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

SHOWCASE 2011

AEROSPACE TESTING INTERNATIONAL

2011 SHOWCASE

www.AerospaceTestingInternational.com


JCO

Showing up to the main event

Six years and four months: that's how long it has been since I first attended Farnborough International Airshow in an 'official' capacity as editor of *Aerospace Testing International*. I had been editor for two whole months, and thought that, as a seasoned journalist, I was getting to grips with the industry pretty quickly: people make parts for planes, people construct the planes, people buy the planes, people fly the planes. Simple.

In 2010, at my fourth official Farnborough, the place was packed. I was based up in the press area, high above the huge front pavilion, which commands fantastic views across the airfield. There must have been a few hundred journalists milling around and several press conferences going on – standing room only; some had to be pre-booked.

It was a stark contrast to the 2004 show, which I summarized in my foreword at the time: 'It became clear that many exhibitors and clients were dissatisfied and unhappy. The magazine *Aviation Week* was particularly harsh, reporting: "The managing director of a leading exporter summed up the views of many, saying, 'It's just too expensive to be here. It has cost us over £1 million this year. We have heard that revenue for the show is in the region of £350 million.'"

This looked bad for the show circa 2004. My foreword continued: 'Walking through the vast cathedral-like halls on the Saturday, a few kids squabbling over pin badges and a torn poster aside, one could imagine the tumbleweed blowing through. I have learned that the aerospace industry is huge, but is also becoming more specialized. Smaller shows are becoming much more appealing than vastly more expensive 'toy shop' shows, which are more about being seen than doing business. There is no mucking about at the smaller specific exhibitions; they are straightforward and do what they say."

Oh dear, how very wrong I was. Farnborough is now the world's largest temporary exhibition, with 6,000 contractors on site at peak time to create the exhibition halls, chalets, company facilities, and public dining areas. In 2008, US$88.7 billion worth of business was announced at the show, and in 2010 the figure remained impressive at US$47 billion (an increase of more than US$5 billion on 2006). Exhibitors hit an all-time high this year with 1,455 from 40 countries, there were more than 250,000 visitors, and 70 delegations attended from 44 countries.

Speaking at the show, Ian Godden, chairman of ADS, the parent company of organizer FIL, said, "The figures demonstrate the mood of strong optimism that has been around the show this year, which is very encouraging given the current global economic climate."

There is speculation that the show might be propped up by a dubious and fragile Middle Eastern economy, but it can still be only a good thing for the test industry. At the 2010 show, there were hard orders for Boeing and Airbus, as well as military orders and upgrades, and even demands for light aircraft. This activity was on top of some exciting UK and European debuts, in the form of the 787 (which was flanked by a Spitfire and Hurricane on the 70th anniversary of the Battle of Britain) and, despite so much controversy, the A400M (what an impressive military transport aircraft) was launched onto the world's stage.

Anyway, back to the press area… UK Defence Secretary Dr Liam Fox was giving a live interview for Sky TV and the BBC on the veranda just a few feet from where I was grabbing a coffee. I was sitting on a stool at a small table on my own, sorting out my day's schedule, when I was joined by Dr Fox and several 'top brass' military generals and security of the dark glasses kind. "What are we up to next?" he urgently questioned me, thinking I was part of his entourage. "Hello, I am the editor of *Aerospace Testing*, I'm not with you Dr Fox," I replied meekly, at which point I desperately attempted to stifle my laughter. He was swiftly moved on by his cohorts. I should have asked him a question about British defense contracts. Missed opportunities…

I was wrong in my 2004 musings. Farnborough has a huge impact on the world's aviation industry. I do hope that in a few years' time I won't be eating my hat again…!

Christopher Hounsfield, editor

EDITOR Christopher Hounsfield (c.hounsfield@ukipme.com)
CHIEF SUB-EDITOR Alex Bradley
SUB-EDITOR William Baker
PROOFREADERS Aubrey Jacobs-Tyson, Frank Millard

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

PRODUCTION MANAGER Ian Donovan
PRODUCTION TEAM Carol Doran, Lewis Hopkins, Cassie Inns, Emma Uwins
SALES MARKETING DIRECTOR Colin Scott (colinscott@ukipme.com)

PUBLICATION MANAGER Cheryl Flanagan (c.flanagan@ukipme.com)
AUSTRALASIA BUSINESS MANAGER Chris Richardson Tel: +61 4207 64110 (c.richardson@ukipme.com)
MANAGING DIRECTOR Graham Johnson
CEO Tony Robinson

Aerospace Testing International Showcase is published alongside the quarterly *Aerospace Testing International* by UKIP Media & Events, Abinger House, Church Street, Dorking, Surrey, RH4 1DF, UK. Tel: +44 1306 743744; fax: +44 1306 742525; editorial fax: +44 1306 887546. The views expressed in the articles and technical papers are those of the authors and are not endorsed by the publishers. While every care has been taken during production, the publisher does not accept any liability for errors that may have occurred. Distributed by US Mail Agent, Clevett Worldwide Mailers LLC, 7 Sherwood Ct, Randolph, NJ 07869, USA. Periodicals postage paid at Dover NJ, 07801. POSTMASTER: Send address changes to: *Aerospace Testing International*, 19 Route 10 East, Bldg 2 Unit 24, Succasunna, NJ 07876, USA. Printed by Nuffield Press, 21 Nuffield Way, Ashville Trading Estate, Abingdon, Oxfordshire, OX14 1RL.

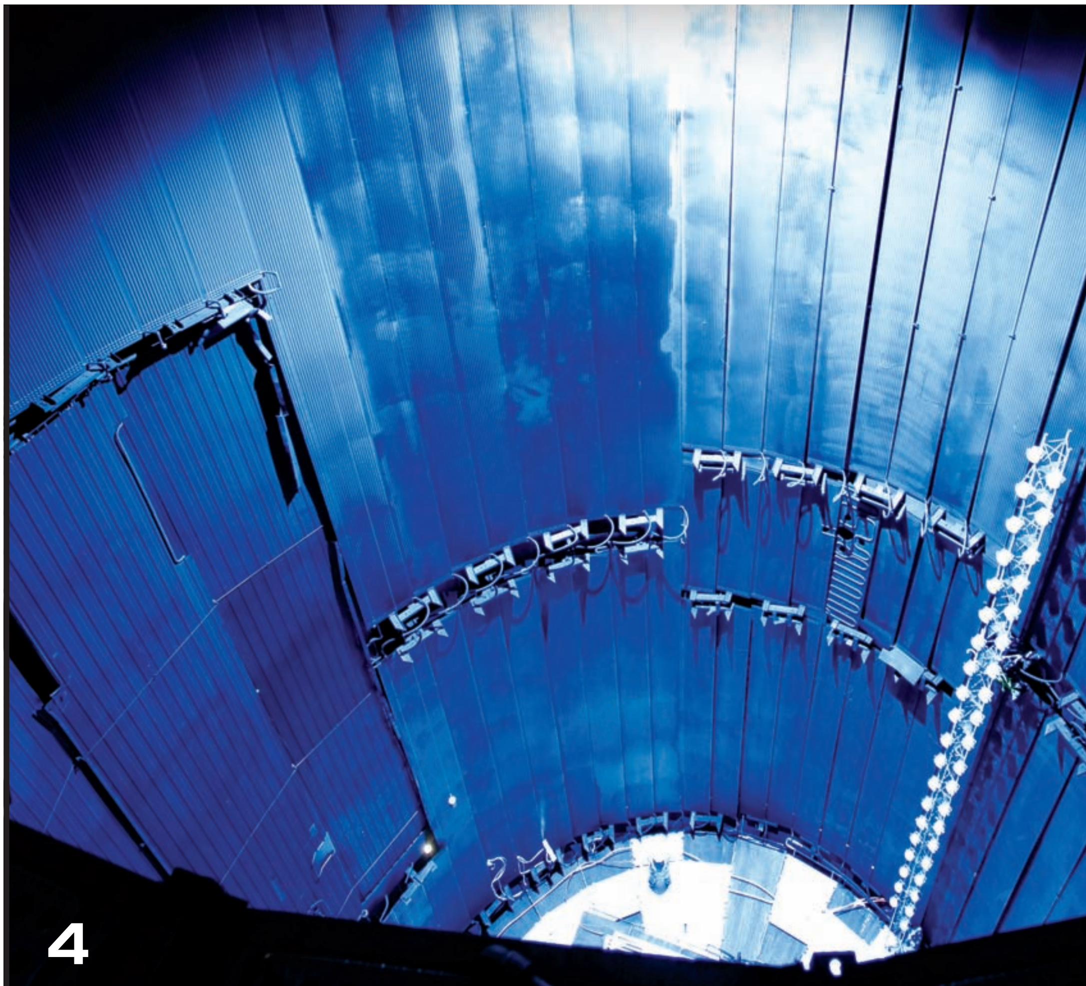
ISSN 1478-2774 *Aerospace Testing International*

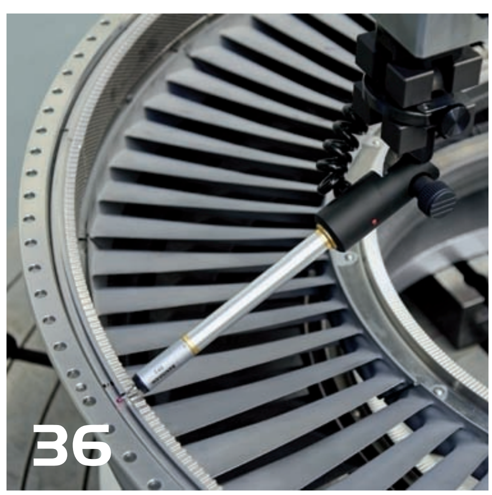
ANNUAL SUBSCRIPTION £42/US$75

ABC *Aerospace Testing International* average net circulation per issue for the period 1 January 2009 to 31 December 2009 was 10,015

Published by UKiP MEDIA EVENTS

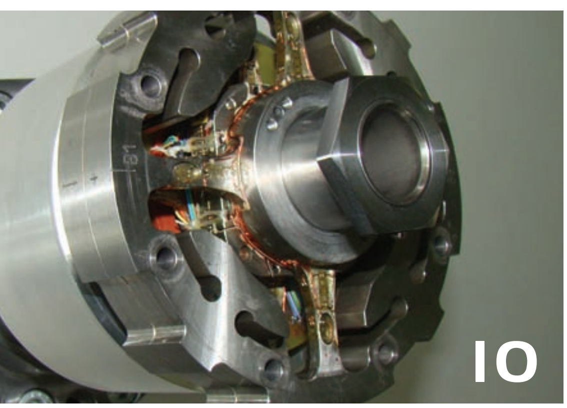
Contents

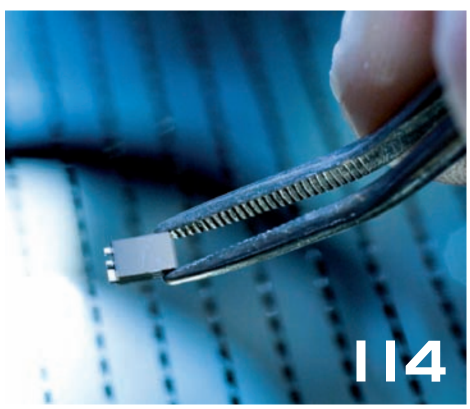


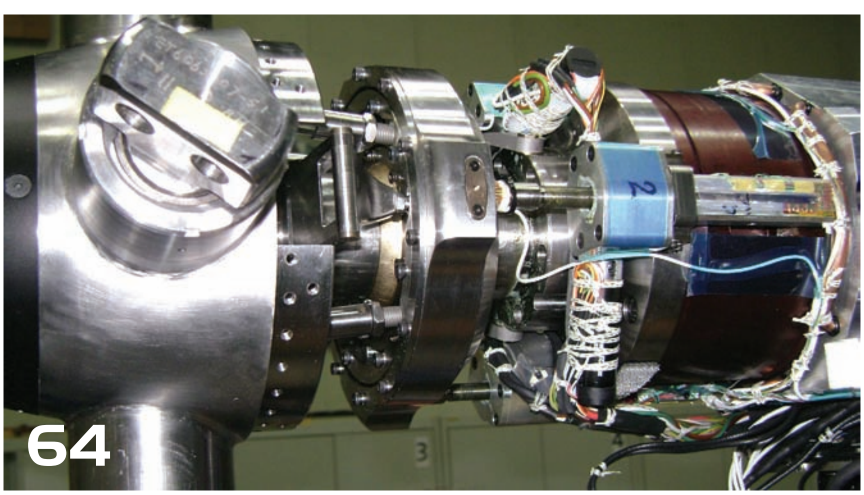



22


50

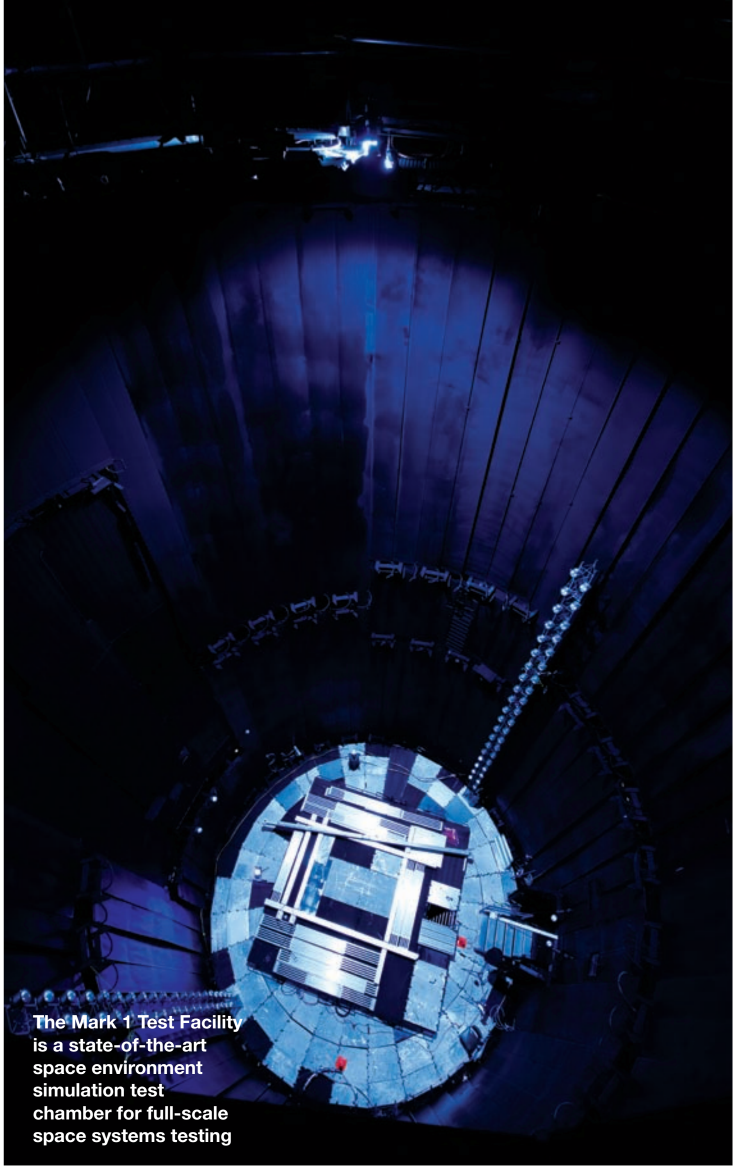

10


114


64

Winds of change

WHY HASN'T THE COMPUTER REPLACED THE WIND TUNNEL IN THE DEVELOPMENT OF AERONAUTICAL SYSTEMS?



The Mark 1 Test Facility is a state-of-the-art space environment simulation test chamber for full-scale space systems testing

BY EDWARD M. KRAFT

The debate over whether wind tunnels or computers are the most useful for the development of aeronautical systems has persisted for many years. On the one hand, the majority of wind tunnels used today in aeronautical research, development, test and evaluation were designed and commissioned in the 1950s and 1960s. These facilities remain the backbone of the aeronautical development process, although they are becoming more challenging to maintain.

On the other hand, rapid advances in computer hardware and software offer the potential to dramatically alter the design and development process for flight systems through the application of computational science and engineering (CSE). However, after 40 years of promises to eliminate the need for test facilities, advanced CSE has still not diminished the need for test facilities or reduced the overall cycle time for development of flight systems. As many wind tunnel test hours are used today to develop a flight system as were used 20 years ago.

The proper debate needs to be centered not on CSE versus the wind tunnel, but how they can be integrated to reduce the overall cycle time for development of an aeronautical system. If CSE could actually eliminate the use of wind tunnels in system development, the net gain to the acquisition program would be fractions of a percentage in cost savings. On the other hand, reducing the overall cycle time by merging CSE and wind tunnel testing could reduce total development cycle time by months to years, resulting in billions of dollars of savings. This article is focused on understanding the challenges to using computational methods; delineating changes required in people, processes and tools to make CSE more effective.

First, for clarity, we need to define what we mean by CSE relative to the ubiquitous phrase ‘modeling and simulation’. Here, we will focus our attention on high-fidelity, physics-based modeling and simulation (CSE) as opposed to engagement or theater wargaming models. Also, we will use the terminology CSE to connote that we are talking about the entire spectrum of physics-based modeling such as computational fluid dynamics (CFD), computational structural mechanics/computational structural dynamics (CSM/CSD), computational electromagnetics and computer-aided engineering.

Why hasn’t CSE replaced testing?

The debate between CSE and wind tunnels has been ongoing for more than 30 years. The incredible American Institute of Aeronautics and Astronautics (AIAA) Dryden Lecture delivered by Dean Chapman in 1979 was the first serious salvo in the debate (Chapman 1979). Chapman’s visionary article clearly identified the rapid growth in CFD hardware, software and modeling capabilities that could transform the aerodynamic design process. Many of his CFD projections have been exceeded over the past 30 years. Sampling of the remarkable advances in CSE applied at AEDC can be demonstrated.

On the other hand, the average number of wind tunnel hours used in development of commercial and military aircraft continued to

> "Obviously CSE has not effectively changed the aeronautical development process to the degree envisioned by Chapman"

grow (Melanson 2008) despite wind tunnel efficiency increasing by at least a factor of four (Kraft and Huber 2009). At the same time, more and more defense programs (and some commercial programs) overrun their original cost and schedule estimates. So what gives? Obviously CSE has not effectively changed the aeronautical development process to the degree envisioned by Chapman.

Very simply, advances in computers even to peta-flop performance and beyond are necessary but not sufficient to transform the aeronautical development process. It takes a holistic advance in the integration of people, processes and tools to enable the kind of revolution people have envisioned for decades. Even more than the tools, the people and processes need to be better understood and integrated with the advanced computer hardware and software to increase the effectiveness of CSE in the aeronautical development process. The technical, intellectual and process issues that impede even more advances in the use of CSE are summarized below.

Technological impediments

Having software that can efficiently and effectively use massive parallel computing power, having robust algorithms for complex and multidisciplined applications, improving modeling of essential physical phenomena, and systematically verifying and validating that the tools will work robustly in the engineering environment, are equally important. In this section we will highlight some of these technical challenges.

With software scalability, the trend in high-performance computing architecture is toward massive parallel processing to upwards of 100,000 CPUs or cores. These trends are being driven by the rapidly growing cost of further increases in processor clock speed and the emergence of power density and cooling requirements as dominant considerations.

High-performance computing centers are now requiring megawatts of power for operation. Although peta-flop computers are already available in select federal computing centers, the legacy CSE software tools routinely applied to design and development problems have not been scaled to maximize the use and gain the efficiencies afforded by clusters with tens of thousands of processors. Most codes have been optimized to run on fewer than 100 processors. CFD solution algorithms tend to scale reasonably well, but many algorithms have topped out at around 512 CPUs and only a few have operated with a few thousand cores.

The very best CFD codes scale linearly to 5,000 cores. Even the highest performing CFD algorithms quickly lose ground when significant Input/Output (I/O) is required to grab and store solutions every few time steps for a graphical representation of an unsteady flow solution. Other CSE algorithms do not scale as well as CFD codes.

Therefore, even though peta-flop machines are becoming available, current software scalability limitations do not enable the solvers to use all the hardware capability. One of the strategies to offset this near-term lack of scalability is to use a large number of available cores to simultaneously solve a number of parallel cases.

This strategy will be useful in either rapidly reducing the design space in the early phases of concept development or in building a significant CSE database in later stages of development.

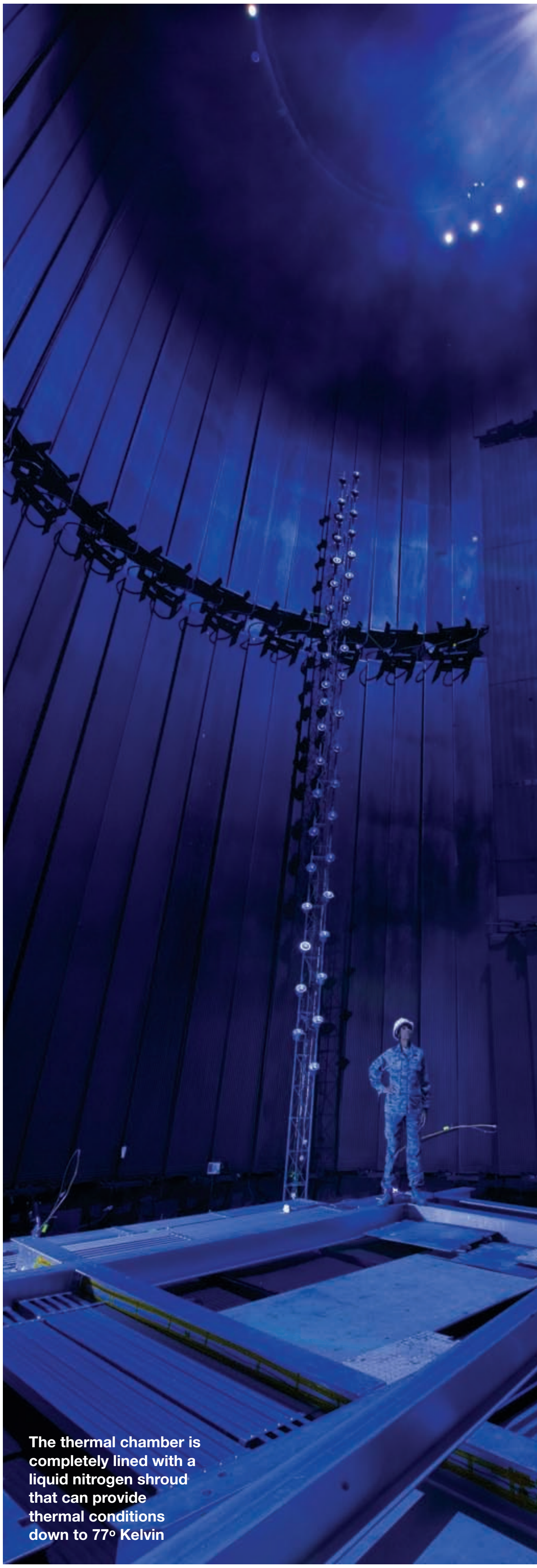
Complexity

As computer systems have advanced, so has the complexity of aeronautical systems. Over the past 30 years, expanded flight envelopes, super-maneuverability, super-cruise, low observables and advances in materials technology have made it more challenging to model the physics of military flight systems. All the advances in computer hardware and software have been absorbed in increasing the fidelity of more complex systems.

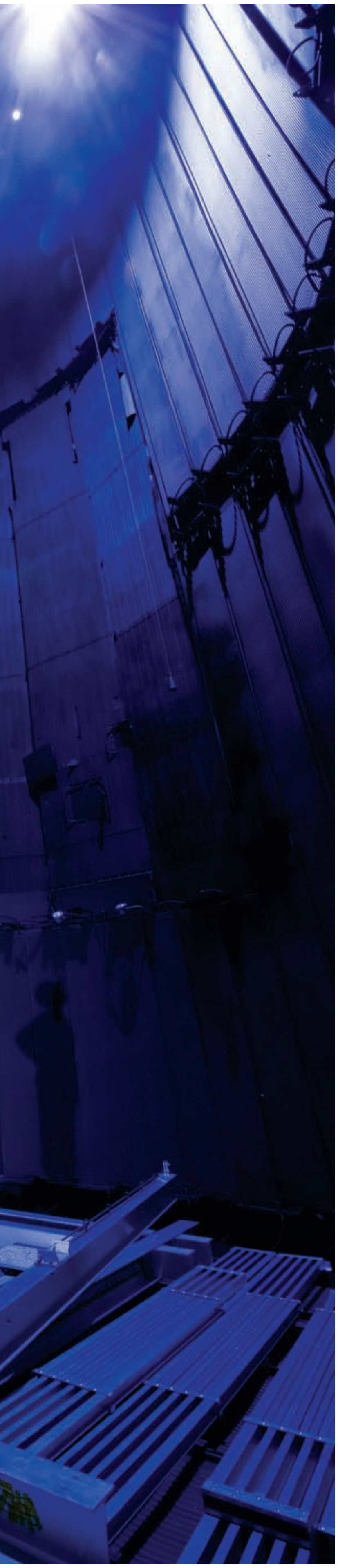
A significant challenge to developing a full flight system is the integration of the major subsystems (that is, airframe/propulsion integration, airframe/structure integration, electromagnetic interference, control systems, and airframe/weapon systems).

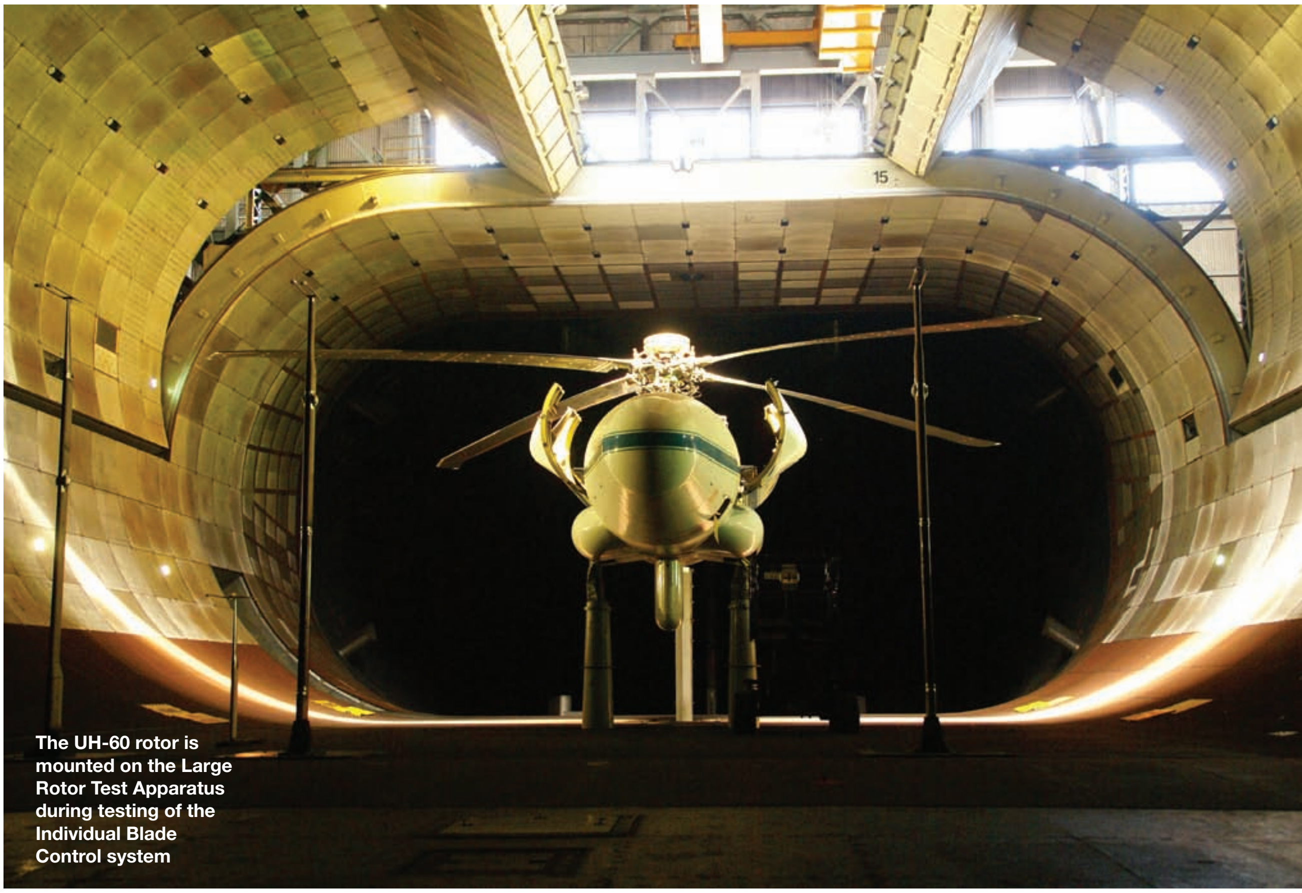
The major defects frequently found late in the development cycle for a flight system usually occur at the interface of major subsystems (such as aerodynamically induced structural failures). For example, on average for military aircraft, 10 structural flaws are found in the flight-test phase even after a comprehensive ground-test campaign and massive application of CSE. The fixes for these structural flaws can range from simple to significant, costing as much as US$1 billion and delaying a program by a year or more.

Although significant advances in multidiscipline dynamic simulations for maneuvering vehicles have been made, the fidelity of current capabilities in terms of grid resolution, model complexity and interdisciplinary coupling is still only a fraction of what is needed in the long run.



The thermal chamber is completely lined with a liquid nitrogen shroud that can provide thermal conditions down to 77º Kelvin





The UH-60 rotor is mounted on the Large Rotor Test Apparatus during testing of the Individual Blade Control system

Stand on turning vanes inside AEDC's 16ft supersonic wind tunnel test facility. The iconic imafe was taken in 1960

Physics modeling

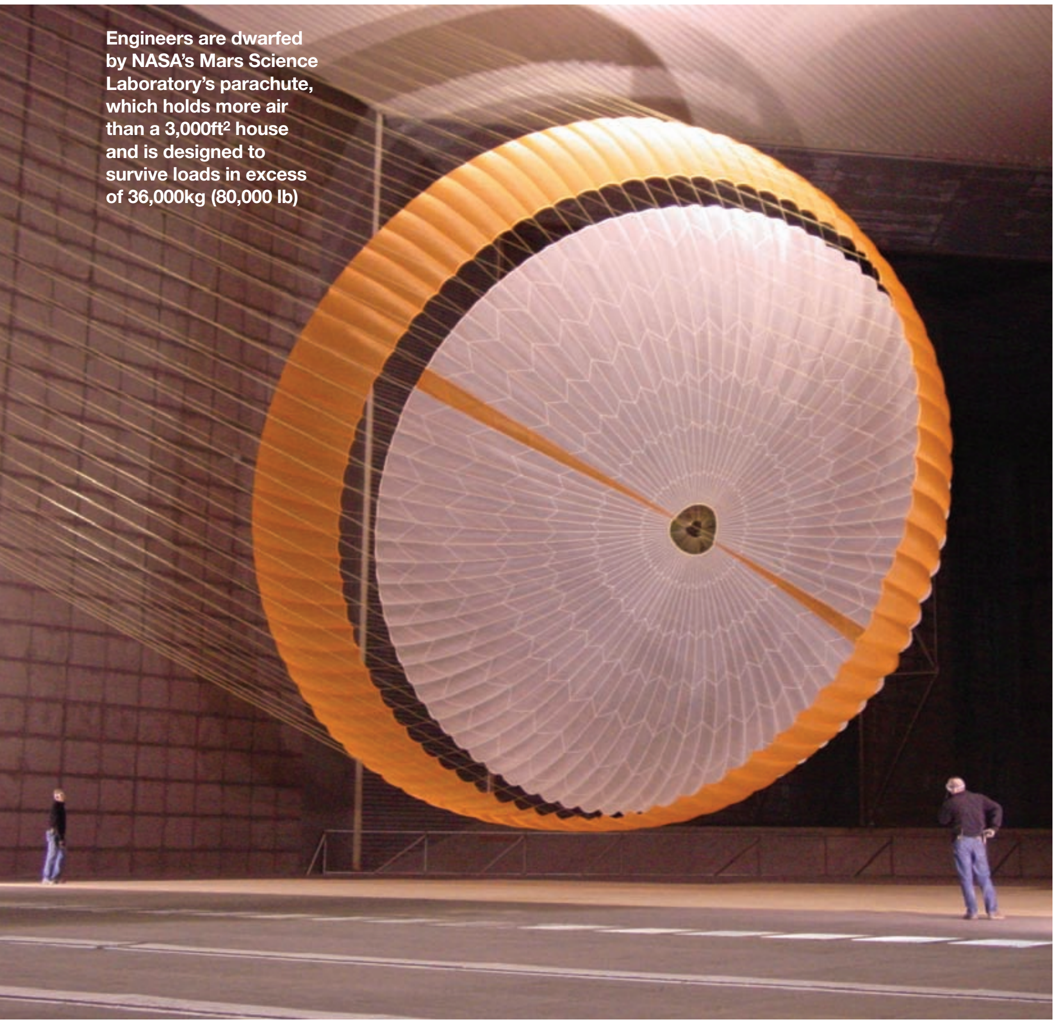
The list of physics modeling that inhibits the robust application of CSE is lengthy. The classical problems in applying CFD include turbulence modeling, boundary layer transition and flow separation. For relatively benign attached or mildly separated flow, the use of Reynolds-averaged Navier-Stokes (RANS) codes with the addition of large eddy simulations has advanced to a very good engineering capability, but still has enough inaccuracy to preclude total reliance on the computed results. For vortex dominated or massively separated flows typical of advanced tactical aircraft at the corners of the flight envelope, the CSE tools are not nearly as capable. The dynamics of separated flow have a large impact on structural dynamics, stability and control, as well as on control surface response.

