocity data must be received with an error <0.5m/s RMS.

step-descent in which it maintains altitude for three minutes before descending 100ft to the next altitude. Once an altitude of 200ft is reached, the aircraft will maintain altitude for the remainder of its operating life.

LOOKING FORWARD

Upon completion of a successful clear-air flight, the next phase of operation will be to demonstrate the Gale UAS under the two CONOPs described above. When successful, a new phase of test and research will begin. The goal of this research is to minimize the cost per unit, while increasing the amount of data that can be collected. If this can be accomplished, the expense of using Gale UAS over traditional dropsonde technology can be better justified.

First, the Gale UAS is currently an expensive aircraft with over US$10,000 in electronics on board including a Piccolo SL autopilot and Iridium modem. The Piccolo was selected given the team's experience with it and to reduce the experimental nature of the vehicle's controls while a new airframe was developed. Once the airframe is proven, the next phase is to develop a custom UAS autopilot or adapt an existing open-source autopilot solution toward control of the Gale. It must be capable of communicating command, control, and telemetry via both a RF line-of-sight radio, as well as beyond line-of-site satellite communication radio. It must also be capable of supporting the necessary flight stability to maintain the target flight path through the storm with minimal deviation due to wind gusts.

Second, the team used commercial off-the-shelf batteries to power the Gale, which will provide an estimated 60 minutes of endurance. There are a variety of batteries that are either experimental, or not available for small batch orders, that can be explored to provide the next generation power source for the Gale. It is the team's goal to ultimately extend endurance to 90-120 minutes.

Lastly, the team wants to expand the Gale UAS's mission and test set. By developing a pneumatic launch system and net recovery system, the Gale UAS could be expanded to support a variety of atmospheric measurement and oceanographic studies. For instance, a ship-mounted pneumatic launcher could be used to deploy Gale over the Antarctic so that it could collect real-time video of marine mammal populations. A truck-based launch system could be used in the US Mid-west using its current payload to study tornado-producing super-cell thunderstorms.

There exists an ongoing collaboration between NOAA and Embry-Riddle Aeronautical University to produce the Gale UAS. From the design, testing, and preliminary flight test, the Gale UAS shows great potential as a platform for collecting in-situ measurements within a tropical cyclone. Unlike traditional dropsondes, which cannot loiter nor steer toward areas of interest, the Gale UAS will become a flyable dropsonde sensor capable of providing access to storm data previously impossible or highly difficult to measure. This data will help scientists build models that can help keep the public safe. ∎

Richard S. Stansbury is an associate professor of computer engineering and computer science within the Department of Electrical, Computer, Software and Systems Engineering at Embry-Riddle Aeronautical University in the USA. Massood Towhidnejad is a professor of software engineering and director, Next-Generation ERAU Advanced Research Laboratory based in the USA

RIGHT: The Gale UAS in flight during preliminary R/C flight tests

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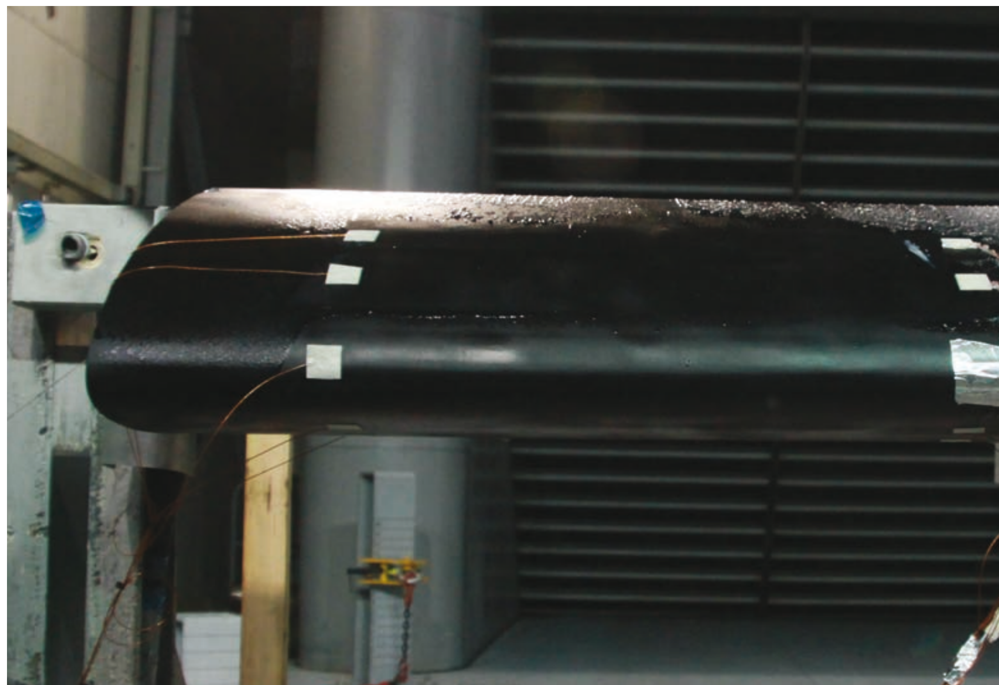
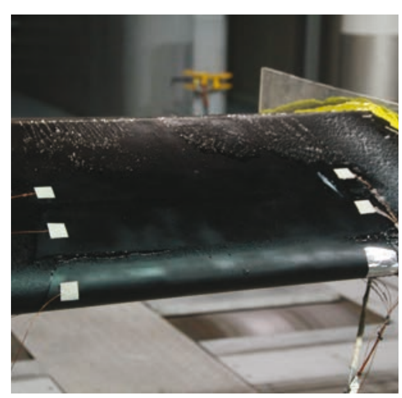
MARTIN LEHMANN

Weight on the wing

When ice builds up on the wing of an aircraft, it can have an impact on safety and even cause an aircraft to crash. New research demonstrates how to keep ice off the wing

BY MARTIN LEHMANN





Regardless of how fluffy and plush white clouds against a blue sky may appear from ground level, the conditions inside them are forbidding for a pilot. If aircraft fly through these clouds, the low temperatures, combined with windspeed, can cause the rapid formation of ice sheets on the wings. This icing could have two serious consequences: first, the ice sheet may cause an up to 40% rise in the aircraft's aerodynamic drag; and second, the aircraft becomes heavier and can lose up to 30% of its lift. Both conditions lead to a marked spike in fuel consumption, impede safety, and, in a worst-case scenario, the ice may even affect the aircraft enough to make it crash.

Aircraft manufacturers must therefore prevent icing, and there are various technologies that can help with this. For example, by conducting the heat from the jet engines to the hollow spaces inside the wing leading edges, the wings can be de-iced during a flight. Other manufacturers are integrating 'rubber boots' – basically, rubber mats that can be pumped up when needed and 'blast' the ice from the wing surface. A major disadvantage of these technologies is the exorbitant energy requirement. Moreover, it is very difficult to combine them with fiber composite materials that are increasingly being used in aircraft construction.

WING HEATING USING NANOMATERIALS

Researchers at the Fraunhofer Institute for Structural Durability and System Reliability LBF in Darmstadt, Germany, have now engineered a heat-based option for the wings that skirts around this material disadvantage. Nanomaterials are now being integrated into the wing materials that generate an electrically conductive layer to heat the wings.

The scientists say they would prefer not to disclose more details than this at the moment. One advantage of this system is that since the electroconductive layer is integrated into the material, it is protected by the overlying fabric. In addition, no metals are integrated: this improves lightening protection and avoids the weak points that the metal would form. Since the Fraunhofer team are combining like with like, the material does not fatigue quickly. The effect of the heat is immense: at ground level, it heats the wings up to 120°C.

The wing heating already passed the first test. In the wind tunnel, at temperatures of -18°C and the relevant windspeeds, the researchers sprayed a wing with water. They initially let an ice crust form before they turned on the integrated heater; they wanted to examine the de-icing process this way first. In a second test run, they switched on the heater just as they sprayed the wings, so that the wings

ABOVE: Testing the anti-icing capability of the nano-based ice-protection-system under -18°C

INSET LEFT: The system showed it is possible to prevent ice build-up under conditions simulating the flight of a cooled down wing through clouds depending on the power applied on the electrothermal heating system

could not even form an ice sheet at all. This approach is referred to as anti-icing. Both test runs were conducted successfully and validated the simulations that the researchers conducted beforehand. In addition, the experts studied two different models in which the hot zones were each set up slightly differently, as well as an unheated wing i.e. the control subject. The heat output was maximized this way because the heater needs to keep the wings reliably free of ice, and yet consume as little energy as possible.

The wing heater undoubtedly works under laboratory conditions; next the researchers want to try out their product design for industrial use. They have already demonstrated one of the segments that they tested in the wind tunnel at the ILA show in Berlin in September 2012.

> "THE SCIENTISTS WANTED TO COMBINE THE ACTIVE DE-ICING OF THE WINGS WITH NEW KINDS OF SENSORS"

SYSTEM SOLUTIONS FOR DE-ICING

Researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Bremen are taking another approach. Through an EU-funded project that is scheduled to began in the autumn of 2012, they will engineer new technical solutions (besides de-icing through heat) for the mechanical removal of ice from the wings. "We will use innovative materials here such as 'shape memory' materials," explains Dr Stephan Sell, a scientist who specializes in paint technology at IFAM.

What's so unusual and special about this approach is that if the temperature changes, or if one applies an electrical current, then the material changes its volume. In this way, scientists can blast the ice off the wing surface. "We expect energy savings from this to reach up to 80% compared with conventional heating methods," Sell explains.

At the same time, the scientists wanted to combine the active de-icing of the wings with new kinds of sensors. If the wings ice up, the sensors detect this through an optical system, and notify the crew. Previous techniques were based merely on indirect measurements. This integrated sensor system makes it possible to identify the icing in real time, and to monitor the success of the de-icing process in real time, too. The result is greater energy efficiency for the entire system, and a manifold increase to airline traffic safety.

PROTECTION THROUGH ANTI-ICE COATINGS

Where there is no water, there can be no ice. Therefore, researchers at IFAM engineered coatings with anti-ice capabilities under the Clean Sky program. Among other things, the hydrophobic, water-repellent coating should protect against run-back ice, which is the ice that forms from the melted ice coming from the wing leading edges. At the wing leading edges, once the heaters melt the ice back into water, it flows down to the lower part of the wing as meltwater, where it freezes again and turns back into ice. "Our hydrophobic coatings are intended to ensure that water at the rear part of the wing flows off the wing instead of cleaving to it. We can achieve that by blending certain additives into the paint, such as fluorinated compounds," explains Sell. "The main challenge is figuring out how to produce water-repellent coatings so that they remain stable for several years – resisting the effects of UV radiation and high erosion stresses."

The areas of application for these new technologies are not limited to aviation. Icing is also a problem for ships, rail-based vehicles, cars, rolling doors, refrigeration aggregates, and wind power farms. For example, iced rotor blades at the wind turbines cause the facility to produce substantially less power – in the worst case, the icing leads to irreparable damage. If parts of this ice drop off, they could even cause injury to people below.

The IFAM researchers have a custom-built ice chamber at their disposal for testing anti-ice technologies. This lets them adjust conditions to a variety of realistic icing scenarios. For example, they can drop the ambient air temperature by up to -20°C, blow wind through the test chamber at speeds of up to 70m/sec, and simulate rain through a nozzle. This means they can identify ice formation on surfaces, quantify the efficacy of de-icing processes, and measure the adhesive strength of the ice. They can also use, for instance, individually produced models of wing profiles, with new anti-ice coatings, for testing purposes. ∎

Martin Lehmann is the deputy head of department, lightweight structures, Division Adaptronics at the Fraunhofer Institute for Structural Durability and System Reliability in Germany


JÖRN HAASE

On the line

The networking of line-replaceable units is integral to aerospace electronics. A new system is becoming a widely used tool for analysis, simulation, and testing of distributed, embedded systems

BY JÖRN HAASE

Over the past several years, the importance ascribed to aerospace electronics has changed fundamentally. Initially, just a few line-replaceable units (LRUs) were used in aircraft, but innovations were soon increasingly based on electronics, and predominated by a share of functionality residing in software and functional integration.

This rising complexity means that extensive, reproducible and effective tests are more important than ever in all phases of LRU and system development. The widespread use of numerous electronic components causes the number of potential error sources to grow disproportionately. Some weaknesses of the overall system are not revealed until the components are integrated under real conditions during aircraft power-up. This has made testing an interdisciplinary activity that is practiced across departments, manufacturers, and suppliers.

Participants in the aerospace industry have learned lessons from the enormous electronics problems experienced in recent years, and they place great importance on testing. Nonetheless, the complex task of distributed testing can usually be made more reliable by systematic use of available tools.

ANALYSIS, SIMULATION & TESTING OF LRUs

The networking of LRUs forms the backbone of aerospace electronics. In this environment, CANoe from Stuttgart-based Vector Informatik is a widely used tool for analysis, simulation, and testing of distributed, embedded systems. It is often used to implement a remaining bus simulation, and monitor multiple bus topologies simultaneously, and it supports all significant bus systems – in particular AFDX/ARINC 664, ARINC 812/825/826 (CAN), IP, and several others. Any combination of supported bus systems can be used synchronized and in parallel from a single test system. Vector also offers multiple I/O hardware products that supplement general options with test-specific functions such as the ability to apply electrical loads and short circuits directly to the LRU ports or simply to monitor and stimulate discrete lines. In addition, commercially available interface cards can be addressed from CANoe.

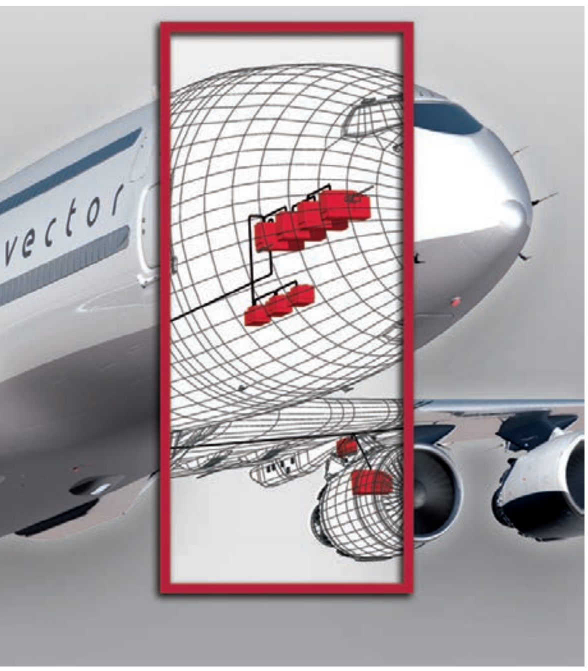
Any standard workplace PC or laptop running under Windows can be used to run CANoe. More powerful test systems with improved real-time capabilities can be set up in a real-time configuration. This approach involves executing the remaining bus simulation and the actual test execution on a dedicated computer under an optimized operating system (Windows XP Embedded), while another dedicated PC is available for the graphic user interface and evaluation. This system configuration can also be used as a test execution environment for a component HIL tester.

INTEGRATION OF TEST & DEVELOPMENT

Today's development models provide tests in various phases of development. In general, the individual tests are considered self-contained and separate activities. In this context, test creation is often also organized as an independent task, detached from other development activities.

This division of work results in a distribution of the many tasks among specialized work groups in the development process. However, if this separation is too strict, the numerous contact points between different development and test tasks cannot be optimally linked. For example, only good coordination between component and system testing can prevent expensive duplicated development of test cases that cover the same content. When compatible tools are used, test cases developed once in the various work areas can serve as the foundation for further developments.

Along with linking the various test phases, development and testing activities should be coordinated with one another. Testing should be understood as an integral part of development. What is important is that the tests should not just be available in the required formal verification phases, but should also support development. Ideally, initial tests could be performed right at the workspace or the LRU developer with the resources available there. For this



ABOVE: Simulation, testing and analysis of avionic bus systems based on CAN and AFDX

purpose, CANoe offers a runtime environment for test execution that can be used in parallel with the remaining bus simulation and analysis functions.

The remaining bus simulation is an important foundation for the tests. It does not need to be set up manually but should be automatically generated and parameterized from available databases of the system description. The actual work can be performed by so-called modeling DLLs deriving from MATLAB/Simulink – for example, the interaction layer or network management, which are supplied with the tool. Standardized interface description documents can also be used for automated scenario setups. The signals that the remaining bus simulation supplies for the simulated nodes can be acquired directly from the test scripts, stimulated or manually operated.

MATURITY ASSESSMENT & ERROR ANALYSIS

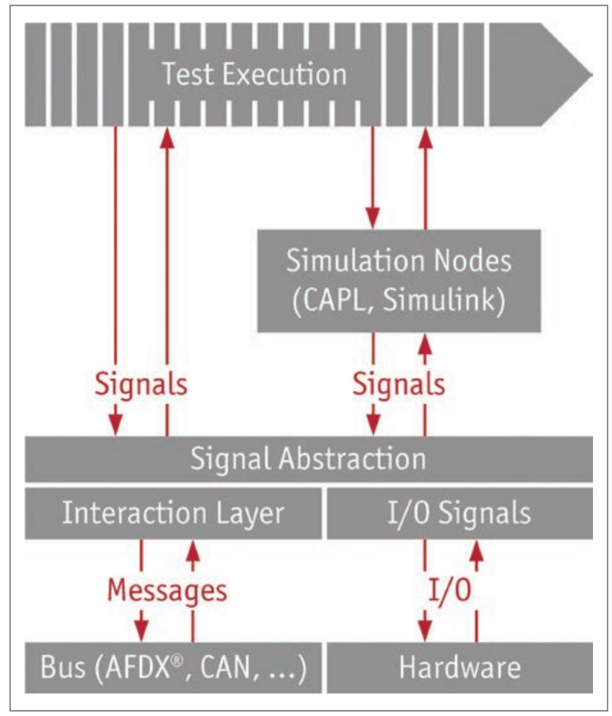
To assess the maturity level of an LRU during development, all executed tests should be comprehensively evaluated. The quality of the individual test results with regard to reliability and relevance is a key feature of a proper verification process. But it is equally important to ensure that suitable tests are used to achieve broad coverage of the required properties. The results of less formally executed tests are helpful for a maturity level analysis. A prerequisite for this is consistent reporting on each test execution.

In each execution of a test with CANoe, whether it is conducted in the test laboratory or at a work bench, a test report is created. The system generates it without intervention by the operator or test case developer, and it is therefore available without additional effort. The XML format of the reports is an open format, so that the report results are available for further processing by other tools. For example, a test management system could evaluate the reports in the context of a maturity level analysis. To ensure a reliable and traceable integration into common development chains, additional DOORS (dynamic object oriented requirements system) modules are available. These modules generate compatible test reports and ensure bidirectional traceability of requirements, test cases, and their results.

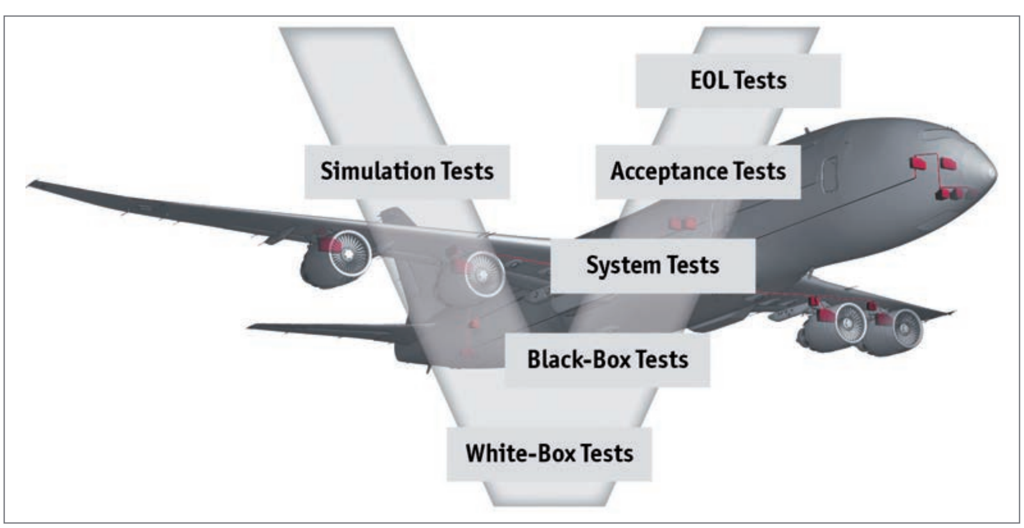
At least as important as recording and evaluating the test results is the analysis of the actual error causes. However, most test tools will do this analysis in a rudimentary way at best, partly because error analysis is often considered a separate task, one for developers to do.

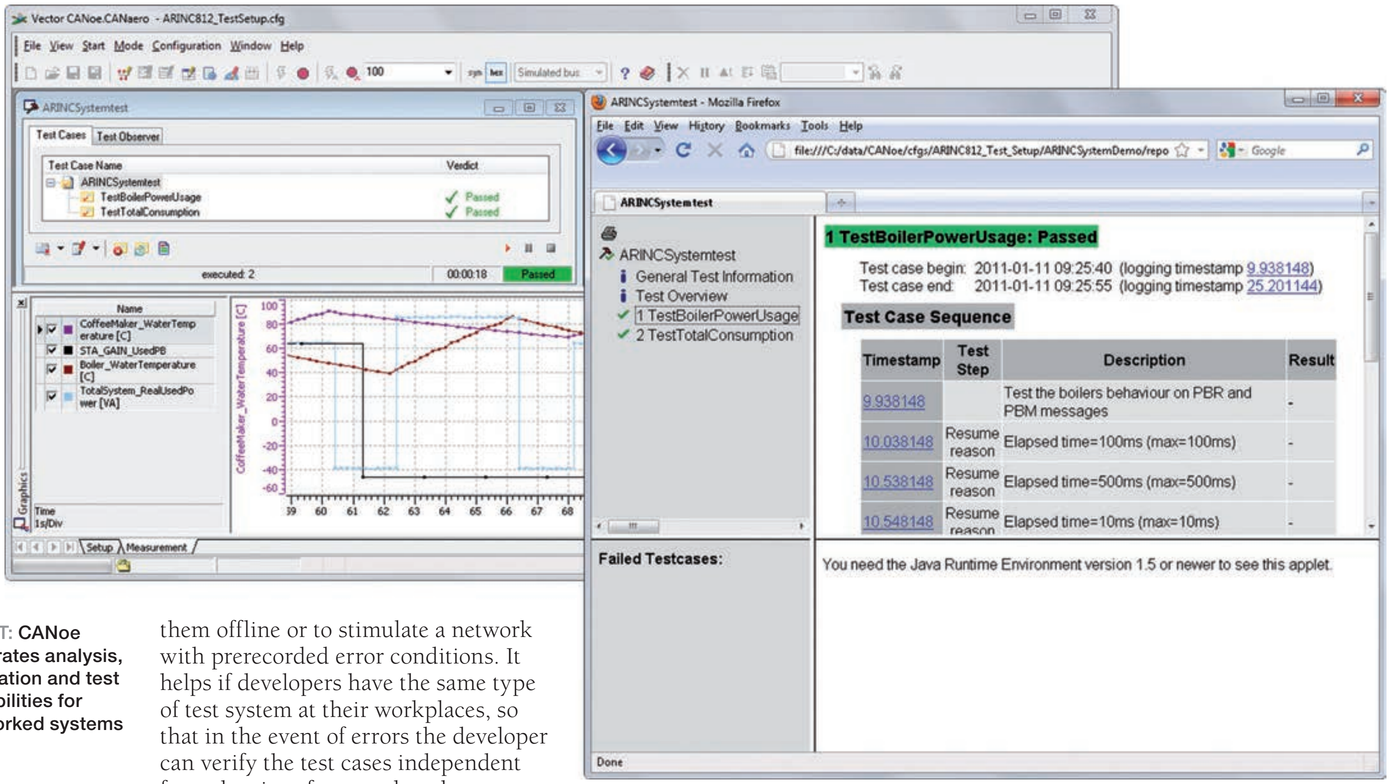
Developers are initially confronted with the problem of understanding the errors detected in the test and tracing them to their origins. Especially in the case of errors reported by test laboratories, the developer usually does not even have access to the systems used in the test.

To enable immediate evaluation of the causes of errors it is vital to obtain a precise log of the test flow and every interaction with the device under test, especially the bus communication. In the context of an analysis, the CANoe user can play back any desired recordings (logs) in order to analyze



ABOVE: Signals offer an abstraction level between messages and I/O connections, on the one hand, and test definitions and simulation models on the other





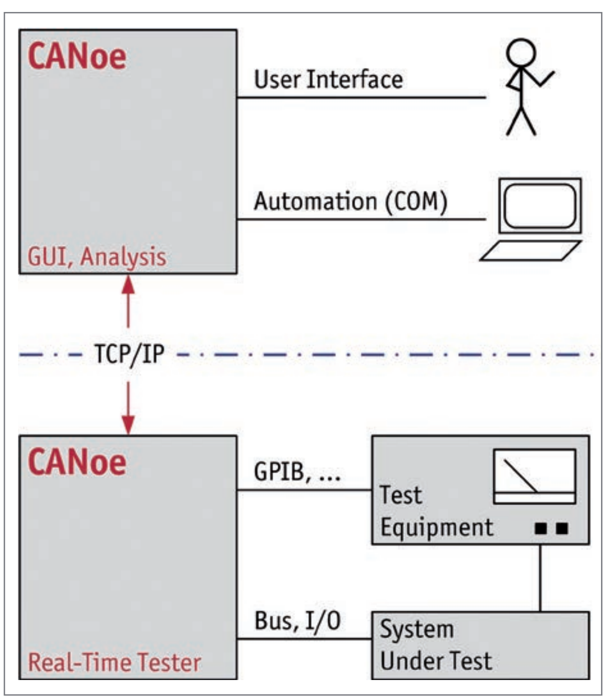
RIGHT: CANoe integrates analysis, simulation and test capabilities for networked systems

BELOW: Two-computer operation of CANoe RT (Real Time) offers improved real-time capabilities

them offline or to stimulate a network with prerecorded error conditions. It helps if developers have the same type of test system at their workplaces, so that in the event of errors the developer can verify the test cases independent from the aircraft or test bench.

SIGNAL ABSTRACTION & DIAGNOSTICS

Increasing functionality in LRUs not only increases the complexity of the systems, but also requires more extensive and complex tests. Selecting the right abstraction level in composing tests reduces the effort (and therefore the costs) required to create the test cases; it also affects the quality of the test cases. Like all other software components, the test cases themselves may even contain errors, and they must be checked before they are used.



In CANoe, the test cases, as well as the analysis options and simulation components, are based on models that are integrated in the form of databases. They might include communication matrices in DBC format for CAN or more general ICD files for various communication means and systems.

Abstraction on the signal level is useful for testing LRU functionality, as is the actual application in the LRU, which is generally placed on a signal abstraction. In the case of ARINC 812/825 (CAN), for example, an interaction layer in the LRU provides the signal abstraction. CANoe also uses an interaction layer; it parameterizes itself from information in network descriptions, which are also used to create the LRU software.

This ensures that the LRU and test environment use the same abstraction layer and are therefore optimally tuned to one another.

At the same time, signal abstraction implements the remaining bus simulation, at least on the protocol level. For example, it ensures that periodic signals are actually transmitted periodically. In testing, this gives the LRU a realistic environment in terms of bus communications. Furthermore, if changes are made to the system's communication matrix, the test cases can continue to be used – usually without modification. With the same application, the abstraction makes it possible to reuse test cases in similar projects.

DIAGNOSTIC & CALIBRATION INTERFACES

Many LRU functions can be tested meaningfully only if deeper access to the LRU is also available. These accesses are provided by the diagnostic and calibration interfaces, which are made via the LRUs' existing bus interfaces. It makes little sense to address these interfaces via simple message sequences, because defined protocols underline the communication. Therefore, suitable abstraction is needed for these interfaces.