Validation and verification (V&V)

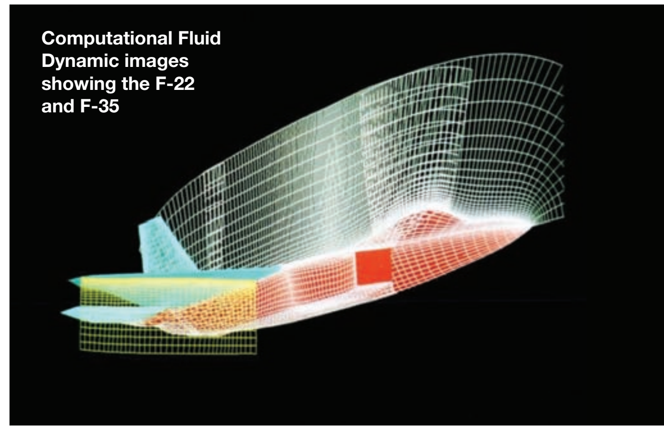
The aeronautics community has given itself a huge headache. There are numerous (and growing) conference articles showing 'good' comparisons between CSE solutions and select experiments. These comparisons have been the basis for many marketing efforts to try to make the argument that CSE can duplicate test facilities. However, an accumulation of anecdotal comparisons does not result in a robust tool. Tinoco (2008) probably expressed it best: "CFD validation cannot consist of the comparison of the results of one code to those of one experiment. Rather, it is the agglomeration of comparisons at multiple conditions, code-to-code comparisons, an understanding of the wind tunnel corrections, etc, that leads to the understanding of the CFD uncertainty and validation of its use as an engineering tool. Examples include comparisons of predictive CFD to subsequently acquired test data."

Experience and intellectual capital

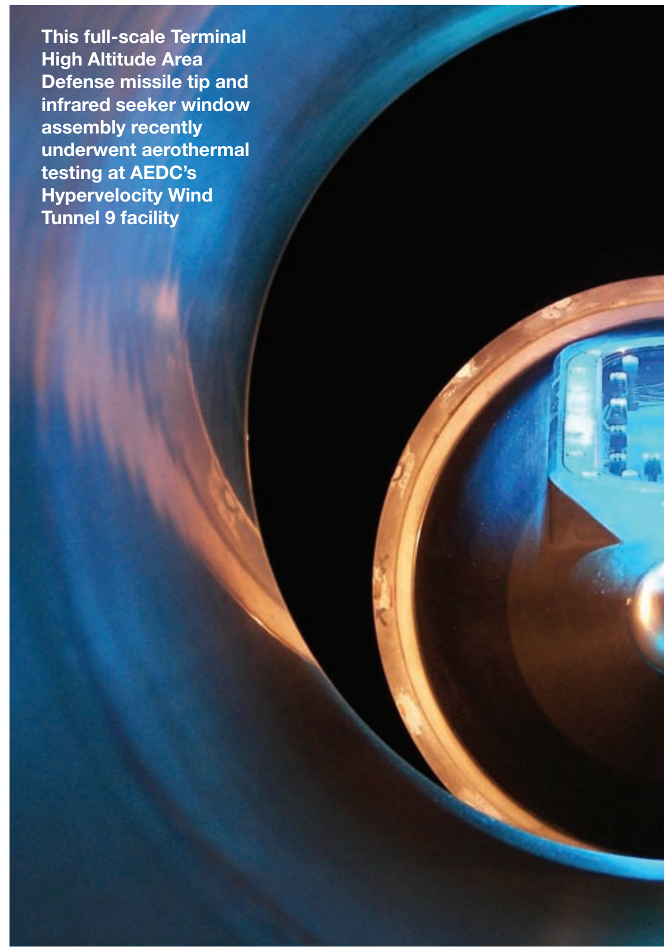
Increasing the use of CSE versus testing is a two-edged sword relative to the technical talent involved in aeronautical system development. On the one hand, visual output from high-fidelity models provides unprecedented insight into flow features that cannot be obtained in any other way. Being able to 'see' streamlines and vortex patterns on flow over a vehicle brings new understanding in the causative relations between aerodynamic shapes and vehicle performance.



Engineers are dwarfed by NASA's Mars Science Laboratory's parachute, which holds more air than a 3,000ft^2 house and is designed to survive loads in excess of 36,000kg (80,000 lb)



Computational Fluid Dynamic images showing the F-22 and F-35



This full-scale Terminal High Altitude Area Defense missile tip and infrared seeker window assembly recently underwent aerothermal testing at AEDC's Hypervelocity Wind Tunnel 9 facility

"CSE is just a single tool in the systems engineering process required to design, develop and field an aeronautical system"

The tools also allow relatively rapid evaluation of changes to the design, which in its own way introduces more insight. On the other hand, having a generation of engineers experienced only in the 'zeros and ones' of advanced modeling has the downside of limiting real understanding of the physics of the problem, especially when extending into realms beyond the physical fidelity of the model. The experiential insight gained from physically measuring phenomena is important in two ways – it provides more depth in understanding and is absolutely essential to guide development of models to capture the physics. There seems to be a circular argument that we can better model the physics than the experiments when the models are only as good as our physical understanding gained from experiments.

Managing the processes

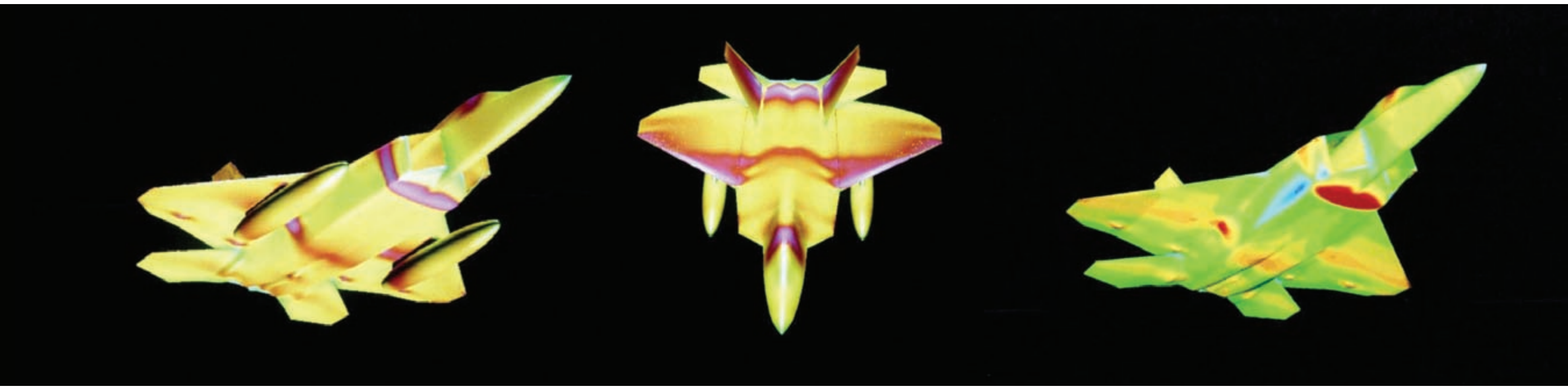
CSE is just a single tool in the systems engineering process required to design, develop and field an aeronautical system. Consequently, if the CSE community and its practitioners are not equally fluent in understanding the overall processes, CSE will generally not have the desired effect on overall development. Ensuring the process environment is conducive to integration of CSE may be the single most important consideration for advancing CSE.

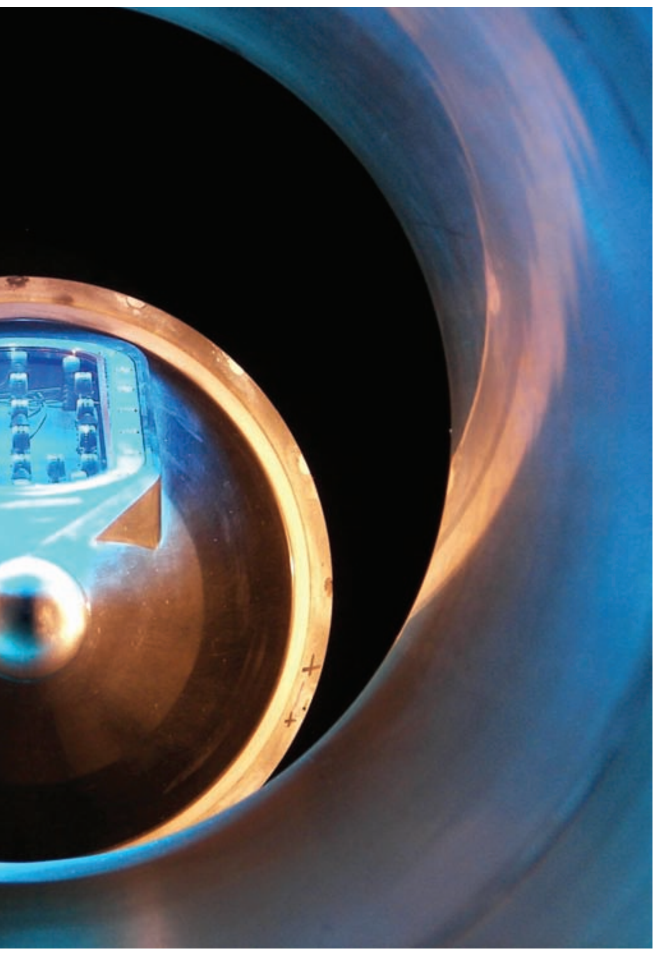
When trying to understand the reasons why high-fidelity CSE has not had a larger impact on aeronautical system development, it is worthwhile to identify the common attributes of those areas where significant inroads have been made. It is the author's observation that CSE has had a significant impact on aeronautical system development in the following instances:

- The process is controlled by a single organization that can ensure the use of CSE in design and development;
- The organization has a substantial and sustained organic capability dedicated to building and applying CSE tools in a rigorous development process;
- The organization has at least de facto V&V of its tools as well as a sustained knowledge base of the lessons learned from the application of CSE across multiple systems.

Conclusions

High-performance computing has advanced to a state that should support more applications of CSE in the aeronautical system development





process. With such advances, a debate has re-emerged on using CSE to replace testing. The author argues that a discussion of replacing testing with CSE is misguided. The aeronautical community would be better served by putting its energy into determining approaches to fully integrate CSE with testing to reduce the cycle time for aeronautical system development. To successfully integrate CSE and testing will require advances not only in high-performance computing, but also in intellectual capital and process management. ∎

Dr Edward M. Kraft is chief technologist at the US Air Force Arnold Engineering Development Center. He is a member of the Senior Leadership service. He has also been instrumental in developing metrics to better assess the value of T&E to the acquisition process. Email: edward.kraft@arnold.af.mil

Open fan technology

THE LATEST DEVELOPMENTS WITH COUNTER-ROTATING OPEN FAN WIND TUNNEL TESTING WITH SWISS-BASED AEROSPACE ORGANIZATION, RUAG

> **"The development of the wind tunnel model propulsor was also the complete responsibility of RUAG Aviation"**

DR PETER ASCHWANDEN

BY DR PETER ASCHWANDEN

The Large Wind Tunnel Emmen (LWTE) has recently been used by Boeing and Rolls-Royce for extended open fan tests with a full-scale model. Equipment from the RUAG Aviation Aerodynamics Center has been used to accurately simulate the propulsors and measure their influence on the aerodynamics of the complete airplane. Due to the unique requirementsof counter-rotating open fans, almost all technical equipment had to be newly developed:high-power/high-speed hydraulic motors, rotary shaft balances, data transmission, data processing and motor control.

Open fan technology was a focus of research in the 1980s but lost its economic justification with falling oil prices. Future ecological and economic constraints have now renewed the interest of the important airframe and powerplant companies in this old idea. Using newly available numerical simulation methodologies and experimentation technology, they gather more insight into the design of airframes driven by counter-rotating open fans.

The combined efforts of Boeing, Rolls-Royce and RUAG Aviation have culminated in an extensive low-speed wind tunnel campaign in the RUAG LWTE. A complete airplane model was tested to assess the performance of open fan propulsion.

In addition to performing the test in the LWTE facility, the development of the wind tunnel model propulsor technology was also the responsibility of RUAG Aviation. Based on its unique experience with hydraulic motor simulators, for example from the A400M test series, motors, instrumentation, data transmission and data processing algorithms were developed in parallel with the design and fabrication of the model.

Hydraulic engine simulators are undeniably inferior with respect to power density when compared with air turbines normally used by the large wind tunnel facilities. But the huge investments and operating costs in air compressors as well as the complexities of their operation make hydraulic engines a very attractive alternative. For decades RUAG Aviation has specialized in the design of high-power and high-speed hydraulic engines for use in wind tunnels. The potential of hydraulic power is formidable when tuned to the task, and allows fulfilling even the highest customer demands. The loads on the complete airplane model are measured by an internal balance. The hydraulic power, therefore, must be routed over the balance in the very limited space available in the model without disturbing its readings.

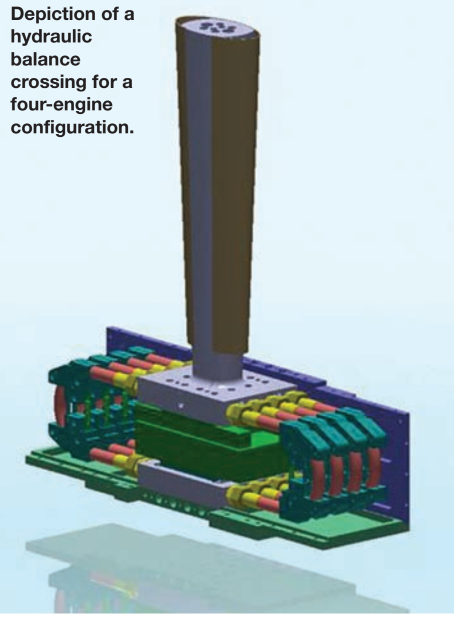
The loads on the rotors are measured by six-component rotary shaft balances (RSB). The RSB readings are transmitted, together with other information, such as blade strains, over a miniaturized telemetry system.

Technical challenges

RUAG Aviation has been designing, fabricating, operating and selling six-component balances for more than 50 years. Most are used in wind tunnels as internal balances. For this wind tunnel campaign the balance 167-6 type was selected and mounted at the center of the fuselage. Due to the expected weight of the model the axial load range of the original balance had to be increased.

To provide power to the motors in the nacelles, whatever motor type is chosen (electrical, air or hydraulic), the main balance must be crossed by the power lines. In the case of

This photograph is reproduced with the permission of Rolls-Royce plc, copyright © Rolls-Royce plc 2010



Depiction of a hydraulic balance crossing for a four-engine configuration.

hydraulic motors, for every motor one high-pressure and two low-pressure tubes need to cross the balance. Through a clever design, the influence of the crossing system on the balance readings is minimized. The remaining small effects dependent on oil pressure, volume flow and temperature are corrected. An intrinsic advantage of the hydraulic motors is that they are cooled by the circulating oil. There is thus no limitation on run time due to unacceptable temperature increases as is often the case e.g. for electric motors. For the balance, though, the warm oil poses a risk of errors due to temperature effects. Therefore the balance is kept at a constant temperature by passive and active means during the test campaign.

From the balance crossing the oil is routed through the center fuselage box – allowing both inverted and upright model testing – to the nacelle, which contains the main parts of the propulsor: motors (one for each rotor); three-shaft system (two counter-rotating shafts and one fixed shaft for telemetry power and data for rotor 1); six-component rotary shaft balance for each rotor; 20-channel telemetry per rotor; blade retention; angle sensors for RSB data processing; rpm sensor for rotor speed control; and various sensors such as accelerometers and pressure sensors.

The motors are obviously the most prominent component of the propulsors and are mounted back-to-back in identical configurations. Their rpm can be individually controlled. For obvious topological reasons the front motor drives the aft rotor and the aft motor drives the front rotor by way of a three-shaft system. These shafts are critical with respect to general stiffness and rotor dynamics. The relatively thin rotating shafts (due to geometric restrictions) are subject to significant lateral loads and, thus, resonances may be excited which may prevent the setup from being safely run at specific speeds (but it may be possible to quickly drive through the critical speed range) or even cause divergent instabilities that prohibit any operation at all above this speed. As a result of our efforts to improve rotor dynamics, restrictions were only minor.

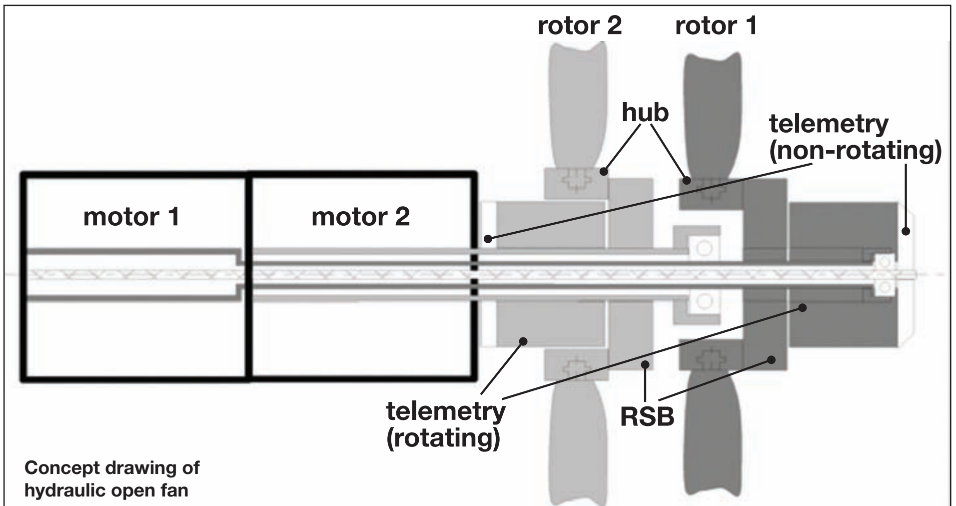
The innermost shaft is a very slim fixed shaft extending over the whole length of the propulsor. It provides direct physical access to the non-rotating part of telemetry 1.

RSB, telemetry and hub are mounted as one single unit on the corresponding shafts, minimizing setup time in the wind tunnel and providing fixed conditions particularly for load transfer between hub and RSB.

Hydraulic engine simulator

Hydraulic motors are a perfect choice for reliable, continuous and inexpensive high-power operation. The power of a single hydraulic engine simulator in the wind tunnel is typically similar to the power of a well-motorized car. Due to the incompressibility of the oil there is no expansion in the return lines. The cross-section of the return line, therefore, remains small and is not excessively cooled by an expanded fluid, simplifying model design and reducing the potential for thermal interferences.

The required rpm levels for wind tunnel testing match quite nicely the technological possibilities of hydraulic motors. Because of this, the rotors can usually be driven without the need for a complex and expensive reduction gear. In the past, piston-type hydraulic engines were the preferred solution for engine simulators. But due to the topological constraints of the counter-rotating configuration and the requirement to route cables from each of the rotors to the stationary model side, a different motor concept had to be selected. After a number of design iterations an inner gear motor concept was chosen. With this motor type, multiple concentric hollow shafts can be built with a sufficiently large diameter to fulfill structural requirements. Moreover, the fact that the shafts are more or less in the center of the motors guarantees a compact setup which simplifies installation inside a given nacelle geometry. The main difficulties in the design of this motor was the optimization of the shaft diameters, the dimensioning of the gears so that they meet the torque and speed requirements as well as the general tolerances, which play a critical role in high-power operation.



Concept drawing of hydraulic open fan propulsor simulator

For accurate wind tunnel measurements it is vital to keep the motor speeds very close to the set value. Based on experience from previous wind tunnel test programs, a completely new control system was developed that allows fully independent rpm control over each one of the motors. Four independent hydraulic power supply units with a maximum power of 250kW feed the motors. They are controlled so that the rotational speed of the rotors can be set to an accuracy better than ±20rpm. A two-way coupling with wind speed prevents critical flow situations that could overload the blades during normal operation or, in the case of an emergency, shut down either of the wind tunnels or the model propulsors.

The hubs connect the blades to the rotary shaft balances (RSB) and provide a precise and stable fixation of the blades. The front and aft hubs are designed in the same way. In principle they consist of two halves that allow insertion and clamping of the cylindrical blade roots. The pitch angle of the individual blades can be manually adjusted, without being removed from the model, with a special blade setting tool that is attached to the hub.

The minimum size of the RSB resulted from the predicted rotor load ranges and the required accuracy levels. As a result, the nacelle dimensions the RSB had to be attached to the side of the hub which, of course, is a compromise with respect to the loading of the RSB and needed special design attention, on the hub as well as on the RSB. Because of their strong influence on rotor dynamics, the weight and stiffness of the RSB were an additional design constraint. In a second design loop the stiffness of the balance was increased by a factor of more than two without compromising the accuracy. At the same time special provisions were made to greatly reduce the influence of the rotary speed on the measurements.

Telemetry system

The transmission of the RSB and blade signals is always a challenge with powered wind tunnel models. Because of the counter-rotating topology and geometric limitations, slip rings, which were successfully used in past tests, could not be adapted to this specific application. Therefore a miniaturized telemetry system was designed and procured with 20 channels per rotor (RSB strains, RSB temperatures, blade strains, RSB angular position). The maximum sampling rate per channel is 54kHz. This generates 4.5MBytes/sec of raw data per rotor, needing very quick storing (raw data) and data processing and reduction capabilities. Moreover, storage and backup capacity, if raw data is required, is tremendous – easily many tens of TB for a single test campaign.

Data acquisition of the standard sensors such as main balance, angle-of-attack sensors is performed using our standard Hottinger Baldwin Messtechnik (HBM) system, allowing very precise measurements using (in the case of the main balance) carrier frequency technology at low to moderate sampling rates. An electronic pressure scanner is used to measure the almost 1,000 pressures on the model surface at low sampling rates. For high-speed pressure readings dedicated pressure sensors were mounted and measured with a high-speed data acquisition system.

Of special interest with respect to data acquisition and data processing is the data coming from the telemetry. The huge RSB data stream is reduced online to 1P loads in several steps.

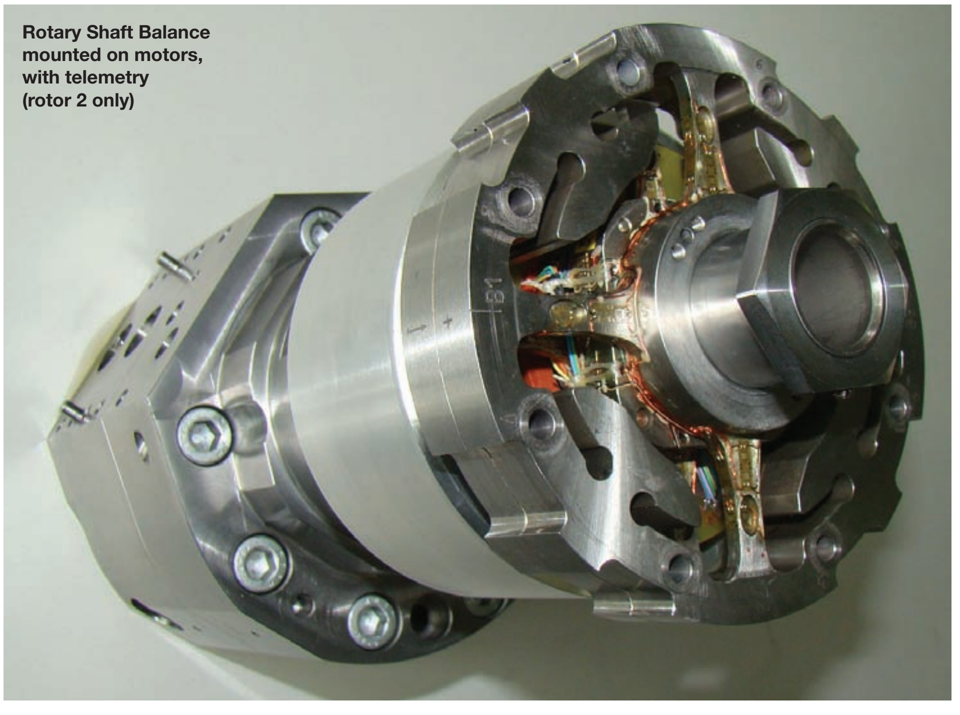
To map the RSB loads on a fixed coordinate system it is necessary to know the angle of rotation of the RSB at the time of measurement. In principle this RSB orientation is derived from a sensor that outputs a very precise pulse at a known angle once per revolution. Assuming constant rpm, this pulse can be used to calculate the actual rpm and the current RSB orientation. In a first processing step the original samples are interpolated onto a fixed set of RSB orientations. Then the loads are transformed into a non-rotating coordinate system and later combined into 1P loads.

Based on previous experience, in a very short period of time RUAG Aviation was able to develop the complete open fan propulsor simulator consisting of hydraulic motors, rotary shaft balances, telemetry, rpm control system, main balance crossing system as well as data acquisition and processing system. The power system was installed in a full model of a generic passenger aircraft concept and tested efficiently and without incident during an extensive wind tunnel campaign.

The potential of hydraulics to allow customized solutions at a very competitive cost both in initial investment and during operation was highlighted. The successful completion of the project and the satisfaction of the customer confirmed the adequacy of the chosen technology and was the reward for the hard work. RUAG is convinced that the knowledge gained from the unprecedented aerodynamic database derived from this test will affect the architecture of a future airplane generation. ∎

Dr Peter Aschwanden and Dr Juerg Mueller are part of Project Management, RUAG Aviation, Emmen Switzerland. *The authors would like to thank Boeing and Rolls-Royce for their support;* *Michel Guillaume is the general manager, Aerodynamics with RUAG*

Rotary Shaft Balance mounted on motors, with telemetry (rotor 2 only)




Transmission Tube Test Rig


JSF (Joint Strike Fighter) Weapons Bay Door Test Rig


787 Thrust Reverser Actuator System


Airbus A350 Thrust Reverser Actuator Test Rig

Hot on the trail of ice crystals

A CANADIAN ORGANIZATION IS STUDYING THE FORMATION AND BEHAVIOR OF ICE CRYSTALS IN AN EFFORT TO PREDICT AND DEVELOP MITIGATING SOLUTIONS TO THIS HIGH-ALTITUDE MYSTERY

> **"We are attacking the ice crystal problem from all angles, building on past successes and moving into a new understanding of the problem"**

BY DR IBRAHIM YIMER

With established facilities in Ottawa and expertise at work in Thompson, Manitoba, the National Research Council (NRC) Institute for Aerospace Research (NRC Aerospace) has become an expert in engine certification icing testing for all sizes of aircraft engines. But its icing studies do not end with testing. There is also a great deal of work underway on the safe operation of aircraft in icing situations, including ice detection and protection systems, the mechanics of ice formation, and appropriate certification standards for engine icing.

The most noteworthy efforts by far have been the organization's efforts to crack the mystery of high-altitude ice crystals. Over the past several years, NRC Aerospace researchers have been building on existing capabilities to gain a greater understanding of the effects of ice crystal ingestion on the safe operation of large aircraft engines. The result should be a better understanding of the phenomenon.

NRC Aerospace efforts have met with great success, and the organization now has proven expertise and capabilities in the formation of ice crystals and the replication of ice crystal effects both inside and outside the aircraft engine.

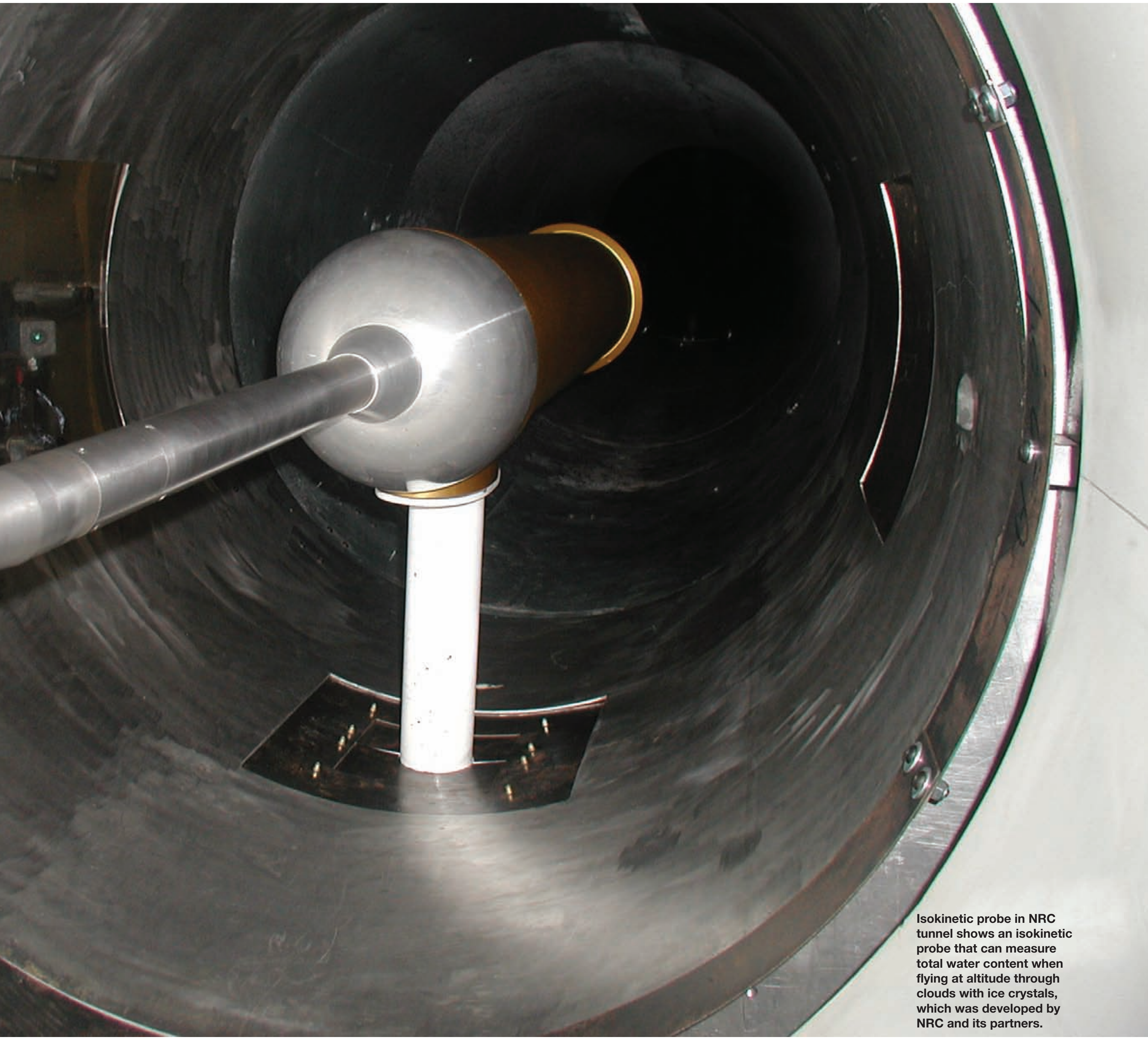
A cause for concern

Although ice crystals have been recognized as a potential problem for aircraft since the 1950s, two high-profile accidents with aircraft icing in the 1990s brought the adequacy of existing icing certification requirements into question. As a result, the US Federal Aviation Administration (FAA) formed two working groups: one to look at airframes and one to look at engine certification requirements.

While the airframe group found issues with freezing rain or drizzle on aircraft structures, the engine certification group, known as the Engine Harmonization Working Group (EHWG) found definite cause for concern with engines operating in mixed phase conditions or ice crystals. While an accident has never been attributed to this issue, the group believed that flying in these conditions could be a serious engine threat, and proposed certain modifications to current certification requirements. Before the FAA could even consider changing the requirements, however, it needed a better understanding of how ice crystals form, behave and threaten the safe functioning of an aircraft engine. This is where NRC Aerospace came in.