Aviation OEMs and suppliers can cope with the growing requirements for LRU tests only by efficient test creation and automatic test execution. With the direct traceability to underlying requirements, even complex duties get manageable. The presented test tool offers a proven solution for implementing test tasks with signal abstraction while incorporating diagnostic, calibration and I/O interfaces. CANoe is a high-performance runtime environment for testing LRUs and networks. The tool permits early creation and execution of tests with a low level of effort beginning right at the developer's workplace. Open interfaces enable users to tightly integrate the tool in a comprehensive test strategy and tool-supported test management. Vector is continually developing CANoe further for use in the noted areas, supporting users with a modern, efficient test platform. ∎

Jörn Haase (Dipl.-Ing.) is the global technical aerospace engineer at Vector Informatik GmbH aviation office in Hamburg, Germany

RANAAT VAN CAUTER

Nosing ahead

Airbus has automated the A340/350/380 composite nose cowl inspection system using a revolutionary metrology called laser radar

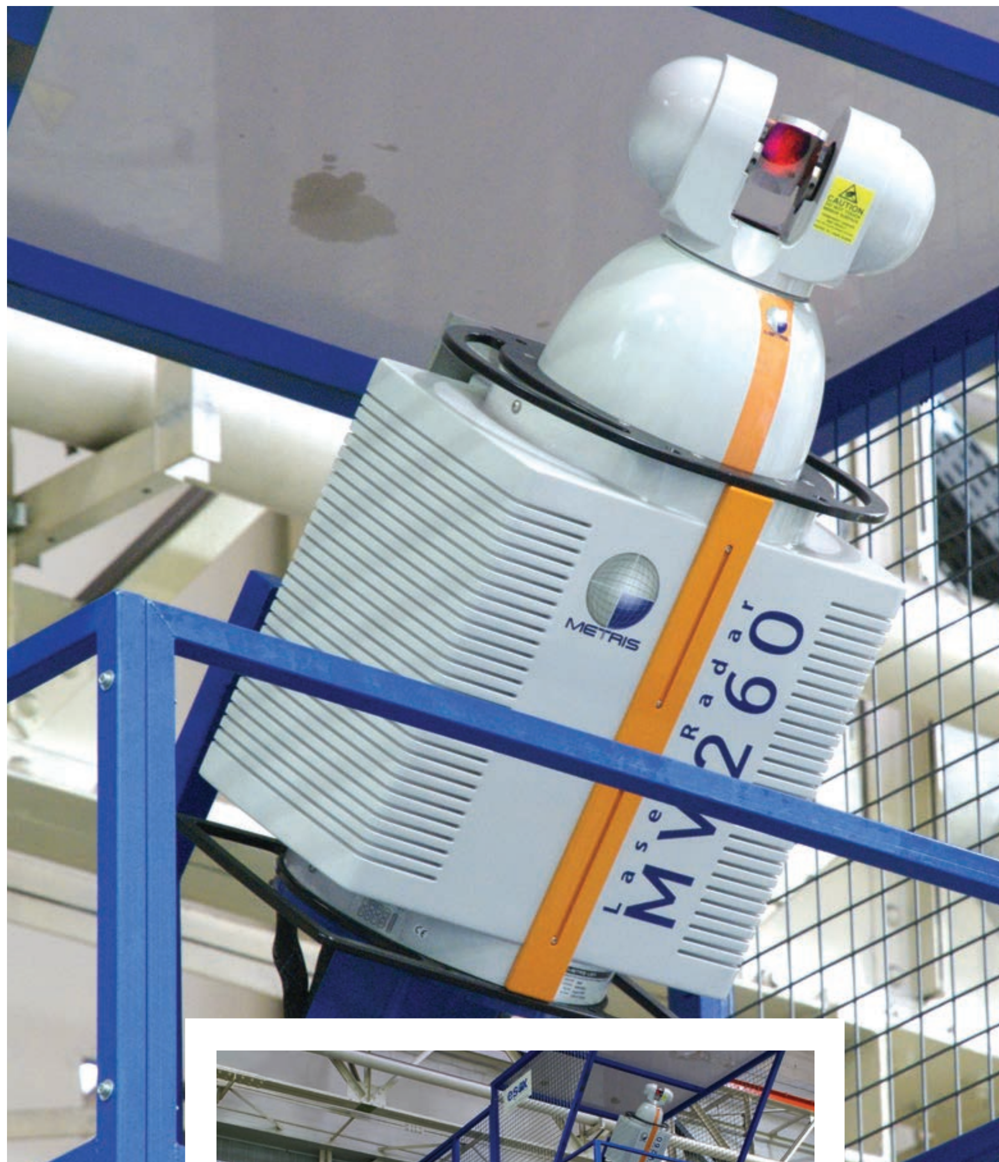
BY RENAAT VAN CAUTER

Every micron counts when aircraft are high in the sky and massive airflows are sucked in to the jet engine inlets. The size and sophistication of composite jet engine inlet cowls for the Airbus A340/350/380 aircraft call for a dedicated metrology approach. To inspect inlet cowl form and assembly, Airbus opted for a laser radar inspection cell that turns around inspection in a fast and automated fashion. Inlet cowl measurements are needed to detect deformations and assembly faults causing aerodynamic disturbances that potentially induce excess vibration or increase fuel consumption. According to Airbus, the laser radar illustrates how an integrated metrology solution offers automated targetless inspection and smooth production-floor operation.

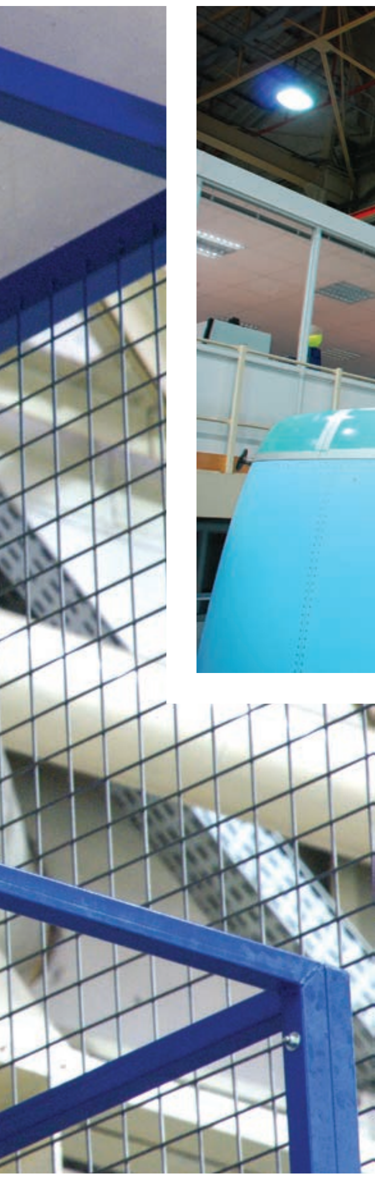
COMPOSITE PART MANUFACTURING

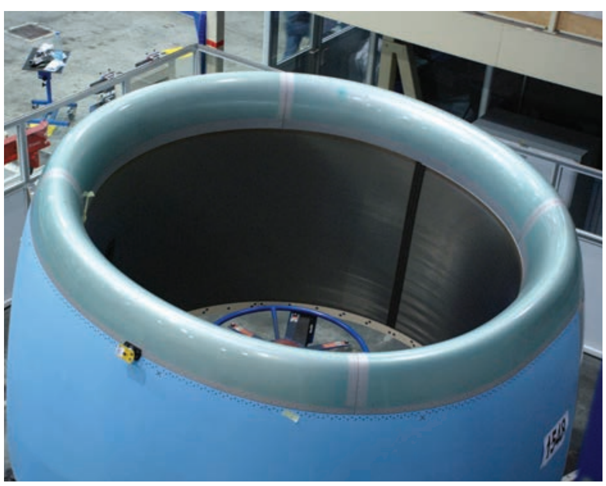
Airbus's Nantes site in France is a leader in the manufacture of composite structural parts, such as the nacelle air inlet cowls for the engines of the A340-500/600, A350 and A380. Composite materials have gained popularity in high-performance structures that need to be lightweight yet strong enough to withstand harsh loading conditions. The inner side of a nacelle air inlet is made of 'nature' composite material and the leading edge is made of aluminum. The inlet cowls are designed for low weight and minimum aerodynamic resistance to help increase aircraft mileage.

The nacelle inlet cowl is riveted and glued to the main jet engine body in Nantes. "To speed up inspection, Airbus was looking for a metrology system that is accurate and fast enough to measure the large nacelle air inlet assemblies more productively," explains Thierry Pavageau, who is responsible for the integration project at Airbus Nantes and is equipment maintenance manager for the A350 unit. The assembly of body components and engine takes place in a dedicated factory, from where the complete engines are sent to the final assembly line in Toulouse.



RIGHT: Inlet cowls are designed for low weight and aerodynamic resistance to help increase aircraft mileage





ABOVE: Airbus opted for an automated laser radar inspection cell, which drastically speeds up nose cowl inspection

LEFT: Laser radar executes automatic freeform surface and gap-and-step measurements at every increment of the rotating nose cowl

"OTHER MEASUREMENTS INVOLVE THE ANTI-ICE INTERFACE, WHICH CAN BE ACCESSED BY THE LASER RADAR USING A MIRROR"

The engines themselves are manufactured by Engine Alliance (CFMI, Pratt & Whitney) and Rolls-Royce, depending on the model and type.

METROLOGY LED TO LASER RADAR

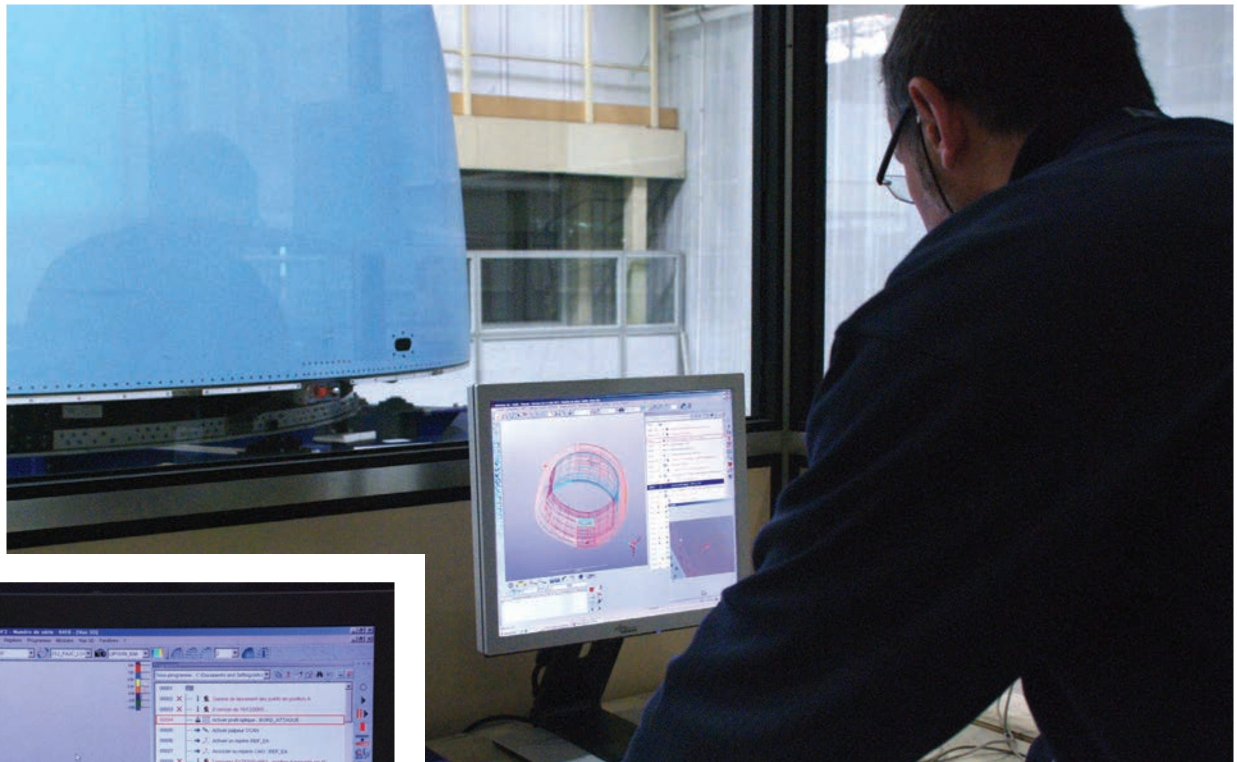
The laser radar measures the freeform internal and external cowl surfaces as well as the precise gap and step between the leading edge and those surfaces. "We analyze the acquired data to ensure high-quality assembly and part mating. From an efficiency standpoint, it was important for us that the entire process from measurement to final report could be executed automatically with just a single mouse click," says Pavageau.

When looking for a suitable measurement solution, traditional CMMs were eliminated as the inspection of composite materials is best conducted using a non-contact technique. Also the necessary foundation on the shop floor and part loading system for a gantry CMM suitable for measuring objects of this size is very costly.

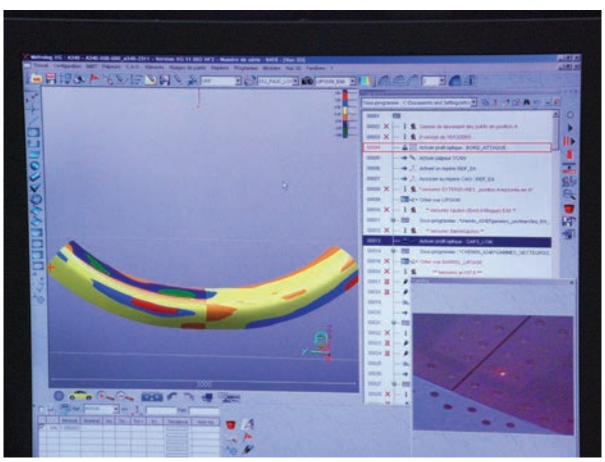
At the time when the system was selected, the use of 3D laser trackers was also not an option for an automated application as they required an operator to hold a spherically mounted retroreflector (SMR) or a handheld probe. Human interaction slows down the inspection process and is too error prone to comply with Airbus's extreme safety precautions. Photogrammetry was also investigated, and although interesting for surface inspection, it did not provide an appropriate solution for 'gap-and-step' measurement. Airbus finally opted for the integration of a laser radar system, which combines automated non-contact laser measurement, surface and feature scanning, and a dedicated gap-and-step analysis function.

COMPLETELY AUTOMATED OPERATION

Nikon Metrology teamed with Metrolog and Spatial Analyzer to deliver an automated inspection solution with fast throughput cycles. In the integrated inspection cell in the



RIGHT: The Metrolog software synchronizes the rotation of the Airbus nose cowl with the laser radar measurements



ABOVE: The color-coded areas graphically illustrate the geometric deviation of the leading edge

> "DURING A SINGLE REVOLUTION, THE LASER RADAR MEASURES OVER 1,000 SURFACE POINTS TO CAPTURE THE 3D GEOMETRY OF THE LEADING EDGE"

Airbus assembly hall, the laser radar system is mounted on a post up in the air, in a fixed tilted position using a custom-designed frame. A technician operates a large gantry crane to correctly position a nose cowl assembly on a large rotating table on the production floor, ready for inspection.

"A single click on a button starts the automatic measurement and analysis procedure," explains Pavageau. "The laser radar references the rotating table by measuring small tooling balls. The Metrolog software controls the rotation increments of the part and the acquisition of data. During a single revolution, the laser radar measures over 1,000 surface points to capture the 3D geometry of the leading edge. The inspection cycle also covers scanning 250 gap-and-step positions to evaluate part mating between leading edge and inlet body. Other measurements involve the anti-ice interface, which can be accessed by the laser radar using a mirror." When directing a focused laser beam to a point, the laser radar only requires a billionth of the reflected light to precisely measure the absolute range to the point, with 250 micron accuracy over a 25m distance," says Pavageau.

He notes that all the results are instantly processed and summarized in an easy-to-interpret report. "Color-coded areas on part-to-CAD comparison charts graphically illustrate the geometric deviation of the leading edge and other surfaces. The operator verifies out-of-spec tolerances, and in case of anomalies informs the quality department for further investigation."

LASER RADAR REDUCES INSPECTION TIME

Airbus is satisfied that the complete inspection cycle from nose cowl positioning to graphic report is completed in only 90 minutes. "The optimization of the automatic inspection cell saves us 2.5 hours of inspection time for every A340/350/380 nose cowl assembly that passes through the cell," concludes Pavageau. "This means a 60% productivity increase in comparison with the old station. Important in streamlining this process was the introduction of the laser radar instrument and the enhanced calculation algorithm for gap-and-step measurement. Furthermore, no operator action is required whatsoever because the laser radar system eliminates the use of photogrammetry targets, retro-reflectors and handheld probes."

The laser radar inspection cell was originally deployed for inspection of A340/A380 engine cowls and has recently been approved for inspection of A350 engines. ▮

Renaat Van Cauter is the director of marketing communications with Nikon Metrology, based in Belgium

KLAUS HAMMERL

Look below the surface

Recent trends in the MRO sector have driven the demand for high-quality endoscopic inspection solutions

BY KLAUS HAMMERL

Industry forecasts have underlined the fact that the aviation industry remains a growing sector with an overall long-term global growth projection. In particular, growth is being stimulated by the rise in air traffic in Asia and India. This sector will undergo strong changes due to key trends that will affect the maintenance, repair, and operations (MRO) sector, driving the need for professional endoscope inspection solutions that ensure the highest level of optical performance, combined with precise measurement and sophisticated documentation.

Established airlines are forced to compete with a growing number of low-cost operators, in particular for regional air traffic, which is projected to grow strongly in Asia and Eastern Europe. In addition, airline operators have to face the challenge of continuously rising fuel prices. Airlines are exerting increasing pressure on vendors to improve cost structures and performance of the supply chain, allowing them to focus on their core business and competence.

Though the dynamics of the MRO business have been changing for many years, the pace seems to be accelerating due to the general trends in the air transport sector. These key changes include outsourcing MRO. As airlines outsource more maintenance work and focus on their core business, opportunities open up for new companies to compete in the MRO space, thereby increasing competition, expanding the potential for improving service, and driving down costs. Low-cost carriers are leading the way in outsourcing MRO.

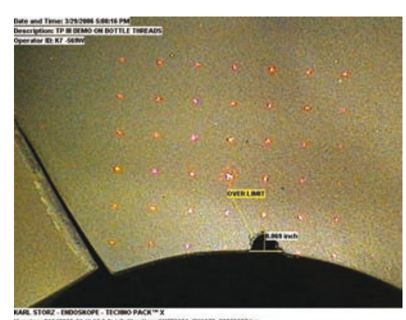
Globalization is also a major factor. Low-cost labor locations, such as India, Latin America, and China, are now set up for MRO service centers. Asia is seeing net inflows in labor-intensive airframe heavy-maintenance MRO activities, whereas the USA is a net exporter.

New technology trends are also an effect and major influence. Several technology trends are further changing the structure of MRO by requiring that service suppliers have the skills to keep up with these advances. Key topics are green engines, composite materials, and more electronic functionality to facilitate prognostics and health management (PHM) – being proactive, rather than reactive, by monitoring and assessing the health of a part or component in real-time, predicting failure and determining appropriate actions. PHM can help optimize maintenance scheduling and possibly change who controls it.

Inspection of a fighter in the German Army

GETTING SMALLER AND LIGHTER

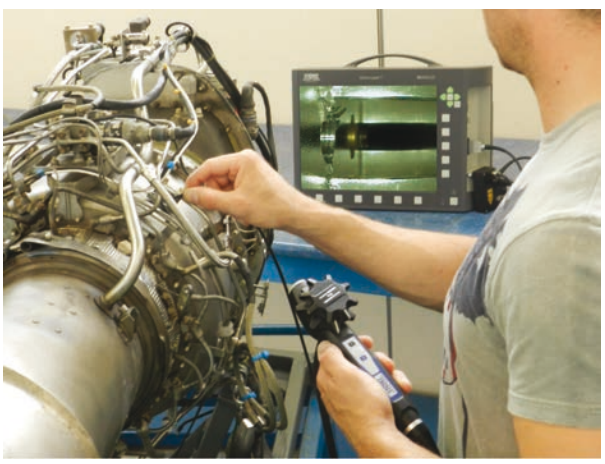
The trend of using of smaller, lighter, and less expensive endoscope systems will not lead to compromises on image quality. Over the past few years, more endoscope manufacturers have launched smaller, lighter systems with smaller diameter probes to meet the



ABOVE: Multipoint measurement (line to point) at a turbine blade

"ANY COMPROMISE ON QUALITY MEANS A COMPROMISE ON SECURITY AND THIS IS UNACCEPTABLE IN THE AVIATION INDUSTRY"

RIGHT: Image made with a videoscope in a combustion chamber



ABOVE: Inspection of a helicopter turbine with the 4mm videoscope with Click4Move articulation and Techno Pack T

Inspection of a turbine in a hangar with Techno Pack X System Case

need to get into very small spaces or to ensure high mobility. The overall performance of these compact systems has improved, due to advances in imager chip and light source technology. However, customers in the MRO business confirm that the drive toward smaller and lighter endoscope solutions must compromise image quality or measurement capabilities and precision. Any compromise on quality means a compromise on security and this is unacceptable in the aviation industry. In addition, use of inadequate inspection tools may lead to higher costs. When technicians decide to keep an aircraft on the ground, this triggers enormous costs – capital costs, repairs, leasing, etc.

The increasing cost pressure and the limited availability of qualified technicians leads to increasing time pressure for engine inspection to ensure more throughput.

Turbines are highly complex. It goes without saying that in many cases different diameters and lengths of probes are required to inspect systems, such as HPC, LPC, combustion chamber, J-hook and even APU engines. The ideal endoscope processor should work with all the probes needed for each type of inspection; customers should not be forced to purchase one processor for each probe.

The aviation sector confirms that customers look at overall systems costs and functionality instead of looking at low-cost systems with small screens, cheaper optics, and LED illumination. Karl Storz offers a complete portfolio of rigid and flexible videoscope probes for each engine and aircraft type. Next to performance, system reliability, and customer service are the most important factors that determine the cost of ownership. The company has established technical support and local service and training centers in key regions, including the USA, Turkey, and Germany.

DIGITIZATION AND MEASUREMENT

Aircraft engine inspectors record all their work as images and videos to keep an archive and for report writing. For future evaluation and comparison, it is fundamental that the quality of live and recorded images should be at the same level. For sustainable evaluation of images and measurement images, high-quality resolution of stored images and sequences is essential. Therefore systems need to ensure that images are stored uncompressed and, if compression is used, the software needs to be very sensitive to prevent any important pixel loss.

The measurement functionality is important for the assessment and validation of defects. Multiple methods are available. Karl Storz has developed a proprietary laser-based measurement technology that is very well perceived due to its preciseness and reliability and ease of use.

It is straightforward, laser-based 3D measurement ensures precise measurement in universal positions and on different surfaces. ∎

Klaus Hammerl is product manager for Karl Storz industrial group, based in Germany

HELMUT FAHRENHOLZ

Composites: one does not fit all

Addressing the major challenge of qualifying composites for aerospace applications

BY HELMUT FAHRENHOLZ

In response to changing market conditions, aerospace industry professionals are increasingly exploring the use of fiber-reinforced composite materials. A primary motivation for their introduction is the drive to increase fuel efficiency while optimizing manufacturability and serviceability.

Leading airframe manufacturers have adopted advanced composite materials to address design and maintenance challenges. The recently introduced Boeing 787 Dreamliner employs advanced composite materials to construct the majority of the airframe.

Composites enable the stiffness and strength of the material to change with directional loading. The most efficient use of composites in aircraft is in applications with high fatigue loads and areas susceptible to corrosion. Unlike metals such as aluminum, which is subject to corrosion and fatigue cracking, composites are more stable in harsh environments.

The use of composite materials in aircraft is highly regulated. FAR 25.603, for example, addresses tests that determine the suitability and durability of the material, including its strength and ability to meet environmental challenges.

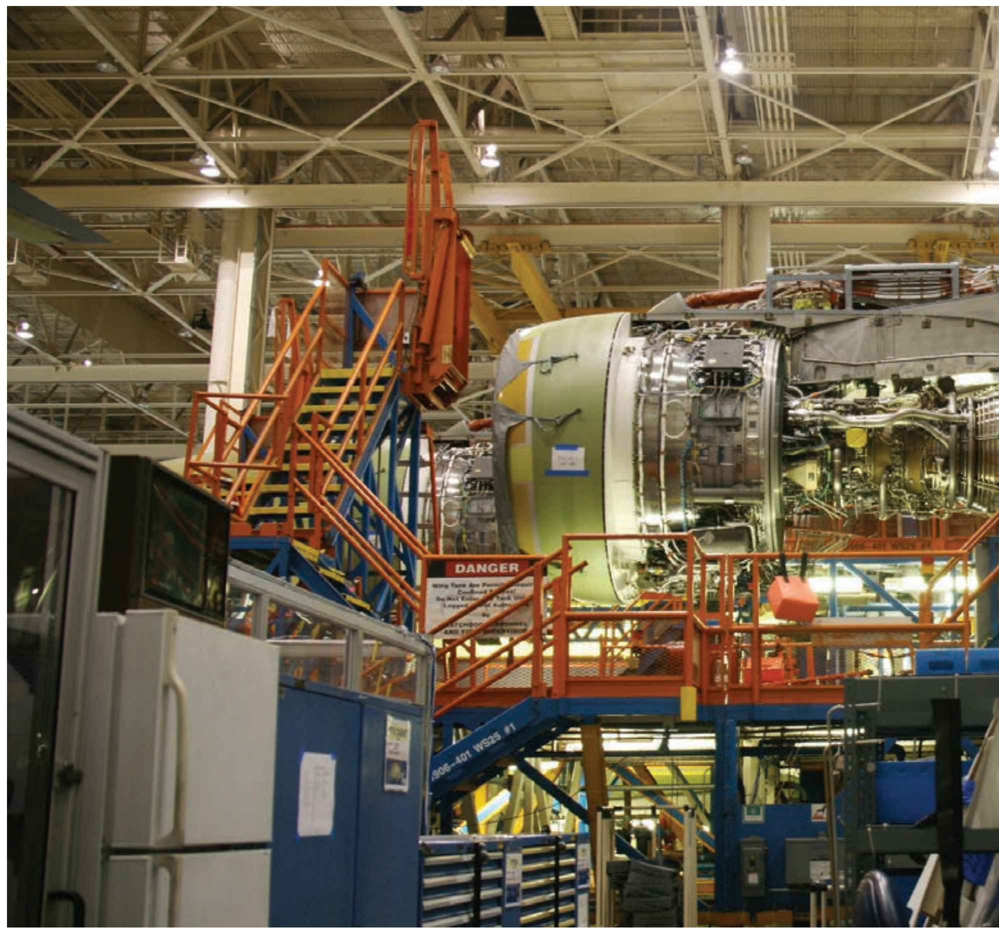
A key factor contributing to the advance of novel composite materials is the growing ability to tailor materials to have specific properties. Proper characterization of those properties through physical testing is necessary to ensure composite materials are meeting specifications.

FIBER ORIENTATION

Fiber orientation in composites makes measuring their properties disproportionately more complex than for other materials, such as metals and plastics, according to Bill Becker, aerospace industry manager at Zwick USA, a subsidiary of Zwick/Roell, a global supplier of composite material testing solutions.

"Fiber-reinforced composites provide high strength and stiffness in combination with low weight. They consist of thin fibers that are either directionally or randomly oriented and therefore require different tests according to fiber orientation," says Becker. Composites have many failure modes, and typical parameter reduction for testing and analysis of homogeneous materials such as metals and plastics are not applicable, according to Dr Douglas Cairns, professor of mechanical and industrial engineering at Montana State University.

"If the coupon being tested has the same materials and manufacturing processes as full scale applications, the testing can be used to predict performance," he says. "Furthermore the coupon should not introduce different failure modes, nor eliminate potential failure modes at the material level compared with the intended



ABOVE: Boeing's C-17 Globemaster III undergoing construction. (Picture: Katrina Brown)

TOP RIGHT **Fully automated set-up for tensile and compression testing of carbon fiber materials at Hexcel Duxford, UK**

application. In some sense this is the holy grail for composites."

Qualifying a new material for a primary aerospace structure using the building-block approach can cost as much as US$50 million, according to Boeing St. Louis, hence the great incentive to streamline this process.

Further motivating airframe manufacturers' emphasis on testing efficiency is the complexity of tests that must be undertaken to ensure robust qualification of fiber-reinforced composites.

"Composite materials are not isotropic, so they exhibit different material properties and failure modes in different planes," Cairns says. "At a minimum, the planes for any material properties in the principal material axes have to be characterized. Furthermore failure modes may interact, such as in-plane failure combined with delamination through the thickness. Typical uniaxial testing may not capture these potentially important interactions," he says.

Multi-axial testing to obtain interactive constitutive and failure property data would be a substantial advance for testing of composites. "This is necessary not only for empirical database development, but also to validate multi-axial failure criteria for composite materials and structures," adds Cairns.

"COMPOSITE MATERIALS ARE NOT ISOTROPIC, SO THEY EXHIBIT DIFFERENT MATERIAL PROPERTIES AND FAILURE MODES IN DIFFERENT PLANES"

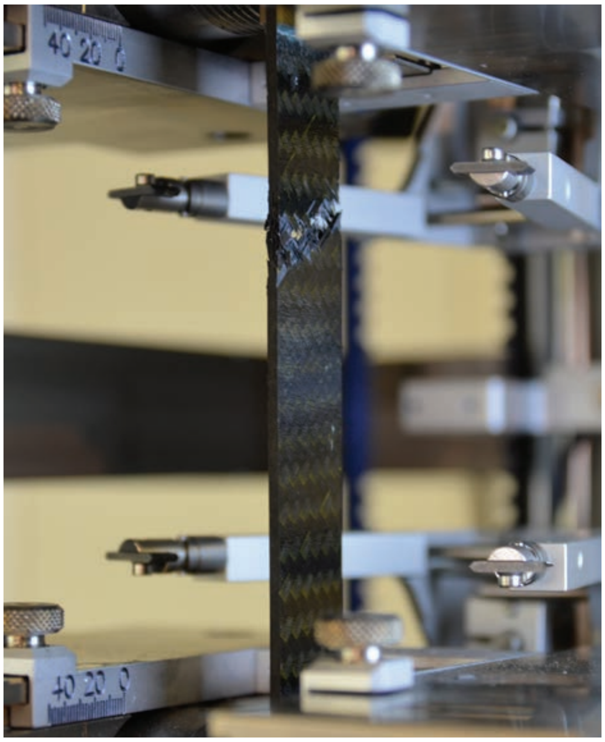
PROCEDURES AND STANDARDS

Testing of composite materials is also complicated by the broad array of standards and test procedures in use. There are currently more than 150 standards – some more than 30 years old – that describe the physical testing of fiber-reinforced composites. In addition to the international and national series of standards from ASTM, ISO, EN, and DIN, there are aerospace industry standards, developed by Airbus, Boeing, and NASA, plus standards from associations that no longer exist, such as the Suppliers of Advanced Composite Materials Association (SACMA).

Materials testing initiatives for fiber-reinforced composites must therefore take fiber orientation into account and apply different tests accordingly. These tests are described in international standards (ISO), in national and regional standards (ASTM, EN, DIN) and in companies' own standards (Airbus AITM, Boeing BSS).

Tests commonly used to evaluate tensile strength, shear strength, and fatigue properties of metals are not as straightforward in the world of advanced composites. For example, characteristics described by the tensile test differ greatly according to fiber direction and structure.

Compressive and flexural properties cannot be predicted on the basis of tensile properties, and must therefore be tested independently. For shear properties, several test methods have evolved to enable the



ABOVE: Zwick's new Allround-Line system for characterization of composites. The system accommodates 13 test fixtures for testing under both ambient and non-ambient test conditions

> **"COMPRESSION TESTING ENABLES MEASUREMENT OF THE PROPERTIES OF THE ENTIRE COMPOSITE IN ADDITION TO FIBER STRENGTH"**

characterisation of properties in different shear directions. Fatigue tests, essential to aerospace structural applications, must also take into consideration a wide range of temperatures and levels of humidity.

In addition to classic tensile, compression, and flexure tests, there are several tests specific to composites. In the aerospace industry compression-after-impact (CAI) testing is used to investigate a composite material's tolerance to damage induced by a bird strike or contact with other foreign objects in flight.

Typical tests conducted on fiber composite specimens include shear, end and end-loading compression; plain, open-hole and filled-hole tensile; and open-hole compression (see figure on left). This characterizes the three normal stresses in a nine-component stress tensor.

The six shear stresses of this tensor can be found by specific test methods such as the ±45° in-plane shear test, the V-notch shear test, lap shear test and, for the materials qualification, the short beam shear test.

"In response to growing customer demand for enhanced test lab efficiency, Zwick has recently introduced a new system in the Allround-Line that streamlines testing and addresses the unique requirements involved in the characterization of composites," Becker explains. "It enables customers to perform more than 20 types of tests in compliance with over 100 standards using a single testing machine."

ALL-ROUND TEST VERSION

To satisfy the varying requirements, companies and testing laboratories previously had to use a number of testing machine arrangements, some of which were very complex. Zwick's efficient modular solution is based on the Allround-Line testing machine and is available in 100 and 250kN versions, with two lengths. A temperature chamber to accommodate non-ambient testing in the range of -70 to +250°C is optionally available.

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

"A major benefit of the new Allround-Line system for composites testing is the wide range of test fixtures that can accommodate tests under ambient and non-ambient test conditions," says Becker.

"With the Allround-Line system, additional fixtures for three- and four-point flexure tests, ILSS, and the Iosipescu V-notch shear test may be conveniently attached via slide-in inserts used in the tensile grips in place of jaws. The inserts enable rapid equipment changes, with the added advantage of maintaining the preset axial alignment of the specimen grips."

FULLY AUTOMATED TESTING SYSTEMS

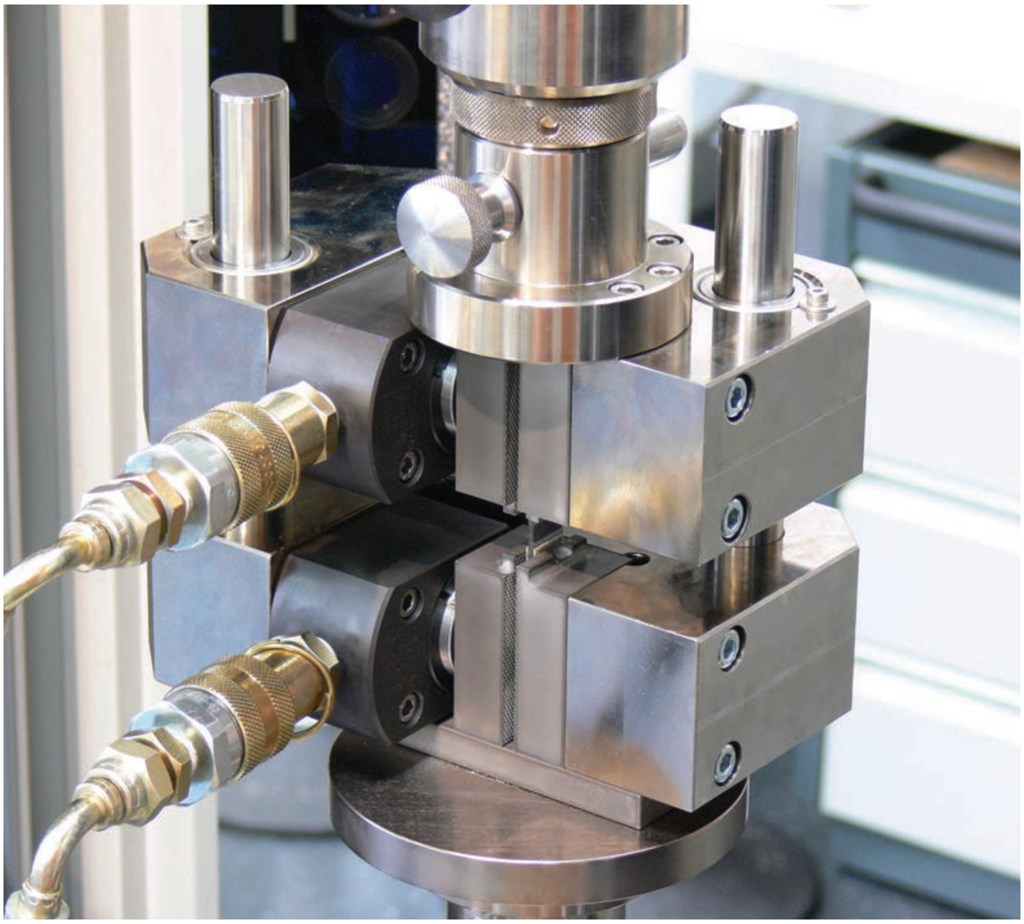
Hexcel Duxford, UK, was the first composites supplier in the world to use fully automated testing systems, according to Alan Thomas, marketing manager, Zwick Testing Machines. Automated systems have since been put into operation on both the OEM and supplier sides of the aerospace industry, performing tensile tests on filament threads as well as test coupons, measuring in-plane shear strength and determining overlap shear.

Fully automated sequences may be used to determine flexural properties via three- and four-point test methods, as well as interlaminar shear strength under ambient and non-ambient temperatures.Among Hexcel's motivations for the introduction of automated testing were the reduction of in-batch variation and the opportunity to precondition test specimens for tests occurring at non-ambient temperatures, thereby boosting test throughput.

According to Thomas, one of the primary strengths of the automated system is its ability to test a set of specimens with very little temperature variation between them.

"Hexcel's applications call for extremely high throughput in the test laboratory. Because of this, the test engineers require a solution that can deliver consistent results while maintaining a pace that fulfills the quota for specimen throughput. The roboTest automated system is synchronized with the Allround-Line testing system. The roboTest system then precisely aligns and inserts test specimens into a set of hydraulically controlled tensile grips, or onto a flexure fixture, through a specially designed door in the temperature chamber. The grips are then engaged and the test sequence begins according to a preset temperature specification," he says.

"Installation of the automated testing system at Hexcel's Duxford site has enabled the company to achieve levels of test throughput not possible with typical systems – and without sacrificing accuracy in results."



Compression testing enables measurement of the properties of the entire composite in addition to fiber strength. The challenge lies in inducing compression deformation up to material failure if possible, without buckling; this means avoiding bending in a flat, planar specimen. Various methods have been developed for this, including end loading and shear loading.

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

To determine the compression modulus, specimen grips without bonded tabs are used to ensure exactly axial loading of the composite in the measurement range. To measure tensile strength, specimens with bonded tabs are used to avoid premature destruction of the composite at loading points.

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

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

COMPRESSION FIXTURE

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

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

While test fixtures form the contact between specimen and test device, software provides the link to the operator, giving access to test sequences, evaluation, data storage, and logging.

Pre-configured standard test programs relieve the operator of complicated set-up operations and ensure test repeatability. In addition to displaying curve graphics and results, Zwick's testXpert II measurement and control software also enables typical misalignment and flexure monitoring functions.

Increased levels of testing and an increased emphasis on test repeatability have placed the issue of automation in the spotlight. Robotic positioning systems ensure exact specimen placement. Additionally routine tests may be performed outside the normal working hours of the laboratory, representing a genuine increase in test throughput. ∎

"WEDGES MUST BE KEPT CLEAN AND UNIFORMLY LUBRICATED TO ENSURE SUFFICIENT AXIAL LOAD TRANSMISSION"

Helmut Fahrenholz is the industry manager for composites at testing machine manufacturer Zwick GmbH & Co based in Germany

DIETER KONNERTH

Closing the net

As aircraft become more and more complex, new concepts are looking at large-scale system network integration

BY DIETER KONNERTH

The drivers for the increase in complexity of aircraft systems from one aircraft generation to the next are: the demand for more functions, more comfort, fuel saving, improved maintenance capability, and more safety. Add to these the increased possibilities of data processing equipment, which, as usual in technology, will also create demands and therefore new complexity.

The latest commercial airliners (Airbus A380, Boeing 787, Airbus A350, and newcomer COMAC C919) have a fairly similar IMA system architecture – an AFDX (ARINC664) backbone network, which connects general-purpose computing, and I/O resources, which are shared by the various aircraft functions. The high-bandwidth network-centric architecture with shared resources, the increased number and complexity of the functions themselves, and especially the huge number of exchanged parameters (millions), have significantly increased the complexity of integration and verification of such systems.

As a consequence, new concepts and technologies are required to cope with these challenges.

SYSTEM TEST APPROACH

The classical approach for system testing is mainly applied at equipment, system, and aircraft level. There is little, if any, interaction between the different verification levels.

Especially when testing at aircraft level, it is difficult to isolate problems by reverting to system or even equipment level testing. Very often, aircraft level testing used to be 'big bang' testing, i.e. connect all systems together, connect to power, and see what happens. If nothing bad happens, start to execute test cases.

The concept of model-based incremental integration helps solve some of the problems: by starting with only a small subset of real systems and simulating the others and then, step by step, replacing simulations with real systems until all aircraft systems are running together with only the environment (flight, weather, cabin, etc.) being simulated.

RECONFIGURABLE NETWORKED TEST ARCHITECTURE

The next level of improvement is an environment where this process is parallel and revertible. This means that integration starts in parallel with multiple individual systems/system clusters, which are integrated step by step with other clusters created in parallel. Revertible means that at any time when a problem needs to be isolated, it is possible to revert to smaller clusters, individual systems, or even equipment level testing.

Such an approach, although very helpful, is extremely difficult to manage. It needs a high degree of test bench hardware and software reconfiguration, which may lead to very long test setup times. To cope with this complexity, powerful tools are needed to automate, verify, and document test environment reconfiguration. The goal is to

CONSIDERATIONS FOR IMA ARCHITECTURE

For IMA-based aircraft architecture, the situation gets more complicated because of the shared computing, I/O, and network resources. Additionally, the approach needs to differentiate between centralized IMA systems, like in the Boeing 787 and the COMAC C919, and distributed IMA systems, like in the Airbus 350.

To be able to separate systems into different autonomous test benches, shared IMA resources have to be duplicated into each individual system or be shared, but then only one system can be tested at a time.

In the event that completely shared IMA resources parallel separate testing of systems is not possible, the complete duplication of IMA resources in every test bench is often unfeasible for cost reasons. Practical solutions to the dilemma will share some and duplicate some of the IMA resources as derived from specific test requirements and budget restrictions.

ABOVE: AFDX switches for LAB and flight test instrumentation

reconfigure a test environment within a few minutes, which manually would take many months.

The basic concept of the networked reconfigurable test architecture is simple. In the first step, individual system test benches are used for testing isolated aircraft functions. The environment of the system under test is simulated by the test bench. By combining multiple benches into a cluster, the corresponding aircraft equipment is interconnected like in the aircraft. This is achieved by providing relays and reconfigurable AFDX switches, which are automatically configured according to the test scenario.

This principle is illustrated in the diagrams shown overleaf. Test bench A is used to test system A. To this end, it needs to simulate system B as well as all other environments of A (summarized as X). The same applies for system B.

For the integration of system A and system B the test environment has to be reconfigured: signals from A to B and from B to A have to be rerouted, and simulations of systems A and B have to be removed; instead, data exchange between system A and system B has to be monitored and finally the test benches have to be synchronized, common state information has to be shared, and the systems need to be controlled centrally.

Care has to be taken to maintain representativeness of the test environment in terms of the tested functions. The two aspects to be considered are: wiring between systems has to be representative in regards to voltage drop, signal attenuation, and noise, even if signals are routed through switches; and simulations on the integrated benches must be synchronized to represent one integrated physical entity, i.e. the aircraft.

NETWORKED TEST SYSTEM PLATFORM

Usually, the complexity of the test environment easily matches, if not exceeds, the complexity of the systems under test. Therefore, powerful tools are needed for the configuration and control of the test environment.

What are the major requirements for a test system technology supporting the networked test approach described above?

It must support the automated clustering of systems by reconfiguration of I/O resources, wiring, simulations, and data flow between test benches.

It must be able to cope with the sheer size of the job: in a real aircraft integration application it must handle hundreds of attached equipment items, many thousands of I/O interfaces, millions of process variables, hundreds of different simulations, hundreds of control and monitor panels, etc.

It must allow for highly representative test scenarios: high fidelity real-time simulations,

"THE GOAL IS TO RECONFIGURE A TEST ENVIRONMENT WITHIN A FEW MINUTES, WHICH MANUALLY WOULD TAKE MANY MONTHS"

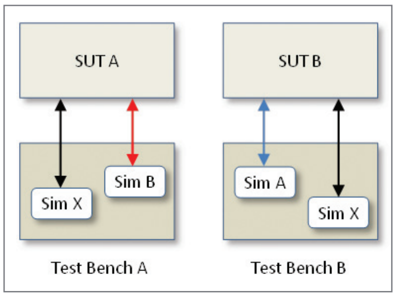


Fig 1.

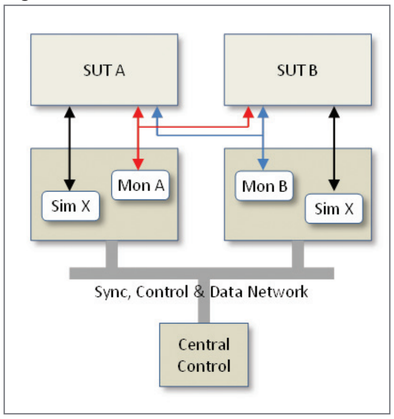


Fig 2.

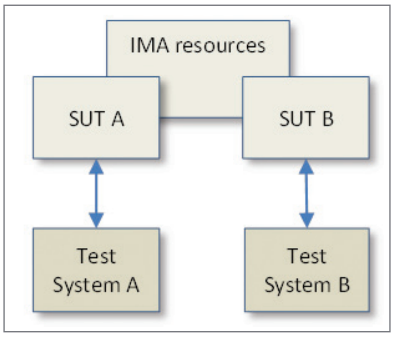


Fig 3.

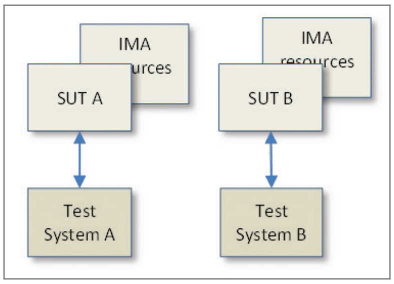


Fig 4.

ABOVE LEFT: **Fig 1: Standalone operation of two benches. Fig 2: Integrated Operation. Fig 3: completely shared IMA resources. Fig 4: completely duplicated IMA resources**

ABOVE RIGHT: **Typical LRU integration station**

original aircraft wiring between components, and accurate signal and load simulation.

It must support a very complex configuration and change management. During the integration of an aircraft there are thousands of changes to requirements, equipment, signal databases, simulations, wiring, etc. All these changes must be traced and it must always be possible to revert to a previous configuration.

TechSAT, a company specializing in large-scale integration facilities for the aerospace sector, together with its partners, responded to the above requirements of the aerospace industry and developed a completely new generation of test system technology supporting incremental integration in a flexible networked environment. The technology was initially used in the integration lab of a major airliner and is currently optimized and adapted for other application domains, mainly avionics and flight control integration. Due to the modular and flexible approach, the technology is also applicable to system or subsystem verification.

The base for the technology is the distributed real-time test engine, ADS2R3. It supports running simulations, I/O, monitors, visualization and control panels, and data recording in a distributed networked environment. Data, synchronization, and control are distributed over the network. The data distribution is automatically configured by the data distribution layer according to the producer/consumer relationship.

The system is scalable from a single PC with a small number of I/O channels to huge networks with dozens of networked nodes and many thousands of I/O channels. The highly optimized data distribution layer can handle a large number of data parameters (millions) distributed at frame rates of a few milliseconds. Faster systems are running at a fraction of a millisecond. Each node can execute several simulations on multi-core CPUs on a real-time OS, as well as I/O under control of a flexible multi-rate scheduler.

The system supports all I/O types commonly used in aerospace. Ethernet-controlled switching devices are used to switch between simulation and real equipment, as well as for electrical error injection, such as open and short circuit.

AUTOMATED SYSTEM CONFIGURATION

On top of these base services, a versatile cluster management tool (ADS2/CLM) can be used to automatically configure all elements of the system. The cluster manager imports the aircraft ICDs, describing the interfaces of all connected aircraft systems and equipment, as well as the interfaces of all available simulations into its database.

Additionally, it imports the formalized description of the test bench hardware with all its computers, I/O resources, UUT mounts, and cables. From this information and a high level session description specifying which systems are to be integrated into a test session, the cluster manager computes the configuration of the complete system. This includes the configuration of all I/O cards, auxiliary AFDX switches, the positions of the relays, and the communication between all the test facility applications and computer nodes.

The test system platform presented here is the answer to the increasing complexity of aircraft system integration. Through its automatic configuration and automatic testing capabilities, it supports the shorter development schedules for new aircraft models. ∎

Dieter Konnerth is the director of research & development at TechSAT GmbH, based in Germany

ESMERALDA CUEVAS

A theory of evolution

Massive developments in NDT have led to the advancement of ultrasonic inspection of composite materials

BY ESMERALDA CUEVAS

In a bid to reduce costs and be more environmentally friendly, the aerospace industry is constantly looking to save weight when manufacturing components. As a result, there are increasing amounts of composites in structures, and new materials and new geometries are emerging.

Ultrasound is a well-known and proven technique for quality assurance, and following this evolution, new techniques are being introduced beyond the application of phased array, such as laser ultrasonics or other complementary techniques, such as thermography. Also, new concepts are applied to the manipulators, based on industrial robots, which bring high productivity, accuracy, reliability, and easy maintenance to the equipment.

COMPOSITE MATERIALS

One of the parameters that influence the definition of NDT is the material of the components to be inspected. The current trend in the aeronautical sector is reducing the presence of metals in the manufacturing of aircraft and increasing the presence of composites. Consideration should be given to the appearance of defects different from those known for metals and the need to prevent the galvanic corrosion of adjacent components made of aluminium. All these are challenges to be taken into account by the inspection process.

In addition, different types of materials have to be inspected. These include solid laminated parts of different thicknesses and sandwich components (single or double) in aluminum or paper honeycomb structures. When defining the inspection of these components, it is first necessary to look at their behavior with respect to ultrasounds, bearing in mind the attenuation of the signal, the need of air-coupled ultrasonics or thermography, and even if the surface can facilitate the inspection carried by laser ultrasonics.

GEOMETRIES OF COMPONENTS

Another aspect that has a fundamental influence on the NDT inspection of aeronautical components is its

geometry. Ultrasonic testing (UT) inspection has to deal with increasingly complex geometries and greater sizes and lengths. Generally speaking, the geometries to be inspected are no more than a combination of defined profiles of the L, T, U, H, and closed H type, in flat and curved surfaces. The most evolved geometries are of the *omega* and *delta* types.

The variety of shapes to be considered, the need to inspect specific areas (radii), and the difficulty in accessing others, raise challenges from the point of view of automated inspection. The essential geometric for defining an adequate inspection technique are the thicknesses, radii and angles, but they may vary considerably. As a result, it is necessary to study each case individually before defining the inspection solution to be applied.

EVOLUTION OF NDT TECHNIQUES

The presence of different materials and geometries, and the different defects to be detected in accordance with different standards, make it important to adhere to a protocol for the definition and development of the NDT techniques to be applied.

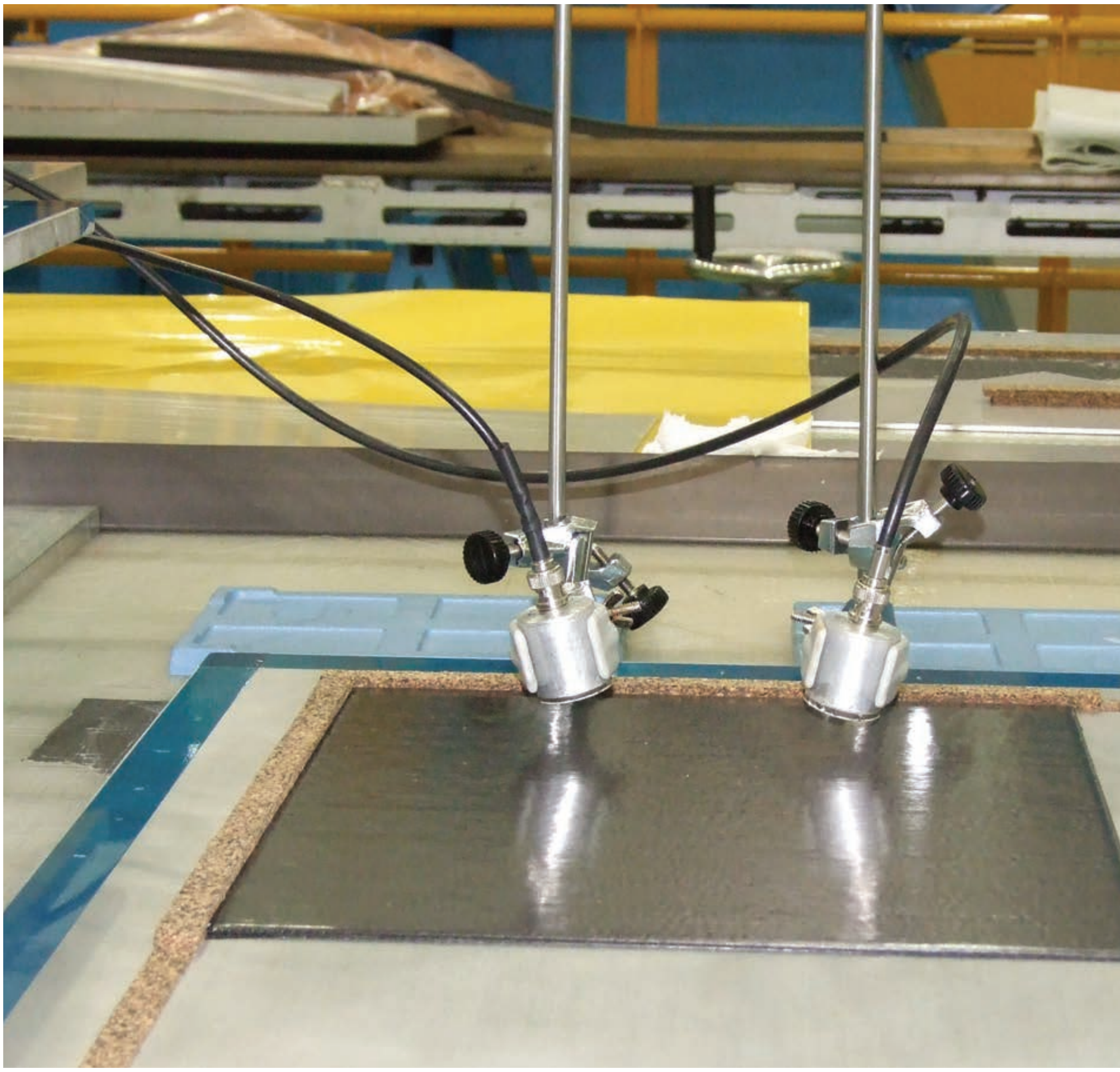
NDT started fundamentally with the use of UT generated by single piezoelectric elements in two possible configurations. The first is through transmission ultrasonic (TTU): generally used for high attenuation materials, since the sound passes through the material only once. Access is required to both sides of the component and no information on the position in depth of the defects is provided.

The second configuration is pulse-echo (PE): access is required only from one side of the component and information provided on the exact position of the indication, including depth. However, it is not the most appropriate for high attenuation materials since the sound passes through the material twice.

The evolution that has taken place in this field in recent years has been the result of in-depth research. From TTU inspections using single piezoelectric elements, PE inspections were developed. This was subsequently extended to include multiple element piezoelectric probes in which several probes inspected simultaneously. The next step in this evolution was the ability for the different piezoelectric elements to interact electronically, providing a control of the orientation and focusing of the beam (phased-array or PA), improving the capabilities of these systems enormously. The use of PA has optimized complex geometries inspections, increasing productivity. Manufacturing and maintenance costs are also much lower than with previous systems, since a lower degree of mechanical complexity is achieved, along with simpler wiring and reduced space requirements.

Once PA technology was incorporated, the challenge was to gradually increase the number of elements in order to achieve versatility and, especially, inspection speed. Engineering company Tecnatom has equipment developed in-house that makes it possible to have up to 2,048 phased-array elements operating. Simulation programs such as CIVA help to simulate ultrasonic beams and their interaction with the defects to be detected, as well as the optimization of the focal laws to be configured.

LEFT: General view of the Laser US equipment during the setting up for inner inspection of a fuselage portion (pictures Airbus SAS)



MAIN: Air-coupled ultrasonics: pitch and catch configuration

NDT TECHNIQUES: THE TARGET

Another result of research and development activity regarding NDT is the optimization of innovative techniques such as laser-generated ultrasonics, air-coupled ultrasonics or thermography.

TARGET is an ambitious project that aims to research and develop new, intelligent, environmentally sustainable technologies for the generation of structures in composite materials. In particular, research will focus on materials, both existing and new, and processes to eliminate the use of large autoclaves, providing the necessary knowledge bases for the development of new concepts in machinery and automation.

As part of a consortium of 14 industrial partners led by Airbus Operations, Tecnatom focuses on the area of NDT inspection, a critical activity in the production processes of these materials. The main activities include the introduction of NDT before the curing phase to ensure the quality of molding parts and discard defects generated at this stage. In this phase no coupling NDT should be used.

Activities also include the introduction of NDT technologies like air-coupled ultrasound, laser ultrasonics, thermography, and advanced phased-array inspection.

The project also covers the use of NDT in new materials, such as the ones with nanotechnology or new developments with composites in civil engineering.

The four-year project, which started at the end of 2009, is supported by the sub-program for National Strategic Consortia for Technical Research (CENIT, issued by the Center for Industrial Technological Development (CDTI)).

LASER-GENERATED ULTRASONICS (LUS)

A pulse of energy from a CO_2 generator laser instantly heats a given area of the composite part, causing an increase in temperature and in volume that produces elastic stresses that push on the adjacent material. This generates ultrasounds in the component, which are detected by the detector laser associated with an interferometer.

The result is a C-Scan with the ultrasonic data of the inspection. The fundamental benefits of laser-based inspections are a reduction of the complexity of the mechanical system and tooling, the removal of the need for coupling for generation, which does away with the need for water in inspection, the promising results obtained for both slopes and edges, and the considerable increase in inspection speed for large and small components. In May 2011, Tecnatom delivered an inspection system based on laser ultrasonics. This means that LUS is finally available for industrial composite inspection and is a new option for NDT. EADS and Tecnatom have won JEC Europe 2012 Innovation Awards with the LUCIE Project (Laser Ultrasonics Composite Inspection Equipment).

AIR-COUPLED ULTRASONICS

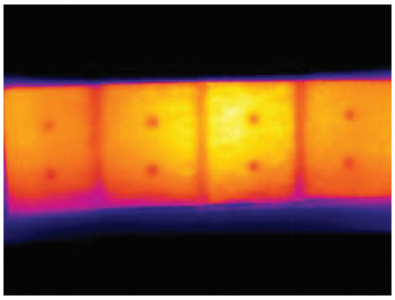
Air-coupled ultrasonics use Lamb waves to detect defects in composite materials, using air as the coupling medium. This also makes it possible to do without water for inspection.

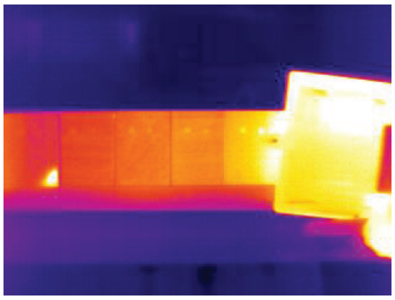
A preliminary study is required to determine the frequencies at which the work may be performed, in order to obtain the resonances of the modes of the Lamb waves in the part. It is also necessary to determine the optimum angle of the probes in order to optimize the resulting ultrasonic signal. Air-coupling provides important advantages when no water can be used during the inspection (honeycomb structures). However, difficulties arise in parts with changes of thickness or of curvature; in such cases the part needs to be oriented to obtain a wave resonance to achieve a good signal-to-noise ratio.

THERMOGRAPHY

Thermography evaluates the infrared radiation of bodies following their excitation by different media (mechanical, thermal, etc.) with the purpose not

"ONCE PA TECHNOLOGY WAS INCORPORATED, THE CHALLENGE WAS TO GRADUALLY INCREASE THE NUMBER OF ELEMENTS"





LEFT: Images showing the results of the thermography tests

of determining their temperature but of obtaining variations in their thermal behavior, allowing detection of the presence of defects in the material. Foreign bodies or porosities (air) present in the material behave differently from the composite material itself, in response to heating or cooling. If these variations are controlled, information may be obtained on the defects present in components.

The combination of thermography and ultrasounds is another of the new fields opened in the inspection of aero components. Tecnatom is now focused in including this combination as part of its inspection kit.

The use of innovative inspection techniques (laser-generated ultrasonics, air-coupled ultrasonics or thermography) means that, depending on the components to be inspected, overall inspection solution proposals could include one or several NDT techniques.

EVOLUTION OF MECHANICAL INSPECTION SYSTEMS

The tendency in recent years is to automate the entire process of manufacturing aeronautical components, including the inspection cell, in order to reduce manufacturing time. Thanks to the high speed achieved, and the length scanned in each run by automated UT inspection, faster, more repetitive and reliable inspections are achieved, covering a larger percentage of the surface to be inspected.

The early mechanical systems based on typical gantry or bridge designs are being replaced by new concepts that take into account the experience of other industrial sectors, such as the automotive. Tecnatom, in collaboration with KUKA, has developed a new mechanical configuration that makes it possible to incorporate industrial robots in NDT inspection systems, in order to increase productivity and flexibility.

This concept incorporates robots in an overall inspection system, bringing together all the hardware and software required to plan and to configure ultrasonic inspections (specification of probes, definition of the part to be inspected, the obtaining of geometries by 2D laser, definition and generation of focal laws, definition of inspection parameters, ultrasonic calibration, generation of inspection trajectories, automatic change of probe-holder modules, robot(s) control, etc.) in a completely integrated system.

The final result is a highly flexible system that incorporates one or two industrial robots integrated with linear tracks, gantries and/or turntables, providing adaptation to different NDT configurations: TTU (two robots), pulse-echo (one or two robots), using conventional or PA technology.

The possibility of automatic exchange of ultrasonic modules (with different probe configurations) allows the system to be prepared for different kind of inspections in the same inspection cell.

The use of industrial robots reduces final costs and the delivery time of the system. Maintenance programs are assured anywhere in the world, with very quick answers. Additionally this concept for inspection systems has lower space requirements.

MATERIAL AND GEOMETRICS

All the developments described in this paper start from the study of aeronautical material and geometries, leading to an optimization of NDT (phased-array ultrasonics, laser ultrasonics, thermography, air-coupled ultrasonics), improvements in mechanical and control systems, and development of a powerful HW-SW technology that allows for the integration of the complete inspection process.

Furthermore, the technology used by Tecnatom allows the use of different types of flexible configurations based on one or two robots on linear tracks and/or gantries, working simultaneously on one or several parts and using pulse-echo or transmission techniques. These developments and improvements made in NDT will lead to further advances in the inspection of aircraft components in composite materials.