Until the mid-1970s, NRC was one of the centers for engine icing certification testing involving ice crystals and mixed phase conditions. When aircraft manufacturers decided this type of testing was no longer needed, NRC mothballed its equipment and moved on to other research and testing areas. Then the

DR IBRAHIM YIMER



Isokinetic probe in NRC tunnel shows an isokinetic probe that can measure total water content when flying at altitude through clouds with ice crystals, which was developed by NRC and its partners.

EHWG announced its findings, and NRC pulled its equipment out of storage.

NRC Aerospace researchers and others around the world believed that there were significantly large concentrations of ice crystals in the air under certain conditions, particularly in areas around the equator where there is a lot of moisture being thrown up to high altitudes. They believed that these crystals would not stick to cold surfaces, but inside the warm core of the engines they would melt slightly, stick to the engine surface and quickly form large chunks of ice. These chunks would then break off and get sucked deeper into the engine, causing it to flame-out. The problem was: the researchers had to prove it.

Breakthrough with Boeing

NRC Aerospace had some early success with replicating the conditions for rapid ice crystal formation with a heated plate, and with experiments that fed ice crystals into a simulated aircraft engine core environment to demonstrate potential flame-out conditions.

However, the organization really began to advance into new research territory during a project it had begun with Boeing in 2008, when NRC Aerospace researchers successfully demonstrated significant ice accretion in a simulated aircraft engine test rig with frozen ice crystals in air temperatures above 0°C. This capability was an very important step forward in the understanding of how ice builds up within aircraft engines under these certain conditions, which can affect in-flight engine performance.

Right and below: Icing build-up in a gas turbine engine

"A wide variety of cloud liquid water content probes have already been developed"

This breakthrough came as a result of a collaborative project to prove that ice crystals could form in an aircraft engine at temperatures above the melting point of ice. In flight, ice crystals can enter the engine, and are believed to cool surfaces from high temperature and form ice on engine surfaces in the core flowpath, even when the air temperature is above freezing. NRC Aerospace researchers conducted the tests in the NRC's Research Altitude Test Facility, in which they could create the cold conditions outside the engine and the warm conditions inside the engine necessary to correctly simulate the in-flight environment. They then produced ice crystals in the range of 70 to 200 microns in concentrations up to 15g/m^3, and blew them into the simulated engine rig for the test.

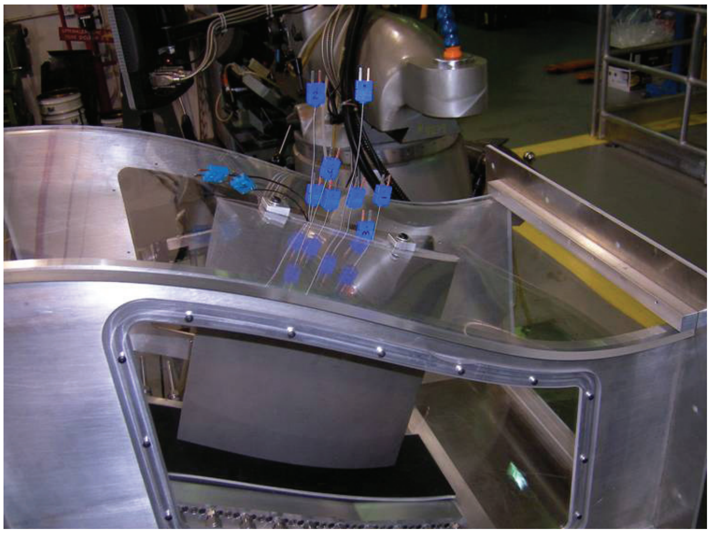
Although the goal of the project was to create ice accretion in any quantity in a simulated engine S-duct in air temperatures above 0ºC, the researchers succeeded far beyond expectations, and were able to build ice formations of a size that could affect engine performance. In addition, because the tests were recorded using regular and high-speed video, the researchers were able to define some conditions in which accretion will and will not occur.

One project leads to another

Building on this capability to replicate the conditions for ice accretion in a simulated aircraft at air temperatures above freezing, NRC Aerospace with its partners developed an isokinetic probe that can measure total water content when flying at altitude through clouds with ice crystals. This probe is the only fully functioning device of its kind in the world, and represents a major step forward in the effort to characterize and fully understand the total water content present in clouds with ice crystal conditions.

A wide variety of cloud liquid water content probes have already been developed, but none appears well suited to ice crystal conditions. In fact existing probes typically underestimate cloud total water content. The NRC-designed and built probe, however, samples the cloud isokinetically and employs an NRC-designed evaporator that ensures an accurate total water content reading.

NRC Aerospace researchers have tested the probe extensively in NRC facilities, including



Above: two 'pictures of rig' photos show before and after photos of a model of an engine's flowpath exposed to icing conditions.

the Research Altitude Test Facility, under simulated flight conditions that included ice crystals in the range of 70 to 270 microns in concentrations up to $15g/m^3$. Total water content readings are proving accurate.

Using the Research Altitude Test Facility, researchers have also demonstrated that air data probes can accumulate ice under certain conditions. They have observed that these probes can handle conditions to a certain threshold, but fail once that threshold has been exceeded. Airworthiness authorities are currently reviewing the test procedures for these probes.

Recognizing the need for larger cold weather test facilities, NRC Aerospace became involved in a multipartner, government-industry bid in the mid-2000s to establish an engine icing test facility in Thompson, Manitoba, a city in Canada's north that is marked by a subarctic climate. Winters are long and bitterly cold there, providing ideal conditions for cold weather testing. The undertaking was successful, and funding was announced in April 2009.

Called the Global Aerospace Centre for Icing and Environmental Research (GLACIER), the facility opened officially in October 2010. GLACIER is a C$43 million, state-of-the-art and globally unique facility that is partly owned by a joint venture between Pratt & Whitney Canada and Rolls-Royce Canada (GLACIER LLP). NRC owns a C$5 million stake in the facility, which comes from its in-kind contribution of engine icing expertise and equipment, as well as ongoing icing technology support.

Co-located with an environmental test research and education center called EnviroTREC, the GLACIER facility is the most modern engine icing certification facility in the world, capable of testing engines with fan diameters up to 140in and that produce up to 150,000 lb of thrust. Most importantly, the facility will provide the aerospace industry with the required operational conditions and capability to meet the growing requirements for icing certification and other adverse cold weather conditions.

Future research activities

At NRC Aerospace's facilities in Ottawa, icing researchers will continue to look at increasing the ratio of liquid water to ice crystals at the ice accretion site, a factor thought to be important in understanding this ice formation. In addition, they will undertake subsequent projects to make use of the altitude capabilities in the NRC research altitude test facility to further investigate the effect of air density on ice accretion.

Engine icing probe research will also continue on two fronts. Flight testing of the isokinetic probe in ice crystal conditions is planned for 2011 and 2012, and icing researchers will continue their efforts to understand the phenomenon of ice accretion on air data probes under certain icing conditions.

Above all, NRC Aerospace will continue to attack the ice crystal problem from all angles, building on past successes and moving into a new understanding of the problem. This new understanding, it hopes, can begin to advance the process of modeling the phenomenon reasonably accurately at sea level in order to predict and develop mitigating solutions. ∎

Dr Ibrahim Yimer is director of the NRC Aerospace Gas Turbine Laboratory. Contributors to the article include Jim MacLeod, leader of NRC Aerospace's Environmental Testing Group, Craig Davison, NRC Aerospace research engineer, and Sheila Noble, NRC Aerospace Communications

Helium bubbles and parafoils

THE NATIONAL AEROSPACE CENTRE (NAC) AT WITS FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT (FEBE)

BY RUDOLPH LOUW & PROF BEATRYS LACQUET

Initial concept validation with 10kg payload

RUDOLPH LOUW

PROF BEATRYS LACQUET

The National Aerospace Centre of Excellence (NACoE) was established in 2006 by the Department of Trade and Industry (DTI) and the University of the Witwatersrand: School of Mechanical, Industrial and Aeronautical Engineering, as a national collaboration between government, industry, academia and scientists for the provision and coordination of specialized services for the South African aerospace industry. The NACoE has since been renamed the National Aerospace Centre (NAC): A DTI Aerospace Sector Skills Development Program, operating as the National Aerospace Centre, due to other centers of excellence having different profiles.

The Wits School of Mechanical, Industrial and Aeronautical Engineering (MIA) is the only institution in South Africa that offers a fully fledged Aeronautical Engineering degree, compared with other universities that typically offer Mechanical Engineering degrees with an Aeronautical specialization. This was the prime motivator for housing the NAC at Wits, although it closely collaborates with all tertiary institutions in South Africa. Professor Edward Moss is the current Head of School of MIA.

The DTI completed its policy framework during 2005 to establish a new program of industrial centers of excellence in order to facilitate the development of new industrial capabilities in specific sectors. Industrial development requires the synchronization and integration of not only different policy frameworks, but also a range of specialist services. These industrial centers of excellence are to provide leadership, synchronization and integration of these diverse frameworks and specialist services, in order to build new industrial capabilities, strengthen existing ones, and also lay a solid platform for enhanced competitiveness of relevant sectors.

Structure

Activities of the NAC are primarily focused on human capital development (HCD) within the aerospace sector, in order to improve the capabilities and competitiveness of the South African aerospace sector globally. Guidance and governance of the NAC takes place in the form of an oversight advisory board, quarterly review meetings and monthly management meetings.

Members of the advisory board are compiled from government, academia including other South African universities, industry and relevant bodies such as NRF and AMD. It is important to note that the advisory board represents attendance from across the country in order to ensure broad-based inputs and interests.

The NAC mission is to conduct leading-edge, commercially significant technology research and development for the aerospace industry in South Africa that would not have otherwise happened, and that enhances the competitiveness and sustainability of the industry.

Key outputs of the NAC are: new or more competitive technologies/products; new knowledge; highly skilled human resources; and technology transfer.

Outputs are achieved in accordance with a long-term development strategy as a collaborative, multi-disciplinary effort between government, industry, academia and research institutions. Self-sustainability in the long term is targeted to be achieved through consistently adding value to all stakeholders during the formation years and beyond. The process followed by the NAC to ensure relevance is illustrated below. It should be noted that significant attention is paid to consultation and representation by all stakeholders, locally as well as internationally.

The center operates in close partnership with several other government programs, and enjoys partnerships with the Aerospace Industry Support Initiative (AISI), the Centurion

Completed launcher

Left: The full-scale launcher being tested in the Simonstown, Cape Town naval dry dock. The test was a resounding success. It was validated with a 30kg payload in this instance

Aerospace Village (CAV), the Advanced Manufacturing Technology Strategy (AMTS) currently restructured under the DST Technology Innovation Agency (TIA) and several universities. Internationally, the center has established a sound partnership with Airbus and is a participant in AeroAfrica-EU, an African and European Union aerospace initiative involving five countries.

There are several important initiatives underway at the Centre. The first of these is an extensive HCD program, which includes human capital sponsorship, providing support for course development, a bursary program and targeted training initiatives. Some specific projects include driving innovation and competitiveness through research, developing aerospace manufacturing processes and materials, building aerospace awareness and facilitating local and international networks. The NAC also manages an industry-focused R&D program through universities and research centers, which aims to specifically address areas identified jointly as priority skills areas that would benefit South Africa's aerospace competitiveness.

In terms of aerospace testing, inherent to skills development is the requisite capability and capacity to test and validate hypotheses, models, actual testing and evaluation of theories in terms of design, development, manufacture and maintenance – that is, the full lifecycle of aerospace platforms, systems and processes that all contribute to the aerospace/aviation experience. As such NAC has, to date, sponsored projects that target validation of theories, designs and tools developed for aerospace applications. Some of these are addressed here.

Helium-bubble flow visualization

The Wits School of MIA, in collaboration with the NAC, has unveiled a new flow visualization tool. The Helium-Bubble Generator produces a steady stream of thousands of micro-bubbles that are neutrally buoyant in air and visible to the naked eye. Helium and air are mixed with a bubble film solution in a micro-vortex; the bubbles are then filtered and piped into a wind tunnel to make airflow visible. This bubble generator can be used to assist with the validation of mathematical models of complex flow phenomena, often referred to as CFD or computational fluid dynamics.

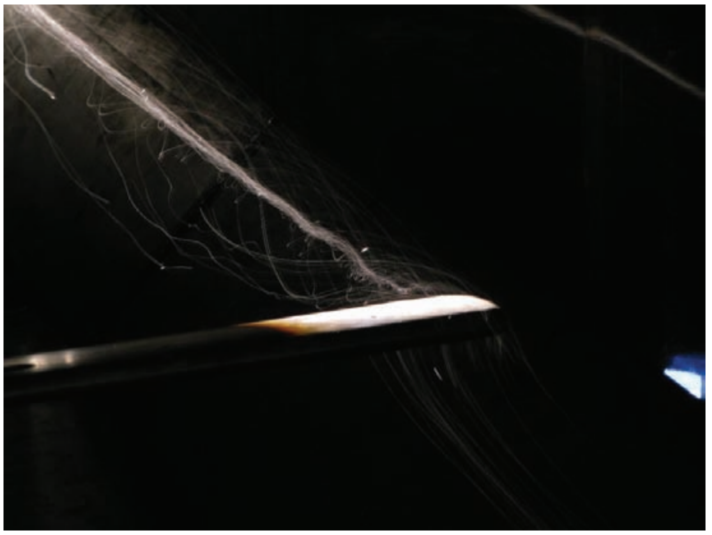
Due to the nature of these helium bubbles being individual particles (as opposed to the alternative method of using smoke, which cannot easily be viewed discretely), this methodology allows researchers to accurately track specific flow patterns and particles. High-speed static and video photography will allow researchers to investigate stable as well as unstable flow over the test surfaces with very high accuracy. The photo at the bottom of the next page shows a typical test article, in this case a wing model, positioned in the helium bubble chamber before testing.

The image at the top of the next page depicts the lift-induced wake vortex created at the tip of a typical aircraft wing, manufactured to scale. Each white line represents a previously invisible air flow streamline. The picture was taken in the Wits School's 1.5 x 1.5m low-speed draw-down wind tunnel at a

Keeping your Wits

The origins of Wits lie in the South African School of Mines, which was established in Kimberley in 1896 and transferred to Johannesburg as the Transvaal Technical Institute in 1904, becoming the Transvaal University College in 1906 and renamed the South African School of Mines and Technology four years later. Full university status was granted in 1922, incorporating the college as the University of the Witwatersrand.

The Faculty of Engineering and the Built Environment (FEBE) is at the forefront of creating wealth, by providing society with well-educated, entrepreneurial graduates for the engineering and built environment professions. The faculty maintains strong links with industry in the form of student bursaries, scholarships and internships, and sponsorships for equipment and infrastructure; it has the highest number of endowed professorships or 'Chairs' in the university. A large amount of contract research is conducted for local and international companies. Professor Beatrys Lacquet is the current dean of FEBE.



Above: Lift-induced wake vortex on wingtip

velocity of 7m/sec. The bubble generator was funded by the NAC.

The bubble generator's unveiling took place on May 21, 2010. The research into vortex instability is being led by Anthony Hoffe, a postgraduate student under mentorship of Wits senior lecturer Michael Boer. The NAC Advisory Board had its annual meeting on May 21, and members who viewed the bubble generator were impressed. The Helium-Bubble Generator will be used for many research projects. It is also available to other institutions including universities and industry, and should help cement Wits as a top 100 university.

Mobile parafoil catapult launcher

Parafoil systems are typically used in one of three applications: recreational, aircraft/spacecraft recovery and military. The South African company Aerodyne in KwaZulu-Natal, for example, is internationally known for its competitive parafoil designs. The process of developing such parafoils traditionally involves computer-aided design, followed by building a prototype(s) and then performance testing. Testing is usually done by means of helicopter lift and release, an approach that has significant cost and weather-dependency risks attached to it.

"Extensive testing and analysis were completed while launching the model 1.2m² parafoil. Scaling up of the system was carefully considered"

The purpose of this project, designed and executed at the University of Cape Town, was to develop a system whereby one can launch parafoils in a deployed state, enabling the study and testing of parafoil aerodynamics and guidance algorithms in an enclosed space such as a large hangar or a naval dry-dock, thereby eliminating the need for expensive helicopters and reliance on fair weather on a selected test date, and to enable affordable and repeatable testing to build up statistically reliable data sets.

A theoretical system model was developed using Pro/engineer CAD software to visualize and assess the interaction of components. Two subsystems – the parafoil inflation subsystem and a full-scale launcher – were planned, designed, built and successfully tested. The main picture on the first page shows the first development model, capable of a 10kg payload.

Extensive testing and analysis were completed while launching the model 1.2m² parafoil. The scaling up of the launch system was carefully considered, and led to a new concept for deploying larger canopies. The results correlated well with the theoretical model. The final subsystem, which accelerates the payload, was then designed and assembled. Final performance parameters achieved are: payload ≤80kg and speed ≤15m/sec.

The second subsystem and testing were done to ensure that the specifications were correct and the actual hardware performed to specification. Both subsystems have been tested independently and integrated to form the complete launching system.

This parafoil catapult launch system is suitable for studying and testing of aerodynamics, flight mechanics and guidance and control of parafoil systems – for example, experimentally extracting glide slopes; experimentally extracting aerodynamic stability derivatives; validation of aerodynamic models; validation of guidance and control models. ∎

Below: Wing model in tunnel for testing

Rudolph Louw is director of the National Aerospace Centre in South Africa attached to the University of Witwatersrand. Professor Beatrys Lacquet is the dean of FEBE


Precision
Powered
Gas Turbine Engine Test Facilities • Services • Test Systems
CLIENT CALIBRATED SOLUTIONS FOR TURBINE TEST
AVIATION • INDUSTRIAL • MARINE
DEVELOPMENT • PRODUCTION • MAINTENANCE REPAIR & OVERHAUL
MDS
Measured by the Power of Precision
www.mdsaero.com
1220 Old Innes Road, Suite 200, Ottawa, Ontario, Canada K1B 3V3 | +1.613.744.7257

Bragging about sensors

JAXA HAS DEVELOPED A STRAIN MEASUREMENT SYSTEM BASED ON OPTICAL FREQUENCY DOMAIN REFLECTOMETRY (OFDR) USING FIBER BRAGG GRATING (FBG) SENSORS

> **"A total of 20 sensors (260 gratings) were installed on the upper and lower skins of the wing structure"**

BY DR HIROTAKA IGAWA

The Japan Aerospace Exploration Agency (JAXA) is an independent administrative institution that carries out research and development of aerospace technologies.

JAXA's Airframes and Structures Group focuses on aerospace vehicle structures and key mechanical elements that are exposed to severe environments. The organization's activities cover a wide range of topics including the environmental durability of nozzles and thermal protection systems (TPS), control of large space structures with coupling due to deformation, aircraft structural vibrations induced by complex aerodynamic forces, the structures of space transporters and satellites, space bearings and harmonic drives, and advanced space lubrication. JAXA also actively contributes to various multidisciplinary projects with other groups.

Strain measurement using fiber-optic sensors is attracting the attention of researchers studying structural health monitoring (SHM) techniques, because it can give information on structural integrity over entire structures. Fiber-optic strain sensors can provide data on harmful deformations or stress concentrations due to damage or unexpectedly high loads. The size of defect or damage that can be detected by a distributed sensor is determined by the measurement system's spatial resolution. Furthermore, to properly assess structural integrity from sensor strain data, a strain measurement system must be able to detect slight anomalies in the strain distribution. A strain measurement system therefore requires both high sensitivity and high spatial resolution.

Brillouin scattering and OFDR

Fiber-optic sensors based on Brillouin scattering have been used successfully for measuring strain distributions in large structures. Their spatial resolution, initially insufficient to allow assessment of structural integrity, has dramatically improved to the order of a few centimeters, but must be further increased in order to monitor strain fluctuations caused by smaller defects or damage in structural members.

In order to meet the demand for SHM, JAXA has adopted a different technology and developed a strain measurement system based on optical frequency domain reflectometry (OFDR) using fiber Bragg grating (FBG) sensors. This is one of the most promising measurement techniques because it can achieve a high strain measurement accuracy of ±5me (1me = 10-4%) and a high spatial resolution of less than 1mm. These features allow us to detect localized strain distributions in a structure along a long-length FBG sensor. By using multiplexed FBG sensors in addition to long-length sensors, a measurement system can also at the same time obtain the overall deformation of the structure.

Strain measurements in a 6m-scale composite wing structure using multiplexed FBG sensors with up to 42 points and long-length FBG sensors of up to 500mm can be demonstrated and discussed. JAXA succeeded in measuring local strain distributions in the wing with high spatial resolution using the long-length FBG sensors, and the overall deformation of the wing using the multiplexed FBG sensors.

DR HIROTAKA IGAWA

OFDR strain measurement

Figure 1 shows a schematic of the OFDR strain measurement system comprising an OFDR

Figure 1

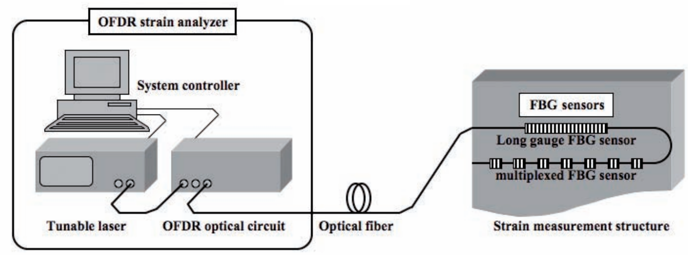


Figure 2

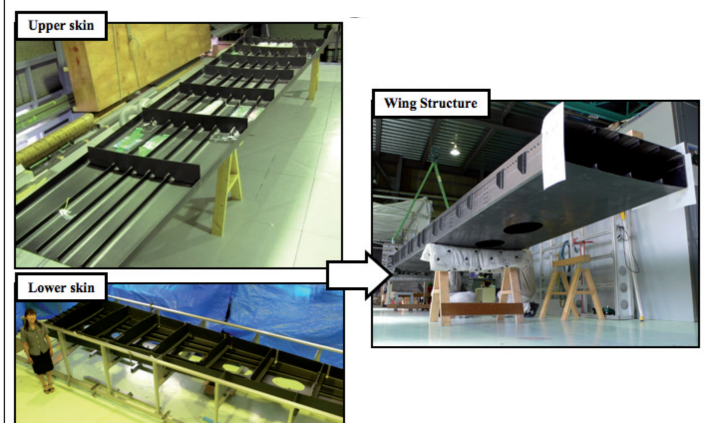


Figure 1: Schematic diagram of the OFDR strain measurement system

Figure 2: Target 6m-scale composite wing structure

Figure 3: Load test of the composite wing structure

strain analyzer, which includes a wavelength tunable laser, an OFDR optical circuit and a data acquisition system controller, and FBG sensors. For strain measurement, only the sensors are installed on the target structure, and the OFDR strain analyzer is set up at a separate location.

Wavelength-swept light from the tunable laser is fed into the in-fiber interferometer formed by the OFDR optical circuit and FBG sensors. The interference signal between reference light from the OFDR optical circuit and light reflected from the FBG sensors by Bragg reflection is acquired by the system controller. Short-time Fourier transform (STFT) analysis of the interference signal yields a spectrogram that indicates the positions and Bragg reflection wavelengths of the sensors.

JAXA's civil transport team and Advanced Composite Technology Center are developing a low-cost manufacturing technique for composite structures. An (approximately) 6m-long composite wing box composed of carbon-fiber reinforced plastic (CFRP) lower and upper skins was fabricated using a vacuum-assisted resin transfer molding (VaRTM) process, as shown in Figure 2, and subjected to a limit load test. The OFDR strain measurement system was demonstrated on this 6m composite structure.

A total of 20 sensors (260 gratings) were installed on the upper and lower skins of the wing structure. Long-length FBG sensors were bonded to stress concentration zones or discontinuous stiffness positions in the wing to measure their strain distributions. Multiplexed FBG sensors were bonded along the wing longitudinally to measure overall wing deformation. Strain measurement was demonstrated by

Figure 3

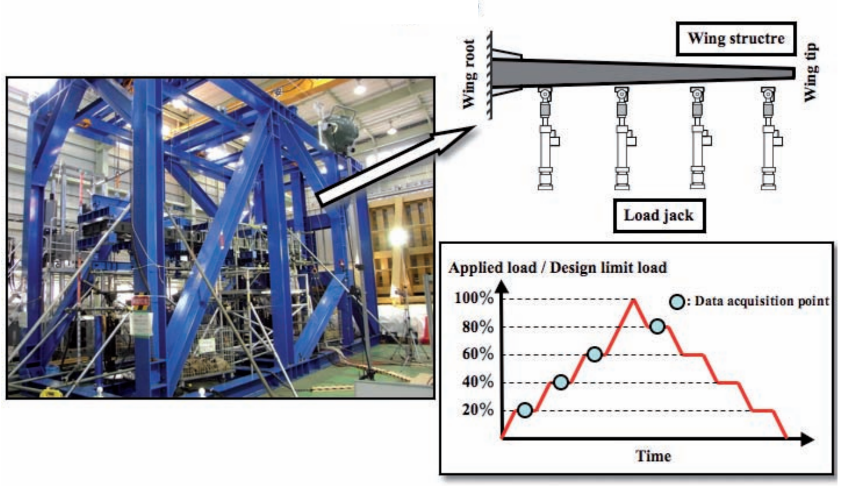


Figure 4

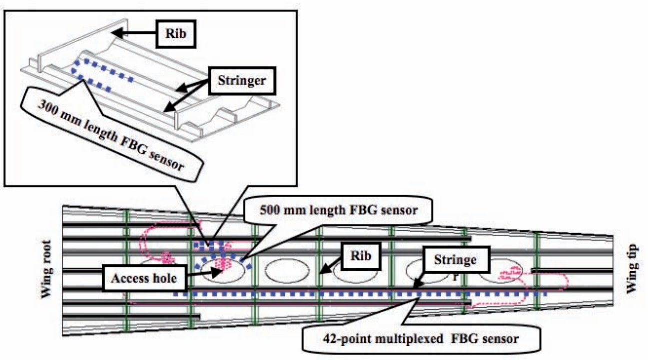


Figure 5

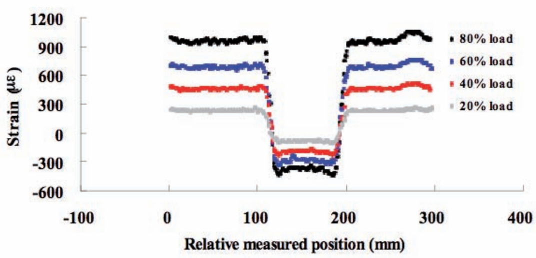


Figure 4: Schematic diagram of strain-measuring FBG sensors

Figure 5: Strain measured along a 300mm-length FBG sensor

Figure 6: Strain measured along a 500mm-length FBG sensor

Figure 7: Strains measured by a 42-point multiplexed FBG sensor

applying controlled loads to the wing tip using the load test equipment shown in Figure 3. Strain data was acquired when the load stabilized at 20%, 40%, 60% and 80% of the design limit load.

Results of strain measurement

This section presents strain measurement results from three typical FBG sensors. The configuration of these sensors is shown in Figure 4.

Figure 5 shows the measured strain from a 300mm-length FBG sensor bonded along two stringers and a rib as shown in the inset of Figure 4. Tensile strain in the wing longitudinal direction and compression strain in the vertical direction were measured continuously along the sensor. This demonstrates that the measurement system has sufficient sensitivity to detect strain distributions in localized areas. Figure 6 shows the strains measured along a 500mm-length FBG sensor bonded along the outer circumference of an access hole as shown in Figure 4. It was possible to measure discrete strains along the sensor at 0.3mm intervals. Setting the measurement interval to 0.3mm also confirmed the measurement system's high 0.6mm spatial resolution.

These results confirmed that the OFDR-based distributed strain measurement system using long-length FBG sensors was able to achieve sufficient strain measurement sensitivity with millimeter-order high spatial resolution. Furthermore, we also succeeded in measuring strain distributions over a 1m span using a 2,500mm-length FBG sensor.

Figure 7 shows the measured strains from a 42-point multiplexed FBG sensor bonded along a stringer to measure overall deformation of the wing structure as shown again in Figure 4. It was possible to measure overall deformation along the over 4m span. The larger strain was measured toward the wing root, and the strain relief was remarkably observed at around the rib positions. This confirmed that our measurement system could also obtain overall deformation of a structure along a multiplexed FBG sensor.

PANDA-FBG

A problem in applying this system to real applications is that the measured strains are influenced by temperature variations. This makes accurate measurement difficult when the structure has an uneven temperature distribution. To solve this problem, JAXA has developed an OFDR system that uses PANDA (Polarization-maintaining AND Absorption-reducing) fiber to measure strain and temperature simultaneously.

PANDA fiber has a slow axis and a fast axis with different refractive indices. By imprinting a Bragg grating onto a polarization-maintaining fiber, two Bragg reflection wavelengths are observed due to the different effective refractive indices of the slow and fast axes. These two wavelengths shift by different amounts in response to changes in strain and temperature, so we can determine strain and temperature simultaneously by measuring each wavelength shift.

Using a PANDA FBG bonded to a tensile test specimen, JAXA confirmed the applicability of this technique for simultaneous distributed strain and temperature measurement using OFDR.

We demonstrated strain measurements on a 6m-scale composite wing structure using an OFDR with FBG sensors. Local strain distributions in the wing were successfully measured with a high spatial resolution of 0.6mm along 500mm-length FBG sensors. Overall deformation of the wing was also measured along its over 4m span using 42-point multiplexed FBG sensors. This demonstration confirmed the feasibility of the strain measurement technique and the validity of the measured data. Considering the accuracy and high spatial resolution of the measurements obtained, the strain measurement system can be applied to not only SHM but also to verification models for the numerical analysis and evaluation of manufacturing processes for various kinds of structure. ∎

Dr Hirotaka Igawa is associate senior researcher in the Airframes and Structures Group, Aerospace Research and Development Directorate, JAXA

Figure 6

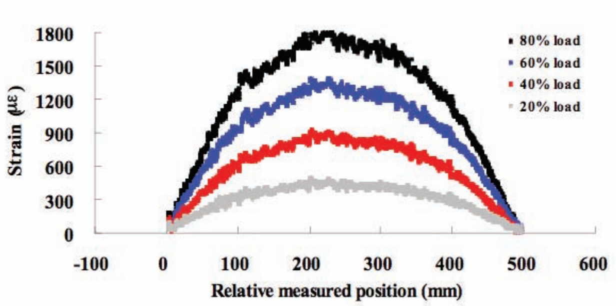
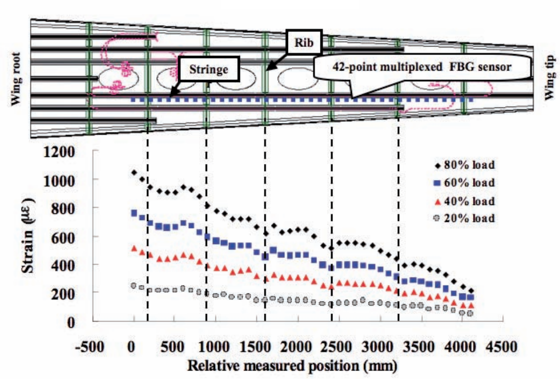


Figure 7



The Clean Sky Initiative

A EUROPEAN JOINT TECHNOLOGY INITIATIVE HAS ENABLED THE AVIATION INDUSTRY TO MOVE AHEAD WITH INTEGRATED TECHNOLOGY DEMONSTRATOR PLATFORMS

> **"Experts are calling for a 50% reduction in carbon dioxide and noise emissions by 2020"**

DR VALERIO CARLI

BY DR VALERIO CARLI

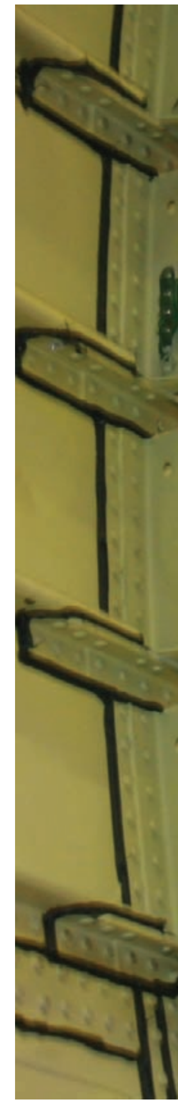
Less noise, less exhaust, less refuse – air travel of the future is expected to be quieter, cleaner, and more environmentally friendly. With the EU's Clean Sky project, Fraunhofer researchers want to help solve this Herculean problem.

The world of tomorrow will be green: low-emission, low-fuel, environmentally sound technologies are revolutionizing automotive and mechanical engineering, as well as industrial design and urban planning. This change in paradigms is also extending its grasp to aeronautics. Flying will become more environmentally friendly. Aviation experts from the Advisory Council for Aeronautics Research in Europe (ACARE) are certain of this. In the guidelines they've compiled for the European aviation industry, these experts are calling for a 50% reduction in carbon dioxide and noise emissions by 2020, and for the output of nitrogen oxides to be reduced by 80%.

These goals may be ambitious but they are certainly achievable. Fraunhofer works with decision makers from eleven renowned aviation firms and partners from almost every European country. Through Clean Sky, the various technical aspects of aviation are put to the test,. They are then evaluated and developed within the framework of this €1 billion program. This may be a Herculean task but it's also an opportunity. Europe has never seen an all-encompassing research project of this kind.

The seventh Framework Programme for Research and Technological Development makes everything possible. The EU fosters cooperation between research institutions and business firms in the new Joint Technology Initiatives (JTIs), which give new room for maneuvering. In the Clean Sky project, for example, participants can not only continue to develop individual technologies for specific applications but they can also evaluate and advance the entire aviation system. Six ITD (Integrated Technology Demonstrator) platforms cover almost every aeronautical product and technology. These platforms are organized in a matrix fashion with three vehicle-based platforms and three system-based platforms. An independent technology evaluator is responsible for assessing the environmental impact of the results arising from these ITDs.

Mock-up of a 4-metre tall composite wing with over 40 embedded- and surface-applied sensors. (©Fraunhofer LBF)



Cooperative advisory board

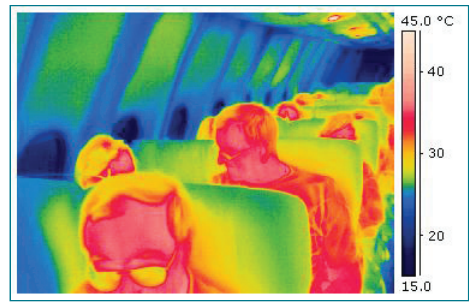
No single research group or company can solve a complex task like this on its own. An advisory board had defined the most important technology fields as engine technology, and wing and fuselage structures. These can now be handled separately, although methodological expertise on design, processes, and procedures is shared. Ultimately, everything is brought together into a greater whole.

The breadth of related subjects is immense: expert groups from dozens of businesses, research institutions, and nations will jointly collaborate, test materials, simulate air flows, calculate methodologies, and conduct and analyze experiments.

To increase the number of participants in the program and to utilize the best people available, several activities are presented via an annual call for proposals, which searches for the best specific technologies. An aircraft is a complex system belonging to an even more complex network. The potential for enhancing

Left: Structural health monitoring for a fuselage panel. (Fraunhofer LBF)

Below: In the flight test facility at the Fraunhofer Institute for Building Physics, researchers can simulate the pressure, temperature, and moisture conditions during a flight. (©Fraunhofer IBP)



the environmental impact of aeronautics is enormous and the objectives are quite challenging. Each component can contribute to improving the ecological balance of the system as a whole. Clean Sky also looks at the impact of aircraft in terms of disturbance and noise pollution. An optimized airflow profile on the wings cuts noise and saves energy; improved engine technology minimizes kerosene consumption and also reduces noise; materials with long lifespans save on raw materials; and the application of recyclable materials prevents the accumulation of waste.

Future aeronautical problems are hidden behind a myriad of research tasks: In the past, for example, material lifecycles were rarely given consideration in airplane construction. Consequently, it was difficult to dispose of aircraft that had completed their economic lifecycle. Other industries have evolved much further: value chains were created that incorporated materials' development, design, construction, manufacture, and recycling.

Disposable parts

Specialists at the Fraunhofer Institute for Chemical Technology (ICT) are developing special plastics that not only possess the exact material characteristics desired by the manufacturer, but can also be disposed of at the end of their economic lives in an environmentally sound manner. In the Clean Sky project, Fraunhofer engineers, along with the partners involved in the program, will apply this expertise to develop new materials for airplane structures.

Other important parts of the value creation chain include production and automation. Here, too, the experiences from other industries can be applied to aviation. Due to its wide range of competencies and structure, Fraunhofer provides innovative ideas, technologies, and manufacturing processes. Airplane manufacturers who had hitherto built their craft at manufacturing plants will want to automate production in the future. The Fraunhofer institutes specializing in the production process can bring their experience into the equation.

The aviation industry places a particular premium on safety because the lives of passengers and crew depend on the materials being used withstanding pressure and temperature variations as well as the vibrations and other forces that occur during each flight. In the Clean Sky project, special attention is being paid to novel materials and to the sensorization of structural components. This represents a step forward in the design and realization of reliable structural health monitoring systems applied to aircraft structures. Together with the Fraunhofer team and the various project partners, as general manager of the green regional aircraft platform, I am working to create a sensor system for the online monitoring of the wings and fuselage components.

Acoustic-based sensors and novel optical sensors combine to monitor the health of the aircraft's critical parts, and actuators integrated into the wings emit impulses. A network of sensors detects these signals and transmits them to an electronic data processing system. Fluctuations in the transfer pathway indicating a tear in the material can be immediately detected. These monitoring capabilities will improve maintenance scheduling and the overall safety of the aircraft structure.

After safety comes health. Prepared by Clean Sky project researchers, the comprehensive concept for the aviation of the future takes passenger well-being into account. Tests will indicate if a newly developed material diminishes the air quality in the passenger cabin. In the flight test facility at the Fraunhofer Institute for Building Physics (IBP) researchers can simulate the pressure, temperature, and moisture conditions during a flight.

Individual project groups have already started work. Their developments, investigations, and calculations should fit together like the pieces of a puzzle and result in an environmentally friendly design for the aircraft of tomorrow. The challenge for the next few years is to look into the value creation chain. It must contain an optimized wing concept, an energy-saving turbine design, new fuselage constructions, and monitoring concepts. Prototypes are planned for the medium term and the results will be incorporated into demonstration models later. With the help of these technologies, the European aviation industry should become much greener by 2020. ∎

Dr Valerio Carli is the Fraunhofer general manager for Green Regional Aircraft

Year of the CATbird

LOCKHEED MARTIN'S CATBIRD IS A HIGHLY MODIFIED BOEING 737-330 DESIGNED AS AN AVIONICS FLIGHT TESTBED AIRCRAFT. IT IS NOW AT MISSION SYSTEM FLIGHT PHASE

"We can simulate situations in this aircraft that we can't simulate in a ground laboratory"

BY ERIC HEHS

The southernmost run station on the Lockheed Martin side of the runway at Naval Air Station Joint Reserve Base (NAS JRB) Fort Worth contains an aircraft that is one part airliner and one part advanced fighter. This curious combination is a Boeing 737-300 transformed into a flying laboratory for the F-35 program.

This aircraft, known as the cooperative avionics testbed (aka CATB or CATBird), was built in 1986 from a former Indonesian Airlines aircraft. It sports a bright red vertical tail with CATB in white block letters. Instead of commercial passengers, the 737 now transports a team of test engineers. It serves as a flying laboratory for developing and demonstrating avionics for the F-35 Lightning II, in particular avionics related to mission systems.

"Mission systems are best viewed as systems that enhance the combat effectiveness of the aircraft," notes Tony Nigro, deputy manager for the CATBird, who has been associated with the CATBird since 2005.

"This aircraft is all about reducing risk for the program. We want to uncover and resolve issues with the mission-system software as early as we can and before they reach the F-35 fleet. CATBird allows us to test mission systems in a dynamic environment against both fixed and moving targets. We can simulate situations in this aircraft that we can't simulate in a ground laboratory."

Mission systems provide the pilot with situational awareness – through the processing, fusion, and display of data from both onboard and off-board sources. The advanced sensor suite on the F-35 collects vast amounts of information that is processed and presented to the pilot through the large color flat panel displays in the cockpit. Certain flight critical and tactical information is also projected onto the helmet -mounted display. The overall process allows pilots to make faster and more effective tactical decisions. Pilots can also transfer sensor information to other aircraft, as well as to maritime and ground forces.

Electronic hardware

Mission systems-related hardware on the F-35 include the APG-81 active electronically scanned array radar, electronic warfare, and integrated communication navigation identification systems; the integrated core processor; the electro-optical targeting sensor; the electro-optical distributed aperture system; and the pilot's helmet-mounted display.

Not coincidentally, this same hardware is found externally and internally on the CATBird. In fact, the most noticeable feature from the outside of the flying laboratory is the F-35 integrated forebody, or nose section, mounted on the front of the 737. The nose contains the active electronically scanned array radar and the front top sensor and two side sensors for the distributed aperture system (DAS). Designated the AN/AAQ-37, the DAS, consists of six electro-optical sensors placed at various locations on the outside of the aircraft. The system, developed by Northrop Grumman, provides situational awareness in a 360° spherical field around the aircraft. As such, it warns the pilot of incoming aircraft and missile threats and provides day/night vision, fire control capability, and precision tracking of wingmen and friendly aircraft for tactical maneuvering.

Moving back from the nose of the CATBird to just behind the cockpit, the sides of the forward fuselage sprout a pair of fixed canards. The nose-to-canard spacing is geometrically identical to the nose-to-wing spacing of an actual F-35. The canards contain forward-facing sensors that are part of the electronic warfare system.

ERIC HEHS

The first flight of the F-35 electro-optical targeting system (EOTS) on the cooperative avionics testbed (CATBird) platform took place in August 2010

A 27ft spine, running on top of the fuselage, contains two more of the six total DAS sensors; the global positioning system receiver; antennas associated with UHF, VHF, and satellite communications; and several datalinks, including assemblies and interface units associated with the F-35's multifunction advanced datalink (MADL). This sophisticated datalink enables the aircraft to communicate within and between flights and share a common view of the battle space.

A structure on the underside of the fuselage, called a canoe, contains additional MADL hardware, another UHF antenna, and the remaining two DAS sensors. Two smaller wing-like surfaces, called strakes, protrude from the fuselage between the main 737 wing and the empennage. These structures contain rear-facing sensors that are part of the electronic warfare system, as well as part of the F-35 radar altimeters. Less visible appendages are two tail cones of the 737 engine fairings. These fairings contain two more aft-facing electronic warfare sensors.

The flight deck of the 737-300 was left mostly intact with the exception of the addition of an electronic flight bag, which provide time/space position information to ground users via a datalink. The flight bag, a common upgrade for commercial 737s, consists of a color moving map that aids navigation and a system that

Electro-optical targeting

The first flight of the F-35 electro-optical targeting system (EOTS) on the cooperative avionics testbed (CATBird) platform was completed in August 2010. EOTS maturation on the CATBird is the final step prior to integration on the BF-4, the first mission systems-equipped F-35 test aircraft.

The low drag, stealthy F-35 EOTS builds upon Lockheed Martin's Sniper advanced targeting pod to provide high-resolution imagery, automatic target tracking, infrared-search-and-track, laser designation and range finding, as well as laser-spot tracking – all at greatly increased stand-off ranges. Modular components enable the F-35 EOTS to be maintained on the flight line for true two-level maintenance.

The CATBird, a modified 737 aircraft, contains an actual F-35 cockpit and test stations to perform real-time analysis

> **"Sensor fusion testing is a key advantage CATBird brings to the table"**

provides satellite weather downloads, flight charts, manuals, and other files for the pilots.

A large area just behind the cabin is devoted to hardware racks. A high-fidelity F-35 cockpit sits to the right rear section of these racks. Twenty workstations fill the back half of the aircraft. The rear lavatories were removed to make room for additional hardware racks and storage. The aircraft retained the forward lavatory and the galley area.

Minimum pilot crew consists of one pilot and one copilot. All four CATBird pilots are Lockheed Martin Aeronautics employees.

Maintaining integrity

The CATBird engineering team spent much time refining the external design additions of the aircraft to ensure that the aircraft retained the standard flying qualities of a commercial airliner. After the 737 was modified, a short flying qualities test program was flown in the spring of 2007 to validate that the aircraft retained those flying qualities. The pilots fly with flight test engineers involved in the development and testing of the mission avionics. The crew also has a designated test director and a test conductor, as well as personnel who monitor the network systems and instrumentation.

The typical duration for a mission-system test flight is 2.5 hours, with the longest mission-system flights lasting slightly more than four hours. All three of the four-hour plus flights were flown on the CATBird's August 2010 deployment to Edwards Air Force Flight Test Center in California. The CATBird has the ability to fly four-hour missions routinely.

"The most complex mission-system testing we perform involves multiship air-to-air fusion scenarios," explains says Ron Kolber, lead for the CATBird mission systems. "These missions require a tremendous amount of coordination and logistics. They are also some of the most challenging for the F-35 systems.

"Sensor fusion testing is a key advantage CATBird brings to the table," continues Kolber. "While the static infrastructure of fusion software can be tested in ground labs, navigation systems and various sensors require moving inputs to test the fusion algorithms."

CATBird testing will follow a block build up for mission-system software through the current system-development and demonstration phase of the program, which finishes with Block-3 software. Given its unique capability, CATBird can also function as an additional static-test laboratory when it is on the ground.

First flight of the modified aircraft occurred at Mojave Air and Space Port in Mojave, California, on 23 January 2007. As of August 2010, it has completed more than 130 flights, most of which have been in direct support of mission-system testing for the F-35 and a majority of which have taken place from the aircraft's home base in Texas.

"In addition to Edwards AFB, we have also visited Eglin AFB in Florida," notes Bruce Patton, flight-test lead for CATBird. "At these government ranges, we can test the F-35 mission systems against high-fidelity threat emitters and various airborne targets. We have also conducted low-level radar altimeter and navigation testing in the mountains near Holloman AFB in New Mexico."

CATBird has flown against one and two air adversaries so far. The targets, both in the air and on the ground, will increase in number and complexity as the software blocks progress.

The F-35 mission systems are maturing at a rapid pace. CATBird is currently being used to test the Block-1 avionics hardware and software. It has successfully demonstrated air-to-air and air-to-ground target detection and tracking with the radar, the electronic warfare system, and the electro-optical targeting system, both independently and cooperatively with sensor fusion. It has also demonstrated synthetic-aperture radar mapping, using the capability successfully to target joint direct attack munition and GBU-12 guided weapons.

"Even in these early software releases, the F-35 mission system avionics have proven to be very capable," says Patton. "The capabilities we are refining with CATBird will provide the warfighter with a weapons system that is second to none." ∎

Eric Hehs is the editor of Code One, the in-house magazine for Lockheed Martin's military-aerospace division

The modernization of trial apparatus

MODERN TESTING FOR A MODERN FLEET WITH THE FOCUS ON SUB-COMPONENTS AND STRUCTURAL TESTS

> "A team of experts continue to push the boundaries on failure theories and their applicability to multi-axial load cases"

DR STEVEN LORD

DUNCAN O'LEARY

BY DUNCAN O'LEARY AND DR STEVEN LORD

QinetiQ provides numerous types of structural and materials testing to support the aerospace industry, ranging from coupon testing through to complex component testing under fatigue and environmental conditions. Many different materials can be tested, including composites, metals, and a range of coatings to provide product technical assurance and certification.

QinetiQ has a track record in delivering turnkey test services to aerospace OEMs. This includes the provision of quality-assured information in all elements of mechanical test programs, from test specification to design and manufacture, through to mechanical test with analysis and reporting.

Several developments have taken place in the design and manufacture of test apparatus for sub-components and structural features. Key capabilities include: tension/compression testing (up to 2MN); fatigue; full scale tests at major component level (for example, wing/empennage); multi-axial testing; combined torsion/tension; fracture toughness; high strain rate; instrumented impact, and environmental conditioning.

Although a range of loading frames is available to accommodate different structures, bespoke load frame design and manufacture is often required, such as a modular wingbox test facility that can facilitate static and fatigue loading in compression, tension or torsion.

Two case studies are presented, highlighting the breadth of the testing capability currently being utilized by the aerospace industry. The first study looks at the use of bi-axial testing to enable the exploitation of the full potential of composite structures, and the second describes the design of a test for thermal fatigue applied to thermal barrier coatings.

Bi-axial testing

The use of fiber-reinforced polymer composite materials in the manufacture of aircraft structures has increased considerably in recent years; their specific strength and stiffness permit significant improvements in performance compared to conventional metallic structures. However, the full commercial and strategic benefits of structural composites have not yet been realized because their failure processes are not fully understood, forcing designs with conservative safety factors.

Despite a large database of uni-axial tests and the reliance of the certification process on such results, the majority of structures are very rarely loaded uni-axially in service. Therefore, an improved understanding of composite failure under multi-axial loading conditions is necessary. A team of world experts continue to push the boundaries on failure theories and their applicability to multi-axial load cases. The next phase of the project is due to report at the 18th International Conference on Composite Materials (ICCM-18).

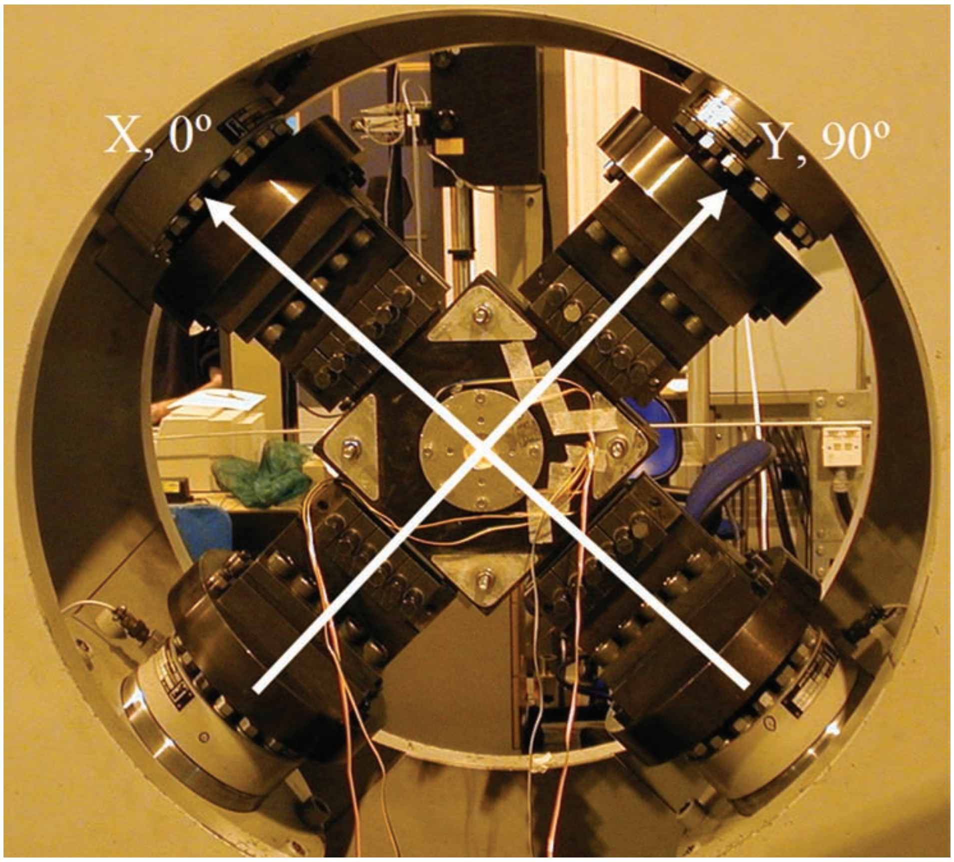
QinetiQ's comprehensive facility for the multi-axial testing of materials and structures includes two purpose-built, four-actuator machines, giving high machine stiffness and good actuator alignment with a load capacity of 1500kN; both have a fatigue capability. The machines incorporate a unique two-axis bolt-hole loading mechanism that has been used to simulate bearing failure and investigate the influence of holes.

This case study was part of a bi-axial test program to determine how the presence of holes affects the structural strength of carbon fibre-reinforced plastic (CFRP). The program tested a number of cruciform specimens to study the effect of hole size, specimen thickness, lay-up and load ratio on failure mechanisms. The bi-axial ratios were selected to be representative of typical in-service loading of a large civil aircraft.

The cruciform specimen was designed using quasi-isotropic pre-preg. To minimize stress concentrations at the corners of the cruciform,

Right: system bi-axial testing machine

Below: bi-axial test arrangement, including specimen loading axes and fiber orientation (specimen is shown fitted with anti-buckling guide)



a design was applied that has evolved from many years of research: the specimen was sandwiched between two layers of glass-fiber composite cladding with a circular cut-out in the center of the cladding (which was tapered to reduce peel stresses). A feature hole was drilled in the center of the test specimen. Aluminum end tabs were bonded onto the arms of the cruciform to allow the specimen to be bolted to the test machine. These were designed with oversized bolt holes to minimize the risk of failure in this location.

The specimen is located in the machine. The specimen can be manufactured such that the principal orthotropic material directions do not necessarily coincide with the loading axes; this allows testing of an expanded number of load ratios and shear cases. However, for this test case, the 0º fiber direction was along the major load direction and the load ratio, defined as major load to minor load, was (+1.0: 1.0).

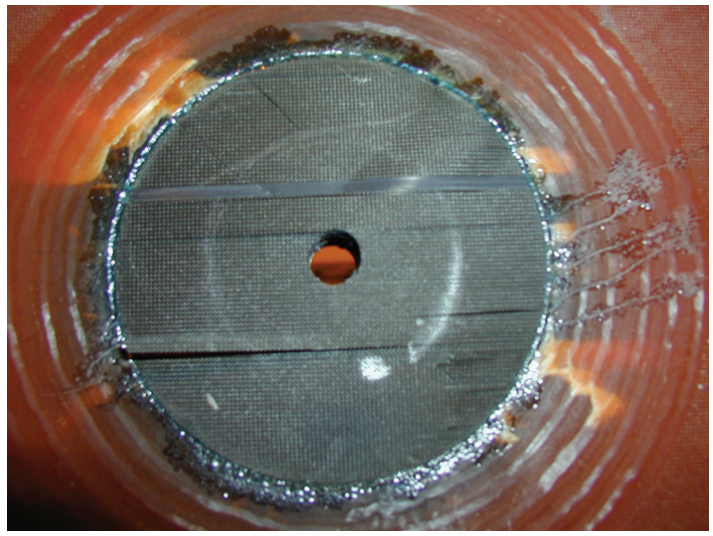
Specimens were fitted with a variety of strain gauges to measure global and local strains. The machine could be operated in either load or displacement control. Prior to testing, specimen calibration was carried out within the test machine in order to establish the loading ratio that would give the desired strain ratio in the test region.

For thin specimens an anti-buckling guide was used. For thicker specimens, a Moiré fringe technique and LVDTs were used to monitor out-of-plane displacements.

In this study, specimens were loaded in displacement control until a valid failure occurred that originated from the hole at the center of the test region.

After testing to failure, under a range of bi-axial loading ratios, specimens can be examined visually, via photography, with dye penetrant X-radiography and fractographically, using a scanning electron microscope (SEM), to determine the mode and extent of fracture.

This test program successfully produced a database of reliable and repeatable material characteristics for all of the loading ratios investigated. Both tensile (dominant) and compressive (recessive) failure modes have been observed simultaneously in those specimens subjected to a (+1.0: -1.0) bi-axial loading ratio, irrespective of the specimen thickness. For other loading ratios the failure is usually clearly either tensile or compressive. The investigation has provided a valuable overview into the multi-axial failure behavior of composite cruciform specimens containing open holes.


Right: failure mode for specimen with 10mm hole, loading ratio +1.0:- 1.0


Below: x-ray specimen with 25mm hole, loading ratio +1.0:- 1.0

Thermal barrier coatings

Thermal Barrier Coatings (TBC) are fast becoming mainstream technology for use in gas turbine engines and, to include the positive effects of the TBC into the lifting calculation for hot gas path components, it is necessary to assess and model the degradation of the TBC during service.

The TBC is a bi-layered system that relies on both physical adhesion and chemical bonds. Commonly used TBC systems consist of a metallic bond coat (BC) and a ceramic top coat. A thermally grown oxide (TGO) layer a few microns thick develops between the BC and top coat. Failure of the TBC in service is caused by spallation initiated by cracks growing along the interface between the BC and TGO.

Heat transfer between hot gas and blade surface takes place by convection. The TBC acts as an insulator that, in conjunction with the inner cooling of the blade, reduces the blade metal temperature. Therefore, the temperature at the outside of the TBC system is higher than at the interface to the blade metal.

Radio frequency (RF) heating systems are commonly used in testing rigs, but they heat the specimen from the inside. Consequently, the temperature profile in the TBC system on a thermo-mechanical fatigue (TMF) specimen is the reverse of that in service. To overcome this problem, QinetiQ's approach uses a susceptor around the specimen that adsorbs the RF and heats the specimen indirectly through radiation.

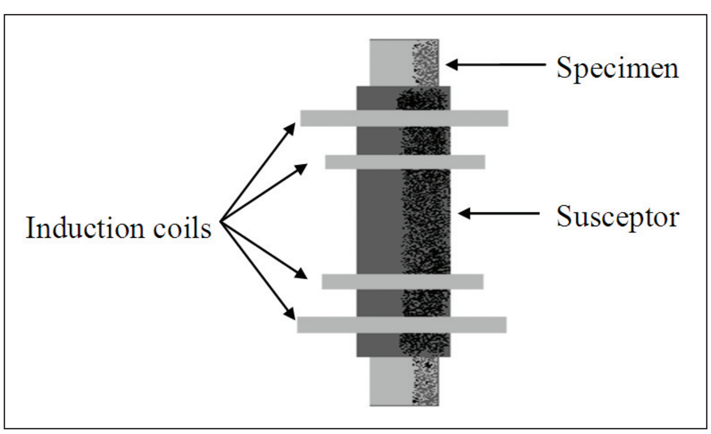
The first step of the study determined a test matrix for the TMF testing. This was established through Finite Element (FE) Analysis of an in-service, high-pressure turbine blade to define a typical cycle for the testing.

The test specimen was a cylindrical dog-bone test piece with a 6.5mm diameter over the 20mm gauge length. The central bore through the whole specimen was 4mm in diameter. In this test case, the specimen was made of the single crystal material CMSX4 in <001> orientation with a TBC.

The figure below left shows the experimental setup of the heating system with a susceptor placed between the specimen and the induction heating coils. The susceptor was made of a cylindrical tube of Nimonic 105.

The tests were carried out using a servo-electric TMF machine in load control. To provide forced cooling, air was supplied through the central hole of the specimen. During cooling, the susceptor is allowed to cool naturally, without forced air cooling. The temperatures of the coating and test piece substrate were measured using thermocouples.

The TMF cycle was defined by the test piece substrate temperature and was derived from the FE analyses. However, to reduce the cycle time to be experimentally acceptable, the dwell periods were shorter, whereas the transition periods were made longer to meet the achievable heating/cooling rates. However, the indirect heating system described is capable of achieving the thermal transients and temperatures appropriate for simulating the thermo-mechanical fatigue behavior of turbine blades. Temperature transients of circa ±10°C/s were achieved, while peak temperatures of less than 900°C have been demonstrated in the substrate.

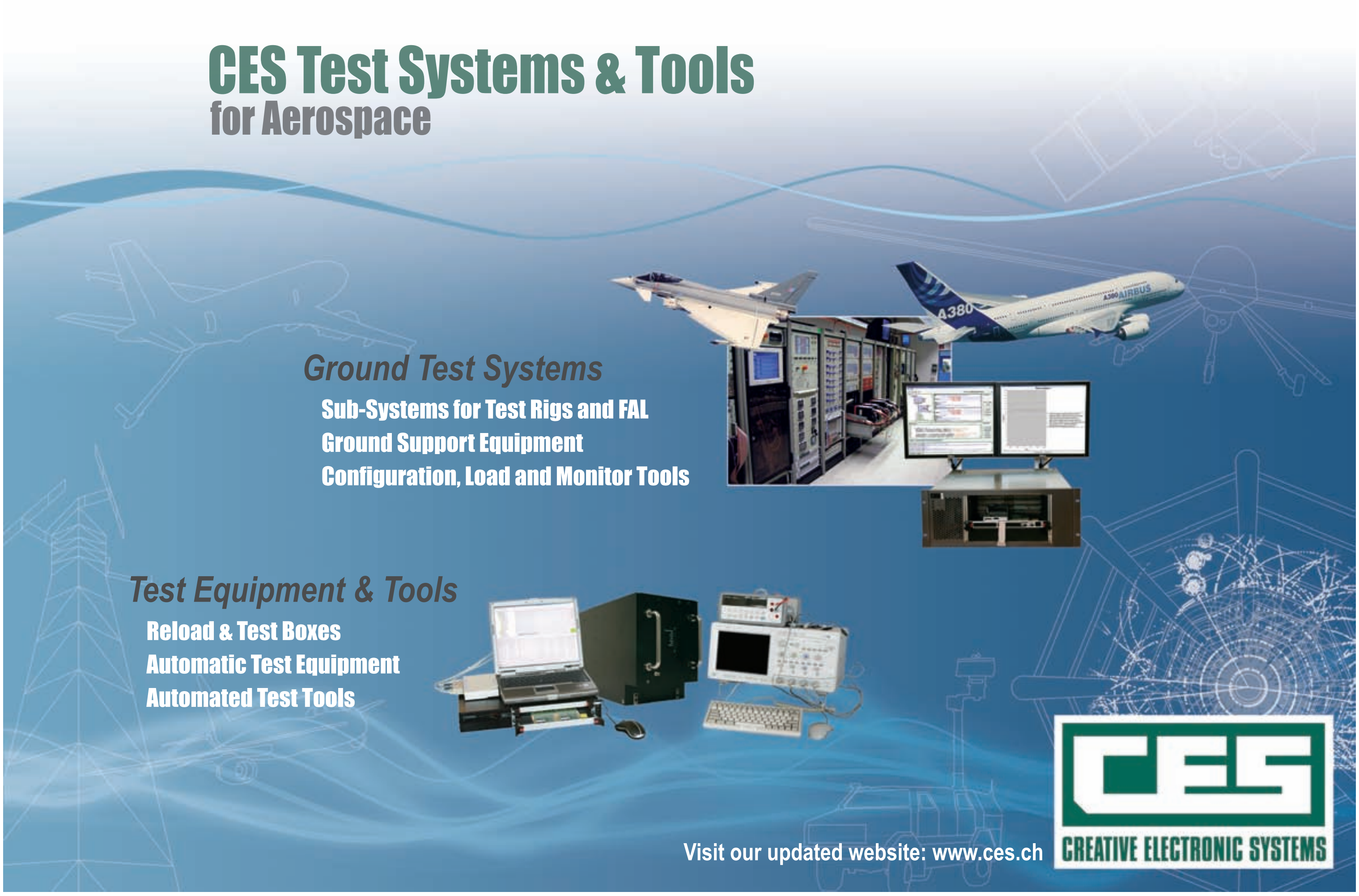


Left: heating system with a susceptor placed between specimen and the induction-heating coils

Performance demand

Testing for aerospace applications can cover a wide variety of requirements from materials and structural tests through to in-service evaluation. The demand for high performance parts continues to increase and industry needs to be available to respond to this with suitable capability and skills. ∎

Duncan O'Leary is the senior structural design engineer; Steven Lord is the senior engineer, Structural Design and Analysis with QinetiQ


CES Test Systems & Tools
for Aerospace
Ground Test Systems
Sub-Systems for Test Rigs and FAL
Ground Support Equipment
Configuration, Load and Monitor Tools
Test Equipment & Tools
Reload & Test Boxes
Automatic Test Equipment
Automated Test Tools
Visit our updated website: www.ces.ch
CES
CREATIVE ELECTRONIC SYSTEMS

Geared up

REDUCTIONS IN FUEL BURN, EMISSIONS AND NOISE: THE GEARED TURBOFAN ENGINE HAS THE EDGE OVER OTHER CONCEPTS

"The engine burns 15% less fuel because the larger fan diameter raises the bypass ratio"

BY DR CHRISTIAN WINKLER

Engine technology has attained a high degree of maturity. Pratt & Whitney, in partnership with MTU Aero Engines and others, has come up with a breakthrough concept with the two-shaft PW1000G Geared Turbofan (GTF) engine – a leader in terms of economy, environmental compatibility, and noise reduction. Rather than a common shaft, the GTF uses a reduction gear between the fan and low-pressure turbine, which decouples them. With its large diameter, the fan revolves once while the smaller turbine makes three revolutions in the same period of time. That enables both components to operate at their respective optimum speed and efficiency, making the engine considerably more efficient overall.

The engine burns 15% less fuel because the larger fan diameter raises the bypass ratio. The slower the fan, the more efficient and quiet it is. The engine noise is 24dB less – only half that of the most popular engines in this thrust category. Additionally, lower stage and blade counts save weight and reduce maintenance costs.