Esmeralda Cuevas is the project manager in the NDE Innovation Area unit, which is part of the Technological Development Direction of Tecnatom based in Madrid, Spain

ERIK SCHWARZKOPF

Complex tests, critical results

Overcoming the inherent challenges of thermomechanical fatigue testing by closely simulating real-world service conditions

BY ERIK SCHWARZKOPF

As aerospace turbine designers push operational efficiency and reliability beyond previous expectations, they need components and structures that withstand higher temperatures for longer periods under a variety of cyclic loading conditions.

Knowing how super-alloys, ceramic matrix composites, and other materials react to simultaneous changes in temperature and load makes thermomechanical fatigue (TMF) essential to the R&D process.

Designed to simulate real-world service conditions as closely as possible, TMF tests characterize the response of materials to simultaneous cyclic mechanical loading and fluctuating temperature. This produces a synergistic response that is not easy to predict using isothermal fatigue testing, which is why data generated through TMF testing helps researchers model component behavior and validate existing models. It is also why TMF brings an enormous amount of complexity.

MANAGING AND MEASURING TEMPERATURE

Most modern test machines can command two different wave shapes on the temperature and mechanical loading channels simultaneously. The difficulties are not in measuring strain and temperature together, but in achieving the desired temperature and strain. Challenges in heating, cooling, thermal variance, specimen geometry, and temperature measurement need to be understood to accurately simulate real-world operating conditions.

The first challenge in TMF testing comes with applying heat to the specimen. Some TMF systems use infrared furnaces to apply heat from the 'outside, in' by heating the surface of the specimen. Others use induction heating coils to heat the specimen from the 'inside, out'. These induction heating systems rely on the magnetic susceptibility of the specimen to resist the magnetic current in the center of the coil. Either way, heating the specimen can create thermal expansion that will affect how the mechanical loads should be applied.

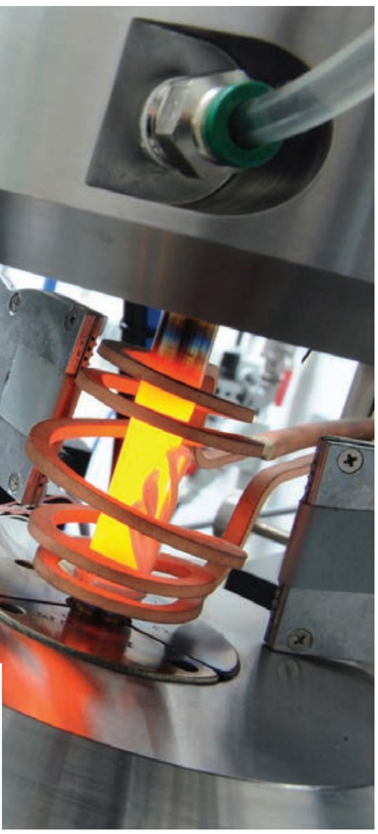
Photos are courtesy of Rolls-Royce

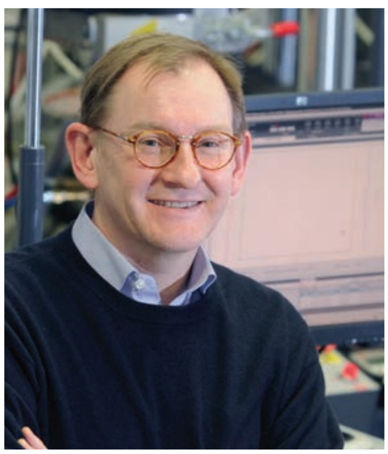
Another issue is that most heating systems can add heat to the specimen but can't remove heat when required, so a related challenge becomes cooling the specimen. Heat is removed from the specimen via radiation, convection, and conduction. Determining when, where, and how much cooling air should be blown on the specimen is of vital importance to convection. And even though the bright, yellow-red specimen radiates heat away at the highest temperatures, conduction through the water-cooled grips is still a major factor at any temperature.

Heating and cooling sound relatively simple until one realizes that most specimens do not heat or cool in a uniform manner. The gauge length of the specimen may heat quickly due to its small thermal mass, but in some instances of specimen and heat source geometries, the shoulders are closer to the heating source and heat more quickly. Commonly, gauge length heats up faster when power is applied, and the shoulders cool off more quickly when power is removed. Modeling the heat transfer of the system and determining the optimal amount of power to apply to keep the specimen gauge length in thermal equilibrium during the temperature cycle is critical.

Another complicating factor is the variety in specimen geometry. Unfortunately, real components in aerospace systems rarely have the same geometry as an idealized cylindrical test specimen. If scientists want to

"DIFFICULTIES ARE NOT IN MEASURING STRAIN AND TEMPERATURE TOGETHER, BUT IN ACHIEVING THE DESIRED TEMPERATURE AND STRAIN"





MAIN: Thermomechanical fatigue (TMF) test

LEFT: Test engineers in the Rolls-Royce mechanical testing operations center

ABOVE: Dr Stephen Brookes, test engineer, Rolls-Royce

study how real features such as holes in rectangular specimens are affected by TMF loading, they need to adjust thermal heating and cooling cycles to compensate for the different temperature change rates throughout the specimen.

Temperature measurement presents additional issues. Temperature is typically measured with a thermocouple that is spot-welded to a specimen. But spot-welding to the gauge length can cause premature crack initiation and failure, compromising test results. Thermocouples can be spot-welded in a non-critical location, such as the shoulder, but measuring temperature at the shoulder is not equivalent to measuring temperature at the gauge length. Similarly, commanding a temperature rate change at the shoulder may not result in the same rate change in the gauge length.

OPTIMIZING RESULTS WITH INTEGRATED SOLUTIONS

Few understand the challenges of TMF as well as the Rolls-Royce Group. The Rolls-Royce Mechanical Testing Operations Centre (MTOC) is an innovative test lab dedicated to the mechanical and structural evaluation of gas turbine components during development, production, and service. TMF is one of the most important tests conducted at MTOC because it accurately represents the operating environment of certain components in the gas turbine engine.

"Our tests are complex and require a combination of temperature-to-load-phases, not commonly associated with standard TMF testing," says Dr Stephen Brookes, test engineer at MTOC and a TMF test specialist. "TMF testing at MTOC includes both strain-controlled and load-controlled varieties. They are separate procedures of similar complexities."

To help overcome the complexity of TMF testing, MTOC employs mechanical test solutions from MTS. Specifically, MTOC uses MTS Landmark servo-hydraulic test systems to conduct stress-controlled TMF testing in its materials laboratory. The complete solution includes a Model 370 load frame and an MTS FlexTest digital controller, with power delivered by its SilentFlo hydraulic power units. The solution also includes a specialized TMF subsystem, which combines induction heating and cooling equipment with grips and extensometers designed for TMF testing. The load frame, heating, and cooling systems are all controlled by the TestSuite software.

Using MTS TestSuite software, researchers can play out non-symmetrical heating and cooling commands to achieve the desired temperature profile in the gauge length of the specimen. They can correct the mechanical loading command for any thermal expansion of the specimen that might affect overall strain measurement. They can also monitor progress such as energy absorbed per cycle (damage accumulation) and model material behavior in real time as the test progresses.

ADHERING TO BEST PRACTICES

Given the complexity of TMF testing, researchers need proven ways to improve consistency from test to test and lab to lab. Recognized standards such as ISO 12111:2011 provide best practices for characterizing materials subjected to simultaneous thermal and mechanical loads. This standard reduces the phase shift command to two possibilities: in-phase (maximum strain at maximum temperature) and out-of-phase (maximum strain at minimum temperature) cycling. It also includes all the steps required to perform the test, from calibration to data reporting.

One way in which researchers can adhere to testing standards is by using advanced software. MTS has created a TMF template for TestSuite Multipurpose software that offers full transparency into its algorithms and calculations, so researchers can use it to interpret standards in different ways, or modify it for their own needs.

LEVERAGING TMF EXPERTISE

Unlike many other tests, TMF complicates every part of the process, from equipment selection to system integration to test management to data capture. Yet TMF is vital to developing the next generation of ultra-efficient aerospace engines. MTS continues to provide the technology and the expertise researchers need to overcome these challenges. Informed by decades of experience, we understand what researchers are up against, what is at stake, and how to make it work.

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

DR JIM HONE

Economies of scaleability

There is a need to share measurement data across aerospace manufacturers in a more agile way than is possible with more traditional measurement equipment

BY DR JIM HONE

Ask any group of test and evaluation engineers to describe their dream networked data-acquisition system and they would probably agree with David Grebe of Apogee Labs who says, "Ask any group of test and evaluation engineers to describe their dream networked data-acquisition system and they would probably say: 'A fast, scalable, interoperable and time-coherent architecture with COTS-based interfaces that implement standards-based protocols with a rich metadata infrastructure'."

A similar question to a group of analysts would in all likelihood elicit the response: "A fast, scalable architecture able to analyze data regardless of its source, both historical and current." They would probably add the need for flexible, customizable processing algorithms with the ability to incorporate locally developed software code. Increasingly in the modern test and analysis world, a raft of automated techniques would also be high on the list of requirements.

Finally a corporate finance officer would almost certainly reply: "A system that gets the job done for the lowest capital outlay and ongoing cost of ownership, with no risk of becoming dependent on equipment that becomes obsolete."

Are these very different wish lists compatible and achievable with modern technology? Historically, measurement equipment has largely had a single use or function, often with little or no connectivity to other instruments or data systems. As digital systems have replaced analog equipment this ethos has to some extent continued (albeit with more powerful, multifunction units) although being constrained by proprietary closed data formats or communication protocols.

This has quite often led to steep initial capital costs and often high ongoing cost of ownership, often for equipment that has relatively low levels of use. This drives customers to keep their high-value inventory in use far longer than might be sensible, quite often incurring high maintenance costs as equipment (and media) become obsolete and spares difficult to obtain.

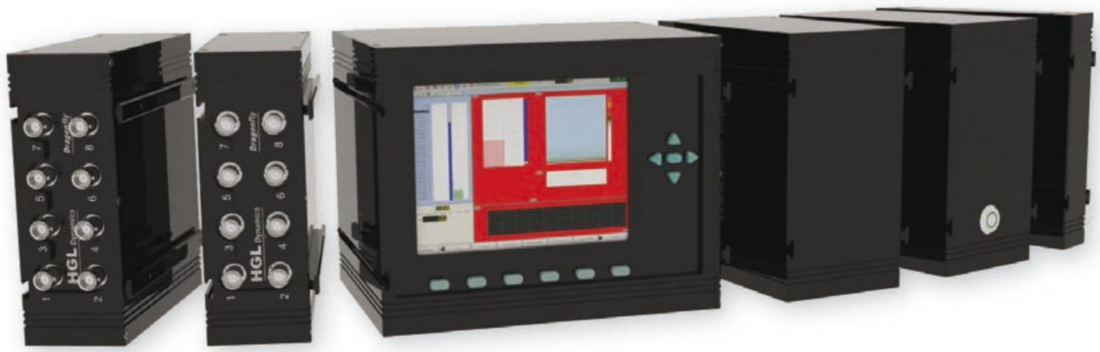
A good example of this is the demise of the Sony range of recorders, which were widely used in the aerospace industry and went out of production a few years ago, closely followed by the AIT series of tape drives, and potentially in the near future the AIT media.

This has left a large number of customers facing either mounting support costs, or the realization that they need to change platform rapidly and potentially convert large amounts of expensively recorded data.

This cycle of events is not uncommon with the inevitable rise and fall of specific or single-function hardware solutions and equipment, and often leads to regular (<10 yearly) revolutions of measurement systems and architectures within customer organizations. This is always expensive, causes disruption to ongoing operations, requires retraining of staff on new systems, and is generally unpalatable to corporate management.

CAN TECHNOLOGY HELP?

In recent years we have all seen technology rushing forward in areas such as more powerful computers (and processors within them), omnipresent fast networks, inexpensive and durable



RIGHT: The Dragonfly acquisition range of modules, with different I/O and processing options, can capture data locally or else stream data to an external host

ABOVE: Large, multichannel systems can be assembled from small modules by passing power and synchronisation from one to another

RIGHT: The Dragonfly 4 channel, 80 kHz module, with different I/O and processing options, can be synchronised to other units and stream data to an external host

solid-state storage, incredible display technologies, and in the rapid evolution of mobile platforms such as ultra-book PCs and touchscreen tablets. All of these innovations have had an enormous effect on most people's lives, particularly in the home environment, but these technologies are also very useful in measurement, analysis and data-storage systems.

Over the same period a large number of aerospace equipment manufacturers, particularly in the power plant and airframe areas, have increased their reliance on distributed manufacturing and testing, both internally and within partner companies. This has in turn led to the need to share measurement data across widely distributed teams and in a more agile way than is possible with more traditional measurement equipment.

It is no surprise that several large OEMs are currently trying to integrate their distributed and disparate measurement systems across the globe, and at the same time break the cycle of costly system replacements by looking instead for solutions that can evolve into the future. To a considerable extent these solutions will be dependent on huge IT infrastructures based on the technologies mentioned above, producing a platform on which modern measurement systems are expected to operate.

One of the expectations of these systems is that any size of test and measurement system will be able to operate within the 'ecosystem'. There is a need to be able to perform a greater variety of test types with the limited resources available, both on home ground and at remote sites. Thus there is a push for vendors to produce equipment that can be used across the spectrum from portable to large-scale fixed systems.

IS THIS POSSIBLE?

A current buzz word is modularity. Many vendors provide modular solutions based on plug-in cards or plug-on modules. Additionally suppliers have increasingly been pushing OPEN buses such as VXI/PXI and network-based solutions such as LXI. There has also been an explosion in the number of portable and ultra-portable systems for data acquisition using USB, Ethernet (LXI) and in some cases more esoteric interfaces.

Even these buses, while apparently modular and expandable, have their limitations. USB, for instance, is good for personal low-power systems but is very difficult to scale to large channel-count, synchronized solutions. VXI/PXI is very effective for large-scale, fixed installations but is of no use for portable or personal systems. Ethernet/LXI is potentially good for both. Ethernet is also extremely inexpensive to implement, globally accepted, long-lived and with a healthy roadmap into the future.

However, though modularity is a start point it is not the complete answer. This is largely because although modular, most vendors' equipment does not communicate with their competitor's equipment. There are some groups of vendors trying to create standards, such as the LXI consortium, but these are still formed of a relatively small number of suppliers who are generally concerned with making it simpler to communicate with smaller single-function devices. While this is useful for portable and small-scale solutions, it does not aid larger-scale requirements.

To provide a truly scalable and cost-effective measurement solution for anything more than a small personal requirement, a number of elements are needed.

First, a truly universal (within an enterprise or even a global standard) data format and command structure is needed,

RIGHT: **Small hardware modules help by permitting the same equipment to be used on both civil and military test programs**

hosted on a long-lived hardware interface with as future-proof a roadmap as possible. Here Ethernet, together with a flexible, simple, open and self-describing data format would seem ideal.

Second, simple and modular front-end hardware is needed. This can and should be in a variety of form factors, ideally from many vendors, but all capable of truly handling the common data format and command structure.

Third, software – which is becoming the key to truly flexible multipurpose systems. Software can turn a relatively generic acquisition front-end into a portable measurement system, an oscilloscope, an FFT analyzer, etc., or can enable the hardware to connect to a much larger system. For a good example look at what a modern smartphone or tablet can do with small single-task applications.

Modularity matters because it permits the packaging of common components into a variety of form factors for diverse situations. Small modules can be used in limited, standalone environments but can also be combined to form large systems when desired. This flexibility of deployment leads to more efficient use of the equipment, which itself leads to a smaller, lower-cost inventory.

Modern CPUs such as ARMs mean that hardware front-end modules can (and usually do) have embedded processing power. This means that they can potentially host multiple software applications themselves, with each optimized to a particular task. These 'apps' permit the same hardware to be used in a multiplicity of roles, replacing single-function devices and past systems.

HGL Dynamics has taken full advantage of embedded processing power and a number of its hardware modules (Dragonfly range) include embedded processors, memory and storage, enabling them to operate autonomously. As an example, the HGL Dragonfly0402CAN includes four 80kHz bandwidth analog input channels with IEPE conditioning, multiple gain ranges, twin analog outputs, twin bidirectional CANbus ports, and support for eight slow rate (10 Hz) analog inputs and eight digital I/O ports. It also includes three embedded ARM processors, a field programmable gate array (FPGA), an SD storage card, and

ABOVE: **Smaller modules can be more easily rated for offshore testing and a wider range of other harsh conditions**

ports for supporting optional GPS & GPRS/3G modems all within a compact handheld package. Finally, it includes an Ethernet port and LVDS sync interface that enables it to link with other units and stream data to an external host.

This and other modules can be used with a more powerful controller such as a laptop PC through the built-in Ethernet interface(s). Furthermore, each module can be connected and synchronized to many others with the built-in synchronization hardware (high-speed LVDS, GPS, IRIG A/B, and IEEE1588).

Modules of many types can be combined (low-speed through high-speed analog, telemetry, digital streams, etc.) because of the common OPEN self-describing data packet format, which makes it a truly multifunction large system.

Finally the Ethernet backbone and open data message formats mean that integration with analysis and data-management systems is easily achieved, whether by vendors or customer IT organizations.

The combination of truly modular hardware with a common backbone such as Ethernet, and open self-describing data messages/formats, leads to true scalability of systems. This in turn leads to higher use of the generally relatively expensive acquisition front-ends and easier, low-cost rental of modules when increased short-term inventory is required.

Customers have greater opportunity to evolve their systems and software gradually over time, incorporating new front-end equipment when appropriate, while avoiding the risk and disruption associated with traditional upgrade projects. The control, monitoring and analysis software either stay the same or are themselves evolving organically.

All this can lead to lower costs of ownership and increased return on investment as the economies of true scalability are realized, while at the same time actually increasing operational flexibility and equipment use for the customer organization.

But can a wider group of vendors and/or customer organizations come together to develop the simple, flexible and open data formats needed to ensure these benefits can be realized? That is a question for another time. ∎

Dr Jim Hone, managing director, HGL Dynamics, UK, with supporting text from Dr Andrew Law, director of technology based in the UK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RAIMUND TRUMMER

E pluribus unum

Why Sync-Clock technology is essential technology for today's aerospace test engineers

BY RAIMUND TRUMMER

One of the biggest challenges facing flight test engineers in recent years has been the sheer number of different signals and data types that need to be recorded simultaneously. The increasing complexity of aircraft makes comprehensive testing more challenging than ever. Swimming against this tide are the fewer people available, who have to do more testing than ever. The result is that there is simply no place for inefficiency or inadequate test equipment.

Making good analog measurements starts with precise signal conditioning connected to a wide variety of sensors, including strain gages, accelerometers, force sensors, pressure, load and flow sensors, thermocouples, as well as voltages and currents. In addition to the analog signals, there is a huge amount of data on the ARINC and/or MIL-STD-1553 data buses that needs to be acquired.

Because the power bus of the aircraft is mission critical, analysis of the 400Hz single-phase or three-phase power system is often needed. As well as just recording the raw voltages and currents, power systems require real time calculations including power factor, harmonics, and many more.

If all that weren't enough, dynamic testing also requires the synchronous acquisition of video feeds from on-board cameras in NTSC and PAL formats, or the addition of higher-speed videography to analyze actuators and other fast-moving events.

SYNC-CLOCK – FROM MANY, ONE

E pluribus unum: 'From many, one' – or one from many – is the ideal slogan for the Dewetron Sync-Clock, because it provides the timing structure that enables all these 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

COMPACT, RUGGED AND SCALABLE

DEWE2-series devices offer increased channel density and modularity, to support a wide range of applications in a compact and rugged form. Depending on the sensors and interfaces used for an evaluation, different TRION series modules – such as analog inputs, bus interfaces and digital or counter modules – can be installed easily into the base unit. The tough nature of aircraft testing requires that test instruments be rugged and portable. Typical plastic lab instruments do not survive in this environment. Flight test instruments also need to be able to run from a wide range of AC and DC power supplies, or from internal batteries. When it comes to data storage, only solid-state hard drives should be considered. Robust, high-reliability connectors are the final touch in ensuring secure signal connections.

For high channel-count applications such as vibration testing, data acquisition systems must scale hundreds of analog inputs. This is easily achieved with the DEWE2 series by adding multiple front-ends to a single acquisition instrument. The aggregate data rate can be quite high in these applications, therefore the front-ends are connected to the main acquisition instrument via a high-speed PCI-Express link. This is a very robust connection and enables distances up to 7m between two enclosures.

An Intel Core i7 processor provides the required system-level processing power.

LEFT: Better results can come in a shorter time due to synchronization during the measurement of hundreds of measurands from analog, digital, PCM, ARINC and MIL-STD-1553

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 are forced to use many separate instruments, such as one for the analog data, another for video, another for the ARINC and 1553 bus data, and so on. Even more important is that the engineers have to learn different user interfaces, and that the data streams are not directly synchronized with each other most of the time.

By combining everything into a single instrument, several major advantages are realized, such as a smaller size, lower power consumption, lower overall cost, and the requirement to deal with only one user interface. Efficiency during the tests themselves, when test engineers are very busy, is streamlined by putting everything onto a single flexible display. Watching the displays of three or more separate instruments at the same time is almost impossible.

But the real power of Sync-Clock is reflected in the analysis of the data. Everything is already recorded in sync, with analysis being performed immediately – even online during the test. Anyone who has tried to correlate data from different devices knows that this often requires many hours using third-party analysis software. The final result of this huge effort is a dataset with manually aligned time axes that are more or less correct but not perfect. Thus the quality of the following analyses depends on the quality of manual data manipulation.

Sync-Clock considerably increases the quality of mixed-signal data and makes editing and analysis three to five times faster.

EFFICIENCY AND ACCURACY ARE CRUCIAL

Signal conditioning is a clear specification that can be compared easily from instrument to instrument. Dewetron TRION series input modules, which plug into DEWE2 series instruments, offer a typical accuracy of 0.02%, which easily exceeds that of most competing products. And because TRION modules combine a separate 24-bit ADC for each channel with the signal conditioning all in one, these specifications are comprehensive and don't have to be added up with a separate A/D card or other electronics in order to find the 'real' accuracy numbers.

Cabling needs to be correct in order 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. With this approach, the modification of existing sensors or the fabrication of adaptors can be avoided. In large sensor systems this can save a tremendous amount of time and money.

Another way that efficiency can be increased is by putting multiple instruments into one. What exactly does this mean? 'Multiple instruments in one' means that a single data acquisition system can serve as a mixed signal recorder, power analyzer, FFT analyzer, XY recorder or modal analyzer. A single DEWE2 instrument can serve as one, two, three, or any combination of these instruments – all at the same time.

An application engineer solving customer's vibration problem by means of a DEWE2 instrument

"SIGNAL CONDITIONING IS A CLEAR SPECIFICATION THAT CAN BE COMPARED EASILY FROM INSTRUMENT TO INSTRUMENT"

The effect of more input features is that there are multifunction TRION modules. These inputs accept strain sensors, IEPE accelerometers, voltage, current, resistance and temperature. There are other modules for high voltages that provide more than 1,000V of electrical isolation. Using this approach, a wide range of applications can be covered by only two module types.

The plug-and-play feature of TRION modules also adds efficiency to data acquisition because the hardware can be reconfigured for different tests in moments. The system software is the same for all kinds of testing, so there is only one user interface to learn. 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 Sync-Clock technology.

DISTRIBUTED SYSTEMS

Sometimes sensors are spread out across a large area, either in a building or in a very large aircraft. In this case, increasing the channel count by adding front-end instruments to a main instrument may not be possible due to the distances, cabling considerations, or aggregate throughput. In these cases multiple DEWE2 systems can be networked, eliminating the need to connect them via PCI-express, and also enabling higher overall data throughput because each instrument has its own processing and storage. So how do test engineers see the data they need on a single screen, and how does everything stay synchronized in a distributed DEWE2 system?

Three methods are available for synchronization, depending on the distance that separates the measuring systems. Up to 50m, the Trion-Sync bus uses a readily available CAT6 cable (typically used for networking). From 50-1,000m, the first system in the chain generates an IRIG compatible signal that is distributed by a shielded BNC cable. Each system also can be synchronized to external time references such as IRIG time code or the PPS and UTC code from GPS. When a DEWE2 network connection is established, selected data from all systems can be transferred live to one master system up to the limit of the network speed. This master system stores a single file with all selected and synchronized channels, just as if it had been recorded by a single instrument. In parallel, each system stores its own data file for protection against the network connection being lost or interrupted.

For even greater distances, GPS Sync is ideal for field testing with several widely separated data acquisition systems. In such a configuration the systems can be spread all over the globe and still be perfectly synchronized. When a TCP/IP connection cannot be established, the use of time codes within each instrument enables the data streams to be precisely aligned on the time axis and combined. A nice application for GPS-Sync is determining the noise emission of an aircraft where one system is in the air and others are on the ground.

ACQUIRING PCM DATA

Data can be transmitted to the ground from aircraft or spacecraft through FM signals that contain PCM streams of data. PCM data often includes hundreds or even thousands of parameters. This data is packed tightly into the PCM stream prior to transmission and must be decoded on the ground and separated once again into individual parameters.

This is the job of the bit synchronizer, frame sync and decommutator. The bit sync and frame sync are handled by hardware in the graphical user interface within the common system software, while the decommutator is entirely implemented in the software. This gives maximum system flexibility, including the ability to handle one or more embedded asynchronous data streams. The hardware can handle PCM data in most common formats at up to 33Mbps. Dewetron systems can serve both as PCM data encoders and decoders, and are also compatible with TMATS and the Chapter 10 data format for interoperability and compatibility with other systems.

Today's flight test engineers now have a new way to make a wide range of measurements, with less equipment, easier setup, and better results in a shorter time. Hundreds of measurands from analog, digital, PCM, ARINC, MIL-STD-1553, the power bus and angle-based sensors, are recorded in sync with each other and referenced to external time from the very beginning, eliminating the need to laboriously align multiple files from several instruments after the mission. This provides a better preview of the data during measurement, which can prevent the need for expensive re-testing, as well as better overall test results. ∎

Raimund Trummer is the head of marketing for Dewetron, based in Austria


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BOB METZ

Notch up a high score

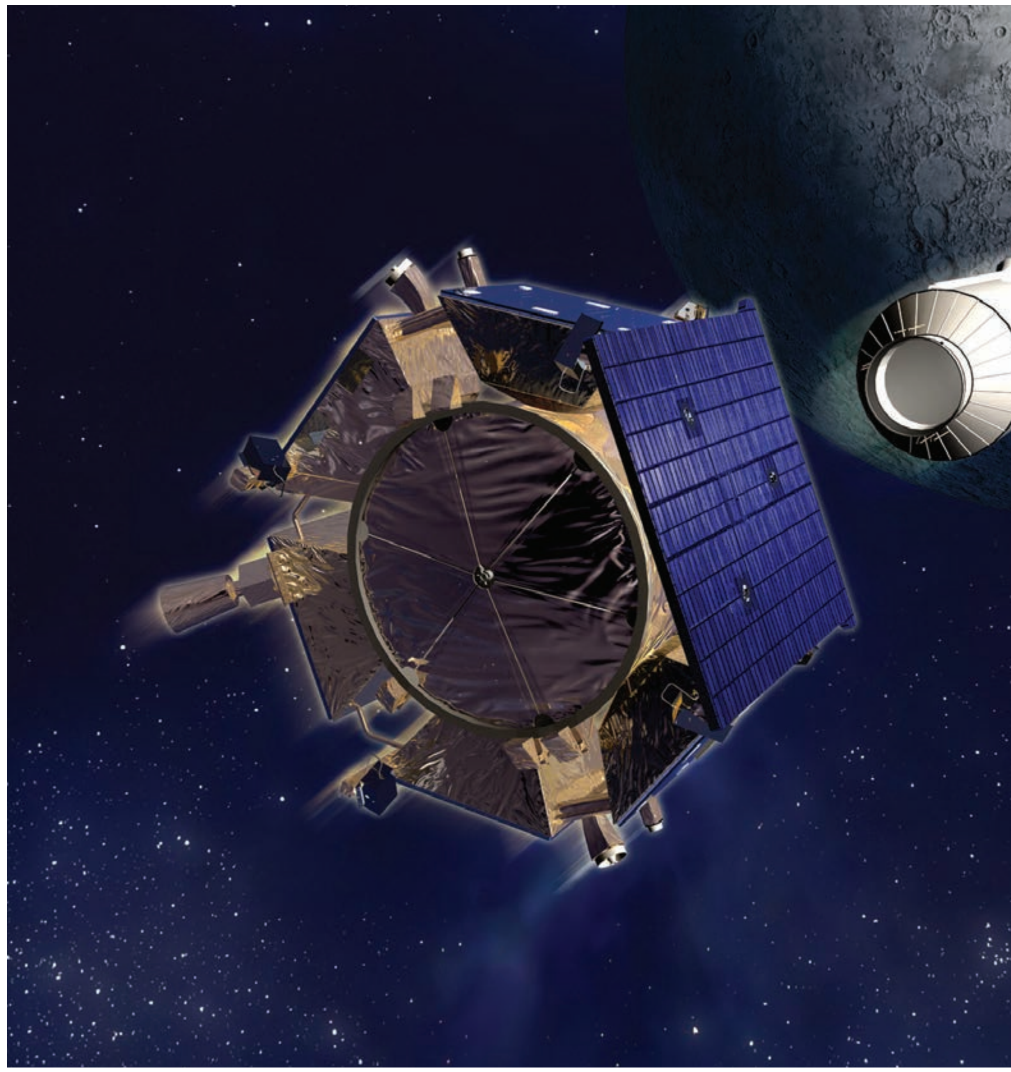
Forced Limited Vibration (FLV) measures the shaker and the test item, limiting the shaker force values to those predicted for actual flight

BY BOB METZ

The major cause of over-testing of spacecraft during random and swept sine vibration tests is associated with differences between the mechanical impedances of the shaker and mounting fixture, and the standard practice of controlling the input acceleration to the frequency envelope of the flight data. The result is artificially high shaker forces and responses at the resonance frequencies of the test item. The high forces can damage some very expensive payloads.

To alleviate the problem of over-testing, it has become common practice to notch the input acceleration in order to limit the responses in the test to those predicted for launch into space. In simple terms, to notch means to reduce the amplitude of the shaker input near the resonant frequency of the test item. However, this creates a paradox, because there are multiple resonant points on complex structures and determining these resonant points on the structure is very much dependent on the analysis, which the vibration test is supposed to validate.