Pratt & Whitney and MTU developed the technological basis for the GTF in a plurality of research programs. Their commitment to the cause is now paying dividends. None of the underlying technologies needed inventing anew. All had already been tried and tested, or checked for feasibility. That included the gearbox developed by Pratt & Whitney, the eight-stage, high-pressure compressor that had undergone comprehensive validation in the test cell at MTU's Munich location, and the high-speed, low-pressure turbine. The fan, low-pressure turbine and combustor had already passed comprehensive trials as well.

measuring of the high-speed low-pressure turbine of the PW1000G engine


DR CHRISTIAN WINKLER

Development history

In 2000, MTU partnered with France's Snecma and others under the CLEAN (Component vaLidator for Environmentally friendly Aero eNgine) program, a research project sponsored by the European Union, to explore a joint technology demonstrator conceived to validate components for future engine concepts. The results from CLEAN enabled MTU to develop the high-speed, low-pressure turbine, the turbine center frame and an integrable heat exchanger. The demonstrator engine did well at the altitude test facility in Stuttgart. The test runs concluded in late 2004, which wrapped up the CLEAN program. It was thought that the turbine would sit around for a few years waiting for a geared turbofan to turn up. But much to the surprise of all involved, Pratt & Whitney a year later, at the end of 2005, launched its geared turbofan demonstrator project and asked the German company to come in on it as a partner. It was fortunate that MTU had designed the high-speed, low-pressure turbine so it could be paired also with a PW6000 core engine.

Testing programs

In 2008, the engine demonstrator was tested on ground at a Pratt & Whitney test stand in Florida and in flight on the company's own Boeing 747SP, located in Plattsburgh, New York. That first test flight phase took 43 hours. The hoped-for fuel consumption and CO_2 reduction targets were hit, both of them running in the double-digit range. Noise was impressibly low, as noted by attendees invited for a symposium. They were able to use their cell phones while standing beside the idling engine. Pratt & Whitney and Airbus now wanted to double-check the results by flight-testing on the A340-600.

In mid-October 2008, the PW1000G GTF engine demonstrator made a flight test on the wing of an Airbus A340-600. The 75-hour flight test schedule aimed to investigate engine

MTU holds design responsibility for the forward stages of the high-pressure compressor

and stall margin were met or exceeded. Further component testing took place at various Pratt & Whitney sites in Connecticut.

The high-speed, low-pressure compressor was put through an extensive testing program. But the most brutal tests where undergone by the fan drive gear system, which was tested to extremes that would never occur in flight, such as extreme g-loads and extremely high oil temperatures. The equivalent of 20,000 running hours were simulated, with the gear itself and the journal bearings remaining in excellent condition.

In late 2008, the first complete engine core started testing at Pratt & Whitney Canada in Montreal. Again, all components – the compressor as well as the combustor and the high-pressure turbine – performed as expected, building further confidence for the whole engine program. The test program lasted 260 hours. More than 1,200 measurements (temperatures, pressures, vibrations and clearances) helped the engineers to fully understand the behavior of the engine core. The results were shared with Bombardier.

Engine of choice

The PurePower engine family is what Pratt & Whitney calls its new line of products that includes the PW1000G GTF and the PW800 engines. The first takers are already on record: Mitsubishi Heavy Industries (MHI) and Bombardier have ordered the GTF as the sole engine choice for their regional jets, expected to enter service in 2013. MTU has secured a 15% stake in either GTF version. It brings to the joint effort its high-speed, low-pressure turbine, considered a key component in the GTF, plus the first four stages of the high-pressure compressor. The new engine concept promises to deliver step-change improvements in fuel burn, CO_2 emissions, noise levels, and maintenance costs.

Desirous to benefit from such advantages is Canadian aircraft maker Bombardier Aerospace. It has ordered the PW1524G GTF with a thrust of 24,000 lb as the exclusive powerplant for its 110- to 130-seat CSeries aircraft family. In addition, the PW1217G is the sole powerplant on the Mitsubishi Regional Jet. This is the first time MHI has ventured into the regional jet business. It was the GTF concept's mature technology that had MHI select a GTF with a thrust of 17,000 lb for its 70- to 90-seat commercial transport.

Late last year, Pratt & Whitney won the race to power the Russian MS-21 airliner, which is slated to enter airline service in 2016 and will directly compete with the Airbus and Boeing narrow-body products as well as with the Chinese C919. Driven by all these new aircraft coming to market in the next few years, Airbus and Boeing are also considering new powerplants for their workhorses, for which the PW1000G is an obvious candidate. A decision is due soon.

The first engine of the PW1000G product family to go on a test stand was a PW1524G. In mid-September 2010, the first light off happened flawlessly, and the first full power run just a few days later. This engine, with more than 2,000 sensors, will tell the engineers all they have to know. Tests are ongoing.

Engine certification is planned for the third quarter of 2012 and entry into service will happen in late 2013, when the Bombardier CSeries is handed over to the first customer. ∎

Dr Christian Winkler is head of business development at MTU Aero Engines


OUR WIND TUNNEL IS PROVEN,
SO YOUR DESIGN CAN BE PROVEN.
BAE Systems is proud to make its Wind Tunnel available for corporate trial and testing. Our state of the art facilities and expertise can support the feasibility, definition and development phase of the air-frame design process. The test capability covers air vehicle flight envelopes from Hover to Mach 6, and when you're testing in the same tunnel used for the Typhoon and Nimrod, that's a real advantage.
BAE SYSTEMS
REAL CAPABILITY. REAL ADVANTAGE.
www.baesystems.com/windtunnel

Structural health monitoring on the wing

A FOCUS ON LATEST TECHNOLOGIES FOR STRUCTURAL TESTING OF AIRFRAMES AND AIRCRAFT COMPONENTS USING OPTICAL SENSORS

"Compressing or straining the fiber changes the wavelengths of the light reflected by the fiber Bragg gratings"

BY DR-ING KARL-HEINZ HAASE

Load monitoring based on experimental stress analysis plays an important role in the development of structural components, as well as in the calculation of their residual life and their structural state, in realistic conditions and under specific loads.

In general, the reliability and price of the chosen sensors and the required durability of the structural system critically influence which new, high-tech materials and components are used and in which quantities.

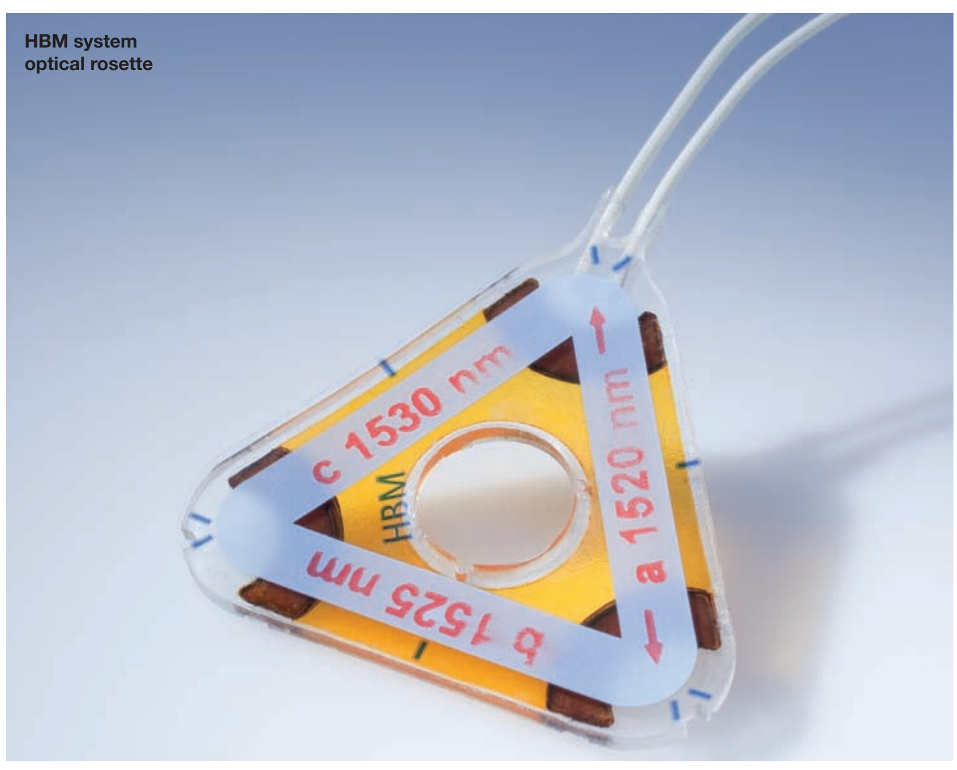
Today fiber-optic sensor technology is being increasingly utilized for measuring strain. Optical strain sensors are made of glass fibers with a very small core diameter of no more than 4-9 micrometers (157-354 micro-inches). The fiber core is surrounded by a cladding layer from purest glass with a diameter of typically 125 micrometers (approximately 0.004in). The most frequently used technology involves inscribing nanostructured measuring grids (Bragg gratings, in the form of periodic variations of the optical refractive index) into the core of optical fibers made of glass. The Bragg grating period represents a length scaling that can be influenced by external strains. The measured strain value is calculated from the wavelength of the light which is reflected by the Bragg grating and transmitted via the optical fiber. Hence, the optical fiber functions as both sensor and signal transmission medium.

Optical strain gauges have the benefit of reducing wiring requirements. Several optical strain gauges can be used on a single fiber strand. Compressing or straining the fiber changes the wavelengths of the light reflected by the fiber Bragg gratings. These changes enable strain values to be determined. When the test piece is subjected to stresses, the strain is transmitted through the measuring body to the optical sensor. HBM provides optical strain gauges in various forms: bare fiber (non-coated fiber); coated strain fiber, with a special coating for strain measurement and experimental stress analysis, and optical strain gauges which are installed like conventional electrical strain gauges.

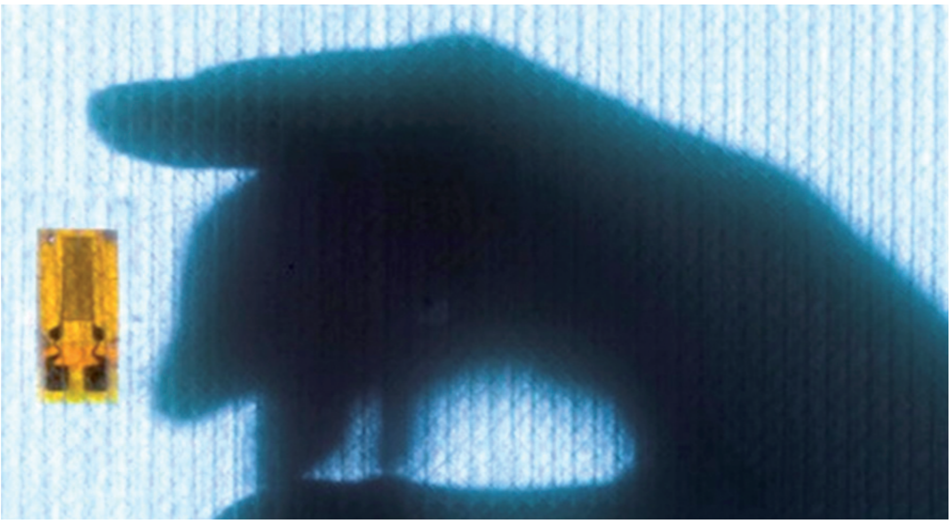
Particularly in experimental stress analysis, large numbers of strain sensors can be easily and quickly installed on a structure, for example, in the form of an array. This permits defined constraints and load assumptions for FEM calculations to be reliably and cost-effectively verified.

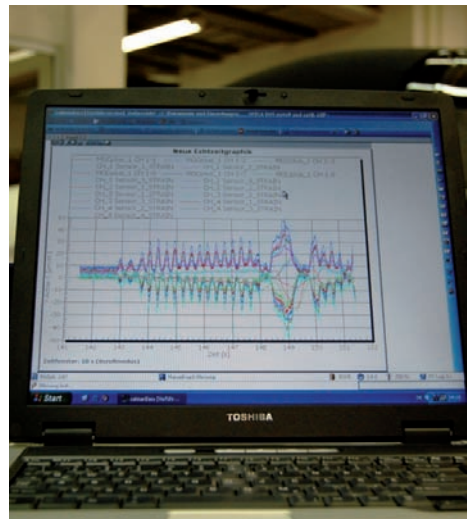
Due to the electromagnetic immunity of optical strain gauges, stress testing can be conducted

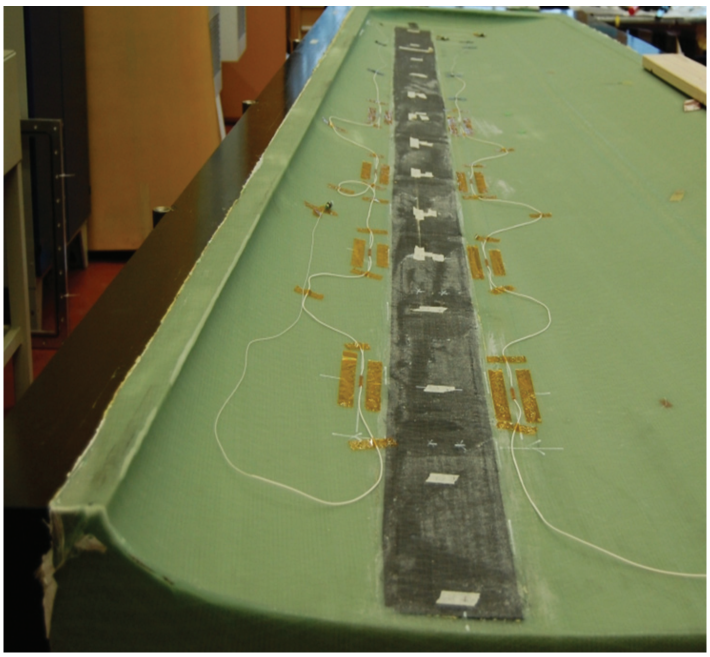
DR-ING KARL HEINZ-HAASE



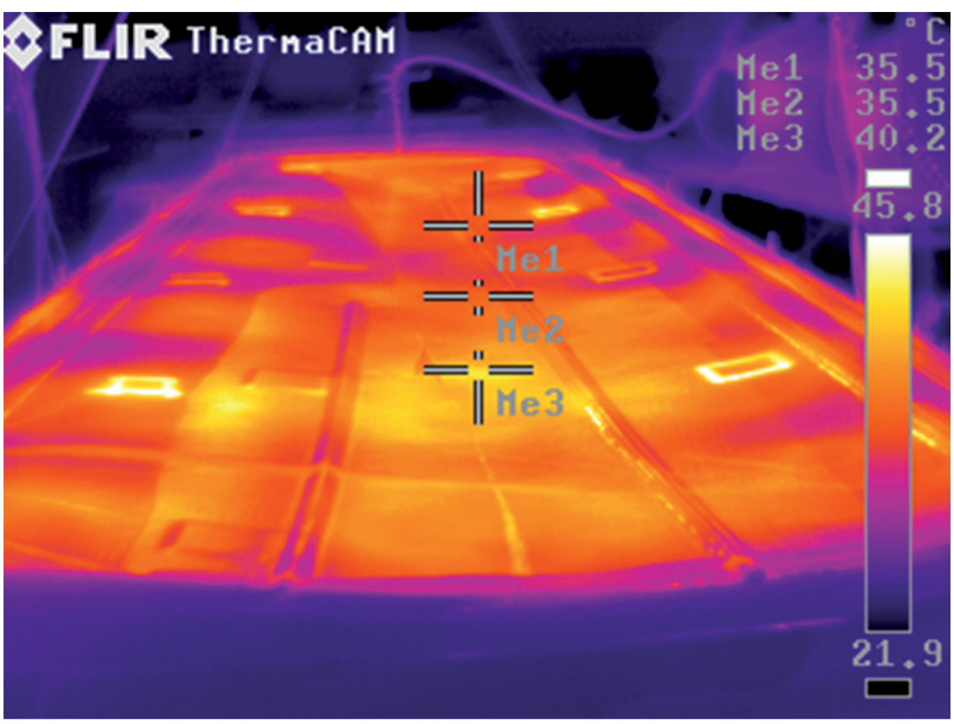
HBM system optical rosette







'Intelligent' sensor-equipped composite structures require a sophisticated combination of sensor and manufacturing technology, as well as data acquisition and analysis software



even on materials subjected to high electromagnetic stress or in highly explosive environments.

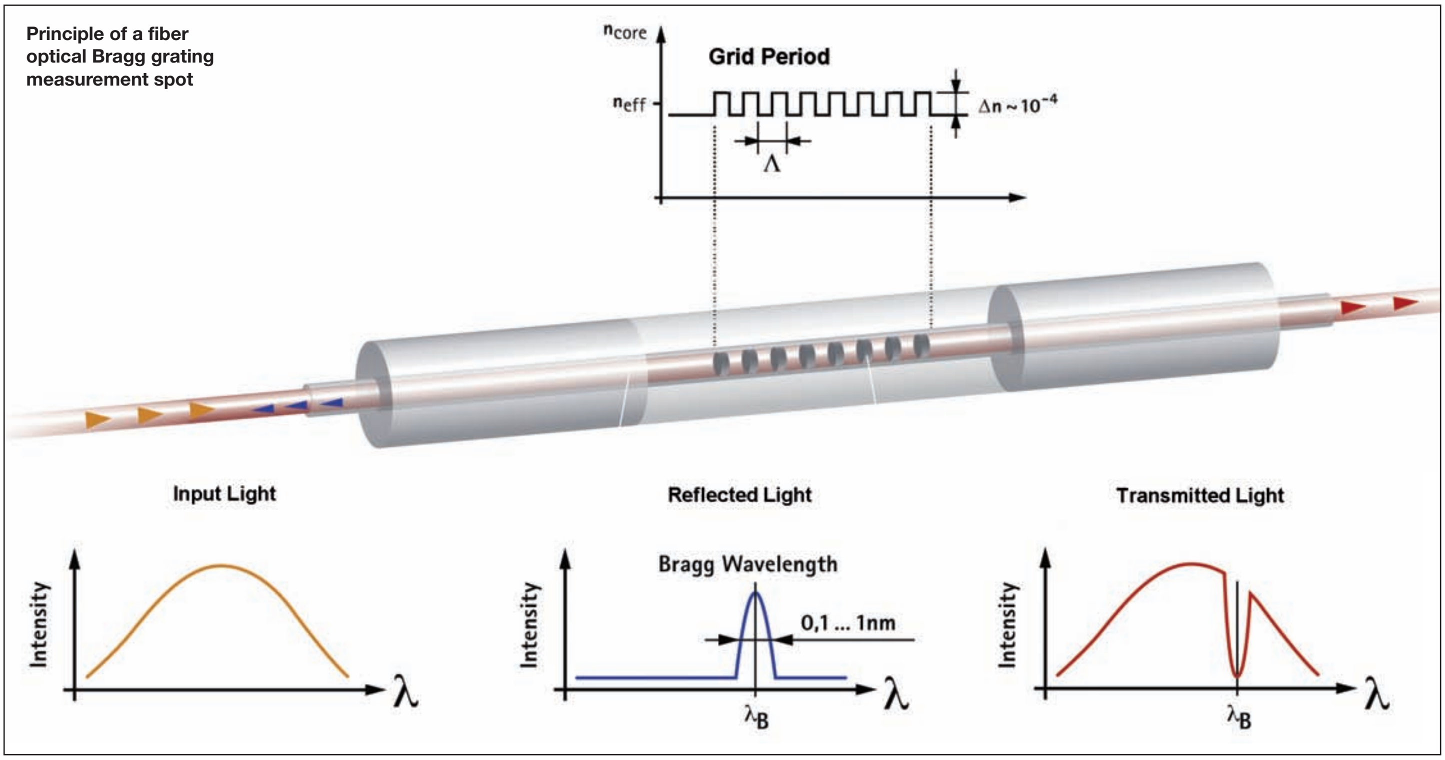
SHM on a wing using sensors

An SHM (structural health monitoring) test on a prototype wing was recently carried out by Fraunhofer LBF (Fraunhofer Institute for Structural Durability), responsible for building the wing structure, in cooperation with the University of Applied Science in Darmstadt, owners of the test aircraft and moulds. Composite materials were supplied by Evonik Röhm, Saertex and Hexion. Optical and electrical strain gauges, piezoceramics and sensor coatings were provided by HBM, Fraunhofer LBF and Fujifilm Prescale, respectively.

Both classical strain gauges and fiber Bragg grating-based strain gauges were installed onto the fiber composite structure in the conventional way, or integrated into the fiber plastic composite material. The method chosen to provide an optimal solution depended on the individual application. Fiber Bragg grating sensors, for example, are predestined for integration into structural material due to their high elasticity and long service life. Installation onto the surface of a component is preferable where frequent repairs will be necessary.

Sensors inside the wing measure the structural strain. The strain in the top and bottom half of the wing is monitored at a sampling rate of up to 1kHz. The signals trigger an alarm when a load limit is exceeded. The smart sensor network developed by Fraunhofer LBF provides online analysis of electrical strain-gauge data. A CANbus is used to connect the sensor nodes with each other and to a PC platform for further post-processing, storage and use of the data. On-line data analysis enables, for example, load cycles to be registered in a rainflow matrix. This method reduces the time data into a matrix of fixed size, requiring a fixed amount of memory only, which can be transmitted on a regular basis to a central PC unit.

The main advantages of a smart sensor network compared with conventional wiring solutions are the excellent scalability and expandability to cope even with large numbers of measuring points, which frequently need to be monitored in real applications. The solution additionally offers enhanced robustness for data transmission over long distances.



Principle of a fiber optical Bragg grating measurement spot

Primary data acquisition of the sensor signals was implemented in HBM's hybrid solution, which enabled optical and electrical sensors to be connected to the same catman measurement software and computer platform utilizing NTP (Network Time Protocol) synchronization.

HBM recently complemented its proven range of products and services for the measurement of mechanical quantities with a new range of photonic instrumentation. This comprises sensor elements such as optical strain gauges, opto-electrical interrogators for processing signals from Bragg gratings, and catman optical measurement software. The software converts the wavelength variations of a Bragg-grating-based sensor into strain (μm/m) / (microstrain), for spectrometric representation to mathematically compensate temperature influences. Electrical strain gauges and transducers are frequently used in addition to optical sensors.

The significance of SHM

Integrated structural health monitoring plays a key role in assuring the technological reliability of measurements. This is becoming increasingly more important to ensure the safety of systems, and is thus especially significant in the development of modern, light, structural components. The sensing equipment used for failure detection during maintenance must provide a very high degree of reliability, otherwise any misinterpretation of signals could endanger lives.

The term 'reliability' in this context refers to the probability that a system will not fail until after a defined period of time in operation. The reliability, along with the expected maximal time in operation for a required safety standard, can be determined by system reliability analysis.

For this reason, the importance of reliability for SHM systems was demonstrated and evaluated using the example of an integrated sensor. The service life and failure probability of each system component primarily depended on specific limitations, such as mechanical loading, temperature and moisture content. Even the term 'failure' needed to be redefined in view of the sensing procedures, which closely link electronic and mechanical components.

System reliability analysis, particularly for integrated SHM systems involving safety concerns, offers the possibility to quantify failure probability.

Requirements and tests

The requirements placed on sensors used in SHM can be shown with the combination of metallic strain gauges on composite structures, which often leads to an early failure of the sensor when the composite structure is tested under high strain. A test on a GFRP (Glass Fiber Reinforced Plastic) compound spring was performed for 107 cycles at a strain of 5000μm/m (microstrain) on the outer fibers. The structure survived while the first metallic strain gauge failed after less than 104 cycles.

Different types of sensors were tested at Fraunhofer LBF: Embedded strain gauges – In this test the interaction between integrated/embedded sensor (sensor failure) and composite material structure (notch effect) was investigated; Wöhler curves were plotted of the composite structure, with and without sensors. Also, Fiber-optic FBG (fiber Bragg grating) sensors. In this test, cyclic, four-point flexure tests on uni-directional GFRP specimens with surface-applied optical strain gauges were performed under different loads. Four sensors on each specimen were tested at a load ratio of R=-1 at ambient temperature. The mechanical test was stopped in logarithmic intervals for investigation of the optical spectrum of the sensors.

Optical strain gauges offer a number of advantages for end users for structural health monitoring in aerospace and in other structural applications. These 'others' include: optimized maintenance cycles, which can help to reduce costs and downtimes for airlines as sensors are pre-installed at critical spots; unusual occurrences like foreign object damage, which can be noticed earlier when maintenance work or repair can be immediately scheduled. The product liability requirement of airframes can also be supported with the load acquisition and storage capability of SHM systems, and automated, built-in maintenance, e.g. after every flight cycle, can help to reduce load-bearing airframe cross sections, resulting in lower weight with retained structural safety properties. Additional lightweight designs can reduce fuel consumption, but would have the effect of increasing the maintenance cost due to the higher frequency of inspection; safe, reliable and sensitive SHM systems would help to overcome this drawback.

The following critical constraints prevent immediate implementation of SHM systems: the reliability of sensor, bonding, cable routing and electronic hard and software for interpretation of the signals (a changing signal caused by sensor fatigue must differ from the signal of an imminent failure in a structure to prevent a false alarm); repair and replacement strategies for sensor networks, and manufacturing strategies for economic production of sensor-equipped structures.

Based on the acquired results, additional steps towards the realization of reliable SHM systems, as well as the evaluation of sensors, need to be carried out to fulfill these multifunctional requirements. ▮

Prof Dr Andreas Büter is from Fraunhofer LBF (Fraunhofer Institute for Structural Durability), Darmstadt, Germany. Dr-Ing Karl-Heinz Haase is from HBM (Hottinger Baldwin Messtechnik GmbH), Darmstadt, Germany

NDT in a nutshell

THE USE OF NDT HAS EVOLVED RAPIDLY. MODERN AIRCRAFT SAFETY DEPENDS ON THE LATEST SYSTEMS. A ROUND-UP DEVELOPMENT METHODS

BY TOM NELLIGAN & DAN KASS

TOM NELLIGAN

DAN KASS

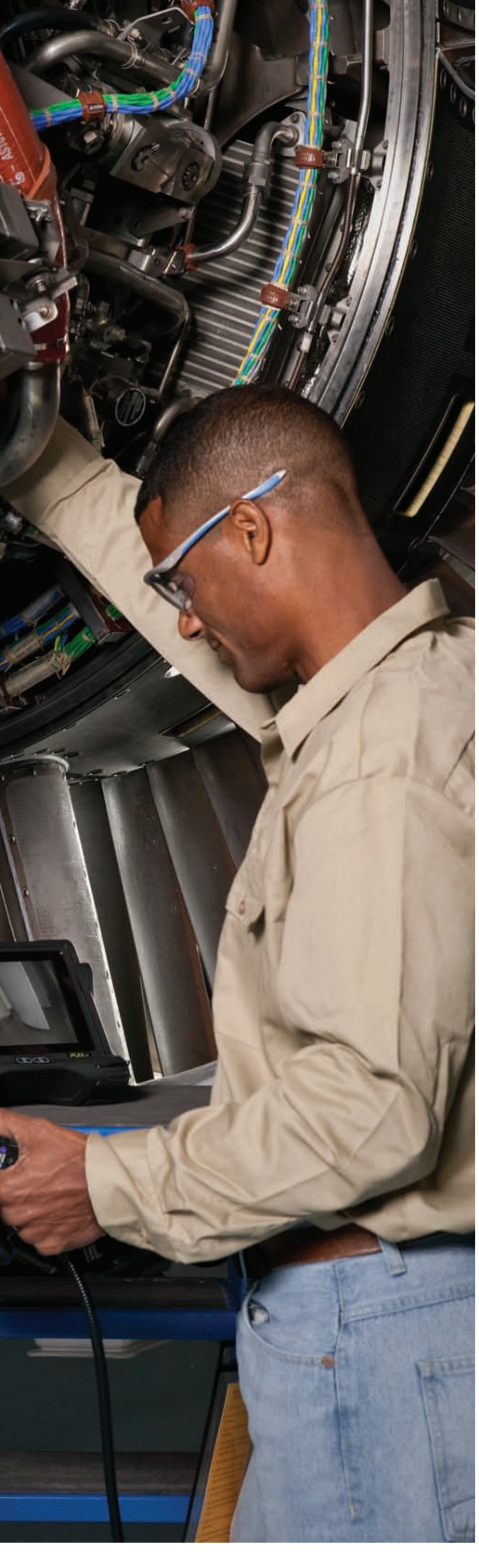
As both military and civilian aircraft have evolved from machines made largely of wood and cloth into modern aircraft relying on lightweight metals such as aluminum and titanium, and thence to contemporary designs based around carbon fiber and bonded honeycomb composites, the need for testing their critical structural components has increased accordingly.

The regular inspection of hundreds of critical parts, as well as careful attention to quality assurance in the manufacturing process, are essential for maintaining the aerospace industry's outstanding safety record. Aircraft manufacturers and operators use a variety of Non-Destructive Testing (NDT) methods and other inspection technologies during these examinations. Different methods are suitable for specific tasks recommended in the manufacturer's test and service bulletins.

NDT as a discipline is a mature technology. The first commercial eddy current instruments and primitive ultrasonic flaw detectors were introduced more than sixty years ago. By the end of the 1960s, both eddy current and ultrasonic testing were established test methods across a wide variety of industries. But, in recent years, there has been a new phase of product advancement. The development of digital signal processing techniques and inexpensive microprocessors have led to the latest generation of miniaturized, reliable portable NDT instruments and in-line inspection systems for flaw detection, thickness gauging, and acoustic imaging. Digital instruments have become the industry standard over the past decade, offering improved calibration stability and precision measuring. They also enhance onboard data logging and the ability to share screen images, test records, and setups between instruments and with computers. Similarly, advances in fiber optic and video technology have greatly improved the imaging capabilities of borescopes and videoscopes.

NDT tools are universally used by airlines and military forces as part of their aircraft maintenance

IPLEX-P&W09-62 remote visual inspection using articulated videoscope of aircraft engine



"Conventional EC instruments display data as an impedance plane plot that must be interpreted by the operator"

programs. They are also used by repair and overhaul contractors, and by aircraft and engine manufacturers and their suppliers for quality testing. R&D groups and space industries use NDT for testing new materials and fabrication processes. All of these tests help assure a safe landing whenever an aircraft takes off.

Eddy current

Eddy current testing (EC) uses electromagnetic induction to assess metal integrity. An eddy current probe (a coil of wire with an AC current applied) generates a magnetic field that creates a current in the test piece. This current creates a magnetic field of its own that modulates the current flowing through the probe. EC instruments record the fluctuations in current patterns caused by changes in thickness, conductivity, or cracking in the test piece.

Eddy current arrays (ECA) make use of the same magnetic induction phenomenon, but employ multiple probes in a single fixture to increase the area covered and speed of inspection.

In the aerospace industry, eddy current and ECA technology is commonly used to detect cracking around fastener holes; for bolt hole inspection; to scan for internal surface skin corrosion or thinning; to detect surface-breaking cracks in flanges, landing gear, and other metal support structures; and to identify doubler edge and scribe line cracking. A wide variety of standard and specialized probes are available to insure optimum resolution and reliability. Conventional EC instruments display data as an impedance plane plot that must be interpreted by the operator. ECA offers the additional advantage of generating color images of the test piece that help with the interpretation of results. Each individual eddy current coil in the probe produces a signal relative to the phase and amplitude of the structure below it. This data is referenced to an encoded position and time and represented graphically as a scan image.

Eddy current is highly sensitive to surface and near-surface flaws, but usually does not penetrate deeply into a test material. Thus it is often used in conjunction with ultrasonic testing, as in the Olympus FBIS and RBIS systems, which combine eddy current array and ultrasonic array instrumentation into a single automated system for full volumetric inspection of metal bars and billets used in critical manufacturing operations.

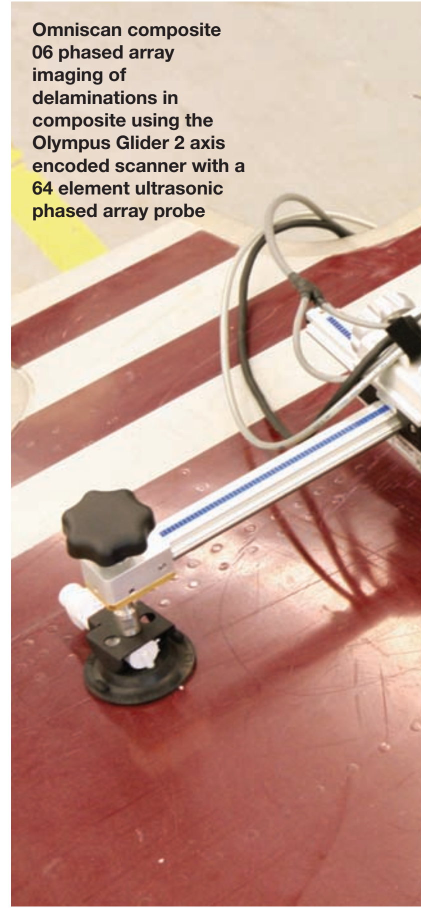
Ultrasonic testing

Ultrasonic testing (UT) uses high-frequency, highly directional sound waves to test common engineering materials from metals, composites, and plastics to ceramics. Access to one side of the test piece is required. By monitoring changes in the timing and pattern of echoes, ultrasonic instruments can find hidden flaws within a test piece as well as measuring its thickness.

The PWS100 analyses data in real time via a high-speed digital signal processor (DSP). Phased array instruments (PA) use multi-element array probes to steer sound beams through test pieces and generate detailed cross-sectional images of internal structures and flaws (similar to the technology used for medical diagnostic imaging). Ultrasonic bond testers use specialized acoustic techniques like resonance and mechanical impedance analysis to locate disbonds and laminar flaws in composites by comparing the acoustic signature of a good part with that of a bad one.

There are many maintenance and manufacturing UT applications in the aerospace industry. Both conventional flaw detectors and phased array instruments can be used for a variety of common tests such as weld inspection (including friction stir welds), detection of fastener cracking, detecting and sizing impact damage from bird or hailstone strikes, and locating cracking in structural metal parts like landing gears, engine mounts, and airframes.

Additional flaw detection applications include detection of scribe line cracking in the fuselage and cracks in turbine rotors and blades. Precision thickness gauges are used to measure turbine blade wall thickness in both manufacturing and maintenance facilities; aircraft skin



Omniscan composite 06 phased array imaging of delaminations in composite using the Olympus Glider 2 axis encoded scanner with a 64 element ultrasonic phased array probe

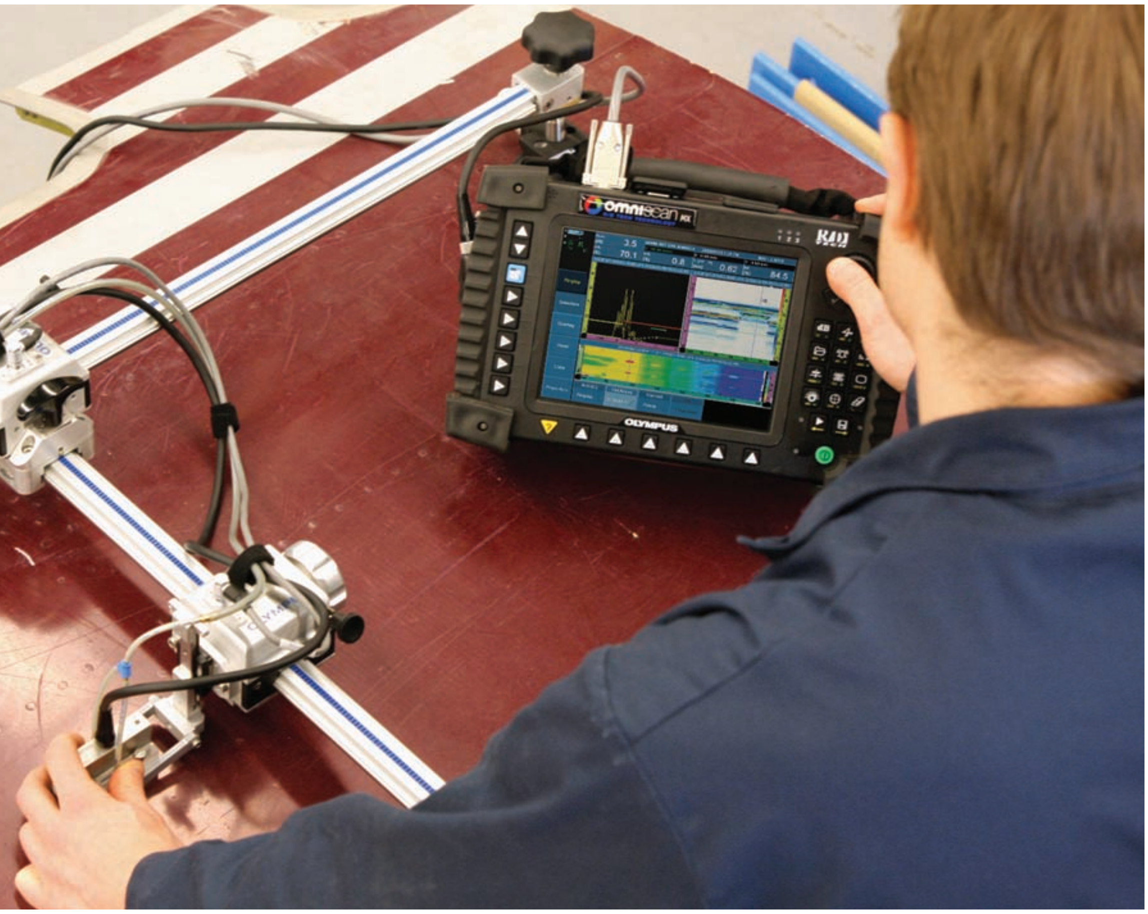
thickness in blending operations; windshield thickness after polishing; and wall thickness of a wide variety of metal, plastic, and composite aircraft components during manufacturing. Also used in aerospace manufacturing are large automated inspection systems that offer multi-channel test capability for composite panels and structural metallic parts. Ultrasonic bond testers can be used to verify the integrity of both solid laminate and honeycomb composites. The latter instrument classes have become more important recently as the amount of composite used in aircraft design has increased.

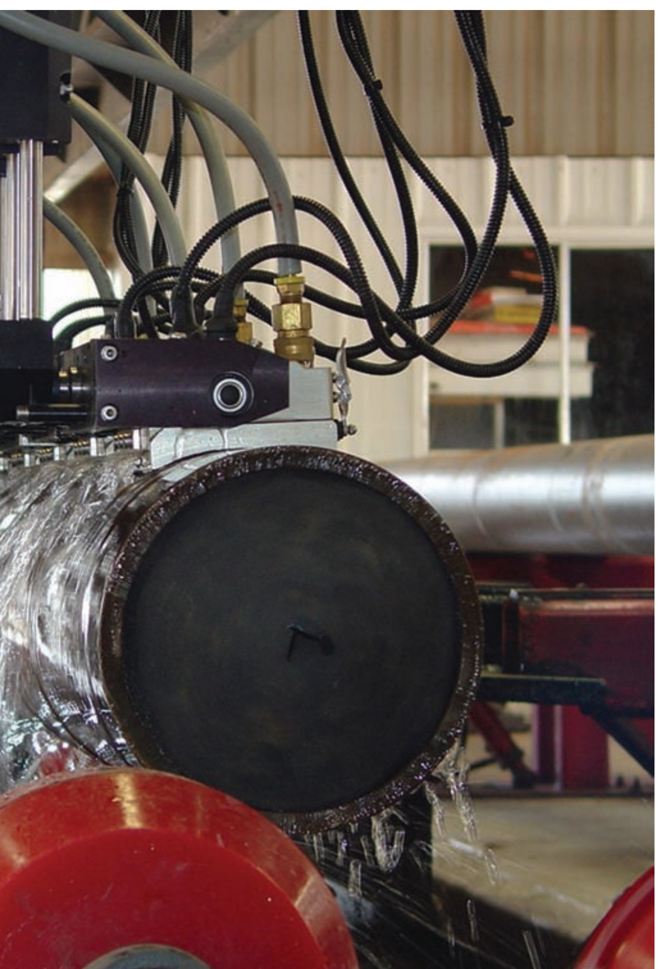
Available ultrasonic instruments and systems range from the simple to the sophisticated, and can be selected according to specific test requirements. For example, Olympus offers four classes of equipment for composite bond, lamination, and impact damage testing. The Model 35RDC Ramp Damage Checker is a simple, inexpensive instrument that can be used by ground crews without advanced NDT training for initial screening of possible impact damage in composite-bodied aircraft. Conventional flaw detectors like the EPOCH series can be used for more advanced testing and verification, as can the BondMaster multimode composite bond tester.

The BondMaster may be the ideal solution for detecting far-side delaminations in honeycomb structures with single-side access. This type of delamination is often difficult to identify with conventional ultrasonic pulse/echo techniques. At the high end of the capability scale are phased array instruments like the OmniScan MX that are used with scanning fixtures adapted to both the flat and radiused areas on the aircraft. The beam

Above: Aircraft Maintenance screen 4 eddy current array inspection using Omniscan MX displaying planar image of cracks emanating from rivets and corrosion of skin

Right: FBIS-27 automated full body inspection system for billets combining eddy current crack and ultrasound for inspection





steering capabilities of phased array offers advantages in inspection speed and simplicity by enabling volumetric imaging from a single probe footprint.

Remote visual inspection

Remote Visual Inspection (RVI) extends the reach of the human eye into small, enclosed spaces that otherwise cannot be seen. It uses a combination of CCD, LED and video-capturing technologies. A slim and highly flexible viewing device is inserted through a small opening into the area of interest and guided by the operator with a joystick. This provides a bright, clear image for the operator to view.

Software usually provides magnification and dimensional measurement of the observed surface. Probe-mounted LED illumination in contemporary videoscopes eliminates light loss due to broken optic fibers and reduces replacement costs compared with older designs.

RVI can be used to inspect turbine blades, compressors, combustion chamber liners, fuel nozzles, and other engine components for problems. These can include combustion deposits, erosion, surface cracking, and foreign object impact damage. Inaccessible parts of the airframe also need to be inspected for visible corrosion and cracking. For example, the Olympus IPLEX FX has been recommended for on-wing inspection of both large and small engines, including those requiring a smaller diameter insertion tube for access to critical compressors. Retrieval tools are then used to remove foreign objects.

High-speed video

High-speed video (HSV) is exactly what its name implies: digital video images captured at speeds of up to a million frames per second enable slow-speed visualization of actions that occur much too quickly for the eye to see. HSV camera systems like the Olympus i-SPEED 3 are used in a multitude of applications including aircraft design and manufacturing processes. These systems can be used to examine and analyze motions like wind tunnel airflow, helicopter rotor motion, bird impacts, and weapons deployment.

X-ray fluorescence & microscopy

X-ray Fluorescence (XRF) uses x-rays as a materials analysis and characterization tool. It can identify the chemical composition of a material within a few seconds by analyzing the wavelength and energy of secondary rays generated when an x-ray strikes a material and momentarily disrupts its atoms. In the aerospace industry XRF is used for compositional analysis of incoming and finished alloys in manufacturing operations. Within seconds, an inspector can determine if these alloys meet material specifications, and they can also identify unknown materials for refurbishing.

Industrial microscopes are used in aircraft design and manufacturing to view the surface characteristics of materials, including surface finish, cleanliness, and surface-breaking microcracks, as well as for the visual inspection of solder joints in critical circuit boards. The latest laser confocal technologies are now being used for advanced surface analysis. This technology can be used to image and measure submicron roughness and heights with very little inspector training. In addition, the latest image analysis software provides detailed customizable reports to the database so that even a large collection of images can be easily filtered for pertinent information. These advances give better control and understanding of surface finish, leading to safer and more streamlined aircraft. ∎

"Software usually provides magnification and dimensional measurement of the observed surface"

Tom Nelligan & Dan Kass are from Olympus Industrial Systems Group


Innovative technologies for the environment
15 percent, 20 percent, 30 percent – in three steps to climate-friendlier air traffic: With its Clean Air Engine (Claire) technology project, MTU Aero Engines has found a solution to the challenges of tomorrow. By 2035, it expects to reduce CO_2 emissions of aircraft engines by as much as 30 percent, and to halve present noise levels.
Germany's leading engine manufacturer is a reliable partner with Pratt & Whitney to provide the future in geared turbofan technology on the PurePower® PW1000G engine. Engine expertise honed to a keen edge is what sets MTU Aero Engines apart.
www.mtu.de
MTU
Aero Engines

Set data format standards

MANAGING STANDARDS, INTEROPERABILITY, AND OPENNESS FOR THE FUTURE OF AEROSPACE DATA SYSTEMS

"Shared test facilities are becoming more common"


DR ANDREW LAW

BY DR ANDREW LAW

The recording and analysis of test data is of vital importance in the development of new aero engines for both civil and military applications, particularly in the field of dynamics. Increasingly, new engine designs are being developed jointly between the major players and smaller partner companies in an attempt to spread the large costs and/or access specialist capabilities.

The interaction required between the parties in these development projects is driving an ever-increasing need to share large data sets between partners quickly and efficiently.

In addition, shared test facilities are becoming more common as engine OEMs try to reduce the burden of running low utilization, expensive facilities that could be considered non value-added to the business. These shared facilities, by their very nature, are required to provide information to one or more customers, which implies a need for interoperability.

The industry is considering adopting standards for sharing data between partners and third party test sites in a similar manner to that undertaken by the automotive industry over the past 10 years, primarily in Europe and Japan.

It is worth taking a step back in time to see how the test and measurement world has changed in relation to the acquisition, analysis, and storage of data, and how the adoption of modern digital technology has provided vital opportunities for measurement techniques but with huge challenges to interoperability.

Sixty years ago, measurements were made by people looking at dials and gauges on the instruments, and writing down their observations by hand. The number of parameters and the volume of measurements were very small by the standards of today, and the need for sharing this information outside of the OEM was virtually non-existent. As gas turbine engines grew and developed, the number of parameters required increased.

Forty years ago, pen plotters and UV chart recorders had become the norm. These devices usually provided their information in hard copy which, while bulky, did enable several engineers to view the output quickly and easily. Commercial pressures for sharing information had not yet developed, and this test information usually remained at OEM manufacturing/test sites.

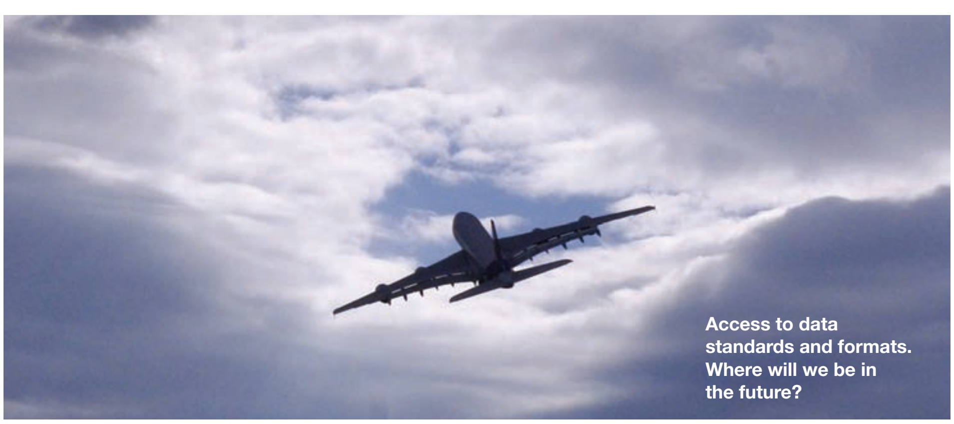
It should also be noted that most of the OEMs back then maintained test facilities on their own sites, requiring many personnel to operate them. Each site was unique and the measurement equipment and techniques varied greatly, but results and information could be accessed as it was mostly in hard copy.

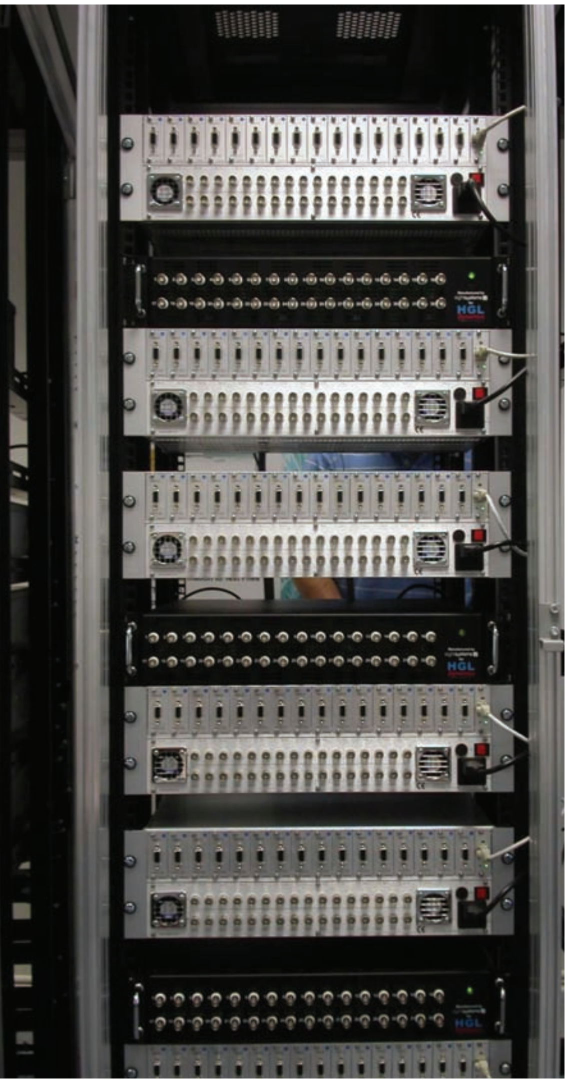
Moving forward

During the 1960s and 1970s, analog tape recording technology advanced enough to provide useful bandwidths for recording most signal types effectively. The majority of dynamic signals were recorded on one-inch magnetic tapes, which until recently were still in common use. In the 1980s computers had become so advanced that analog information could be extracted from the tapes and digitized for analysis and storage.

This trend has continued to the present day, with a range of digital tape drives (such as the ubiquitous Sony SIR1000 series) dominating the marketplace for about ten years. More recently, the advent of completely digital data acquisition and analysis systems has seen HGL Dynamics become a major participant within the recording field.

Measurement systems have grown into large and complex patterns with thousands of inputs and hundreds of subsystems, all generally


Access to data standards and formats. Where will we be in the future?



Left: Synchronised dynamic data acquisition on hundreds of channels, using modular components and standard network infrastructure

Below: Using networked display screens and client-server technology, users can review test data from remote locations

hosted on specialist computers with a single large monolithic software system to provide the measurement functionality. These are initially expensive to install and expensive to maintain as the world around them changes.

As with other areas of technology, the pace of change is increasing every year. This can be clearly seen in the area of recording techniques; analog tape systems were available for over 40 years, digital tape systems for around 15 years, and now digital systems can sometimes become obsolete within three or four years.

This pace of change provides an enormous challenge to the aerospace industry, where longevity and stability are important, both in relation to the length of engine/airframe development projects, and later on for access to data during the increasing lifetimes of both airframes and engines (40+ years is now common).

It seems obvious that industry-wide adoption of data format standards within the aerospace sector would instantly resolve the problems of interoperability and data sharing but is this really the case? Can standards be developed that can cope with these dichotomous requirements, or is a new principle such as 'standardizing for change' required?

Setting standards

Standards imply convergence on a single way of doing things, ideally converging on the best technical and commercial solution. However, it is not uncommon, particularly in the commercially driven consumer world, to have multiple standards competing at the same time. It is also not uncommon for the technically superior solution to lose out to the competition and be eradicated (such as Betamax losing to VHS). In such cases, commercial pressures may outweigh the technological advantages, to the longer term detriment of the industry. Is this sensible in the aerospace sector?

Standards' bodies can take several months or (more commonly) years to create, update, and grow the standard as new requirements emerge. In the fast-moving aerospace world this is often too long for commercially sensitive projects and companies to stand, so they generate their own new standard, and data sharing becomes a challenge all over again.

One of the biggest opportunities in the digital age is the ease with which new techniques and methods can be developed and commissioned. Small- and medium-sized enterprises are often the cornerstone for these techniques and can bring them to OEMs quickly and inexpensively. However, if they are constrained by rigid standards, will this stifle this advancement?

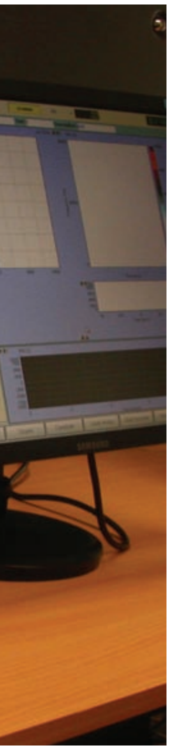
As mentioned earlier, the automotive industry in particular has started adopting some standards for data measurement and access, of which ASAM is probably the most talked about in the aerospace industry. The ASAM standard is all encompassing and actually consists of several interacting standards. Each of these standards is well defined and described in a set of comprehensive documents, and there is a supportive standards association to help new members adopt these standards.

However, the flexibility (which can lead to complexity) of standards such as ASAM ODS, HDF5, CDF, and others cannot be ignored, and there is still scope for misinterpretation, both of which provide potentially large barriers of entry to suppliers and OEMs alike. The practice of having a single standard that is capable of providing infinite complexity ultimately becomes a false solution that leaves the situation unchanged.

Some standards, however, have been remarkably successful; for instance, Ethernet is probably the most pervasive standard for digital data transport across the globe. The RJ45 connector is more common than just about any other in any industry. Ethernet is a standard. Some of its protocols have adapted and grown as technology has progressed to provide faster speeds and more services without changing the underlying standard.

The same cannot really be said for the world of computers that use Ethernet; indeed, the range of hardware, software, and operating system platforms is continuing to proliferate rather than standardize down to one common form.

One area of technology that may provide insight when discussing standardization is the IBM-compatible personal computer. During its history, the PC has hosted several different bus standards (ISA, Extended ISA, PCI, PCI Express etc), and operating systems have been able to support virtually any card on any of these busses simply through the use of a small piece of driver software. In essence, the base functionality of the PC has become immune



Left: Real-time access to test sites in out-of-the-way locations allows remote analysis and decision making, reducing the cost of testing

Right: Modular, networked test cell systems provide flexible configuration and rapid transfer of data, whether for real-time display or mass storage

Below: Multimodule test cell system linked by multiple real-time networks

from the variation of some of its constituent parts. More importantly, those parts can be replaced or upgraded with relatively little impact on the host PC, both in terms of operability and cost.

Today, aerospace companies (and others) are besieged by a host of legacy and current systems all with different standards, and all of which contain potentially vital data that is critical to the success of their business.

In the push to reduce costs and to work cooperatively where appropriate, companies are increasingly turning to partnership programs, joint ventures, and use of third party facilities for test execution. There is an increasing need to be able to take test equipment to remote sites and be assured that it will be compatible with systems brought in by other partners, and with the fixed infrastructure already in place. With this in mind, let us try and imagine 20 years into the future. What platforms, interfaces, and technologies will still be recognizable?

The goal

In our search for systems integration and selection (or definition) of standards that will still be meaningful and effective in 20 years' time, should we be focussing on the data format standards as the end goal, or is this missing the point? PCs have shown that it is possible to have a set of smaller flexible standards that can be integrated together to provide a complete operational system. Ethernet provides a long-lived and growing standard for connecting functional nodes such as PCs into a network of functionality, where parts of it can be added or removed at will. Perhaps this should be the model for the future.

Over the past 10 years, HGL has developed its dynamics' measurement systems to this model. It has enabled us to provide a continuously growing modular software system on an increasingly powerful hardware platform. The use of Ethernet as the software backbone has enabled effective and transparent operation locally and internationally, and has enabled a high degree of plug and play to be achieved.

Adoption of simple, self-describing OPEN data formats and interfaces have allowed transmission by file, network, or archive media to be achieved with relative ease. Migration to new hardware and mid-life upgrades have been met with little expense to existing customers through a process of modular evolution.

During the same timeframe, the industry has seen the demise of hardware (such as the Sony AIT range of tape drives) and the rise and fall in popularity of various file formats and standards. New products have emerged but some have fallen by the wayside.

The aerospace measurement industry is large and complex and has traditionally been burdened with large and complex solutions. With more cooperative projects between engine manufacturers and airframe suppliers, there is a need for easier data access and possible interoperability of their equipment.

The adoption of large standards may not be the way forward as these can constrain adoption by both suppliers and customers which can, in turn, limit advances and/or actually increase divergence through the development of competing implementations.

Modular network-connected systems with well defined, simple, and above all open data structures and interfaces are probably a better solution. They permit easier adoption by customer and supplier, and provide a longer term evolutionary path for everyone.

New systems being designed today must take into account that there will be a need to coexist with current legacy systems and as yet undreamed of systems in an undefined future environment. Change is inevitable, and the only way to handle the change that the future brings is to accept it now and be prepared by pushing for interoperability in the present.

The customer base needs reassuring that data systems will work together, that data sets will remain accessible. Ultimately, the data sets belong to the customer, and therefore information that is locked into proprietary or other closed file formats or standards is unhelpful, and can hinder innovation that might otherwise provide benefits.

Historical techniques for securing a customer's loyalty are no longer appropriate in today's ever changing world. We've been witness to the fastest period of technological growth in mankind's history. The momentous cost associated with continually replacing test equipment becomes impossible to maintain when industry standards change every two or three years. Instead, as suppliers we can offer our customers the most value by giving them access to their own data through open interfaces, seeking genuine interoperability between systems, and innovating without fear that the next change in standards will render current product lines obsolete. ∎

CONTACT

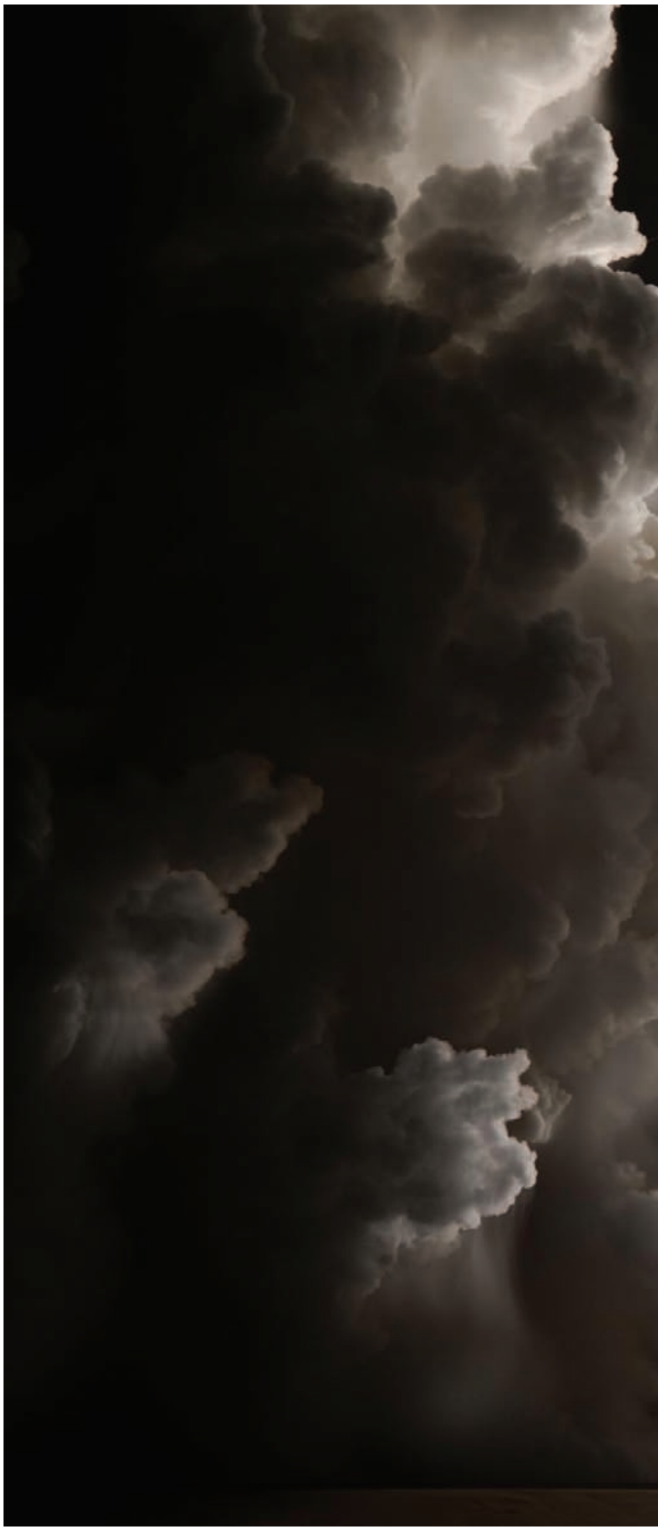
Dr Andrew Law & Dr Jim Hone are from HGL Dynamics Ltd, UK. Rob Sparkman, HGL Dynamics Inc, USA, also contributed.

www.hgl-dynamics.com

Tel: +44 1483 415177

Shake and shock

DESIGN AND DEVELOPMENT TIMEFRAMES OF MODERN SPACE PROGRAMS DEMAND 'RIGHT-FIRST-TIME' ENGINEERING. HIGH-QUALITY, GOAL-FOCUSED, TIME- AND COST-EFFICIENT VIBRATION TESTING IS CRITICAL TO MEETING PROGRAM MILESTONES



"The concept of vibration testing as we know it today is relatively new"

JULIAN SIMPSON

BY JULIAN SIMPSON

Picture, if you will, a multimillion euro altar to the triumph of function over form, precisely oriented and silently gliding in orbit about Earth in a smooth, graceful state of freefall. Satellites appear serene and fragile in their often ungainly forms, designed for a life in orbit, untroubled by the earth-bound stresses of gravity and vibration. But they are not. That same ungainly mass of technology, solar arrays not yet extended, must endure being stowed as the payload or part of the payload of a launch vehicle. The satellite must endure the noise and subsequent vibration of the ~145dB interaction between the rocket engines and launch-pad environment, the jarring transonic climb phase, pyroshock as stages separate, turbulent boundary layer excitation… the list goes on. These forces can induce fatigue in resilient metal structures, not to mention the sensitive electrical components of satellites.

The space industry probably has the most demanding requirements of vibration testing anywhere in the world. Given the huge stresses involved during launch, and the fact that you cannot easily repair a damaged satellite once it has been deployed, it is best that the system has been thoroughly tested before the violent ride into orbit.

Shaking and shocking

Vibration testing, in brief, is shaking or shocking of a component or assembly to model real-world conditions in order to see how the item will stand up to them. Conducting these tests in the field or the laboratory involves the use of data analyzers, climatic chambers, controllers, instruments and vibration exciters.

Even though the development of vibration testing techniques quite naturally has been closely connected to aerospace and space, it is worth mentioning that vibration testing, often supplemented by shock and bump testing, is today also used in many other fields. Typical examples are the field of packaging (for example, for shipping flat-screen TVs that should arrive in your home flat and not buckled) and the automobile and agricultural machine industries.

The concept of vibration testing as we know it today is relatively new, intensively developed and continuously refined since its origin during World War II. The impetus for its development was the desire to test parts and equipment for use in airplanes before a first flight.

Even then, structural and mechanical failures due to vibrations were not the only problems. The use of complicated electronic and electromechanical equipment made control systems and communication instrumentation sensitive to the vibrations encountered during mobile operation. Leveraging the experience gained from aircraft work, the aerospace industry has taken onboard

vibration testing as one of the main parameters of overall environmental testing. Environmental testing of satellites tries to ensure that the odds of Murphy's Law coming into play are greatly reduced. Vibration testing is concerned mainly with what is happening around the satellite during launch – one could say under the influence of Earth's gravity. When in space, the effects of vacuum and extreme temperatures are in focus. For these tests, satellites are put into vacuum chambers cooled down to temperatures below -100°C, or exposed to artificial sunlight at, typically, 1.4kW/m² – the intensity normally experienced in orbit.

The four side boosters (Stage 1) and the central structure (Stage 2) ignite at the same time, just before lift-off. About two minutes after launch, at an altitude of around 50km, the four side boosters run out of fuel and are ejected while the second stage continues to burn.

Test regimes

The seriousness of malfunctions due to vibrations is, of course, greatest in manned vehicles where human life is at stake. But protecting the multimillion euro investment made in satellites is also high on the seriousness scale. Therefore vibration testing is a prized tool for establishing the make-or-break robustness of components, subsystems and ultimately fully assembled craft. Depending on the stage of a project, different testing regimes are adopted.

Design qualification tests are usually carried out on the structural model during the early development phase, in order to demonstrate that the design enables the equipment to withstand the extreme vibration level it will see during launch, plus a qualification margin. The tests also allow verification of the spacecraft mathematical model by measuring motion at 'resonant frequencies', at which elements of the spacecraft

"Elements of the spacecraft structure are prone to 'self-vibrate' once vibration is initiated"

Space Shuttle Discovery 17 seconds after launch

structure are prone to 'self-vibrate' once vibration is initiated.