Another difficultly with vibration response testing is that it requires placing accelerometers on the test item at all of the critical locations, each having its own resonant frequency, and many of which are often inaccessible. Since each location will have a different resonant frequency and exceed the control limits at some point during the test, from which accelerometer does the test engineer select to control the shaker?

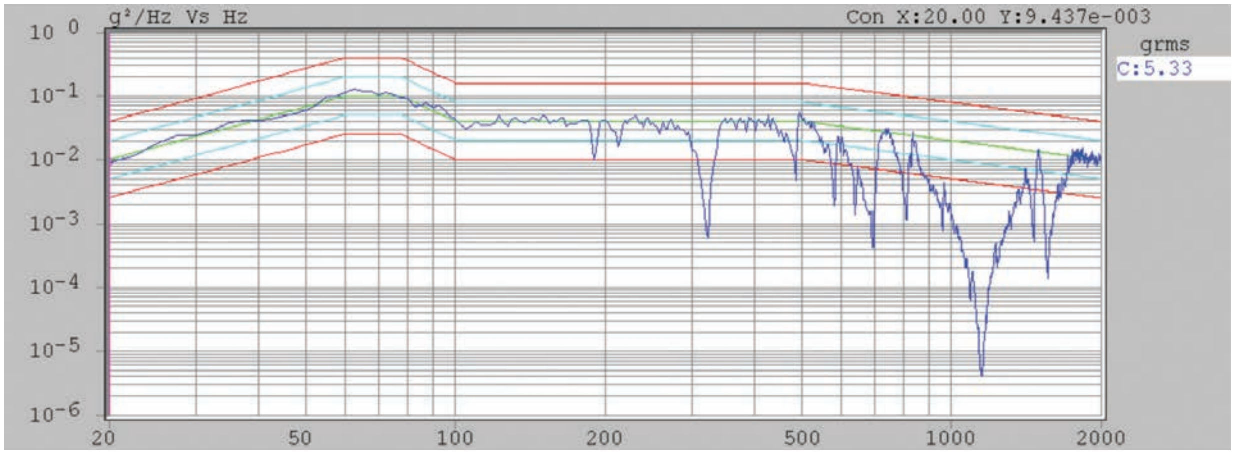


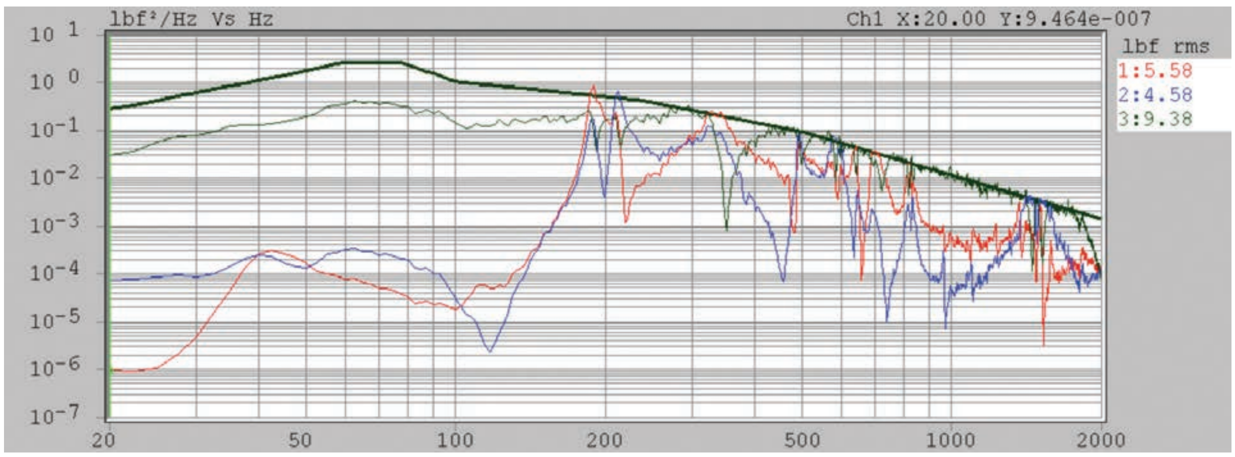
Forced limited vibration (FLV) is an alternative that improves the vibration testing approach based on measuring and limiting the reaction force between the shaker and test item. By using this method, the acceleration input to the test item is automatically notched at the equipment resonances by limiting the shaker force values to those predicted for actual flight. With force limited vibration testing, the force measurement signal is actually used in the vibration shaker's feedback control loop. This signal is compared to established force limits in the controller. At frequencies where the measured force exceeds the limit, the controller's output signal (i.e. the input signal to the shaker) is 'notched' by reducing output amplitude. By reducing the input to the shaker at these frequencies, the reaction force between the test fixture and structure is maintained within specified limits.

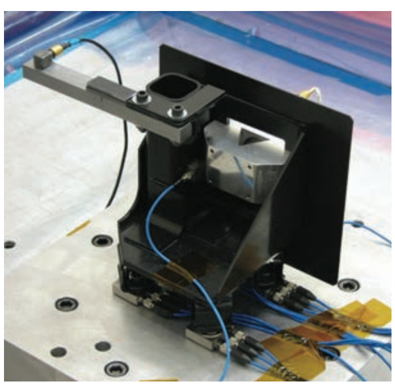
Force control limits are typically predicted using Finite Element Analysis or actual launch data from prior flights, a safety margin added, and then the values used to control the force input. So, instead of a control accelerometer, the test engineer uses piezoelectric force sensor control.

Accelerometers may also be used in the control loop. They serve to limit the shaker's excitation with respect to acceleration at frequencies other than resonances for which force limiting prevails. In order to accomplish this, the shaker control system must have 'extremal control' capability. Extremal control is the ability to establish feedback control with respect to the greater of several inputs, either force or acceleration, as a function of frequency, and several modern-day shaker controllers now have this capability.

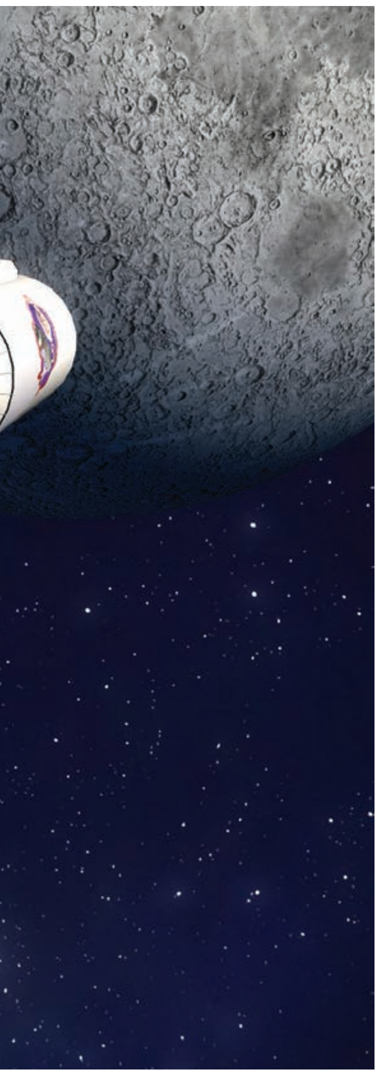
The figure above right (lower graph) shows that the force limiting curve







ABOVE: **JWST NIRSpec bracket assembly undergoing FLV test at the Space Dynamics Laboratory (Utah State University)**



MAIN: **Lunar Crater Observation and Sensing Satellite (LCROSS) Image Credit: NASA**

(bold green curve) and the force sensor responses of Fx, Fy, Fz (thin lines) stay within the tolerance values of the curve. The figure above shows the notching that took place for the random base input. This notching occurs automatically based on feedback from the force sensors.

To accomplish FLV, multiple forces sensors are mounted between the shaker and test item. The sensor signal must be 'summed' (to sum the forces in x, y, or z direction from multiple 3-component force sensors). The summed signal is then sent to a vibration controller to limit to forces that are imparted into the unit under test through various other cables and multiple charge amplifiers, which can be cumbersome.

The figure above left shows 3-component piezoelectric charge output force sensors mounted between the shaker and unit under test. Also visible are ICP accelerometers placed at critical points on the structure for response testing.

New ICP technology is now available for these 3-component force sensors. ICP means 'integrated circuit piezotron', or 'built-in charge amplifier'. The benefits are easier cable management, hermetic sealing, simplified summing amplifiers, and reducing the overall labor cost to perform the testing. The most prominent change between charge output and ICP is the single, four-pin connector versus the tradition three connectors on charge outputs styles. Each sensor may be connected, via a single cable, to a 'summing' amplifier that provides power, conditions the sensor signal and then sums each sensor's inputs and provides Fx, Fy and Fz outputs.

The use of ICP 3-component force sensors for force-limiting shaker inputs limits the chance for over-testing a spacecraft or other structures. It is now possible to provide three 'pre-summed', low impedance input signals to the shaker controller to properly notch the acceleration input to the test item. This new ICP 3-component technology eases the burden of running multiple cables and reduces the great care required when handling more traditional charge output force sensors. ▮

"NEW ICP TECHNOLOGY IS NOW AVAILABLE FOR THESE 3-COMPONENT FORCE SENSORS"

Bob Metz is the product manager for the Aerospace & Defense Division of PCB Piezotronics Inc, based in the USA

BRIAN DUFFY

Conversion force

Load cells are the sophisticated technological weapon in aerospace ground and flight testing

BY BRIAN DUFFY

Proving performance, integrity, and safety within aerospace applications remains the number-one mission for engineers and designers of some of the world's most dynamic, powerful, and technologically innovative flying machines.

Whether commercial or military, advances in materials and technology, fuel costs, and environmental concerns are all playing a role in evolving aircraft designs. Efficient, accurate, and precise component testing has never been more crucial in all phases of aircraft development and use. Faithfully performing behind the scenes to ensure success is a small but powerful weapon: load cells.

The secret to the prevalence of load cells in many aerospace ground and flight test applications is their flexibility in design and form factor, enabling them to handle testing scenarios and environments that can be rigorous and harsh. These include initial design and build stages; pre-flight, structural and fatigue testing; in-flight testing and monitoring; and flight-qualified force monitoring and control. (See sidebar.) Three common load cell structure designs – multiple-bending beam, multiple-column, and shear web – are what make these extensive skillsets possible, creating countless load cell profiles and/or configurations.

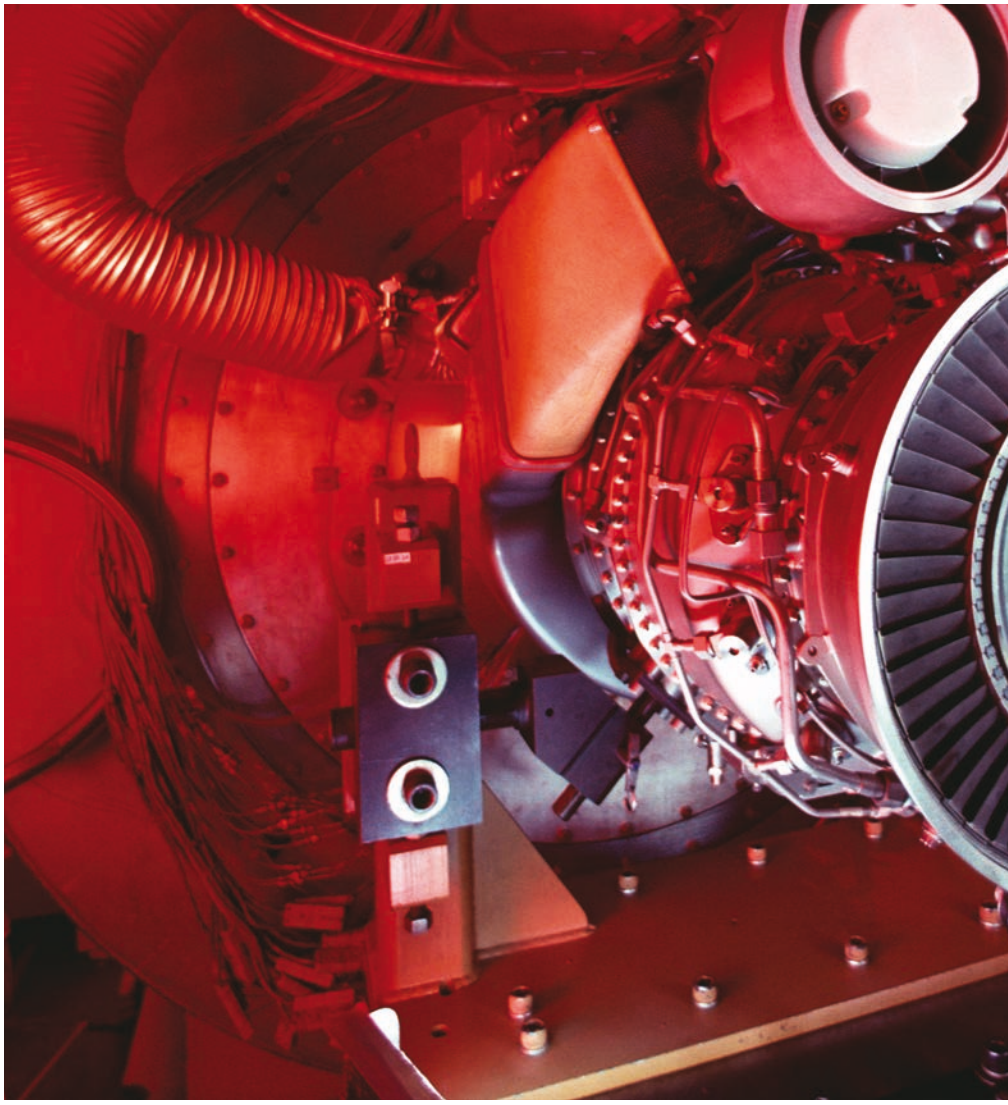
FLEXIBILITY IN DESIGN

Customized dual-bridge designs provide increased capability and offer flexibility in testing, performing as two independent force measurements from the same load cell. For example, in airframe testing the first force measurement can be used to control the loads applied to the aircraft. The second independent force measurement verifies what the load actually is, with the result being collected for data analysis, along with various other measurements on the airframe being tested.

This is a key feature and benefit in certain applications. Typically load cells in airframe testing have to compensate for off-center loading. This is because they are mounted directly in-line with the hydraulic cylinder providing the force, where imperfect loading conditions may be present.

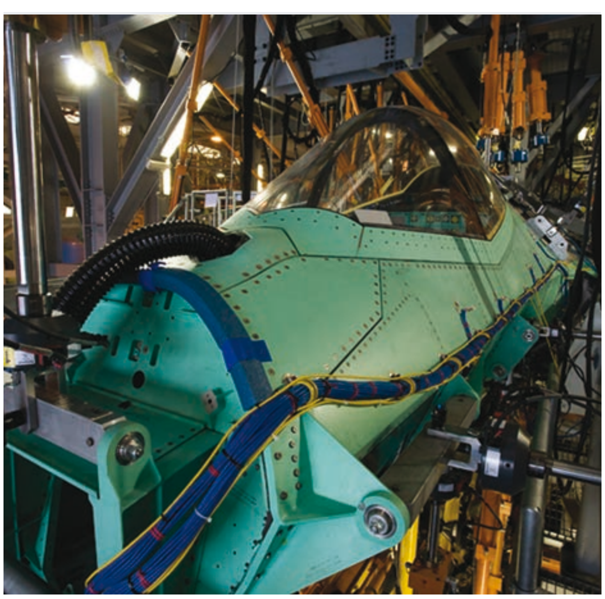
Load cells also provide dependable, effective performance. This is extremely important within aerospace testing applications because load cells measure forces and transmit data needed to validate components, products, and complete aircraft to help ensure integrity and safe operation.

In addition, when required, load cells can be designed with a high



ABOVE: From initial design and build stages through flight-qualified force and control monitoring, load cells are used extensively in aerospace test applications. Engine testing is one example

RIGHT: Load cells, which have the ability to compensate for off-center loading, can be used to test airframe structure integrity, endurance and life cycles (photo courtesy of BAE Systems)



POSSIBILITIES WITH LOAD CELLS

From initial design and build stages through flight-qualified force and control monitoring, load cells are used extensively in aerospace test applications.

INITIAL DESIGN AND BUILD

Load cells are often instrumental in testing generic components for strength, force endurance levels, component longevity, and the like. Components can be anything from seat belts to individual linkages, and aircraft flaps to cockpit instruments. For the majority of component-testing applications, a standard load cell design can be used.

PRE-FLIGHT, STRUCTURAL AND FATIGUE

Load cells can be used to test frame structure integrity, endurance, and lifecycles, with the goal generally being to validate aircraft design and ensure that specified criteria are met. For instance dual-bridge load cells (with two independent outputs on a single load cell) are used for airframe testing.

IN-FLIGHT AND MONITORING

Load cells are often used to test and monitor airframe structural forces. For example, bolts and pins used on critical points of the airframe can be redesigned, fabricated, and calibrated to perform as load cells and can be used to ensure that structural integrity is maintained.

FLIGHT QUALIFIED FORCE MONITORING

After new builds and designs pass the necessary performance testing and are ready for commercial or military applications, load cells can be used in the monitoring of the flight control system itself. In commercial uses, load cells are designed for pilot force input. Another example is the measurement of the pilot's touch on the control stick. The force is measured and the data is stored in the Flight Data Recorder black box. A redundant load path is used to ensure the mechanical integrity of the linkage.

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

fatigue life, or long lifecycle. They can be built for reliability and longevity of use. Often they can maintain performance through more than 100 million force/load cycling tests, making them a cost-effective choice for aerospace engineers, who often conduct a multitude of tests on the same component.

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

Of course, redundancy goes hand in hand with both long load cell life

> **"HIGHLY SENSITIVE LOAD CELLS ENABLE THE PILOT TO RETAIN DIRECT, ACTIVE FEEDBACK TO CONTROL THE AIRCRAFT"**

and a robust design. Redundancy can actually be designed into the load cell and is a key benefit within aerospace applications. A back-up mechanism can be built-in to maintain the mechanical integrity of the flight control system.

PERFECTING THE IMPERFECT

In the aerospace world, imperfect conditions are the norm. Load cells can be designed to compensate for off-center loading, enabling sensor functionality and performance despite less-than-ideal situations. One example is in helicopter lift operations. Several hook load sensors can be used to confirm a safe lift. The load cell design compensates for uneven loading, so even if the load is not applied directly through the primary axis of the load cell it will still perform to specification.

Load cells, by design, have minimal deflection when fully loaded, but still retain high force sensitivity. A typical example is load cells used in throttle, wheel, and pedal linkages detecting pilot input forces on the aileron, rudder, and elevator. Highly sensitive load cells enable the pilot to retain direct, active feedback to control the aircraft, while providing data to the black box and throttle control. The sensing element provides a direct linkage between the pilot's touch and immediate feedback to the control systems. An example is in aircraft autopilot situations. If required, a pilot need only take hold of the throttle with an active feedback load cell to disengage the autopilot and take direct control of the aircraft.

MISSION ACCOMPLISHED

While there are many standard product designs, custom load cell designs are often needed for specific applications. Depending on the function, load cells can be created in different sizes and profiles, with varying ranges, and for specific accuracy and sensitivity needs. Load cells provide this flexibility and are proven performers in the aerospace testing world.

They are designed to adapt and be versatile to changing testing parameters and needs. While design engineers are challenged to create more streamlined, efficient designs under tighter cost and time constraints, load cells will continue to provide dependable data that ensures performance, integrity and safety that can never be compromised. ■

Brian Duffy is the global applications engineering manager for Honeywell, Sensing and Control – Test & Measurement Products, based in the USA

Highly sensitive load cells enable pilots to retain direct, active feedback to control the aircraft, while providing data to the black box and throttle control

DR.IR. JAN LEURIDAN

On the right road

Test and simulation will have to develop an even closer relationship as one day they will be fully integrated as part of a new engineering methodology

BY DR.IR. JAN LEURIDAN

Test engineering will have to become smarter. It will require a fundamental, innovative, new approach as part of the redesign of the end-to-end development process.

To meet consumers' and society's expectations, next-generation aircraft will be far more economical and ecological. The aviation industry is facing major design, development, and assembly challenges. Successful programs must deal with new materials, new technologies, and more complexity while staying within budget and meeting shortened time-to-market demands.

Given this 'new normal', the traditional aviation industries' engineering process is under scrutiny. Earlier aircraft maturity has become a priority, so controlling the element of time-to-market has become critical for every aircraft manufacturer. Rework needs to be limited to an absolute minimum or, ideally, avoided. Because of the increasing use of new technology to meet the shift toward new performance and ecological standards, traditional system and subsystem design needs to be increasingly re-evaluated.

The increased use of advanced composite materials in airframes and electrically powered systems – replacing heavier counterparts and therefore making the aircraft more economical to operate – raises new and unexplored test issues. Furthermore, modern-day aircraft can be considered as a 'system of systems'. These systems and various subsystems dynamically interface with each other to perform a specific function, raising various structural and integration issues.

Traditional test processes – extremely important during the aircraft design, development, assembly, and validation stages – will need a major structural overhaul. Test time needs to be shortened; tests need to be performed as early as possible; and test methodology must be able to cope with increasingly complex systems.

Test engineering must become smarter. It will require a fundamental, innovative, new approach as part of the redesign of the end-to-end development process. This new approach will have to deliver an adequate answer to five highly interconnected challenges, elaborated below.

ABOVE: Test engineering will have to become smarter. This will require a fundamentally new approach. Picture courtesy of CIRA, USV program

> "TEST SERVES SIMULATION AND SIMULATION SERVES TEST"

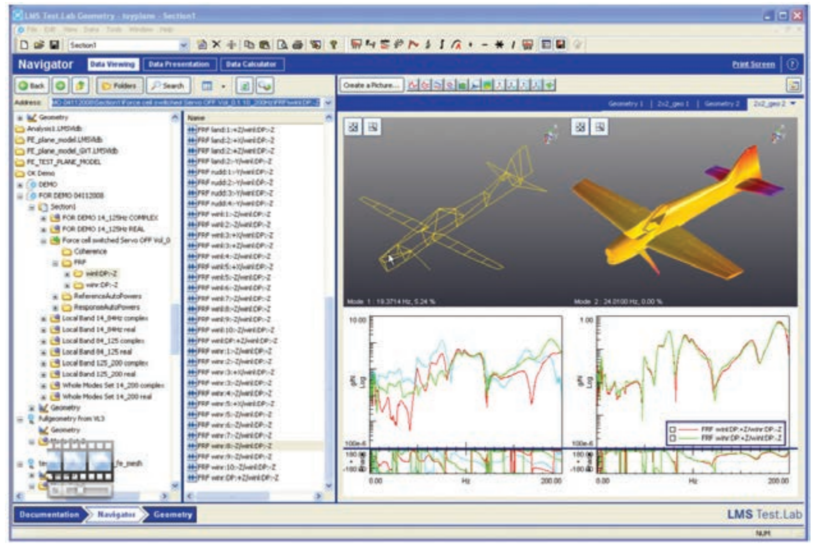
BATTLING THE PRODUCTIVITY ISSUE

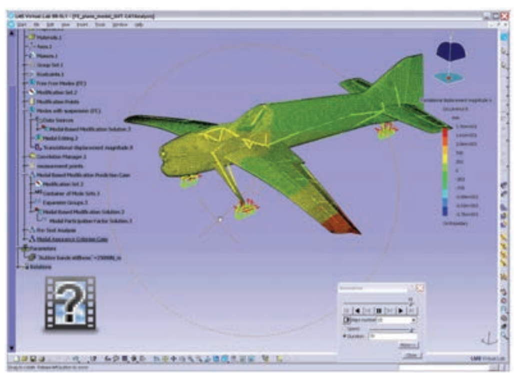
First of all, new test engineering procedures must help solve the productivity issue. Time constraints will become more dominant. Extreme time constraints make it necessary that all tests can be performed quickly, efficiently, and accurately.

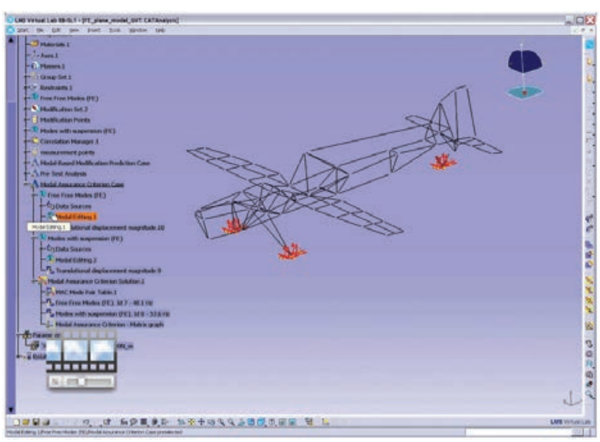
The same constraints call for a more efficient engineering team. This means more intelligent testing systems, more consistency and ease of use, more results in a shorter time-frame. Growing complexity also necessitates enhanced computing power. This enables the collection of more data through more channels, for networked systems and for software that shares data seamlessly between different applications, with built-in scalability and customization possibilities, for data to be more easily interpreted.

At the same time, reconfiguration costs should be limited, so test environments need to become even more generic and adaptable.

Last but not least, test data should be considered as a knowledge base, which processes could benefit from. This opens possibilities for new productivity wins. Obtained test data







should not only be used as a proof of the systems' capabilities but should also be made available for the optimization of other possible projects in a similar context.

ABOVE: Simulation can be used to build more focused and accurate test set ups. e.g. virtual GVT to pre-test and de-risk the GVT campaign

CONTROLLED SYSTEMS

Secondly, controls have become of major importance in modern aerospace systems. This increased use of controllers stretches the testing environment. Given this new context, classical test strategies will need to be adapted, as those controllers become a major contributor to reach the uplifted performance targets.

Ignoring their presence when planning the validation testing of subassemblies is asking for integration problems later on in the program. That's why today's development programs intensively use MIL-SIL-HIL technologies, allowing more realistic test configurations. The test planning needs to fully support this updated development process. Component and subsystem validation testing becomes more complex, as the interaction with controllers and other systems becomes an integral part of the testing environment. Full system testing requires specific procedures to analyze controller behavior in its interaction with physical hardware to understand the impact on the final product performance characteristics.

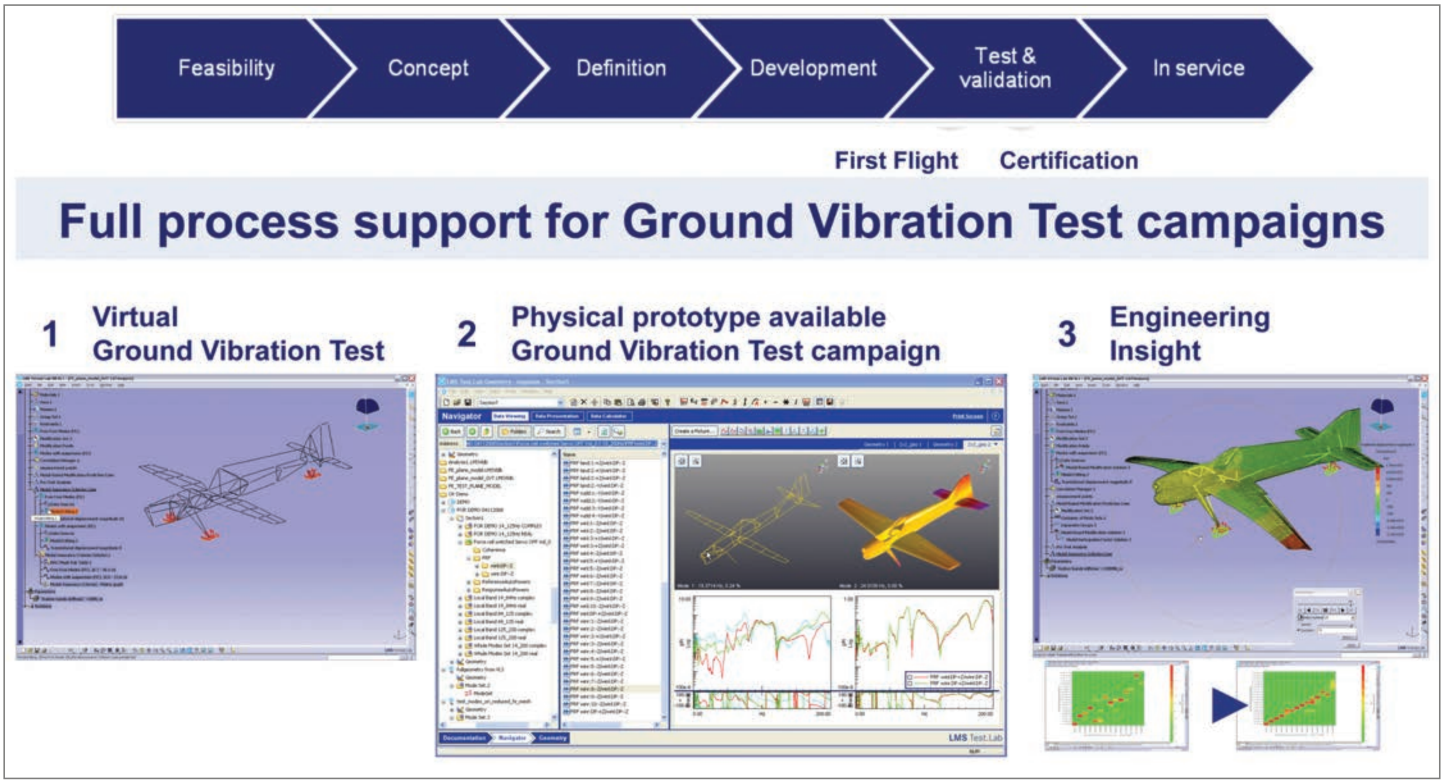
MODEL-BASED TEST STRATEGY

Going into the world of the unexplored, as one does when adopting new materials, design concepts, and technologies, requires more testing in order to fully understand the physical phenomena involved and to control risks. Validation testing is very expensive.

The trick is to be smart in how you combine testing and simulation. As matters become more complex, engineers need deeper physical insight in how systems behave in order to secure the system function and performance. Models should be used to carefully plan the validation test campaign.

Those models – even prior to calibration by test – are a vital source of information about sensitivity of parameters in view of the target performance criteria. At the same time, model-based test strategy development will provide a baseline data set, which can be used during the test campaign by the design team for real-time correlation. This will help test and design engineers to collaborate efficiently, be more agile during the campaign, possibly adapting planning based on preliminary correlation and ultimately maximize the physical insight gained during the testing. All of this results in a better test results feedback toward the development process.

A good example is the LMS solution for aircraft structural dynamics qualification. The LMS ground vibration testing solution and its corresponding engineering services cover the process from pre-test structural dynamics simulation to ground vibration testing and the use of GVT results for calibrating structural dynamics models for flight flutter testing.



ABOVE: The ground vibration testing solution and its corresponding engineering services cover the process from pre-test structural dynamics simulation; to ground vibration testing, to the use of GVT results for calibrating structural dynamics models for flight flutter testing

VALIDATING THE DEVELOPMENT PROCESS

Traditional development testing serves prototype validation. Today's testing campaigns should also provide information to calibrate the parameters of the models that were developed to support the design. But even after calibration, those models sometimes do not deliver the expected fidelity required to predict the performance characteristics of the end product.

Often, the root cause of this flaw is model incompleteness, rather than inaccuracy of the parameter values. This is sometimes a consequence of not having taken into account some relevant physical phenomena in the model. But with today's complex designs, the most probable cause of inaccuracy lies in the dynamic interaction between the systems, the connections between the various models used in the design. These are new tasks for the test engineers: spotting the flaws in the models and capturing the phenomena that are not included in the models. In a sense, testing will serve as a validation of the design process as such.

THE NEED TO TEST UP-FRONT

Finally, aircraft programs are increasingly engineered on a global basis, involving a geographically extended eco-system of suppliers. Furthermore, because the modern aircraft has become increasingly a 'system of systems', the risk of high-profile program failures needs to be avoided. Therefore engineers must be able to analyze conflicting requirements and various interaction scenarios to anticipate any system level challenges from the start. Recent program delays and cost overruns illustrate the importance of considering dynamic interaction on a system level, as early and efficiently as possible.

To meet this challenge, test and simulation have to be combined and tests have to be performed upfront, as early as possible in the development program, ideally even before any hardware has been built. Engineers also need to increase simulation realism and productivity for component and subsystem verification. They need to combine test and simulation to frontload subsystem validation and therefore advance the test process for final system validation.

This is another reason why test and simulation will develop an even closer relationship and will be further integrated. Test setups will become more intelligent.

Thanks to the present ability to create high-fidelity real-time simulation models of systems and subsystems, it has become possible to frontload hardware-in-the-loop tests. This capability could eventually result in the virtualization of the aircraft's iron bird: the creation of what the industry refers to as a 'virtual iron bird'. This possibility opens new potentials in terms of frontloading and validating integrated systems, and avoiding integration and rework issues.

SMART TEST ENGINEERING

The industry needs an answer to cover all existing challenges, and 'smart test engineering' delivers that answer. We have talked about the productivity issue, about model-based test strategies, about updating development strategies through feedback from test data, about the testing of subsystems in a modeled environment mirroring a real life situation. All of this means that test data should also be used to build better simulation models. Simulation should be used to build more focused and accurate test setups (Figure 2). Test serves simulation and simulation serves test. To make this 'smart test engineering' happen, the frontiers between simulation and real-life test should fade out.

Test and simulation divisions will have to exchange results, adapt, and learn from each other. Test and simulation should be integrated. LMS' hybrid approach toward more effective and efficient product engineering completely embodies this idea. ∎

Dr Jan Leuridan is the executive vice-president and chief technical officer of LMS International based in Belgium

Appeal to the sensors

For years the aerospace industry has relied on foil strain gauges to test materials. But an emerging technology, fiber sensing, is offering advantages over more traditional methods

BY DAWN K. GIFFORD

While each foil gage requires at least two copper wires for a single point of sensing, a distributed fiber-optic sensor can provide thousands of sensing points with a single optical fiber and connection. Optical fiber sensors are immune to electromagnetic interference and they are efficient and cost effective to install. And because they are small and lightweight, they have little effect on the structure being tested.

With distributed sensing using optical backscatter reflectometry, introduced by Luna Technologies in 2004, strain can be measured at any point along the fiber with spatial resolution as fine as a few millimeters.

This makes it possible to measure the strain profile of structures at many locations rather than at a few points. This is beneficial for the aerospace industry, which is increasing the use of composite materials and their complex strain profiles. The use of composite materials is being pursued to achieve material and structural component-tailored design and to reduce the number of structural components, which leads to a valuable reduction in aircraft weight, and more efficient and environmentally friendly aircraft. The challenge in the application of composite materials resides in their complex nature at the material level, leading to the mentioned complex strain profiles. High-resolution distributed fiber sensing is ideal for measuring the non-uniform strain profiles in composite structures and identifying defects within the composite parts well before fatigue turns to catastrophe.

Despite these advantages, and though fiber sensing has been available in some form for more than 20 years, it has not yet been commonly adopted in aerospace. However, due to the advantages of and advances in the available technology, distributed fiber sensing is emerging as a desirable method for aerospace testing.

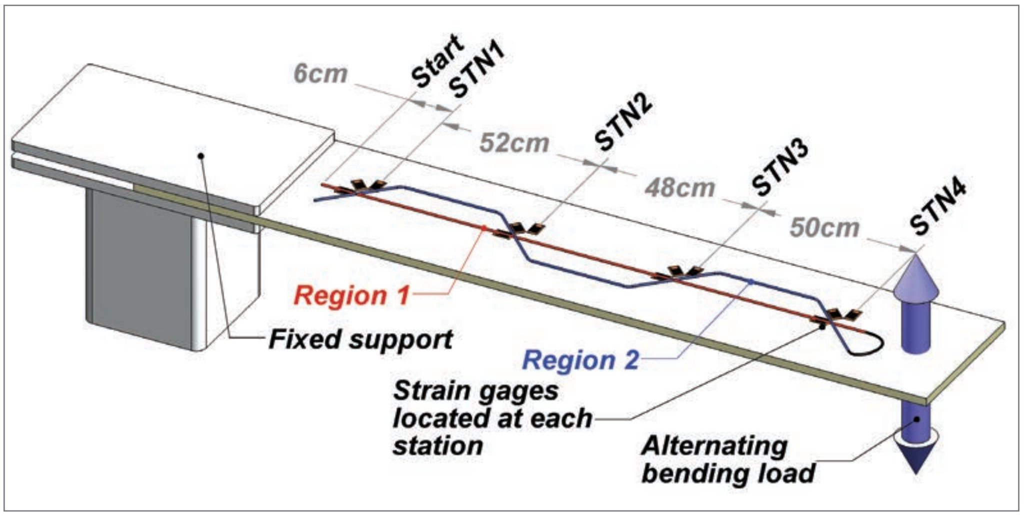
TESTING THE OPTIONS

One common concern with an emerging sensing technology is validating its performance against known techniques. The National Research Council Canada (NRC) recently performed independent comparative testing of Luna's distributed fiber sensing versus traditional foil gages on a test rig designed to simulate loading on a representation of a solid aircraft wing spar-web structure. NRC operates Structural Health Monitoring test facilities for load monitoring and damage detection sensor testing and validation. These testbeds present a range of structural complexity, from spar structures to the intricacies of the outer wing of a fighter jet.

The test, conducted earlier this year consisted of two aluminum beams clamped to a central pedestal, acting as the simulated wing root. The beams were loaded at the tips in a simple cantilever configuration. Though the pressure loading experienced by an aircraft wing would be better simulated with a distributed loading configuration, such a complicated setup was not required for this initial test.

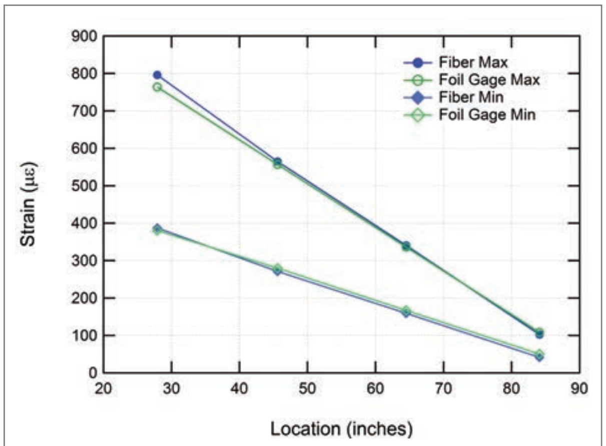
An optical fiber to be used as a continuous sensor was bonded to one side of the beam, first running along the center line from root to tip and then returning in a pattern crossing over the center line at a 45° angle in four locations, running from tip to root. Foil strain gage rosettes were placed at the four points along the center of the beam on the underside opposite the fiber. Luna's optical backscatter reflectometer was used to measure the strain along the fiber sensor, while the MTS data acquisition component of the actuation equipment was used to acquire the strain data. The figure below illustrates the test configuration.

Data was collected with the fiber sensor and the foil gages with the beam fully deflected 4in up at the tip (maximum strain) and deflected 2in



LEFT: Test configuration showing fiber layout and strain gauge locations

"ONE COMMON CONCERN WITH AN EMERGING SENSING TECHNOLOGY IS VALIDATING ITS PERFORMANCE AGAINST KNOWN TECHNIQUES"



ABOVE: Comparison of foil gauge results with results from Luna fiber sensor at four locations along the test article. The max strains were taken with the beam deflected upward 4in at its tip, while the minimum strains were recorded when the beam was deflected downward by 2in

down at the tip (minimum strain) and compared at four locations in the fiber corresponding to the placement of the foil gages.

The figure above shows the plot of the maximum and minimum bending strains measured with both sensor types at each of the four stations along the span of the beam. The displayed strains are absolute values as the foil gage and fiber sensor were on opposite sides of the beam and therefore experienced strains with opposite signs.

The results showed good correlation between the two sensor types, with strain measurements differing typically by less than 10 microstrain. The highest difference of 32 microstrain occurred in the maximum loading condition at station 1 near the root of the beam. The percent difference was lower than 6% in all cases except for the minimum strain at station 4. The percent difference in this data point is high only because the overall strain value at the beam tip was low.

	Location (inches)	Fiber Max (με)	Foil Gage Max (με)	Difference (με)	% Difference
Station1	27.9	796.1	763.9	32.2	4.2
Station 2	45.6	564.7	556.9	7.8	1.4
Station 3	64.5	340.4	336.0	4.4	1.3
Station 4	84.1	102.6	108.5	-5.9	-5.5

	Location (inches)	Fiber Min (με)	Foil Gage Min (με)	Difference (με)	% Difference
Station1	27.9	387.3	380.3	7.0	1.8
Station 2	45.6	270.9	279.8	-8.9	-3.2
Station 3	64.5	159.2	166.9	-7.7	-4.6
Station 4	84.1	41.4	50.4	-9.0	-17.9

Tables 1 and 2 (above) show the comparative results.

FATIGUE LIFE COMPARISON

Composite structures used in aerospace are often tested at strain levels higher than a few thousand microstrain, a point where metal foil gages are known to drift and eventually fail by fatigue[10,11] (of electrical circuitry, bonding, connectors, etc.). Optical fiber, however, is made of fused silica, which has a high fatigue life.

Separate from the Canadian research, Luna recently performed tests demonstrating the fatigue life of fiber sensors versus foil gages for high-strain fatigue life testing. A fiber sensor was bonded along the length of a fiberglass coupon 1⁄16in thick and ¾in wide. A foil gage was bonded immediately beside the fiber at the root of the coupon when placed in a simple cantilever configuration.

Vishay M-Bond 200 adhesive was used to bond both sensor types to the coupon. After placement in the test configuration, the cantilevered length of the coupon was 3.7in. The tip of the coupon was displaced cyclically by 0.65in to produce strains at the root of ±4,000με. Measurements were recorded with both types of sensors at the maximum, minimum, and zero load conditions after every 50 cycles. As expected, the foil gage deviated from the expected strain value with increasing number of cycles.

The fiber sensor, however, continued to make accurate strain readings throughout the fatigue testing, deviating by less than 2%. These results are illustrated in Figure 4. The foil gage used in this testing was a Vishay EA series gage in a quarter-bridge configuration. The optical fiber sensor was a commercially available polyimide-coated, low-bend loss fiber.

In subsequent tests, similar fiberglass coupons were loaded in a four-point bend configuration and cycled to ±4,250με. While foil gages bonded to the coupons typically failed after a few hundred cycles under this high-strain fatigue cycling, the fiber sensor continued to make accurate measurements over several thousand cycles. In the maximum tested case, the fiber sensor was unaffected after 28,000 cycles.

These results demonstrate the advantage of optical fiber sensors over foil gages for high-load fatigue testing, which is commonly needed for composite aerospace structural and material testing.

NRC said in its report, issued in March 2012, that: "It is evident that the use of Luna's fiber optic system compares very well with the strain gages applied by NRC to SHM Platform 1A for static loading conditions. The Luna fiber optic system has several advantages over strain gages, such as their immunity to electromagnetic interference. The values obtained from Luna's fiber optic system are accurate and repeatable as shown in this report. This technology shows promising results for static and quasi-static loading conditions, making it a promising technology for full-scale tests of aerospace structures in a laboratory environment."

As part of future work, Luna will apply its sensing system on additional testing platforms to evaluate capabilities on a more complex structure, as well as in the outer wing of a fighter jet testbed. ∎

Dawn K. Gifford, PhD, is director of technology development at Luna Innovations Inc, based in Virginia, USA

THOMAS KOPPENSTEINER

MICHAEL DANNINGER

Keep the lines open

A new solution for cleaning aircraft waste lines using citric acid has been successfully developed and tested

BY DR THOMAS KOPPENSTEINER & MICHAEL DANNINGER

When people think of a journey by airplane, they usually do not think of all the technology that guarantees a safe flight. Very often we take for granted a service, but only value it when deprived of it. Toilets are essential in any passenger aircraft, something that everybody only really notices when a toilet is out of order. The history of delays in flights caused by clogged toilets is a long one and airlines are forced to spend a huge amount of money to solve system problems.

When the toilet system is clogged, the toilet itself is rarely the issue – usually it is the waste line, the tube system that conducts the wastewater from the toilet to the wastewater tanks. When a toilet is used regularly, scale builds up in just the same way as scale builds up in the drain pipe of a kitchen sink. Due to the minimization of weight, an aircraft toilet requires a minimum of liquid to flush, and therefore the scale in a waste line builds up much faster than in a kitchen sink. The more the toilet is used, the more scale builds up. An incredible 12mm of scale accumulates in a waste line tube during a period of one year, making the diameter of the waste line systems significantly smaller, and putting them at risk of clogged waste lines.

Airlines are aware of this issue and use special chemicals for prevention of the problem. These chemicals are expensive to purchase, and the storage, application and disposal of these aggressive substances can be time consuming. Another method of removing the scale in the waste lines is to dismantle the entire waste line system and let the components soak in an acid bath for 24 hours. Following the bath-cleaning process, the segments are reassembled and leakage tests performed to guarantee the passengers a quiet flight without surprises. Of course, this method is extremely time consuming and cost intensive. Another method of removing scale from waste lines is to clean them with high-pressure hoses, which is problematic because a waste line works with negative pressure and should never be treated with high pressure. The risk of damaging seals is very high and the results are not satisfactory due to the fact that the waste lines are not straight and have bends that are impossible to access. When using the high-pressure hose method, it is also necessary to dismantle parts of the system.

A DIFFERENT SOLUTION

Different airlines have different methods of avoiding or removing the scale in waste lines, but none of them are 100% satisfactory. But now, technicians who had been working on the removal of scale for years, together with the Austrian-based company TEST-FUCHS, have developed a solution for clogged waste lines – a citric solution called WALICLEAN. This new waste line cleaning method comes in the form of a trolley, is easy to move by hand, and can be placed wherever it is needed, inside or outside the hangar.

WALICLEAN can be connected during a scheduled maintenance visit; it takes 30 minutes to prepare the trolley for operation and to connect

The WALICLEAN trolley in front of a Boeing 777

ABOVE & RIGHT: The WALLICLEAN in action, with the hoses connected to the A/C

BELOW: The operating panel, the operator is programming the operation time.

hoses to the waste line system. The operator clicks the 'start' button and the process begins – and then stops automatically when finished. For safety reasons, the WALICLEAN automatically performs a leakage check of the waste line system. There is no need to monitor the cleaning process, which takes five hours and can easily be performed overnight. The secret of this revolutionary cleaning trolley is its simplicity. A solution of water and commercially available citric acid is pumped with negative pressure through the waste line system, softening and removing the scale gently, and reaching even the most complicated areas of the tube system. The manufacturer has also integrated an inspection glass so that the maintenance technician can see the amount of scale removed during cleaning. After five hours, all the scale has been washed out of the tubes and gathered inside the WALICLEAN tank, and the waste line system is clean again. The waste water can be disposed of in the ordinary sewage system since the citric solution is biodegradable and therefore environmentally friendly, so there are no additional disposal costs. Another advantage of WALICLEAN is that the trolley executes a leakage test before and after the process, thus avoiding unpleasant surprises during the cleaning process, as well as saving the time and cost of an additional leakage test on the system before returning it into service.

TEST PROCESS

Throughout the entire design and manufacturing process, the cleaning trolley was tested on a variety of aircraft types to optimize its performance. The prototype is now complete and ready to go to work in the world of waste line cleaning. The last and most important test was performed on an Airbus A380, an aircraft with four waste line systems (two on each deck). Not only were the manufacturers delighted with the results of the test, the members of the airline crew were also pleasantly surprised. Even in the most challenging applications, the WALICLEAN system is fast and easy to use, and reduces both price and risk compared with traditional methods of removing or avoiding scale. No matter how big the airline fleet, cost savings will be significant, inflight security will improve, and the costs of unscheduled maintenance of clogged waste lines will be a thing of the past. ■

Dr Thomas Koppensteiner is head of the project team and Michael Danninger is a developing engineer with TEST-FUCHS based in Austria

THIERRY LAFFONT

Mix the old and the new

There are a number of new inspection techniques available for composites, components, and castings in the aerospace sector

BY THIERRY LAFFONT

Today's aircraft are made up of a huge number of parts manufactured from a vast range of materials. Although composites are increasingly being specified, as manufacturers strive to increase fuel efficiency or payload by reducing aircraft weight, there is still a role for conventional metals, especially, aluminum, steel, and titanium. Inspection techniques and technologies are continually evolving to meet inspection requirements of new materials and recent methods of manufacture, for both old and new materials.

As well as airframe fabrication, the majority of components and structures in many of today's aircraft are manufactured from composites or by casting conventional metals. Composites are used for items ranging from fairings and spoilers, to flaps and elevators. Castings are used for turbine and fan blades, engines, and for a wide range of structural and functional components. Various non-destructive testing (NDT) techniques are used during aircraft manufacture and service. Ultrasonic inspection finds wide application, both in terms of portable equipment, which can be used both on the production line and in service, and fixed systems, which are now found extensively in aircraft manufacture. Modern fixed systems feature transducer manipulation heads and can have robotic arm, component handling systems, with up to 11 axes of movement so that they can automatically handle the largest and most complex components.

However, the technique that is most widely used for castings is radiography, while computerised tomography and radiography is assuming greater importance in the inspection and metrology of both conventional castings and composites.

THE INSPECTION OF CASTINGS

Film radiography has long been the preferred method of castings inspection. Inspectors are comfortable with film and believe the results. However, film radiography has many accepted disadvantages, not least being its environmental unfriendliness, with regard to the treatment and disposal of chemicals, and an increasingly rapid shift to digital radiography is now taking place. This has recently gathered some impetus as more and more barriers to implementation have come down.

In metals inspection, this impetus has been greatly aided by the Metals Affordability Initiative (MAI). This was created by the US Air Force Research Laboratory's Materials and Manufacturing Directorate, with the aim of spurring technology development. One of the programs in its initiative aims to allow lower cost

RIGHT The X-Cube System in operation for spot tests and inspection

THE LANGUAGE OF INSPECTION

Handling and communication of data is a vital component of any inspection procedure, whatever the modality. It is important that this data can be accurately gathered, communicated, reviewed, and often archived for traceability. DICONDE is a protocol that has been specifically developed for the non-destructive testing sector. It is a derivative of the DICOM protocol, which is the definitive and successful data-handling protocol in the medical sector, but incorporates many features that are purely NDT-focused. For example, all images are tagged with the location, inspector, technique, and date, as well as user-specific information.

Additional information can include the resolution and bad pixel maps for radiographic inspections. All critical raw data is retained, as is meta data – the data obtained by digital manipulation of the image. The first version of DICONDE was released by ASTM in 2004.

Rhythm, from GE, is a software platform that is fully DICONDE compliant. DICONDE compliancy ensures that operators are not constricted by current proprietary formats, eliminates the need for future data conversion, and simplifies data integration from other NDT information sources. Moreover, DICONDE images can be exported in other file formats, such as jpeg, bmp, and tif, and a copy of the DICONDE viewer can be included on a burnt disc to allow the content to be displayed on any standard PC.

The data from tagged images gathered by Rhythm is analyzed in Rhythm Review. This features application tools for image analysis, measurement, and enhancement, such as GE's Flash!Filter, which uses a dynamically adjusting algorithm to provide consistent and clear image presentation with a single mouse click.

The system's ability to create workflows enables inspection data to be shared across multiple workstations so that review can be carried out in line with inspection, avoiding bottlenecks. Rhythm Archive is a comprehensive solution for the management and archiving of large volumes of inspection information, and stores not only the raw inspection data but also any enhanced images developed at a Rhythm Review workstation. Furthermore, the tagging of each image facilitates any database searching, which can be carried out according to location, inspector, technique, etc.

material and manufacturing methods, as well as reducing the time required for development and production manufacturing of metallic components. This has resulted in standards authorities and manufacturers working together to produce guidelines and specifications, including the creation and validation of reference radiographs for aluminum, steel, and titanium, and a library of film-to-digital comparisons.

RADIOGRAPHY INSPECTION SYSTEMS

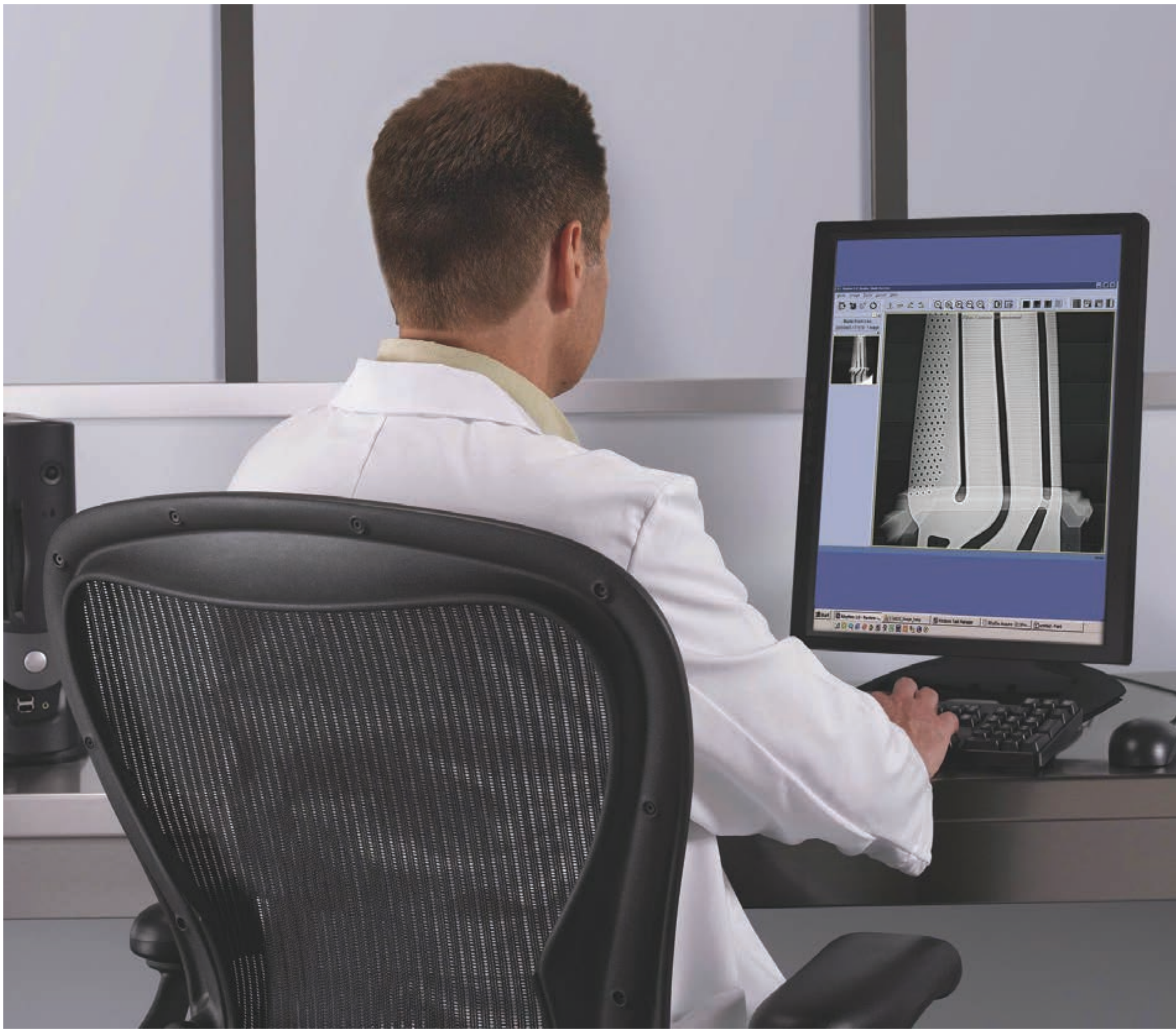
In line with software, the radiography imaging chain technology has advanced significantly over the past few years with the introduction of computed radiography equipment, the development of new detector arrays, and the introduction of new-generation x-ray machines. This has seen innovations in radiography systems, specifically designed for efficiency, productivity, and reliability in the castings shop.

X-Cube was introduced by GE some 10 years ago. It features an x-ray source, a patented source manipulation system, and a component clamping table within a shielded chamber, an ergonomically designed control desk, and provides high-quality x-ray images and an integrated image enhancement system. The fast and reliable x-ray tube manipulator allows exact positioning of the source without the need to tilt the object under inspection. All movements can be visually controlled through a lead glass window. Door loading times are less than three seconds and to accelerate mounting times of testing parts, a special, three-jaw chuck and dedicated part fixtures are available. User-friendly software allows easy programming and intuitive operation of the system, and a variable speed mode can further shorten inspection cycles in line with inspection tasks and operator experience.

A recent addition to GE's portfolio is the X|blade, which combines robotic positioning of parts to be inspected, with an imaging chain that can be customized to meet specific applications and a DICONDE-compliant image review, sharing and archiving system to offer fast, flexible inspection and immediate review. It is specifically targeted at the aerospace sector, where it can be used in the inspection of cast turbine blades, up to 400mm in length and 8kg in weight, in line with the guidelines of the MAI and ASTM standards.

It features a number of synergies with the X-Cube family and represents an additional workflow enhancing option in the digital radiography inspection portfolio, with a capability to handle around 280 images/hour. However, it is important to point out that a digital X|blade system is different to a standard film system and to maximise the system's considerable benefits, training is very important. MAI courses are available as an introduction to digital technology for Level II and Level III technicians.

The latest GE development in radiography for the aerospace sector is Blade|line. This exciting new product has been created to meet the challenge of inspecting turbine blades of ever-increasing geometrical complexity, where internal wall thicknesses become very difficult to measure. Blade|line uses the latest Isovolt Titan x-ray generator and the latest linear detector array, with robotic handling of the blade to be inspected.

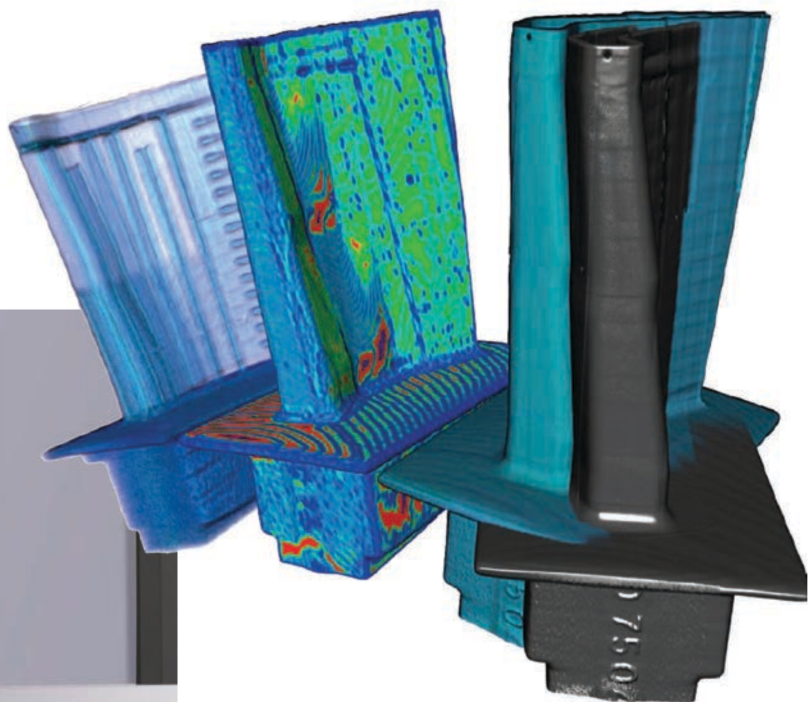


ABOVE: **Reviewing digital images with Rhythm**

COMPUTED TOMOGRAPHY FOR INSPECTION AND METROLOGY

Industrial computed tomography has been used for quite some time, but has been restricted to test laboratories for random sampling and test sampling. Over the past few years, the technology has made great advances in increasingly high resolutions and even greater reconstruction speeds for 3D volume data, so that computed tomography (CT) results are now available within minutes.

Recent developments have seen the introduction of the Phoenix v|tome|x 300kV CT system, which has less than 1µm detail detectability. It offers excellent resolution and magnification for high-absorbing metal samples, while its optional dual tube configuration allows high-resolution nanoCT of low absorbing samples. The system's Datos|x 2.2 means the whole scan and reconstruction process can be run without any operator interaction, while Click & Measure|CT functionality enables display and analysis of the 3D results on the screen in just three steps, so



"FILM RADIOGRAPHY HAS LONG BEEN THE PREFERRED METHOD OF CASTINGS INSPECTION"

LEFT CT of aviation turbine blades Computed tomography for composite materials

that operator skill requirements are dramatically reduced.