Acceptance tests are carried out on the flight model in order to verify workmanship and ensure that the equipment does indeed operate satisfactorily in its final configuration, and will not degrade when subjected to the vibrations encountered during launch.

Shakers, exciters and systems

Shakers, or vibration exciters, come in a variety of sizes and operating configurations. The shaker might be small with a permanent magnet for the field, or large using an electromagnet for the field. Also, as more electrical power is used, more current flows and more wasted heat energy is produced, so small or medium shakers can be cooled using ambient air, while larger shakers require a water cooling system.

The LDS V900 series of water-cooled shakers has a long-established reputation in aerospace and space industries. Water-cooled shakers are able to deliver higher forces than equivalently powered air-cooled shakers. The water cooling is applied to the field coils and results in quieter operation and a cooler body temperature, minimizing the temperature effects on the equipment under test. This makes water-cooled shakers ideal for applications requiring high forces or large payloads tested for short durations. The absence of air blowing around the shaker and test equipment makes water-cooled shakers particularly appealing in clean-room environments or when testing hazardous materials.

The accelerometer is used to measure the applied vibration levels in gravitational units. The accelerometer can be used in controlling the test by sending feedback to the controller, or it can be used to measure acceleration and act as a monitor on the unit under test.

The controller interfaces with a computer to allow the operator to enter test parameters and observe channel information. The controller will provide a low-voltage drive output to the power amplifier by using a closed-loop control method. The controller constantly monitors

and modulates the output drive signal to meet a programmed specification.

The power amplifier provides the current and voltage to the shaker. The provided current and voltage are proportional to the output from the signal source. For a medium-sized air-cooled shaker the field supply is also integrated within the power amplifier cabinet.

The operator is responsible for correctly attaching the unit under test to the shaker, attaching accelerometers and general preparation of the setup. Finally, the operator programs the controller and observes the vibration test to completion.

Various types

There are three characteristic modes of vibration testing that are usually done in satellite testing. Sine testing involves subjecting the test item to a progressive sweep of frequencies and amplitudes; random testing randomizes this progression; shock testing induces a sudden severe excitation, simulating the shocks felt during stage separations and engine firings.

One form of sine test is a resonance search. This is a low-amplitude sine sweep run from a low frequency to a higher frequency, usually at a constant logarithmic rate to search for any natural resonances within the unit under test. Typically, a transmissibility or transfer function plot is produced to show the ratio of response to the controlled input.

Another form of sine test is an endurance test. This is applied to the unit under test by sweeping up and down over a frequency range for a specified number of sweeps or a test time, typically hours. This test does not simulate a real-life environment but does test for material fatigue.

For a more realistic simulation of a real-life environment, broadband random vibration is used. The random vibration excites a defined band of frequencies. The resonant frequencies of the unit under test are excited regularly and together to cause and show interaction.

For a shock test, a rapid pulse of short duration and high energy is imparted to the unit under test by the shaker system. The damage potential of shock pulses can be readily simulated using a classic shaker setup and have the advantage of being very repeatable.

Quad shaker

In 2008 the European Space Research and Technology Centre (ESTEC) invested in a quad shaker system using LDS V984LS shakers, delivering forces up to a staggering 640kN of sine force (each shaker is capable of delivering a maximum sine force of 160kN/36000 lbf) The four shakers are mounted on a seismic block and connected to a head expander level with the floor. This is used to test satellite solar arrays, large satellite communications antennas and complete satellites, from 400kg up to 10,000kg. These satellites will be launched using a variety of rockets including ARIANE5 and SOYOUZ.

The QUAD vibration system is used for a variety of tests. It can be used for large, light specimens, doing sine and random tests at levels up to 20g. Or it can be used for complete satellites that are submitted to sine sweep test at acceleration levels around 1g and quasistatic tests up to 12g. The new quad system is a vital component in ensuring that ESTEC and ESA maintain their position at the forefront of the space industry.

Environmental testing has long been known to provide a repeatable and controlled way of introducing a satellite to a testing regime that simulates real life, or to stress a satellite in a controlled manner. Vibration and shock can be measured in the real world and then reproduced using electrodynamic shaker systems under laboratory conditions. Testing combinations of temperature, pressure and mechanical stress can make or break a satellite prior to launch. This, of course, increases the cost of development in the short term, but more than pays for itself in the long term as the cost of fixing a problem prior to launch is much preferable to the alternative. ∎

Julian Simpson, Kim Boldt, Trevor Harrison and Jens Broch of Brüel & Kjær, Denmark. *Brüel & Kjær would like to thank Alexandre Popovitch and Gaetan Piret (ESA/ESTEC Test Centre Division) for their contribution*

A Soyuz/ST Fregat rocket consists of three stages, all of which use liquid oxygen and kerosene as fuel. The four side boosters (Stage 1) and the central structure (Stage 2) ignite at the same time, just before lift-off

Below: Space Shuttle Atlantis taking off. The extent of the fumes indicate the violence of the operation

Satellite outgas contamination

LOW OUTGASSING ACCELEROMETERS AND CABLES FOR SPACE VEHICLES

> **"DC accelerometers are well suited to measure rocket sway and structural modes"**

Above: PCB low outgassing accelerometers

BOB METZ

BY BOB METZ

Exposure to the high vacuum of a space environment induces material outgassing in ordinary accelerometers and cables. Any substance subjected to a high vacuum has the potential to release trapped gases. Contaminants from outgassing can condense onto nearby surfaces such as photo-optic devices and obscure them, rendering them useless in their final space application.

During random vibration or shock testing prior to flight, spacecraft payloads are often fitted with accelerometers in hard-to-reach mounting locations. As the space structure is built up around them, it can become impossible to remove the accelerometers after ground test, and they must enter a full-scale thermal vacum chamber or fly with the structure. In some cases, the sensor becomes part of in-flight vibration monitoring to telemeter back initial payload vibration data resulting from actual launch conditions.

Many hermetic accelerometer designs naturally have low outgassing qualities. Cables with rubberized boots or shrink tubing typically do not have low outgassing qualities. For all non-metallic materials outside a hermetic package that may be required for an application in a vacuum environment, PCB verifies that the material has less than or equal to 1% total mass loss (TML) and a collected volatile condensable mass (CVCM) less than or equal to 0.1%. This is verified using NASA documentation or the materials can be sent to an outside laboratory.

Leak testing on hermetic sensors can be performed in two stages, depending on the required level of hermeticity documentation.

In stage one, a gross bubble test is provided on all hermetic accelerometers. The test verifies $<1x10^{-3}$cc/sec flow. This is a quick bubble-out test with a heated fluid. The heated fluid causes any internal gases to bubble out and become visible during the test.

In stage two, a fine helium test uses a helium bomb to pressurize the sensors, then a fine leak detector to verify $<2x10^{-8}$cc/sec flow. The fine leak test is a vacuum test, whereby the helium bomb is pressurized at 300psi for a minimum of 30 minutes, then a mass spectrometer vacuum leak detector verifies $<2x10^{-8}$cc/sec.

Sensors fall into four basic categories: mini-triaxial, miniature high-temperature, shock, and DC (meaning zero hertz response).

Spacecraft structures are often made of thin, lightweight materials and require low-mass accelerometers. Full-scale spacecraft random vibration responses are three-dimensional, so the combination of a triaxial, low-mass accelerometer with low outgassing properties is highly sought after.

PCB Model 356M208 meets this requirement with a low mass of 1g and 100% low outgas materials for construction. It is supplied with a low outgassing cable, Model 034M22.

Separation of the booster stages causes shock events that may be transmitted to the spacecraft payload. Low outgassing accelerometers such as PCB Model 350M72 may be launched with the payload, or used in a vacuum chamber to simulate launch conditions.

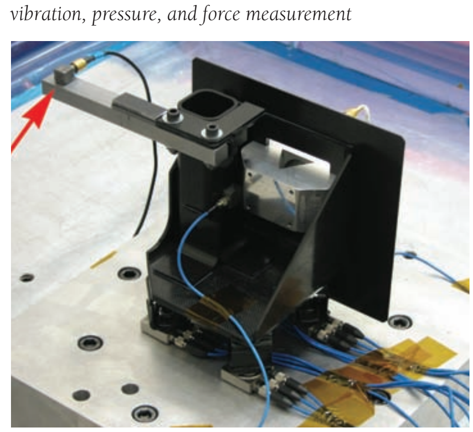
Environmental stress screening is often performed in thermal vacuum chambers to verify operating characteristics at the component level rather than for the full-scale spacecraft. PCB Model 357A07 offers a hermetic, low-mass package with a wide operating temperature range from -100°F to +500°F (-73°C to +260°C), and is supplied with a low outgassing cable.

Large structures, such as robotic arms and umbilical cords for launching satellites from cargo bays, have low-frequency vibration modes. DC accelerometers are well suited to measure rocket sway and structural modes due to wind or launch platform instability conditions. As with higher frequency random vibration, low-frequency structural vibration responses are also three-dimensional. The PCB Series 3713 DC triax, with zero to several hundred hertz, can capture this 3D structural response for analysis or monitoring purposes.

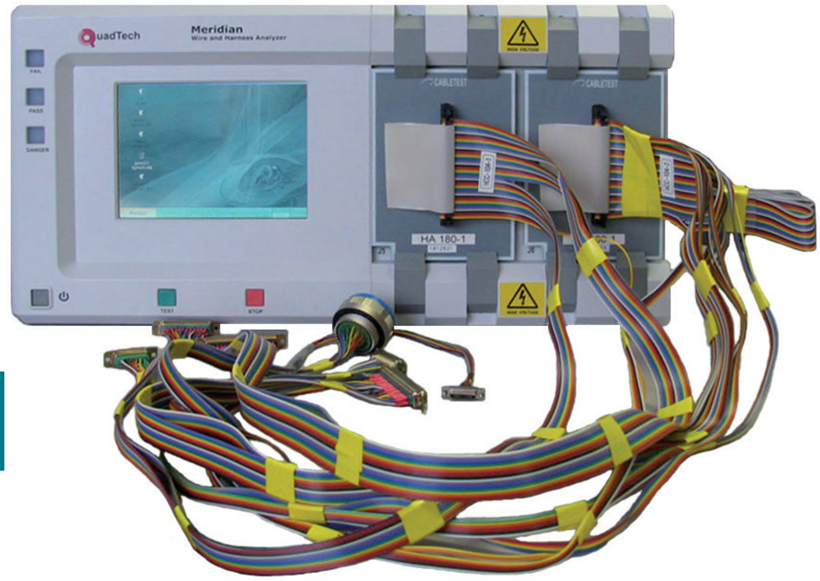
Signal output transmission through ordinary cables offers the greatest source of outgassing contamination. PCB offers multiple cable options and all materials are verified for TML and CVCM. Insulation and strain relief at each connector end are the greatest contributors to outgassing contamination. Some examples of cables use materials such as Viton and Teflon, which are known to have low TML and CVCM values.

In any application involving a vacuum environment, the important things to consider when selecting low outgassing accelerometers and cables are welded hermetic housings, polymers and epoxies that have are verified for TML and CVCM, and finally, the availability of leak testing services for low outgas verification. ∎

Bob Metz is a product manager for the Aerospace & Defense Division of PCB Piezotronics focusing on vibration, pressure, and force measurement



PCB Model 356M208 (arrow) used during vibration testing of bracket assembly at the Utah State University Space Dynamics Lab



Getting connected

PUTTING THE PIECES TOGETHER FOR AEROSPACE CONNECTOR TESTING

> "The seals prevent water and other fluids from entering the connector. A seal is placed on each end of the connector"

YE RONG

SHARI RICHARDSON

BY YE RONG & SHARI RICHARDSON

There are 217km of cabling in a 747 airplane. On the ends of these cables are connectors. High performance is a requirement to meet the harsh conditions of space. Space is unforgiving; and thousands of good decisions can be undone by a single engineering flaw or workmanship error, and these flaws and errors can result in catastrophe. This article will discuss various electrical test requirements for connectors used in aerospace.

The connector

A typical aerospace connector is comprised of five basic components: shell, pins or socket, socket retainer, seals, and accessories. The shell consists of holes and openings to house pins and wires, and it is designed to hold everything in place by locking in pins and holding seals. The shell of a connector acts as the first line of defense against environmental hazards. It protects the internal components and uncovered electrical wires from external environmental hazards.

The pin or socket is the point in which electricity is conducted through the connector. Pins and sockets connect to one another. They fit snuggly together to ensure connections. However, they are loose enough to make disconnecting them easy.

The socket retainer functions as it is named retains the socket and pins from loosening. The retainer, attached to the connector from the front end, presses up against the plastic latches to hold the pins and sockets in place.

The seals prevent water and other fluids from entering the connector. A seal is placed on each end of the connector. Wires enter the connector through the seal using pressure to block water and moisture. The accessories include backshells, strain reliefs, and dust caps. Backshells protect connectors and cables from the many forms of destructive treatment mother nature has to offer.

Connectors can be divided into classes, series and receptacle styles. When specifying a connector, the intended use needs to be specified. The Class of a connector describes the contact type and how the connector is

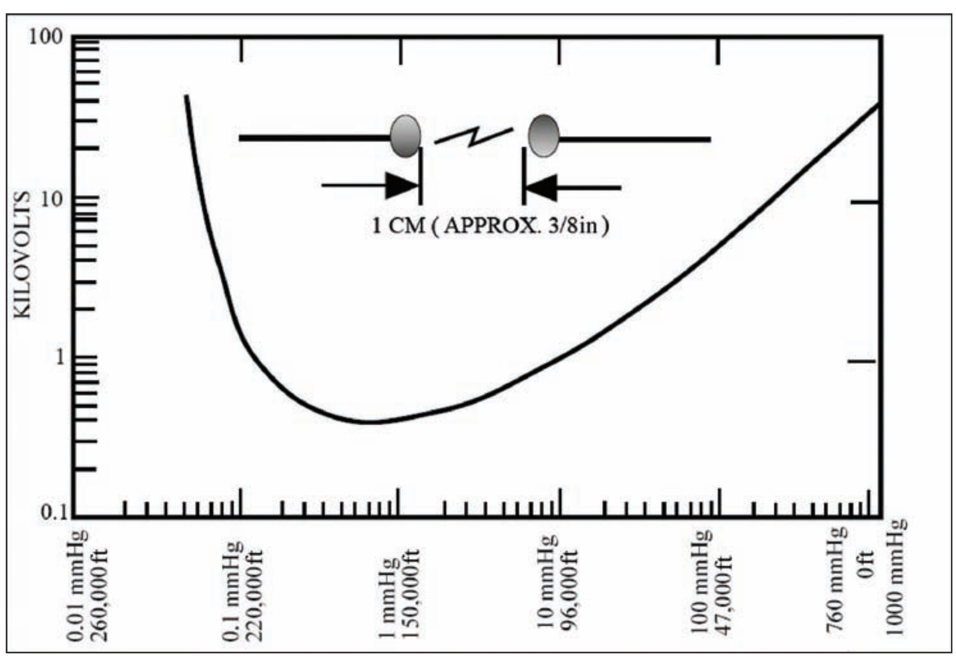


Table 1: Contact type by Class of a connector

Class	Description
Class A	Solid shell solder contact
Class B	Split shell solder contact
Class C	Solder contact connector Used for pressurized equipment
Class D	Crimp & solder contact Used for high impact shock conditions
Class DJ	Crimp contact with backshell connector assembly Used for high impact shock conditions
Class E	Solder contact Environmental resistant
Class F	Solder contact with clamp Environmental resistant
Class H	Hermetic solder contact
Class K	Crimp and solder firewall connector
Class L	Fluid resistant crimp contact
Class P	Potted solder contact Environmental resistant
Class R	Crimp and solder contact with grommet seal without clamp
Class U	Crimp contact Fluid resistant
Class W	Crimp contact General purpose

Table 2 MIL-STD-1344 Electrical Tests

Class	Electrical Test
3001.1	Dielectric withstand voltage
3002.1	Low signal level contact resistance
3003.1	Insulation resistance
3004.1	Contact resistance
3005	Standing Wave Ratio
3006	Magnetic permeability
30007	Shell to shell conductivity

intended for use. Table 1 outlines the contact type and use for the various classes as described in MIL-STD-1344.

Series

In addition to classes there are four 'series' of connectors. The series are as follows: Series I – Solder contact; Series II – front release, crimp contact; Series III – rear release, crimp contact; Series IV – connector accessory. Receptacle styles of a connector also include: flange, jam nut, cable connecting and solder mounting.

Class, series and receptacle style determine the classification of a connector. Connectors also have a service rating. The service rating is the maximum voltage or current a connector is designed to carry continuously. The service rating is determined by the amount of creepage or insulation between the contacts. Each service rating will have its own specifications for testing.

The components of a connector

An ideal connector would have a low contact resistance and high insulation value. For aerospace applications it is imperative for the connector to be resistant to vibration, water, oil, and pressure. Most connectors intended for aerospace applications are tested in accordance to one of two core military standards; MIL-STD-1344 and MIL-STD 202.

MIL-STD-1344 specifies the standard test method for electrical tests of connectors. There are three classes of tests: 1001-1999 outline environmental tests, 2001-2999 mechanical tests and 3001-3999 electrical tests. The electrical tests consist of 11 tests as outlined below.

The tests

Dielectric withstand voltage/high potential voltage breakdown, or more commonly known as a Hipot test, stresses the insulation of the connector beyond what it may encounter in normal use. It is used to ensure the connector and contacts can operate safely at the rated voltage. The dielectric withstand test applies a voltage which is 75% of the minimum breakdown voltage of the connector. The voltage is applied to the contacts that are spaced the closest together and between the connector shell and the contact closest to the shell. The voltage is applied at a rate of 500V/sec and held for 60 seconds (five seconds for production). Once reached potential voltage, leakage shall not exceed 5mA.

The dielectric withstand voltages are governed by the service rating, the altitude, and in some cases, the connection type (mated or unmated). Each connector has a service rating based on the amount of creepage and air spacing between contacts. The operating voltage of the connector with the specific contact arrangement is associated with a service rating. Combined with altitude and connector type the dielectric withstand voltage can be determined.

Why does altitude govern dielectric test voltage? Electrical breakdown in air is caused by electrons being accelerated in a sufficiently strong field. At higher pressures the breakdown characteristics of a gap are a function of the product of the gas pressure and the gap length or V=f(pd), where p is the pressure and d is the gap distance. This theory is known as Paschen's curve (Figure 2).

As pressure is reduced, the breakdown voltage curve reaches a minimum and then as pressure lowers further the voltage rises again.

Breakdown voltage in a gas can be seen in the equation:

$$V = \frac{a(pd)}{\mathrm{In}(pd) + b}$$

V is the breakdown voltage in volts; p is the pressure in atmospheres, and d is the gap distance in meters.

The constants a and b depend upon the composition of the gas. For air at standard atmospheric pressure, a = 43.66 and b = 12.8. Air pressure above sea level can be calculated as p = 101325 (1 - 2.25577 10-5 h)5.25588 where p = air pressure (Pa), h = altitude above sea level (m). For small gaps in air, the breakdown voltage is almost a linear function of the gap length: V = 30pd + 1.35kV, where d is the gap in centimeters and p is in atmospheres.

At sea level, 30,000VDC is required to create an arc across a one centimeter gap. At 47,000 feet, the voltage drops to 1,200VDC to create an arc across the same distance. At 150,000ft, 300VDC will arc across the 1cm gap. Aircraft electronic systems require high voltage connectors to function at altitudes up to 70,000ft. Missile-borne systems increase the requirements to 150,000ft. Table 3 shows the decrease in test voltages for higher altitudes per MIL-STD-1344 for some of the most common service ratings.

Table 3: Dielectric Withstand Voltage per MIL-STD-1344

Altitude Feet	Service Rating I		Service Rating II		Service Rating M		Service Rating N	
	Mated	Unmated	Mated	Unmated	Mated	Unmated	Mated	Unmated
Sea Level	1800	1800	2300	2300	1300	1300	1000	1000
50,000	1000	600	1000	800	800	550	600	400
70,000	1000	400	1000	500	800	350	600	260
100,000	1000	200	1000	200	800	200	600	200

> **"Magnetic permeability is the ability of a material to support the formation of a magnetic field within itself"**

The contact arrangements for MIL-C-5015 are specified in MIL-STD 1651. Based on the arrangement and spacing the service rating is defined. Table 4 lists the dielectric withstand voltage and minimum spacing per MIL-STD 1651. It can be seen as the spacing increases, the test voltage increases.

Since there are no test stations flying around at various altitudes, connector manufactures perform the dielectric withstand tests under the corresponding pressure. Table 5 shows the corresponding pressure to simulate common altitudes used in testing connectors.

The low signal-level contact resistance test, also known as a dry circuit test, is intended to measure the resistance of the contact in a way that voltage and current will not change the physical and electrical condition of the contact junction. This test is performed with an open circuit voltage of 20mV or less and a short circuit current of 100mA or less. Details can be found in MIL-STD-1344 Class 3001.1

An insulation resistance measurement is similar to a DC hipot test, except that it measures the total resistance between any two points separated by electrical insulation rather than the leakage current between these points. Insulation resistance test is performed at 500V and the minimum value of insulation measured shall be greater than the value specified in the requirements of the samples being tested. The measurement is performed between the contacts spaced close together and between the connector shell and contacts closest to the shell.Contact resistance is a key metric in the stability of a connector over time. Contact resistance is measured by mating a pair of contacts, such as a socket and a pin, and recording the millivolt drop across contacts while they are carrying specified current. Table 6 shows specifications for various contact size.

Standing wave ratio (SWR) is measured in a transmission line scenario that involves a source and a load. SWR compares the maximum amount of voltage that can be delivered by the radio to the minimum voltage that actually leaves the transmission line.

Magnetic permeability is the ability of a material to support the formation of a magnetic field within itself. The relative permeability of a connector accessory shall be less than 2.0 for aluminum and 5.0 for stainless steel. The test uses a 2.0 pellet and a permeability indicator to perform the measurement.

Shell-to-shell conductivity is used to determine the ability of the mated connector to carry current. One ampere with a maximum voltage of 1.5V DC is applied across the connector and the milivolt drop is measured at various points which are defined in the connector specification.

Mil-STD-1344 is the core standard for most aerospace connector electrical tests. However, there are many deviations from this standard. Defining the connector requirements and the application in which it will be used will help define the specifics of each test outlined here. There are many pieces of equipment on the market to help meet these specifications. It is probable that the equipment used in qualification will not be the same equipment as in manufacturing, as the qualification tests are more stringent. ∎

Table 4: Dielectric withstand voltages and minimum contact spacing per MIL-STD-1651

Service Rating	Test Voltage (volts-rms) Sea level	70,000ft	Air Spacing (inch)
Instrument	1000	260	---
A	2000	360	1/16
D	2800	400	1/8
E	3500	440	3/16
B	4500	480	1/4
C	7000	560	5/16

Table 6 Contact Resistance specifications per MIL-STD-1344 method 3004

Contact Size	Test current (amperes)	Maximum Voltage Drop (mV)	
		Initial	After Corrosion or Temperature Durability
12	17	85	100
16	10	85	100
20	5	60	75
220	3	85	95

Table 5 Altitude vs Atmospheric Pressure

Altitude Above Sea level		Absolute Atmospheric Pressure		
Feet	Meter	Psia	Kg/cm^2	kPA
Sea level	Sea level	14.696	1.0333	101.33
50,000	15,255	1.69	0.119	11.65
70,000	21,357	0.65	0.046	4.48
100,000	30,510	0.16	0.011	1.10

CONTACT

Ye Rong, applications engineer, QuadTech, Shari Richardson, director of engineering, QuadTech
www.quadtech.com


The new global leader in Data Acquisition …
… with an incomparable range of DAQ solutions
for the most demanding test applications
Sensors
Software
DAQ Systems
ULTRA HIGH SPEED
MOBILE + RUGGED
UNIVERSAL + COMPACT
SCALABLE + VERSATILE
EFFICIENT + COST-SAVING
DAQ instrumentation and software …
____ For every budget
____ For static and dynamic measurements
____ With any number of channels
____ In laboratory or field
____ From industrial through maximum precision.
Turnkey software solutions for data acquisition, visualisation and analysis.
Perception
catman®AP
nCode GlyphXE™
www.daq-systems.com
measure and predict with confidence
HBM
HBM GmbH · Im Tiefen See 45 · 64293 Darmstadt · Germany · Tel. +49 6151 8030 · Email: info@hbm.com

Speeding up laser inspection

A LOOK AT LASER SHEAROGRAPHY INSPECTION OF COMPOSITE HELICOPTER BLADES, FOCUSING ON THE BELL 429

"This system is going to enable the company to inspect 429 blades at a rate 400% faster than the current process"

JOHN W. NEWMAN

BY JOHN W. NEWMAN

In the highly competitive environment of today's aerospace industry, high-speed non-destructive inspection (NDI) technology is critical, and shearography non-destructive testing (NDT) is providing a better and faster means to inspect new aircraft both during manufacture and in the field. The drive to reduce manufacturing costs and maximize aircraft fuel economy, performance and range has turned the attention of engineers from riveted and bonded metal structures to composite laminates and sandwich panels with honeycomb or foam cores.

The traditional methods for NDT, such as ultrasonic (UT) c-scan and tap-testing may not provide the best defect detection capability for these new materials and geometries; they are also slow, with a typical throughput of just 10ft^2/hr (1.1m^2/hr). Furthermore, UT c-scan generally uses water jets as a couplant for the ultrasonic signal. Honeycomb panels and blades can absorb water that requires drying. The complete inspection cycle can take many hours or days to complete. Today's lean manufacturing demands high-throughput inspection as well as a means for near real-time process control to ensure product quality and reliability at the lowest possible cost. In many aerospace programs today, laser shearography is providing a large part of the solution.

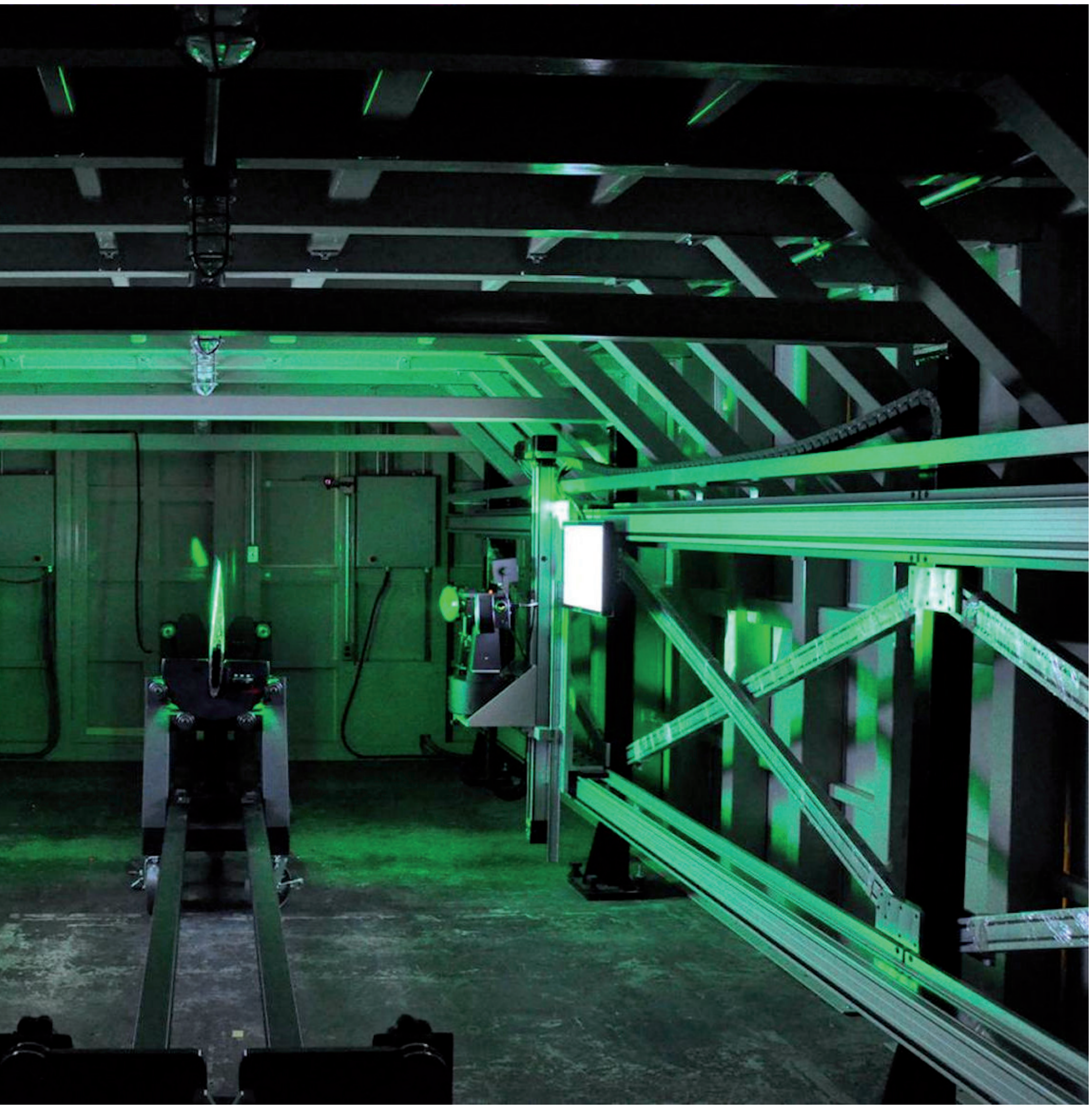
Shearography is finding its way in the manufacture of Bell Helicopter's newest designs for advanced main rotor blades. At the company's new rotor manufacture facility, the newest addition to the inspection toolbox is a dual robotic scan gantry, vacuum/thermal system with a 32ft chamber. "This advanced system is going to enable the company to inspect (Bell) 429 blades at a rate 400% faster than the current process," explains Jeffrey Nissen, Bell engineer responsible for the development and qualification of shearographic systems.

The electronic laser shearography imaging interferometer was pioneered in the early 1980s by three researchers: Dr John Butters at Loughborough University in the UK, Dr S. Nakadate in Japan and Dr Mike Hung at Oakland University in the USA. The author's team at Laser Technology Inc led the commercial development of the shearography camera as a tool for NDT. The world's first production electronic shearography NDT system was delivered to Northrop Grumman in 1987 for the manufacturing of the USAF B2 Stealth Bomber, the first aircraft to incorporate shearography in the manufacturing of highly complex composite structures. Today shearography is widely used in the F-22 and the F-35 aerospace programs, as well as many civil aircraft. In the last 20 years, more than 1,200 shearography systems have been integrated into the manufacturing process for aircraft composites, tires and high-reliability aerospace electronics.

Inside the shearography test chamber for Bell Helicopter main rotor blades the dual 32ft gantry scanners provide fast, highly repeatable scan coverage of blades with two robotic digital shearography cameras

NDT efficiency

As with all NDT methods, the strengths and weaknesses of the inspection technology must be completely understood, and applications qualified through a probability of detection (PoD) verification with written procedures and rigorous training for operators and engineers. Once qualified, however, shearography systems can operate with extraordinary efficiency, reaching throughputs from 25-1,200ft^2/hour, which is 2.5 to 120 times the typical 10ft^2/hour inspection rate for ultrasonic c-scan.



In the development of the advanced designs of Bell's newest product offering – the Bell 429 light twin helicopter – Bell engineers looked at conventional ultrasonics, bond test, flash thermography. After the evaluation process they selected a vacuum/thermal shearography chamber system to fulfill the company's manufacturing requirements for the main rotor blades. Working with LTI engineers, the Bell engineers developed automated fixtures for scanning blades, leading to demonstrated throughput increases of 400%. Furthermore, while the move to shearography is justified by the unique nature of the 429 composite main rotor blades, it is broadly applicable to most other blade types and materials too.

Unlike UT c-scan, which uses a single transducer that requires a raster scan over the part to build up an image, shearography is a whole-field, real-time imaging technique that reveals out-of-plane deformation derivatives in response to applied stress. With a slight pressure reduction or a small temperature change, voids, delaminations, disbonds and foreign material (FOD) cause submicroscopic surface bumps due either to tiny amounts of entrapped air or changes in the thermal expansion properties around flaws. Today's digital shearography cameras can image small deformations due to defects as small as 2-3 nanometers in real time. Large parts, such as composite helicopter rotor blades, are scanned, with dozens of shearograms made in seconds.

Inspection capabilities

Vacuum shearography is highly effective for imaging disbonds, delaminations, core damage and core splice-joint separations; it also offers a strong inspection capability on foam-cored materials that usually have very low thermal and acoustic conductivity precluding the use of thermography and ultrasonics. Other shearography NDT techniques that are frequently used include thermal pulse shearography for non-visible impact damage and pressure shearography for damage to composite-wrapped pressure vessels. Vibration shearography using audible acoustic energy has been highly developed over the last several years to inspect the foam on the external tank of NASA's Space Shuttle.