This functionality and capability also allow CT to be used for 3D metrology, especially for complex parts with hidden or difficult-to-access surfaces, where the technology can offer significant benefits over conventional tactile or optical coordinate measuring machines.

Obviously, foundries supplying precision castings to the aerospace sector would prefer to have 100% production line inspection rather than random sampling. Apart from offering more accurate quality control, continuous sampling also allows a rapid response to flaw detection, resulting in important feedback to the pouring or casting station.

The new Speed|scan AtlineCT system brings high-speed 3D CT for the first time directly to the production line for the up to 100% inspection of castings. By incorporating much of the technology that has been proven by GE in the healthcare sector over four decades, the new CT system is up to 200 times faster than conventional 3D CT inspection and offers important additional quality control features, including exact 3D defect location and classification, wall thickness analysis to allow dimensional control, and actual CAD data comparison. GE's Speed|scan AtlineCT is suitable for any production line where there is a constant requirement for stringent quality control of light metal castings or composite structures, but is particularly targeted at the automotive and aerospace sectors.

Both the Speed|scan systems work on the same principle as computed tomography in the medical field. The object to be examined is moved along its longitudinal axis through the beam plane at constant speed while the beam source/detector unit rotates at a constant angular velocity.

In the struggle to make aircraft ever-lighter, composites are accounting for more and more of an aircraft's total weight. All these composite components and structures demand inspection during manufacture for quality-control purposes and composites must also be inspected during service, especially when they have incurred damage. Unfortunately, by their very nature, composite materials either preclude many conventional NDT techniques or, at best, limit their application. For example, although carbon fiber composites are conductive, eddy current has very limited application and conventional x-ray cannot detect a delamination, except when there is an inclusion of substantially different density. Ultrasonics is very much the preferred technology, but CT is fast becoming specified.

High-resolution x-ray CT enables the 3D visualization and failure analysis of the internal microstructure of composite materials – even where 2D x-ray microscopy would give only the integral information of the overlaying bundles of fibers. Consequently, CT is fast becoming ideal to accompany the manufacture of composite structures and components from development to final quality control. CT is used to detect voids, micro-cracks, delamination, and wrinkling in composite structures and components. It can also be used to establish whether a composite component is resin-rich or resin-poor, and is a suitable technology for all conventional composite manufacturing processes from standard lay-up to vacuum bag moulding and resin transfer moulding.

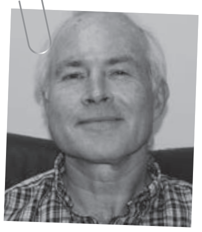
Apart from its role as a quality control tool, CT has also been used successfully at the German Aerospace Center in experiments simulating damage in service, such as damage caused by hail impact, bird strike, tire debris impact, runway debris impact, and tool drop. The full 3D information provided by CT has enabled researchers to create a tetrahedron network of the impact damage site.

TECHNIQUES

Radiography, in its many forms, has an important role to play in the aerospace sector. Film radiography is still widely used, but with the development of relevant standards and specifications and the widespread application of the MAI initiative, digital radiography is now increasingly accepted as a productive, efficient, and reliable inspection technology.

Similarly, computed tomography is also moving out of the laboratory and onto the production line with significant benefit to all. However, it must be borne in mind that these new techniques differ widely from conventional film radiography and it is not merely a case of buying equipment. It is first of all important to establish that equipment will meet the necessary requirements and it is also important that there is an infrastructure to provide the necessary training and after-sales support. ∎

Thierry Laffont is from GE Measurement & Control, based in the UK



LADD HOWELL

Go with the flow

Advances in 'smart' turbine meters are improving flow sensing capabilities in the aerospace industry

BY LADD HOWELL

For research, development, and testing applications in the aerospace industry, advanced 'smart' turbine flowmeters are providing significantly improved volumetric and mass flow sensing performance. In particular, this new breed of turbine meter is being used by manufacturers of advanced aircraft because of its many benefits: extended turndown, fast response time (30m/sec typically), compact size, and ability to operate in harsh environments (-40°C to +125°C) found at both ends of the flight test envelope.

Designed for mass or volumetric liquid flow measurements, the smart turbine flowmeter is a fully integrated, microprocessor-based flow sensing system. The characteristic that sets this meter apart from traditional turbine meters, and most other flowmeter designs, is its ability to perform temperature compensation internally, and thus correct for changes in fluid viscosity and density without the need for bulky external temperature sensors, signal conditioners, and linearizers. Because space for sensors and other electronic equipment is limited on board today's sophisticated aircraft, this feature is key.

TYPICAL APPLICATIONS

A manufacturer prototyping a new helicopter platform, for example, may need to test the performance of an orifice or pump, or monitor engine heating, under various flight conditions. Flow measurements must not only be extremely accurate, but data must also be provided on a 'real-time' basis. Once the flow data is collected, the manufacturer will make the necessary design changes in order to keep the aircraft within specified performance tolerances.

In addition to initial prototype flight testing, manufacturers often employ turbine flowmeters for a host of recurring tests. For instance, a flowmeter may be mounted along with several other sensors on a panel that is installed under the helicopter's engine cover. The helicopter is taken through its flight envelope, and the flow of various engine or hydraulic fluids is measured and recorded. The wide range of temperatures encountered during these tests requires that the meter be able to accurately compensate for temperature changes that significantly affect fluid viscosity.

After the helicopter lands, data is transferred to a computer that performs computations and prints out reports covering a host of performance parameters. The panel is removed from the aircraft after the testing is completed. Another use for flowmeters is to measure fuel consumption as part of an aircraft's onboard fuel management system, or as part of a ground-based engine test stand. These applications often involve aircraft designed for commercial and industrial service, including law enforcement and medical transport.

The high resolution of the turbine meter also makes it ideal for detection of leaks in fluid systems. With

LEFT: This flowmeter has integral electronics in a lightweight compact design providing an accurate temperature compensated flow output

LEFT: The MQ-4C Triton is a derivative of the RQ-4B Global Hawk 'Smart' – turbine flow meters are used for various flow applications on board (Photo: Northrup Grumman)

BELOW: The Apache Longbow helicopter requires state-of-art instrumentation to ensure mission success

"THE LINEARITY OF A SMART TURBINE METER IS +0.1% OVER A 100:1 TURNDOWN"

resolutions up to 48,000 pulses per gallon for small turbines, minute fluid flow can be detected.

ENHANCING TURBINE METERS

Although turbine flowmeters have long been popular in aerospace applications due to their high accuracy and rangeability, the advent of a 'smart' turbine offers significantly enhanced performance, often allowing a single meter to replace the multiple flow metering devices that were previously required to achieve adequate turndown in many applications.

The linearity of a smart turbine meter is +0.1% over a 100:1 turndown. This is achieved using either cubic spline or linear interpolation methods. When viscosity compensation is required, there is a reduction of turndown due to the curve fitting process of developing a universal viscosity curve. The universal viscosity curve is a semi log plot of the sensitivity of the flowmeter as a function of the ratio of the output frequency to the kinematic viscosity.

The curve is formed by plotting K and Hz/CTS for every calibration data point. Typically, 30 points are used, 10 each for three different fluids. The 30 points are plotted on a common graph to form a smooth curve and are stored in memory. Once this is done, the K-factor may be determined for any flow rate in fluid of any viscosity so long as the ratio Hz/CTS is within the range of values covered by the graph. Total system accuracy is dependent on the fluid type, flow range, and temperature excursion required by the application.

Unlike flow computers or similar electronic hardware, a smart turbine meter's surface-mounted electronics are integral to the flowmeter body, making it a desirable solution for aerospace applications requiring miniaturized sensor packaging. All temperature compensation, linearization, and signal conditioning is performed by an internal sensor. As a result, this design eliminates the possibility of mismatching external electronic components within a flow measurement system.

Smart electronics are also available for interface to existing turbine flow meters. These devices simply replace the turbine meters pick-off. Temperature and rotor sensing is built into the smart electronics package. Advances in microelectronics have enabled the packaging of these devices to become very compact, the latest versions being not much larger than a standard turbine flow meter pick-off.

RIGHT: Temperature compensated electronics in the size of a standard turbine pick-off are now available due to advances in microelectronics. This photo shows Flow Technology's new microLink pick-off compared to its older SIL product

Smart turbine meters provide a logic pulse output (5V) that is transmitted to an aircraft flight computer for fuel consumption metering. Using microprocessor-based components allows meters to be reprogrammed to accommodate recalibration, while maintaining the same pulses per unit of measure output. Other options for data output include RS-232, RS-485, and CANopen (CANbus) serial communications.

Because of its typical 30m/sec system response time, the smart turbine flowmeter provides a flow output that eliminates the long settling times commonly found with other flow measuring techniques. The meter's fast response time is of particular benefit to aerospace users who require almost instantaneous feedback on flow conditions that effect engine performance. These users cannot rely on flow sensors with excessive response lag times that are difficult to correlate. Typical response times for small turbines are 2 to 5 milliseconds; additional signal processing increases the latency depending on the configuration.

Also, turbine flowmeters can withstand the extreme g forces encountered during the flight of high performance or military aircraft. They can also withstand harsh environmental conditions and operate in temperatures from -40° to +125°C.

Safety and reliability considerations dictate the use of turbine flowmeters in some aerospace applications. For example, the turbine's in-line rotor configuration ensures the presence of fluid flow (including fuel, hydraulics, and coolant) even if the meter's rotor is not rotating (locked). Other flow sensing devices, such as positive displacement meters, would not permit the passage of fluid. The result would be engine overheating or fuel blockage.

From a maintenance standpoint, a smart turbine meter provides a number of advantages. Its fully scalable pulse outputs can be matched to the user's engineering units and amplified for signal strength.

These scalable outputs also mean the meter can be removed from service and replaced with another turbine meter that has been scaled for an identical K-factor. This permits flowmeters to be interchanged without the need for adjustments or rescaling to other electronics on the aircraft.

OPERATING SEQUENCE

The smart turbine flowmeter's ability to compensate for viscosity and density changes in a known liquid provides for an accurate, continuously updated K factor that represents the actual flow volume or mass. A typical sequence for performing compensated flow measurement can be described as follows:

- Measure temperature of liquid;
- Determine actual kinematic viscosity by calculating kinematic viscosity versus temperature;
- Measure flowmeter frequency;
- Calculate frequency kinematic viscosity (f/v);
- Determine K factor versus f/v;
- Calculate: flow rate = frequency actual K factor;
- Determine liquid density by comparing density versus temperature;
- Calculate mass flow rate = volumetric flow rate x actual density.

The emergence of the smart turbine flowmeter is due, in large part, to the demanding flow measurement requirements of today's high technology aircraft.

Advances in electronics have allowed the "Smart" turbine flow meter to reduce in size and mass to accommodate legacy flow applications, as well as new flow applications where the benefits of turbine flow meter technology can be utilized. ∎

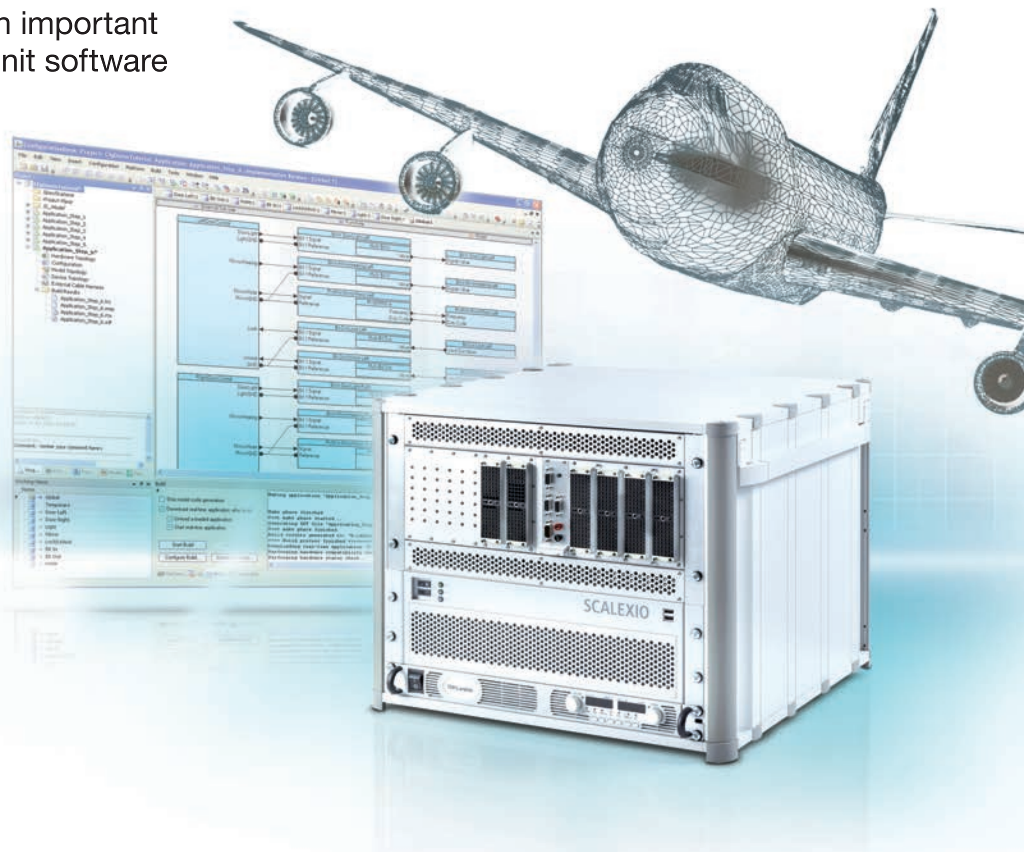
Ladd Howell is the aerospace market manager, FTI Flow Technology Inc, based in Arizona, USA

DR ANDREAS HIMMLER

Take control

Modern HIL technology is an important basis for validating control unit software

BY DR ANDREAS HIMMLER



Hardware-in-the-loop (HIL) testing is indispensable in the software development process for control units (e.g. LRU, FADEC, IMA). It has been an integral part of numerous companies' development processes for years. HIL simulation is regarded as the tried-and-tested method for function, component, integration, and network tests for the entire system. This holds especially for model-based design. In all the years HIL testing has been used, users have continuously optimized their processes. Therefore, requirements for HIL simulation have changed and they need to be addressed by new HIL technology.

Today, specialization among the members of HIL teams is usual – in other words, the division of tasks. There are tasks to design the electrical aspects of a simulator, and others to model the I/O and plant, and to create and execute tests. Because of this HIL technology must now enable different team members to work simultaneously on different tasks on the same project. For example, while one team member is setting up the I/O configuration of the HIL system, another team member is setting up the plant model. This separation of tasks also supports confidentiality, if required.

CHANGED WORKFLOWS – TASK DIVISION

Today, most companies have set up central HIL departments, although sometimes the individual engineering departments also take care of their HIL systems. In either case, teams solely dedicated to HIL are typical. They are responsible for planning the electrical aspects of a simulator (HIL hardware, connecting real and substitute loads, cable harnesses), for modeling the I/O and plant, and for creating and executing tests. Having dedicated teams means that the team members can specialize, and task division is the usual case. Powerful HIL systems support this by enabling working practices such as:

- Early project planning and configuration, even without simulator hardware;
- Separating simulator configuration and plant modeling (also separating code generation, which saves time for individual users);
- Model exchange between component tests and integration tests;
- Automated model generation and parameterization (enables use of in-house databases to put together models and associated parameters);
- Use of identical HIL systems and tools by OEMs and suppliers (simplifies exchange of models, parameters, hardware configurations, tests, and test results);
- Worldwide use of test platforms (requires multi-user or remote access to a distant simulator, and manual setup of the simulator for different test cases by an on-site engineer); and
- Linkage of tests to control unit requirements (i.e. dedicated interaction between the test tool and requirements management tools such as IBM Doors and MKS Integrity).

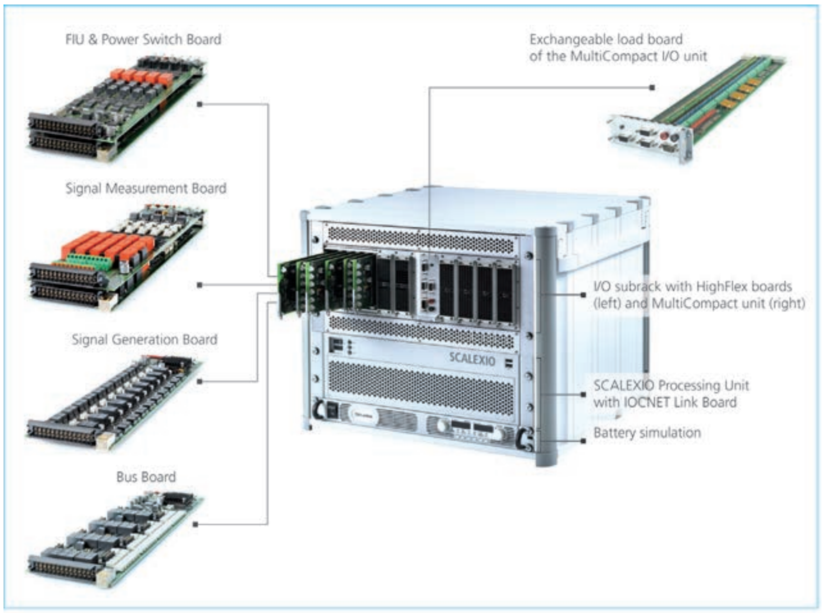
FLEXIBILITY AND ADAPTABILITY

Flexibility is needed if different control units or variants have to be tested on one system, either individually or in a network. It often happens that the HIL systems have to be specified and built at a point in time when parts of the final control unit specifications might still be changed. A further common requirement concerning adaptability is executing additional tests for new components added to an existing vehicle (e.g. airplane, satellite).

For reasons of cost, when one project has been successfully finished, it is becoming more and more common to completely convert the HIL system in order to use it for the next project. Moreover, a HIL system is frequently used both for network testing of the entire network or parts of the network, and for dedicated tests of single components. This may be because a section of a HIL test system has to be isolated in order to intensify troubleshooting for a single control unit, or it may be that after successful component tests, the component test systems are interconnected to run network tests.

NEW TECHNOLOGY: SCALEXIO

Consistent implementation of the above requirements involves some extensive changes in existing hardware and software concepts. The HIL technology SCALEXIO was therefore developed as a completely new hardware and software architecture that fulfills these requirements. Its most prominent



RIGHT: New HIL technology

AEROSPACE BUS INTERFACES

Aerospace bus interfaces based on PMC modules are available for Scalexio. They are integrated into the real-time processor using PCIe interfaces. This enables the same optimal bandwidth between I/O and real-time processor as with IOCNET for the Scalexio I/O boards. The optimal real-time performance (e.g. for testing large numbers of bus channels) is ensured by PMC device drivers specifically developed for the Scalexio real-time operating system.

> "CONSISTENT IMPLEMENTATION OF THE ABOVE REQUIREMENTS INVOLVES SOME EXTENSIVE CHANGES IN EXISTING HARDWARE AND SOFTWARE CONCEPTS"

features are related to channel flexibility, granular extensibility, and complete software configurability.

The real-time processor is the heart of SCALEXIO. A SCALEXIO processor core is based on an industry PC with an Intel Core i7 quad-core processor, a real-time operating system, and a PCIe plug-on card designed by dSPACE for communication with the I/O and with further real-time processors. The real-time processor sets up a connection to the host PC via Gigabit Ethernet, which is used to configure the entire simulator, load real-time applications, and finally monitor and control the HIL simulation itself.

Using standard PC technology allows a fast response to growing performance requirements and new technologies on the PC market. Standard PC technology also enables easy integration of third-party hardware into SCALEXIO by using standardized PC interfaces.

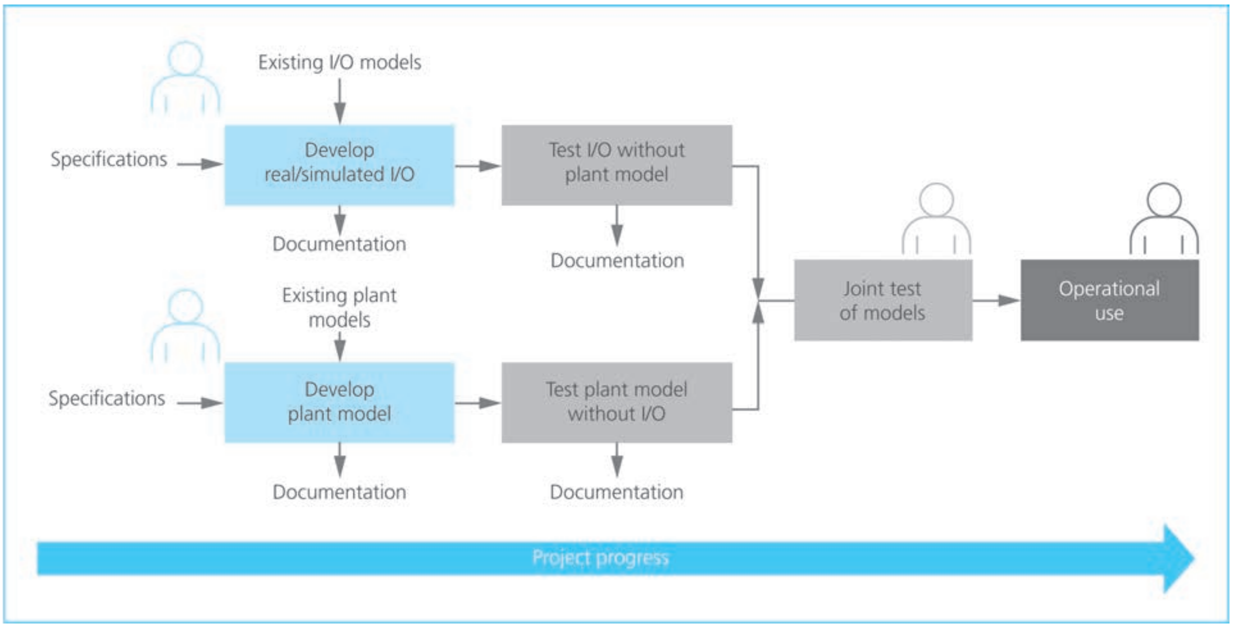
Communication between real-time processors and I/O boards has a considerable effect on the minimum cycle time of a simulation step. Therefore, dSPACE has developed the new serial I/O network IOCNET (I/O carrier network), which is being used for the first time in SCALEXIO.

IOCNET is based on the physical layer of Gigabit Ethernet and integrated into the real-time processor via the PCIe card developed by dSPACE. To guarantee dSPACE's accustomed real-time capability, network protocols for real-time communication and highly precise time and angle synchronization were developed. Intelligence and preprocessing on the I/O boards reduce the load on the real-time processor.

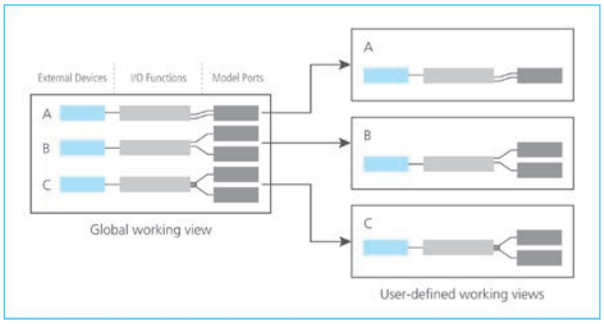
IOCNET's transmission rate is higher than previously used technologies by a factor of approximately 10. More than 100 I/O nodes can be connected to a real-time processor, and each of these I/O boards can comprise considerably more than 100 I/O channels. Optical media can be used for distances of 100m (328ft) and more between the real-time processor and the I/O boards to address aspects of spatial distribution (decentralization), modularity, and flexibility.

The HIL signals can be roughly divided into four classes: signal generation (e.g. simulating sensor signals); signal measurement (e.g. measuring actuator signals); bus systems; and supply signals. The SCALEXIO technology provides two different, software-configurable I/O board types for each of these four classes: the HighFlex I/O boards and the MultiCompact I/O unit.

What both types have in common is a local PowerPC processor for signal preprocessing and relieving the load on the real-time processor, an IOCNET interface, typical signal conditioning,



RIGHT: **Division of tasks**



ABOVE: **User defined views for I/O configuration**

converters, and parts of the electrical failure simulation. The two I/O board types can be combined in any way desired and used both in small component testers and in large network test systems. Integrating the signal conditioning and failure simulation reduces internal wiring and simplifies the technical setup, which makes reuse much easier.

The outstanding features of the HighFlex I/O boards are their flexibility and performance. Each of the signal generation and measurement boards implements 10 galvanically isolated channels, and each channel provides several software-selectable physical interfaces (such as digital, analog, resistance simulation). The bus board has four galvanically isolated bus channels, which are software-configurable as CAN, LIN, FlexRay or UART channels, and which provide the necessary transceivers and terminations. Thus, simulator project planning with HighFlex I/O boards has to include only the number of channels, but not their types. The physical interface that is actually used is configured via software and can be changed as often as required. This results in a very high level of flexibility and reusability.

The special features of the MultiCompact I/O unit are its large number of channels, its channel density, and the attractive price per channel. The MultiCompact I/O has more than 150 channels in total, and is galvanically isolated as a unit. For compactness, the unit mainly has dedicated rather than multifunctional channels.

SCALEXIO: CONFIGURATION SOFTWARE

The versatile configuration options of the I/O Carrier Network hardware can be accessed via the new ConfigurationDesk tool. The configuration process is roughly divided into three tasks: describing the externally connected devices (e.g. control units, real loads); selecting the I/O functions for each signal; and linking the I/O functions to the plant model. Configuration can be performed in any order in a three-column display. When the complete configuration process is run through, documentation is automatically available on the entire signal path from the control unit pin to the external cable harness, control unit/load connector pin, internal cable harness and I/O function, to the model variable. The system configuration is therefore constantly traceable.

Separating I/O configuration and modeling increases the modularity and reusability of the individual configuration items. It also supports a workflow involving parallel work on different tasks. A great deal of time can also be saved: for example, modification of the I/O configuration only requires generation of new code for the I/O part, but not for the plant model.

A large number of I/O functions are available in library form, from simple digital/PWM functions or wheel speed signal simulation, to complex angle-based functions for internal combustion engines. In addition, there are I/O functions for the most important aerospace and automotive bus systems, such as ARINC 429, MIL-STD-1553, CAN, LIN, FlexRay, and UART. Because the I/O boards are programmable, further I/O functions can be added.

These I/O functions are configured at an abstract, logical level, and not on a specific hardware channel. This means that functionality can be reassigned to another I/O board, for example, and it is even possible to use several physical channels if the current/voltage capacity of a signal has to be increased. This abstract configuration level also allows virtual project planning while the HIL hardware setup is still evolving, so that configuration work can begin very early in a project. The (incremental) build process is also run from within ConfigurationDesk, resulting in an executable real-time application that can be loaded straight to the HIL simulator. ■

Dr-Ing. Andreas Himmler, product manager of hardware-in-the-loop simulators for dSpace, based in Germany

Rapid Control Prototyping | Autocoding | HIL Testing

Hardware-in-the-Loop Testing with dSPACE – For Certain Success

With the complexity of today's highly-integrated vehicle systems, testing is more important than ever. In "iron birds," integration test facilities, and model-testbed applications, dSPACE hardware-in-the-loop (HIL) systems, emulators, and model-driven testing tools are best-in-class when it comes to performance, quality, and value. dSPACE products have set the standard for quality for over 20 years. Whether the application is for air, land, sea, or space, dSPACE has provided world class support on programs as diverse as Joint Strike Fighter, the USS Makin Island, Future Combat Systems, and the Joint Polar Satellite System.

When quality, reliability, and performance are critical, you can rely on dSPACE.

Central figure

The cooperation between Lufthansa Technik AG and DAUtec GmbH is an essential link in the Hamburg aviation cluster, central to European aviation, and offering a range of test infrastructures to the aviation industry

BY BUNNY RICHARDS

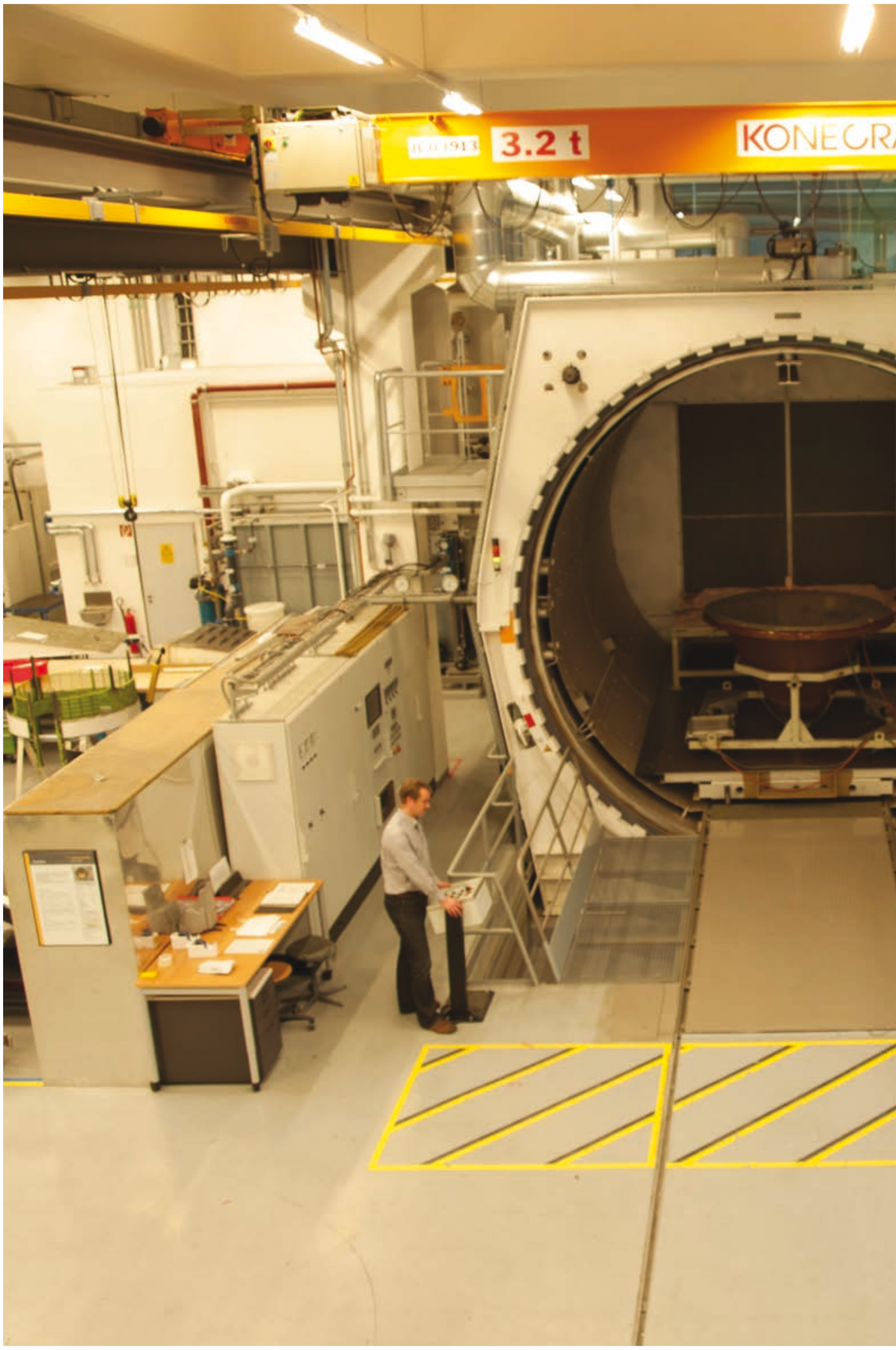
Sitting within the confines of Hamburg Airport is the company office for DAUtec. At first glance during my visit, it appears surprisingly small, with just 10 employees housed in a small area. But this belies the importance of the test work it does and the integral part it plays in an aviation cluster that has the highest concentration of aerospace companies in Europe. It is at the core of what is known as 'Lufthansa City', home to some 6,000 employees.

Lufthansa Technik (LHT) is based in the same complex, and while being guided through the vast maintenance hangars by Jörn Abraham, section manager of production operations innovation with LHT, my first question is simple: "Why do you work with DAUtec?" He replies, "Because they are the best. We have worked with them in the past, and we like the way they work."

The collaboration between the behemoth that is LHT and DAUtec only started in 2009 when DAUtec put its know-how into a number of qualification projects. This went on until LHT decided it needed something more permanent within its base in Hamburg and the blossoming relationship developed further when DAUtec began operation from the LHT test lab in 2011.

DAUtec CEO and aerospace engineer Hans-Jörg Dau is looking forward to exploring the partnership: "Lufthansa Technik's guiding business maxim is focused on quality, with annual turnover and the size of LHT's choice of partner not being that crucial. As a much smaller business, we have been given the opportunity to prove ourselves each and every day, reflecting LHT's core values."

This agreement means DAUtec advises LHT engineers on the design of technical specifications, preparing the documentation required for qualification, and with the planning and supervision of laboratory tests. More specifically, DAUtec carries out qualification tests, including electromagnetic compatibility and environmental tests according to RTCA DO-160 regulations and the



BUILDING FOUNDATIONS

The grandfather of Hans-Jörg Dau started his engine overhaul business in Stettin, Germany, in 1919. Founded in 2003 by Dipl.-Ing. Hans-Jörg Dau, Hamburg-based DAUtec moved from its original hometown of Lübeck in 2006 to be closer to where a high number of customers were based, to make it easier to connect and work alongside them. In 2007, DAUtec became DIN EN 9100 certified, and since 2009 has been collaborating with Lufthansa Technik.

MIL-STD-810 standard. "Accreditation of the laboratory will be performed by DAUtec at Germany's national accreditation body, Deutsche Akkreditierungsstelle, according to DIN EN ISO/IEC 17025, the European regulation setting out the general requirements for the competence of testing and calibration laboratories," explains Dau.

Initially LHT will use the laboratory for in-house engineering and qualification tests, while subsequently the environmental laboratory will be enlarged and ultimately integrated into the test center of the ZAL Zentrum für Angewandte Luftfahrtforschung (Center of Applied Aeronautical Research).

ZAL intends to enter into an agreement with LHT and DAUtec, and will commit to providing further investments in the test infrastructure, which will benefit ZAL's partners during the initial development phase, and for certification and qualification purposes.

ABOUT THE COMPANY

DAUtec takes a company from the first stages of aerospace development, through production, up to authorization. Its services include involvement in compiling specifications; formulation of test plans; test procedures; supervision of tests in its laboratories in order to aid design engineers, including the execution of acceptance testing; creation of test reports and other documents up to DDP; and certification consulting (LBA/EASA) for civil and military aircraft systems and equipment.

DAUtec can develop individual test plans or assist in coordinating entire test programs for any company or aircraft.

RECENT PROJECTS

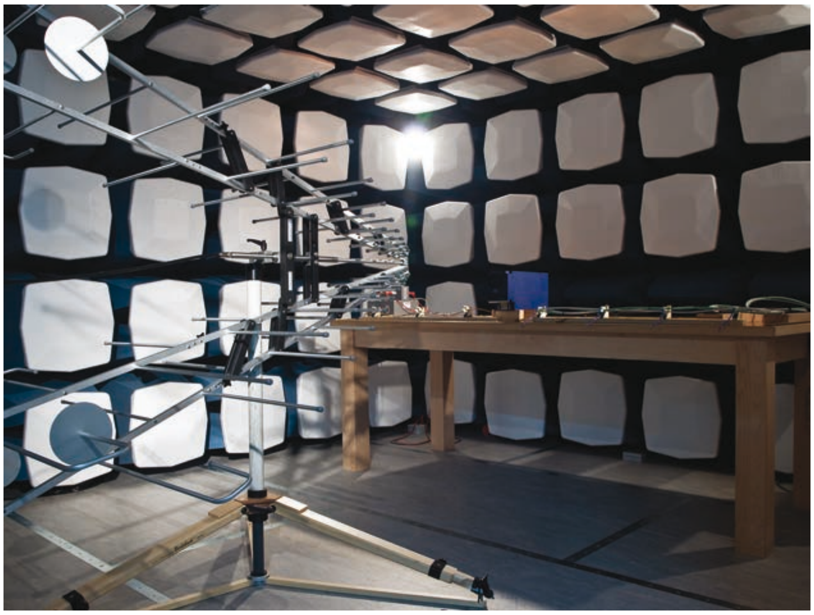
Over the years, DAUtec has gained its experience by completing a lot of very different projects. Dau says, "We have gained our widespread knowledge by having the best possible team on the job. Each team member has a background in aviation, and most, if not all, are keen pilots."

"Some of DAUtec's most recent projects include: qualification of IFE systems; LHT's networked integrated cabin equipment; cockpit devices; fuel systems and avionics for military vehicles; pre-qualification engineering tests and subsequent qualification of mechanical components for Airbus aircraft, for example, tie-rods and shock mounts produced by RO-RA; and guidance and consulting around aspired qualification of RFID tags for multifunctional use in aircraft.

MAIN: **Unique in aerospace testing: Scholz autoclave available for overpressure and thermal testing of bulky units and equipment**

LEFT: **The new innovation center of Lufthansa Technik in Hamburg**

RIGHT: **HASS/HALT chamber (Vötsch Model Star Galaxy 36 Premiere)**



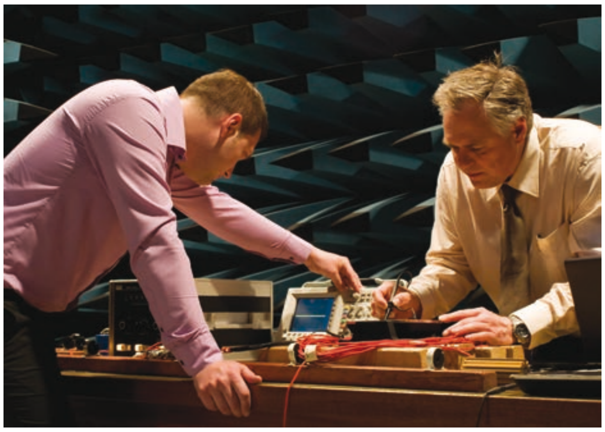
"We have worked on a selection of civil aircraft," says Dau. "These include Airbus A380, Boeing 747-8I, Airbus A350, and Boeing 737, as well as military aircraft such as Airbus A400M, Eurofighter, Puma, CH-53, and Tornado."

With experience on such a wide range of aircraft, it begs the question, are there any major differences between working on civil or military aircraft, and does this pose a problem?

Dau replies, "The strategy and the tailoring process are more or less the same, which means we need to ensure that the unit will work safely during the live time-cycle and will not disturb other systems. The major difference is the specifications for testing. The military uses the MIL-STD 810 for environment and MIL-STD 461/462 for EMI, whereas civil aircraft use RTCA DO-160 or special test descriptions from Boeing or Airbus. For Airbus, for example, we use ABD 100, but this specification is based on RTCA DO-160 in a lot of cases. In general, the MIL specs are physically stronger and heavier than the civil specs."

ACCIDENT INVESTIGATION

Dau is an accredited investigator for Germany's Federal Bureau of Aircraft Accidents Investigation. Know-how obtained from this function is available to DAUtec and provides valuable expertise, especially with regard to new product developments in the aerospace field. Dau says, "According to the law relating to the investigation into accidents and incidents associated with the operation of civil aircraft, all accidents and serious incidents that occur during the operation of civil aircraft over 2,000kg, rotorcraft, balloons, and airships operated by an air carrier, must be investigated."



ABOVE: **Andreas Gerlach and Hans-Jörg Dau (CEO) performing EMI (electromagnetic interference) testing**

TOP: **Emission test with regard to DO-160 Section 21 in the absorber chamber**

In the case of incidents involving aircraft up to 2,000kg that are not operated by an air carrier, gliders, motor gliders, and other aircraft, the bureau starts an investigation only when new or important findings for aviation security are to be expected. As a result, flight accidents have increasingly had to be investigated by public prosecutors, police, or insurance companies. Dau says, "DAUtec makes available its expertise for the investigation of aircraft accidents."

NEW VENTURES

DAUtec has also discovered a new business area – the repair industry. "We develop and modify repair manuals for small parts, which will otherwise be scrapped," reveals Dau. "We work with different design organizations, and we are beginning to see an upcoming interest from our customers for certifications under the regulations of the FAA. To be better connected with the FAA, we are considering opening a branch office in the USA next year."

LOOKING TO THE FUTURE

"DAUtec is a small but smart company and grew up on its own, without help from banks or sponsors," adds Dau. "Because of this, you have to 'maneuver' the company very carefully, especially as we are working in a niche aviation industry within a niche qualification testing and certification business. At the moment, we are still growing within the European market; we get between five and seven new and/or returning customers a year.

"In Germany, we are in touch with 80% of potential customers; however, in Europe we only work with around 5%. So we want to grow within this market.

"LHT is one of our biggest customers and we are proud to be working for it," he continues. "But DAUtec is not Lufthansa – we are independent and that's important for our customers to know. In the future we will work together with LHT to increase the workload of the existing lab and to add more test facilities… this is very much only the beginning of this cooperation." ∎

RETO HUBER

Camera eye

An in-depth look into the transition to GigE Vision-compliant high-speed cameras for airborne applications

BY RETO HUBER

Camera systems, whether video, thermographic or high speed for MIL applications, are in most cases proprietary. Cameras, system components, accessories and spare parts have to be purchased by the original manufacturer, making them expensive.

When the original manufacturer no longer exists, or has phased out that particular product, a replacement or system extension is in many cases impossible. In the worst case, the complete system has to be replaced.

Standardized system components would minimize these risks. Using and integrating standardized components, as long as they fulfill the requirements of a particular application, will reduce the total cost of ownership since other components, accessories, and spare parts can be integrated much more easily.

STANDARD COMPONENTS

Until a few years ago, such a common camera standard, harmonized and supported by a range of leading system and component manufacturers, did not exist. Automated Imaging Association's (AIA) GigE Vision standard is supported by renowned manufacturers of industrial vision cameras and components. Compliant components have been a standard in the industry for years, making the integration and extension of new components into existing systems simple and inexpensive.

Expanding existing camera and vision systems with additional cameras of any make, or replacing defective or worn out components such as cables and connectors, is now not only possible but also much less expensive. Standardized components are produced in bigger quantities, resulting in lower costs per unit, as well as being in competition with similar products from other suppliers.

When replacing an existing camera system, or planning a new one, choosing components that are GigE Vision compliant is in most cases a wise decision. GigE Vision products are widely available, so there is no reason not to give them a close look.

Most owners and users of military/defense-oriented video instrumentation systems face problems such as the use of proprietary data and control interfaces as well as data formats. The control of various systems is not compatible with others, and data storage is always closely related to the camera. Upgrading the system with additional or more modern components is impossible, unless the system supplier is able and willing to do this job.

Due to the incompatibility of the various systems, data formats, and interfaces, existing systems have to be regarded as standalone. In many cases, systems of a certain age have outdated technology, and technical support is often difficult to get – if at all – when the manufacturer no longer has in-depth knowledge about specific products.

When an existing system needs to be replaced, questions about data formats, system and camera interfaces, command and control syntax and protocol, system and camera configuration information formats, compatibility with other sites, using similar systems, and controlling purchasing and maintenance costs have to be answered. But the most important question is: What standards are being followed?

For airborne and other defense-oriented applications, this could be addressed by implementing a standard driven by the interoperability for video and camera instrumentation systems, supported by multiple vendors. Developing a specific IRIG timing

ABOVE: Even complex systems are better off with standardized subsystems for easier integration and less dependence on suppliers

ABOVE RIGHT: AOS Q-MIZE EM – an example of a GigE Vision/IRIG 106-compatible and MIL-461 tested high-speed camera

> **"VIDEO INSTRUMENTATION AND CAMERA SYSTEMS ARE NOT – YET – STANDARDIZED FOR AIRBORNE APPLICATIONS"**

standard for video instrumentation systems as well as network-based solutions with the ability to integrate all instrumentation and test systems would also be another key element.

The major requirements for an airborne high-speed camera are standardized commands and control settings, the ability for real-time changes of the camera settings in flight or on a remote test vehicle, time correlation of all test instrumentation and mission data (IRIG time standard) as well as local storage or streaming of data, including image data, to a storage media.

The necessary control devices should be able to configure multiple cameras, initiate trigger commands, manage real-time views, manage a different camera group and act as the master timing source.

WHY STANDARDS MATTER

Video instrumentation and camera systems are not yet standardized for airborne applications. Some may say they never will be and that their technical details and specifications differ too much. The same may have been said when other products where in an early stage of their product life. It is hard to believe that light bulbs had proprietary sockets, just to name one example of an everyday product. Without standardization, burned-out bulbs could not be easily replaced, and new bulbs were certainly much more expensive than they are today.

The GigE Vision was defined standard by an AIA committee, comprising companies from all product segments of the vision industry. Components compliant to this standard have been available for several years and have become the industry standard for industrial vision applications.

Since GigE Vision is based on the Ethernet standard, most – if not all – PCs are equipped with compliant interfaces. Most components, such as cameras, are easily available at competitive prices; accessories like cables, connectors, and interfaces are offered in a wide range of specifications by a vast range of vendors. Since the data transmission technology is so widely available, extra costs for data interfaces are eliminated.

In the past, some cameras came fitted with standard interfaces, in some cases IEEE1394/Firewire or CameraLink. For technical restrictions, the distance between data nodes was restricted to several meters. Longer distances could only be reached by using additional components, such as routers or bridges. GigE Vision, like all Ethernet interfaces, offers a comfortable 100m distance, without the need for any extra devices.

While previous versions of Ethernet – like the ordinary 10Mbit/s and the 100Mbit/s Fast Ethernet have been widely used for office and industrial applications for the past 20 years, their data transmission rates are simply too limited to transfer image data from camera systems. GigE/GigE Vision, which operate at 1,000Mbit/s, finally offer the bandwidth needed to transmit uncompressed images in real time. GigE and GigE Vision networks have also the potential for higher bandwidths as offered by the future 10Gbit Ethernet.

IMAGE DATA FORMATS

Ethernet, including Gigabit Ethernet-compliant network components, are standard for home, office, and industrial applications. Only companies offering the most modern, innovative, and reliable components will survive. Buying these standardized components, rather than specialized but proprietary products, greatly reduces not only the purchasing price but also the costs for spare parts since most are no longer exclusively available from the original manufacturer.

The GigE Vision standard describes the camera interface; hence GigE Vision-compliant cameras can be controlled and operated by the same control software. However, the standard does not describe the image data format.

High-speed cameras record and store images in a proprietary RAW data format for performance reasons. Even if all high-speed cameras in a video instrumentation system are GigE Vision-compliant, their image data cannot be played back by the any video player software since the image data will likely not be compatible. Matching image sequences recorded by different cameras along a common timeline is practically impossible. However, a standard for image data formats does exist and was created and issued by the Inter Range Instrumentation Group in form of IRIG 106, Chapter 10.

INDEPENDENCE AND FLEXIBILITY

Why is the migration to GigE Vision-compliant video instrumentation and camera systems for airborne and other defense-related applications not only a possibility, but almost a necessity for all owners and operators of such systems?

ABOVE: Standards matter. Imagine if light bulbs had proprietary sockets

"ETHERNET, INCLUDING GIGABIT ETHERNET-COMPLIANT NETWORK COMPONENTS, ARE STANDARD FOR HOME, OFFICE, AND INDUSTRIAL APPLICATIONS"

There is no question that standardized video instrumentation and camera systems are a reality. Their implementation requires a strong and dedicated endorsement and unity of all parties involved.

Commonality and interoperability will be realized as the new GigE Vision systems focus on users, not vendors. Furthermore, necessary tools and processes can be developed by third-party providers, no longer applying to a specific product of one supplier but rather to a group of products from multiple vendors.

Plug-and-play will provide the ability to purchase from multiple vendors, leading to procurement leverage. Common business approaches can be used to evaluate and select not only the best performing, but also the most economic, products. Purchasing costs, as well as the total cost of ownership, can be greatly reduced for all systems, maintenance, technologies, and analysis tools.

The technology needed for all the above is actually available now – and in fact formally standardized and compliant components have been available for years, having long found their way to the machine vision world in the production industry.

Some leading manufacturers of specifically designed and MIL-certified cameras for airborne and range applications, such as the ultra-compact Q-MIZE EM by AOS Technologies, offer at least some of their cameras in compliance with the GigE Vision standard. ∎

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

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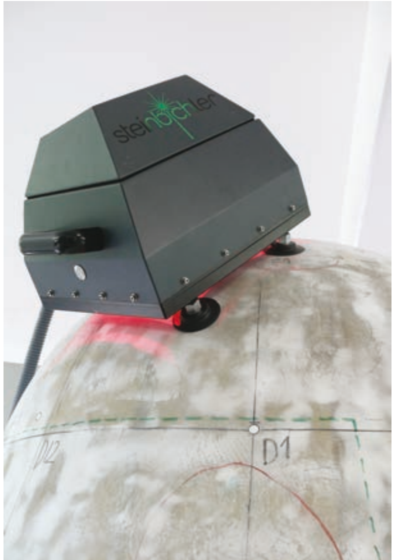
Damage limitation

As the use of lasers becomes more widespread, there is a growing need for filters to prevent damage not only to the human eye, but also to sensors and other equipment

BY DR THOMAS FRÖHLICH & FRANK BILLHARDT

Laser technology plays a growing role in all fields of manufacturing technology, metrology, production, testing, and defense. Depending on the strength of the laser, employees involved in laser application may be legally required to use appropriate protective eyewear. This is the most common application of laser safety filters, but they are also found in industrial applications as windows or vision panels to look into laser chambers or laser machine centers.

The expansion of laser applications into the measurement and testing market (aerospace or even automotive), calls for protection not only of the human eye, but also of the cameras, sensors, and detectors used to generate or observe measurement signals. Importantly, the protection of the pilot, cameras, and detector systems within an aircraft against enemy targeting systems is essential in airborne military scenarios. For this purpose, customized laser safety filters with precise optical densities and properties are needed.



FILTER SELECTION

There are different types of technology available to create appropriate protection of the eye and of the sensors. In general, laser protection filters have to block the laser radiation of a particular wavelength or range of wavelengths. In addition, the filter typically has to be as transparent as possible for all other wavelengths.

For laser safety eyewear, high transmission in the visible spectrum for all remaining wavelength is needed so that the filter does not unduly affect color recognition. But first, the optical density of a filter needs to be adjusted to create the requested attenuation. For eyewear, this means attenuation of the transmitted radiation to an energy or power level that is legally considered to be safe for the human eye or that falls into the range of sensitivity for the sensor in technical applications.

Absorbing materials are the common standard to block light in a defined wavelength area of the spectrum. Absorption means that, at the specified wavelength, the light energy of the laser is transformed into heat when the beam hits the filter. Therefore the filter material must be carefully selected with respect to the maximum power of the laser, otherwise there is a risk of thermal damage to the filter, which may lead to blindness or sensor saturation or damage.

The most commonly used materials are special optical filter glass, or amorphous polymers with

"CLASS 1 LASERS ARE CONSIDERED AS NOT DANGEROUS, WHEREAS EVEN THE SCATTERED LIGHT OF CLASS 4 LASERS IS EXTREMELY DANGEROUS"

ABOVE: An example of a optical 2D measurement system with red laser using the ISIS sensor for non-destructive test measurement

LEFT: The radome of a C-130 Hercules (pictures courtesy: Steinbichler)

absorbing dyes. Both of these have advantages and disadvantages with respect to protection, daylight transmission, and color view. Furthermore, damage marks look quite different when the filters sustain a laser impact. Plastic filters carbonize at high power densities and can be quickly penetrated. Glass filters will 'shiver' due to thermal distortion in cases where the damage threshold is exceeded.

ABOVE: Laser protection goggles against UV, blue and green radiation

A more advanced, but more complicated, technology to create high optical density filters is the coating of optical substrates with dielectric interference layers. By special design of the layer sequences and by appropriate selection of coating materials, multiple coating layers are applied to a substrate, which allows a tailored profile of absorption to be created. It is only for the 'blocking wavelength' that the filter reflects almost all the laser light; the remaining parts of the spectrum are unaffected.

FILTERS FOR MEASUREMENT

Optical measurement systems using lasers are characterized by contactless measurement principles, which guarantee extremely high accuracy. Common applications are alignment and distance measurement. Measurement of extremely small displacements in one dimension is possible by means of interferometer systems.

For two-dimensional measurements of material expansion and/or deformation, laser speckle interferometry is a commercially used technique. 3D laser scanners are able to create a 3D image of the scanned area or object with the highest resolution.

Lasers are categorized into different classes according to their optical parameters. Class 1 lasers are considered not dangerous, whereas even the scattered light of Class 4 lasers is extremely harmful to the eyes and skin and can cause fire. For safety reasons, and to avoid the need to use protective eyewear, most optical measurement systems are designed to work with lasers of Class 1 to Class 2M, which typically require no laser protection for the user.

However, this classification represents only an evaluation of the potential risk to the human eye, not of the risk to technical systems.

As an example, if the optical power limit of a Class 2 laser is 1mW, which is considered to be harmless to the human eye, it will in most cases cause a saturation of naked optical CCD camera sensors. Adding a broadband filter with high attenuation to the sensor can reduce the incident optical power to a usable level, but will also attenuate all ambient light by the same amount. As a result, useful data may also be lost. Therefore in nearly every case, optical sensors need to be combined with selective attenuating filters, which block only the critical wavelength.

As another example, it might be necessary to allow the optical source

TESTING NEW MATERIALS

Laservision works closely with its partners, continuously developing, producing, and testing new materials and absorbing dyes.

In glass technology, its worldwide partners are well-known suppliers of raw glass and have been specialists in glass processing for many years. With its extensive experience and research in the field of coating technology, the combination of both technologies – absorbing filters with reflective, interference filters – allows the company to create an almost unlimited number of variations for all possible wavelengths. It is able to offer customized filters for nearly every kind of laser and laser combination, including highly specialised systems used in R&D.

(laser, LED, or flash light) to emit more optical power for service or alignment reasons. Here, and for all higher power applications, attenuation is becoming crucial for the sensors, but also more essential for the user as laser eye protection.

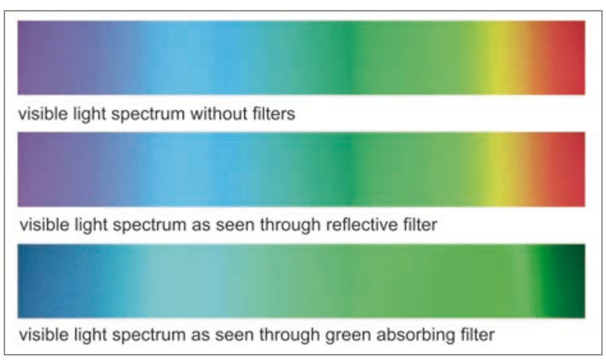
ACRYLIC ALTERNATIVE

The choice for filter technology depends, of course, on technical parameters, but also on economic factors. Acrylic laser protection filters can be made using injection molding of plastic substrates mixed with absorbing

ABOVE: Custom laser safe glass and reflective filters for protection of optics

RIGHT: Principle of reflective laser safe coatings

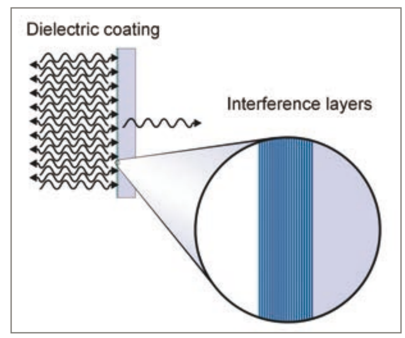
BELOW: Comparison of spectra



dyes in nearly every shape and concentration. For high-volume applications, this is often the best and most cost-effective solution and can be performed according to customer specifications. But the optical behavior of the dye means acrylic filters will feature a more or less broad absorption band, resulting in a colored filter.

Like acrylic filters, most of the absorbing mineral glass filters have a broader range of absorption, but usually also a higher laser resistance. Polishing enables adjustment of the filter thickness and, therefore, of the optical density. By laminating different optical filters to form a single optical element, customized absorbing filter profiles can be created. For prototypes or small series production, this technology gives the best compromise between performance and cost.

If low absorption at well-defined single or multiple wavelengths is required, dielectric interference filters are the ultimate solution. Compared with absorbing filters, reflective coatings have many benefits. In the case of a laser hit, most of the laser



energy is reflected by the coating layer itself. So, reflective coatings against infrared high-power military rangefinders can be made on a 1mm thin neutral glass substrate, which is then laminated onto optical components such as telescopes and tracking optics. The small band absorption also has a positive effect on transmission of other wavelengths and therefore increases the transmission of visible light. ∎

Dr Thomas Fröhlich is product group manager and Frank Billhardt is sales and marketing manager for Laservision, based in Germany

Index to advertisers


DR STEVE SHARPLES

Making waves

A British university's research has recently shed new and groundbreaking light on the secret world of materials

BY DR STEVE SHARPLES

The detailed understanding of materials is vitally important. The structure and make-up of a material holds the key to its performance in terms of strength, lifetime, and toughness. Developments in materials technology are fundamental to delivering the performance demanded by the aerospace industry. Innovative materials solutions permeate throughout such aircraft, including the airframe, engines, and equipment systems, delivering reduced weight, improved specific fuel consumption, lower emissions, and greater endurance, while maintaining safety as the overriding priority.

Materials research at The University of Nottingham in the UK covers a range of technologies, including the development of low-cost composites; the development of new coatings to reduce wear and friction; investigation into novel light alloys; methods of reducing drag; ways to understand and measure material properties; and the safe and economic recycling of composites. This work is helping the likes of Rolls-Royce, Airbus, Boeing, and GE to develop and exploit these materials.

NEW ULTRASONIC TECHNIQUE

Now a new ultrasonic technique known as spatially resolved acoustic spectroscopy (SRAS) has been developed by researchers at the university. This is not an evolution of something else, but an entirely new technique that breaks from the mainstream research in ultrasonics.

SRAS is a technique for mapping the surface acoustic wave velocity of a material. The technique is analogous to optical spectroscopy techniques in that analysis of the optical spectrum and the wavelengths that are most readily transmitted or absorbed tells us some of the properties of the sample being examined. In the acoustic sense, the spectrum of sound waves emitted from a grating source can be monitored.

This allows researchers to directly image the microstructure of materials to measure properties, such as the grain orientation, grain size distribution, and texture. This includes titanium, steel, and aluminum. It can also be used to measure and image coating thickness.

The ability to map the material microstructure across a broad range of sample sizes and surface finishes quickly and in a non-destructive manner is useful for non-destructive evaluation and process control. The research team was given funding of just £186,000 (US$297,000) by the East Midlands Development Agency to undertake a two-and-a-half-year 'technology demonstrator' project in order to develop the SRAS system for materials characterization. This involved reducing the size of the SRAS instrument from one which takes up an entire optical bench, to one where all the optics could fit inside a shoebox. The instrument will gain the ability to scan rough surfaces and the lateral resolution will be pushed down below 25µ.

Traditionally, companies in the aerospace industry have relied on spot-checks and rigidly audited processing controls, because the inspection is either highly subjective or extremely expensive and destructive. However, SRAS has the capability to completely revolutionize this area or work. So far the research team has made a single specialist SRAS machine, but is working closely with end users and an instrumentation manufacturer to bring SRAS closer to market.

BELOW: University researcher using the SRAS equipment

A PLACE OF EXPERTS

The SRAS research has been a collaborative effort supported by industry and based around a core team of researchers led by the Applied Optics Group at the university. The group is a world leader in the application of optical, ultrasonic, and instrumentation engineering. It conducts multidisciplinary research spanning physical scales from the sub-molecular to the largest structures in the solar system.

The Applied Optics Group also hosts two platform grants in bio-imaging and advanced ultrasonics. Key areas of expertise lie in ultrasonics, optics, electronic hardware and software processing, wave mechanics, and tackling inverse problems.

Many businesses in the aerospace industry have been working closely with the university in order to access the SRAS technology. Over the past six years, aerospace companies have, between them, invested almost £150,000 (US$240,000) to gain access to the technique to assess samples and test components. ∎

Dr Steve Sharples is from the Applied Optics Group, Electrical Systems & Optics Research Division, with the University of Nottingham, based in the UK

CENTER OF EXCELLENCE

The University of Nottingham is committed to continuing to play a leading role in aerospace research in a range of areas. Earlier this year, the university opened a new £5.1 million (US$8.2 million), 2,000m^2 Aerospace Technology Centre. This center will house 100 staff, including secondees from the industry.

The Aerospace Technology Centre will also be at the heart of the university's Institute for Aerospace Technology, which brings together a number of internationally leading research groups involved in aerospace materials, advanced manufacturing, electric aircraft, aero engines, and propulsion and aviation operations.