Shearography helicopter blade Inspection System control console. The Closed Circuit IR Video cameras display gantry motion inside the test chamber, even with the lights turned off

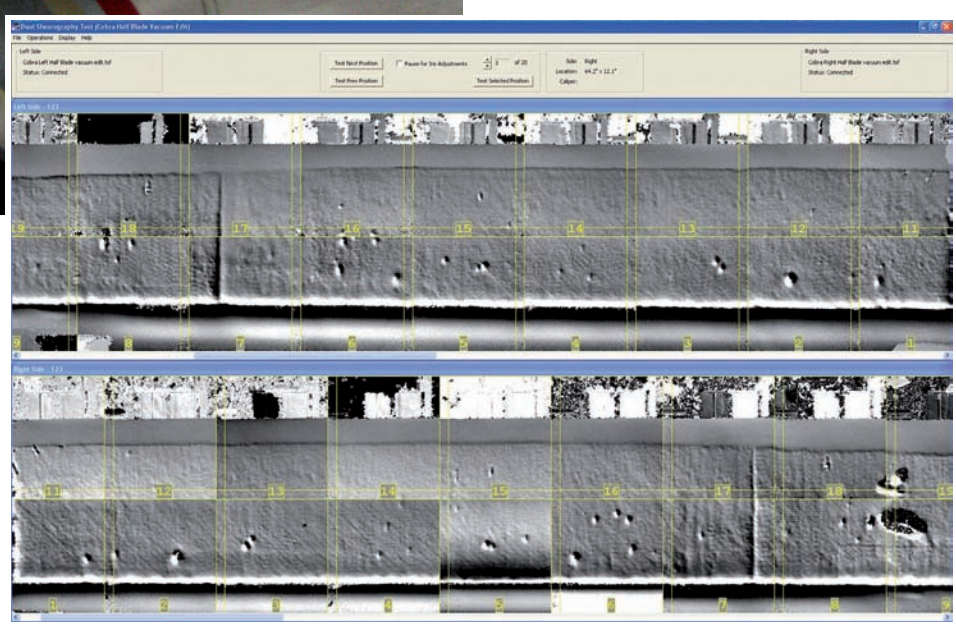
Shearography provides inspection results in minutes, without any part contamination or wetting of the test part. System features such as teach/learn part-scan programming; automatic image stitching, creating a single image of the entire part; image analysis and defect measurement tools; and automated operation are comparable to c-scan systems. In addition, shearography cameras do not require part contour following because the part imaging is effective even as steep angles.

For helicopter blades, the dual camera scan gantry configuration allows simultaneous shearography inspection of the upper and lower sides of the blades. Leading-edge erosion strips can also be inspected. To demonstrate this capability, a main rotor blade with honeycomb core, shown in Figure 3, was inspected on both sides in just nine minutes. Voids, impact damage and entrapped water are detected. Interpretation of the shearography test data may be accomplished during the shearography testing in real time at the system control console, Figure 4, or off-line.

In conclusion, laser shearography is a mature and highly cost-effective NDT technology for many aerospace applications, particularly for composite structures. Shearography can provide large productivity and quality gains over traditional NDT methods such as UT c-scan, thermography or tap-testing. Automated shearographic systems provide very rapid inspection, such as the 400% increase in throughput for the Bell 429 main rotor blades. Results are provided as digital-image data with defect location, size and area. Recent publication of industry consensus documents such as 'ASTM E 2581-07 Standard Practice for Shearography NDT of Composites in Aerospace Applications', inclusion in 'ASNT SNT-TC-1A' and 'NAS 410 Rev 3', have brought recognition of the technology as a means for aerospace manufacturers to gain a competitive edge. ∎

John Newman is the president and founder of Laser Technology Inc, based in the USA. He is also chairman of the ASNT Laser Methods Committee and the ASTM Shearography NDT

"Shearography can provide large productivity and quality gains over traditional NDT methods"



A display of how shearography results of honeycomb core main rotor blades show, defect size, area and location

CONTACT

Email: JNewman@LaserNDT.com

Putting a tiltrotor in the tunnel

THE PREPARATION AND COLLABORATION BEHIND REMOTELY CONTROLLED TILTROTOR WIND TUNNEL TESTING

NICETRIP powered wind tunnel model

"The calculated blade pressures in the validation case strongly agree with the experimental blade pressures"

BY JOOST HAKKAART

The European rotorcraft industry and its partners are working on various research aspects of ERICA (Enhanced Rotorcraft Innovative Concept Achievement), a hybrid tiltwing/tiltrotor concept. This research is partially funded by the European Commission in the sixth framework program: NICETRIP (Novel Innovative Competitive Effective Tilt Rotor Integrated Project).

ERICA is designed to overcome the operating and performance limitations associated with traditional tiltrotors. The planned 10-ton transport aircraft will have small diameter props to enable running take-offs, outer wing sections that tilt independently of the nacelles to reduce rotor downwash, and a continuous tubular structural connection between the prop rotors.

Recent successful first pilot-in-the-loop simulation studies were conducted by NICETRIP partners to evaluate the introduction of tiltrotors into the European Air Traffic Management system. The NLR Helicopter Pilot Station (HPS), in cooperation with the Sphere Eurocopter Simulator, the HeliFlight University of Liverpool Simulator, and the SICTA control tower simulator, was involved in an integrated scenario to evaluate specific non-interfering tiltrotor ATM concepts and procedures.

To reduce future risks on the critical technologies, like tiltrotor aerodynamic interaction and rotor performance, a complex large-scale (1:5) research model has been developed by NLR for further testing in strategic European wind tunnels.

Computational aerodynamics

To prepare for this wind tunnel testing, aerodynamic simulation of the tiltrotor aircraft has been conducted to mitigate the risk of the test campaign. The simulations help define critical flow configurations.

To consolidate and validate the simulation codes for flight mechanics, aerodynamics, aeroacoustics, and performance, hover to forward flight conversion conditions are simulated with several advanced CFD methods. CFD calculations have been performed by the participating European research institutes: CIRA (Italy), DLR (Germany), NLR (Netherlands), and Onera (France); and were analyzed by AgustaWestland (Italy) and Eurocopter (France).

The CFD method from NLR can combine data from the rotating propeller and the fixed wing by applying the sliding grid approach. In this approach, two grid systems are used – a rotating system about the rotor and a fixed system about the wing – with a non-overlapping interface. Flow states are interpolated on the interface. The computations are compared with the results of previous wind tunnel experiments, which have been executed for wing/nacelle/rotor configurations in flight conditions ranging from hover, through conversion, to cruise mode.

The calculated blade pressures in the validation case strongly agree with the experimental blade pressures, although the wing pressure comparisons are only satisfactory. Deviations between simulated blade pressures and experimental blade pressures are attributed to the inviscid flow model assumption of the simulation and known uncertainties in the experimental results. Through the successful simulation of the tiltrotor/wing configurations during

JOOST HAKKAART

Calculated instantaneous pressure distribution on the ERICA rotor and wing

conversion it has been demonstrated that the sliding grid approach is capable of vortex convection through the interface.

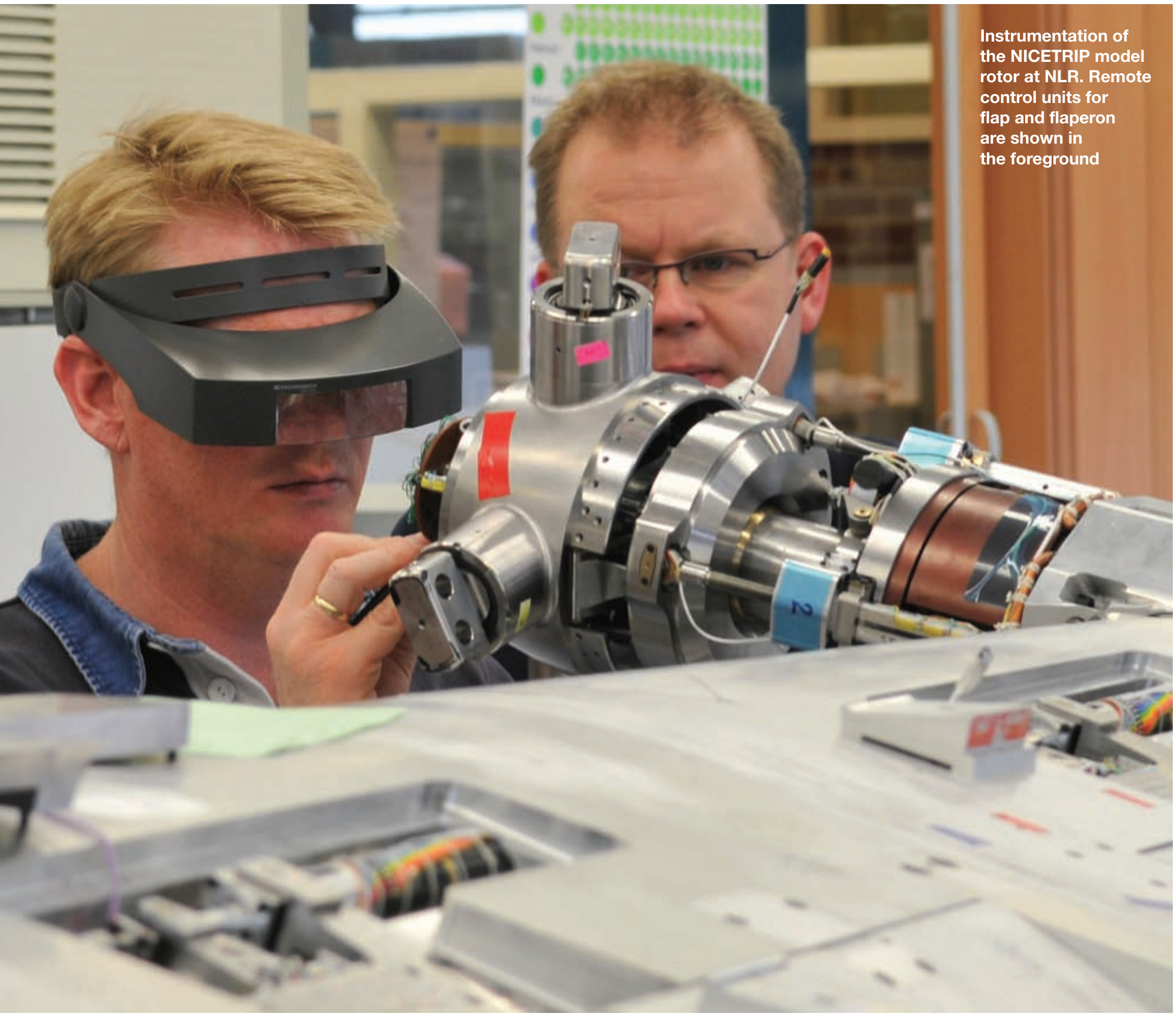
Based on the validated CFD results, further simulations have provided aerodynamic data and insight into the behavior of the aircraft in terms of drag and interference characteristics for the configurations being tested in the wind tunnels. These simulations have been performed by the aforementioned research institutes as well as Italian outfit Polimi. The wind tunnel model combined with the other requirements did not permit the representation of a gimbaled rotor. The model rotor with collective and cyclic settings is stiff in plane. Therefore, models of the flight mechanics are adapted to include the hub configuration of the experimental rotor system and are used to predict the trim parameters for the wind tunnel test conditions.

Wind tunnel model development

NICETRIP has manufactured an NLR-designed full-scale powered wind tunnel to prove the ERICA concept liability with respect to low-speed interaction and high-speed performance so that, in turn, the general architecture, flight control systems and laws, and operational performance can be frozen.

The research model has a central gearbox with two out-going driveshafts that are connected to gearboxes in the relevant nacelles. Two stiff rotors are mounted on these gearboxes via rotor balances (supplied by Onera). The rotors are equipped with swash plates enabling the setting of both collective (with a total range of 80°) and cyclic blade pitch to be controlled remotely. Both the outer wing and nacelle can be tilted independently, which is consistent with the ERICA configuration.

To enable efficient tunnel operation, without the need to stop the wind tunnel for model configuration changes, all control surfaces (two flaps, two flaperons, rudder, and aileron) are remotely controlled by compact units developed at NLR. The hinge moments of these control surfaces are measured separately.



Instrumentation of the NICETRIP model rotor at NLR. Remote control units for flap and flaperon are shown in the foreground

Every RC system consists of a drive unit, a kinematic mechanism, a position sensor, and a control system. NLR applied self-braking RC systems, which can take the full (aerodynamic) load without giving way. The drive unit (motor) is a commercially available electromechanical motor. A kinematic mechanism is required to convert the mechanical output of the motor into the rotational movement of the model part. It is of NLR design and dependent on the model requirements. Position sensors and RC control systems are selected from commercially available products and then modified to meet the demanding requirements.

The integration of a complete RC system into the model is again NLR-designed and it depends on the model's requirements and available space.

After assembly, all of the remote controls were tested to make sure they were working and the end-switches were set to their correct positions. The loads on the T-tail are measured with a dedicated six-component balance mounted in the aft fuselage. Several of the external model contour parts were manufactured by TsAGI (Russia) and were integrated at NLR. The model is also equipped with a large number of static pressure ports (672). Correct port distribution enables users to calculate pressure loads on the outer and inner wing separately. Furthermore, 54 dynamic pressure transducers monitor unsteady airflow.

NICETRIP powered wind tunnel model mounted for pre-testing by DLR

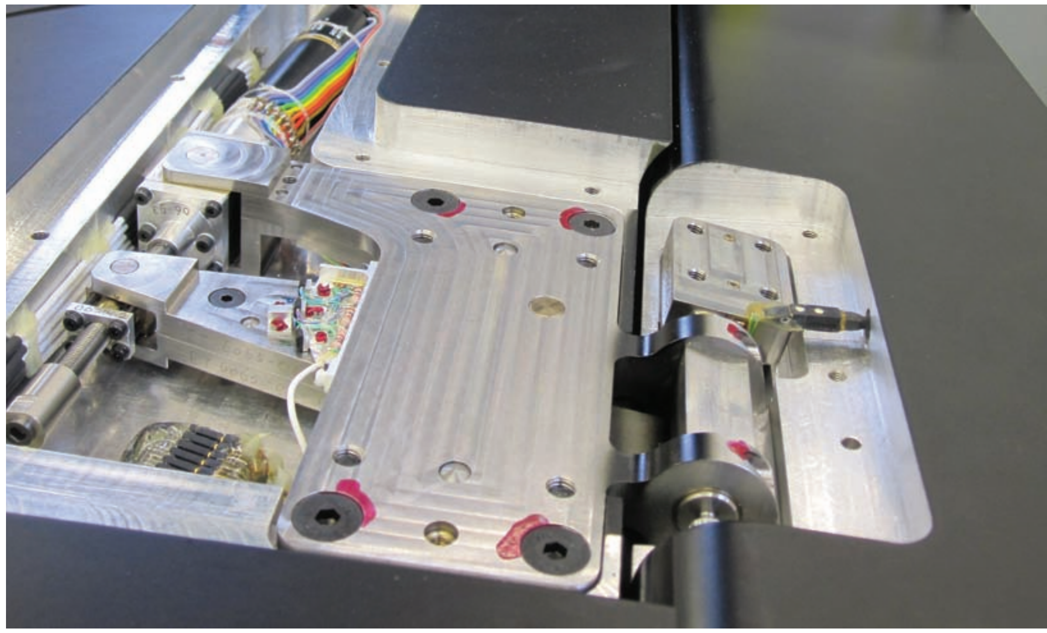
For safety-of-flight monitoring, the rotor blades are fitted with strain gauges to measure blade bend and torsion. Likewise, temperature sensors are used to monitor gearbox operating conditions.

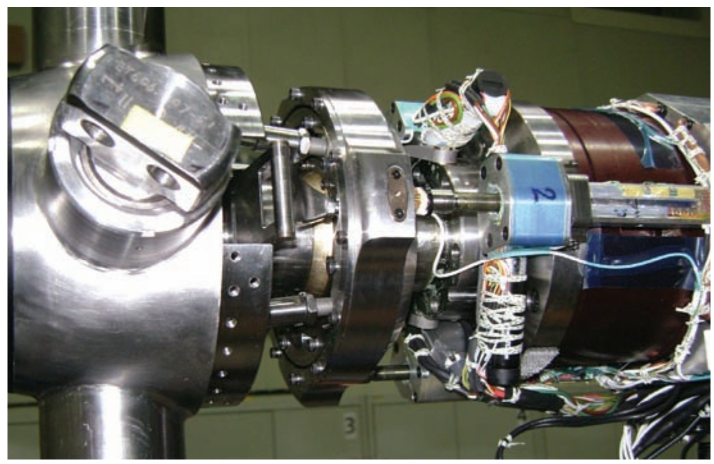
The model is equipped with three compact 48-channel amplifiers (developed by DLR) to supply independent sensors and boost output signals so they can be transmitted to the data acquisition unit.

The complexity of this model in the field of remotely controlled systems, powered rotor simulation, and embedded sensors exceeds any wind tunnel model yet developed.

During the two-and-a-half-year development period, around 50 NLR employees spent more than 20,000 man-hours producing 171 CATIA drawings, 23 wiring diagrams, and installing 2.5km of pressure tubing, 70 pneumatic connectors, 5km of electrical wires, and about 300 electrical connectors.

To limit the number of wires and tubes being fed through the wind-tunnel sting,





Above: Detail of the rudder remote control unit

Right: Remotely controlled rotor head

Left: Function testing and calibration under simulated aerodynamic loads of the elevator remote control with hinge moment balance

onboard acquisition systems combined as many as possible. Furthermore, the integrated EPOS2 remote-control drive units were combined in two CANbuses: three rotor actuators were connected to the pilots' HMI via the first CANbus; and the surface control system linking the 10 remaining actuators with the PC were grouped in the second CANbus.

Having completed the wind tunnel model integration and sensor system wiring, function and calibration tests were performed. During this phase, the proper functioning of the remote controls was validated by applying expected aerodynamic loads.

> **"Two different sting configurations will be used, including mounting the model vertically"**

Wind tunnel test and preparation

NLR having delivered the research model to the project coordinator, AgustaWestland, DLR then performed extensive pre-tests at their rotor test stand in Braunschweig, Germany.

Besides preparing and testing the control software, instrumentation calibrations were validated after they were integrated into the DLR data acquisition system.

Before spinning the rotors up to full speed for the first time, ground vibration tests (GVT) were performed by DLR to assess their structural behavior (Eigen frequencies, mode shapes, etc). During these tests, 107 acceleration sensors were installed to observe the structure at frequencies up to 200Hz, with special focus on nacelle and outer wing movement. Although about 55 modes in the range from 0-200Hz were detected, no un-damped modes were found.

Having completed their preparatory activities at DLR, model installation in one of the DNW large, low-speed wind tunnels (DNW-LLF) will start. In this final preparation phase, the model will be mounted on an internal balance equipped with an airline bridge for powering the air motors and driving the central gearbox. It will also be tested with high thrust, while GVT tests will be repeated on the final sting configuration.

Building so many sensors, equipment, and technologies into one model – as well as putting it through a thorough pre-test phase – results in the smartest and most complex wind tunnel model ever developed.

If the model is accepted by the coordinator of the NICETRIP project, wind tunnel testing will start in 2011. The first tests will be performed in the DNW-LLF (tiltrotor helicopter mode and conversion corridor at low speed). Two different sting configurations will be used, including mounting the model vertically for interference-free hover testing, and studying autorotation and vortex ring state conditions. The aircraft mode phase will be performed in the Onera Modane S1 wind tunnel at speeds up to 0.6 Mach.

The 17 remote control units used for steering the model's rotor heads and control surfaces will limit the need to stop the wind tunnel. Indeed this should only be necessary during inspections and maintenance.

With the need for more efficient tunnel testing on the increase, this remotely controlled model is a major step forward. ∎

Joost Hakkaart is the principal research and development manager at NLR in the Netherlands

A hand with XRF spectrometry

ANALYZING ALLOYS USING A HANDHELD SDD-BASED XRF IN THE AEROSPACE INDUSTRY

"Mobile OES analyzers are awkward and require the use of argon gas"

JOHN I. H. PATTERSON

BY JOHN I. H. PATTERSON

In the aerospace industry, the positive identification of incoming materials and alloys used in the manufacturing process is a critical aspect of building safe aircraft. Aluminum and titanium alloys, along with the nickel-based superalloys used in turbine blades, are primary materials of interest. A materials mix-up can cost millions.

Laboratory x-ray fluorescence (XRF) and optical emission spectrometry (OES) have traditionally been the preferred methods of analyzing light metal alloys (Al, Mg) as well as alloys with significant quantities of light elements such as Ti alloys and Ni alloys (Inco 713 and B-1900, both of which contain about 6% Al). However, testing generally involves cutting off a piece of the material and sending it to the laboratory. Mobile OES analyzers are awkward and require the use of argon gas; furthermore, they produce a 'burn spot' on the sample surface. In contrast, current handheld XRF analyzers provide a completely non-destructive alternative for those engaged in the positive materials identification (PMI) of these alloys.

Several important developments in handheld XRF have occurred over the past decade. They are pushed heavily by the increasing trend toward on-site rather than laboratory analysis. Some understanding of XRF basics is required to set the groundwork for these technological advances.

What is XRF?

In XRF spectrometry, an x-ray source ejects electrons from the inner shells of the sample atoms. When an outer shell electron makes the transition to fill the void left in the inner shell, a second x-ray, characteristic of that atom, is emitted. This process is called fluorescence.

Elements mostly emit x-rays at their own characteristic energy. If the energy is a result of an electron filling the innermost or K-shell, the x-rays are called K-lines; if it is a result of an electron filling the next electron shell (the L-shell), the x-rays are called L-lines; and if the result is from an electron filling the third electron shell (the M-shell), the x-rays are called M-lines. These released x-ray energies identify the elements present in the sample, while the intensities of the x-ray lines, which are proportional to the concentration of the elements, allow quantitative chemical analysis.

Any x-ray instrument must contain a source of x-rays (to excite the sample), a detector, and a readout system. Traditionally, handheld XRF analyzers have used a radioisotope source for the sample excitation, and a detector using a silicon positive-intrinsic-negative (PIN) semiconductor. The readout system consisted of a multichannel analyzer and computer system.

Recent technological advances

The miniature x-ray tube was developed in 2000, although other small x-ray tubes had been produced earlier. Today, handheld x-ray analyzers generally use miniature x-ray tubes for the excitation of the sample atoms, although sometimes radioisotope sources are still used for special applications.

In 2003, Keymaster (now part of the Bruker-Elemental group), in collaboration with NASA scientists and engineers, developed a handheld XRF analyzer with a compact vacuum attachment. This allowed handheld instruments to analyze light elements, down to magnesium, with both precision and accuracy, something that had not been possible before. Of course, the industry quickly responded and Niton (now part of the Thermo-Scientific group) produced a handheld instrument with a helium gas purge.

The latest generation of detectors, called silicon drift detectors (SDD), were developed in the mid- to late-1990s and were used extensively in laboratory-based XRF analyzers. SDD detectors were first applied to handheld XRF analyzers in 2008, providing significantly better resolution than the Si (PIN) detectors, with the ability to count over 200,000 x-ray photons per second. Greater detector resolution is necessary to distinguish between spectral lines of elements in close proximity to one another, such as the aluminum K-line (E = 1.49 keV) and the magnesium K-line (E = 1.25 keV). A greater detector count rate allows more x-ray photons to be counted, improving statistical reliability. Most importantly, the use of SDD detectors meant that light element analyses could be done in air, without the need for portable vacuum or helium gas accessories.

The importance of detector resolution is illustrated by the graph in Figure 1, which shows the x-ray energy spectrum of a nickel-base superalloy, similar to Mar M002, with about 59% Ni, 10% W, 3.2% Ta, and 1.5% Hf. The spectrum was made using a SDD with a resolution of about 140 eV. Note in particular the small peak labeled Hf-La1 in the valley between the two large nickel peaks: this peak is lost in the background noise of the two nickel peaks when using the older SiPIN detector.

Today's handheld analyzers use multiple excitation conditions, also common with laboratory XRF instrumentation; therefore, they can provide superior performance for the analysis of aluminum and titanium alloys, as well as for the nickel-based superalloys. For most applications, this analysis can be done in air without the need for vacuums or helium purges, and directly on the bar stock or forging. Although this is generally sufficient for simple alloy grade identification, good sample preparation is crucial for applications where identification of the lighter elements like Mg and Al is required.

Also noteworthy are the advances in electronics, which have led to the use of a programmable Digital Signal Processor (DSP), and computing, with appropriate displays to present the results of the analysis.

Alloy identification and analysis

Calibration is defined as determining the relationship between a measured value and a known value. Each analyzer must be calibrated to work properly. In the case of XRF, the relationship between the measured x-ray counts per second at the element spectral line of interest and the concentration of that element in the measured certified reference materials (such as NIST standards) must be determined. In this way, it is possible to transform an x-ray measuring machine into an instrument for chemical analysis. The calibration process involves the measurement of many certified reference standards. Measured intensities for each element of interest (Mg, Al, Si, Ti, V, Cr, Mn, Fe, Co, and Ni) are plotted against the certified element concentrations to generate calibration curves. This is often called an empirical calibration. Empirical calibrations have the advantage of being the most accurate, providing traceable results, and allowing fast result computation.

In XRF, a theoretical calibration can be created based on x-ray physics. This approach is called the Fundamental Parameters (FP) approach, and is useful for measuring exotic materials where few or no standard reference materials exist. Some manufacturers of handheld XRF analyzers provide both empirical and FP calibrations.

Analytical data

In practice, Bruker Elemental's S1 TURBO SDD provides analytical data for light metal alloys with two excitation conditions: 40kV for five seconds, and 15 kV for 55 seconds. Both the precision and accuracy of the analysis are explained in the following sections.

Table 1 presents precision data for a 6061 aluminum alloy measured ten times (for 60 seconds each time). The precision (or reproducibility) is the primary figure of merit for any measuring instrument: if the results are not repeatable, further evaluation is meaningless. Precision is characterized by the standard deviation of the repeated measurements. In general, this should be low with respect to the average measured value. The percentage of relative standard deviation (RSD) is a measure of this ratio as defined in the following: RSD = standard deviation/average x 100.

Measure	Mg	Si	Ti	Cr	Mn	Fe	Cu	Zn
1	1.16	0.568	0.0323	0.224	0.124	0.436	0.302	0.0127
2	1.41	0.619	0.0315	0.217	0.112	0.444	0.296	0.0115
3	0.952	0.573	0.0302	0.225	0.137	0.476	0.29	0.0126
4	1.39	0.558	0.0315	0.222	0.133	0.456	0.296	0.0146
5	1.42	0.609	0.0311	0.214	0.152	0.461	0.287	0.0107
6	1.37	0.601	0.0304	0.218	0.0996	0.45	0.298	0.0116
7	1.38	0.587	0.0307	0.221	0.129	0.419	0.298	0.0149
8	1.14	0.548	0.0298	0.219	0.118	0.473	0.29	0.013
9	1.39	0.552	0.0284	0.215	0.144	0.431	0.288	0.0138
10	1.43	0.568	0.0288	0.215	0.132	0.442	0.291	0.0099
11	1.09	0.567	0.0295	0.222	0.12	0.459	0.311	0.0135
Average	1.285	0.577	0.030	0.219	0.127	0.450	0.295	0.013
St. Dev.	0.167	0.024	0.001	0.004	0.015	0.017	0.007	0.002
% R.S.D.	12.995	4.088	3.946	1.732	11.629	3.890	2.404	12.485
Certified	1.1	0.62	0.031	0.21	0.115	0.415	0.26	0.01

Table 1 (Above) Precision Data for Alloy 6061

At the limit of detection, the RSD is, by definition, 33%. At the limit of quantification, where we can begin to make reasonably quantitative measurements, the RSD is by definition 10%. Several factors play roles in the precision of XRF analyzers including: measurement time (the greater the measurement time, the better the precision); concentration (the lower the concentration, the worse the relative precision); excitation conditions (the excitation conditions must be tailored to the analytical task; using a second excitation at 15kV improves the precision for the lower atomic number elements; and, finally, element atomic number (the lower the atomic number, the lower the count rate, which adversely affects precision). To compensate, the lower voltage excitation is extended to 55 seconds to increase the total counts

Accuracy

Accuracy is defined as the correspondence between the measured value and the true value, so it is a measure of the deviation between what is measured and what should have been found. This is often referred to as bias. If the agreement between the two values is good, then an accurate determination has been made.

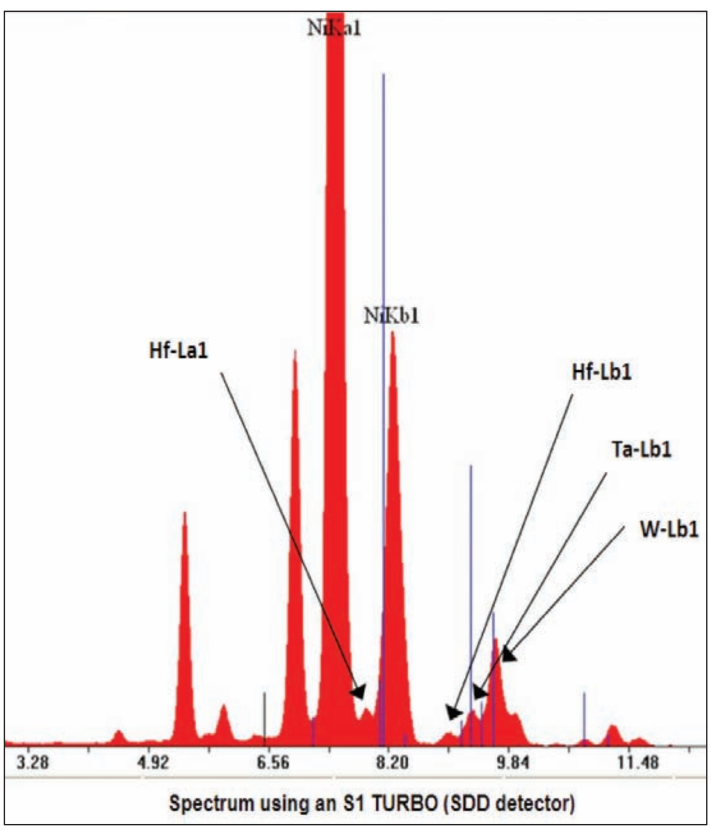
Since certified values of the standard sample are included in Table 1, the table provides a preliminary view of the accuracy of a handheld XRF analyzer. The agreement between average measured values and the certified numbers is quite good.

The best way of assessing the accuracy of an analytical method is by the use of correlation curves: measure a number of certified standards and then plot certified values versus measured values for each element of interest. Such a curve is presented in Figure 2 for magnesium, the lightest element available.

A correlation curve needs three criteria to demonstrate high accuracy: the correlation coefficient (R^2) must be close to 1.0 (preferably greater than 0.95); the slope of the regression line must be near 1.0; and the intercept of the regression line must be near zero. All these criteria are fulfilled in the example of Figure 2.

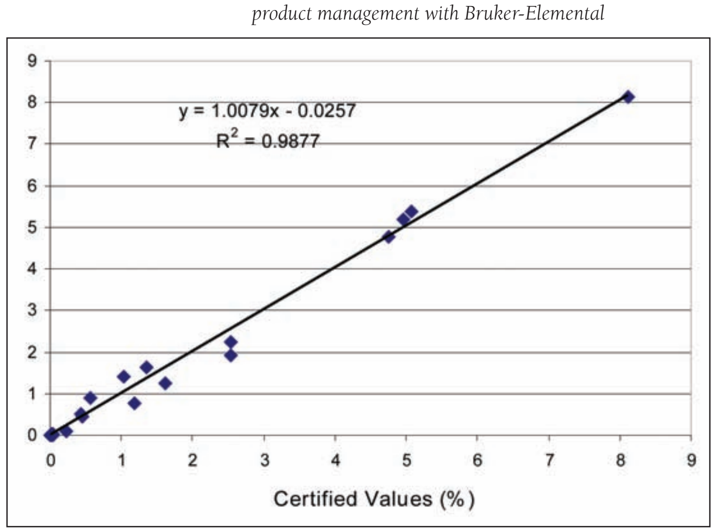
Handheld XRF analyzers with silicon drift detectors (SDD) that use a dual excitation mode in an air atmosphere are clearly suitable for the analysis of all alloys of interest to the aerospace industry. Non-destructive, precise, and accurate, these analyzers are an important tool for the quality control and assurance engineers. ∎

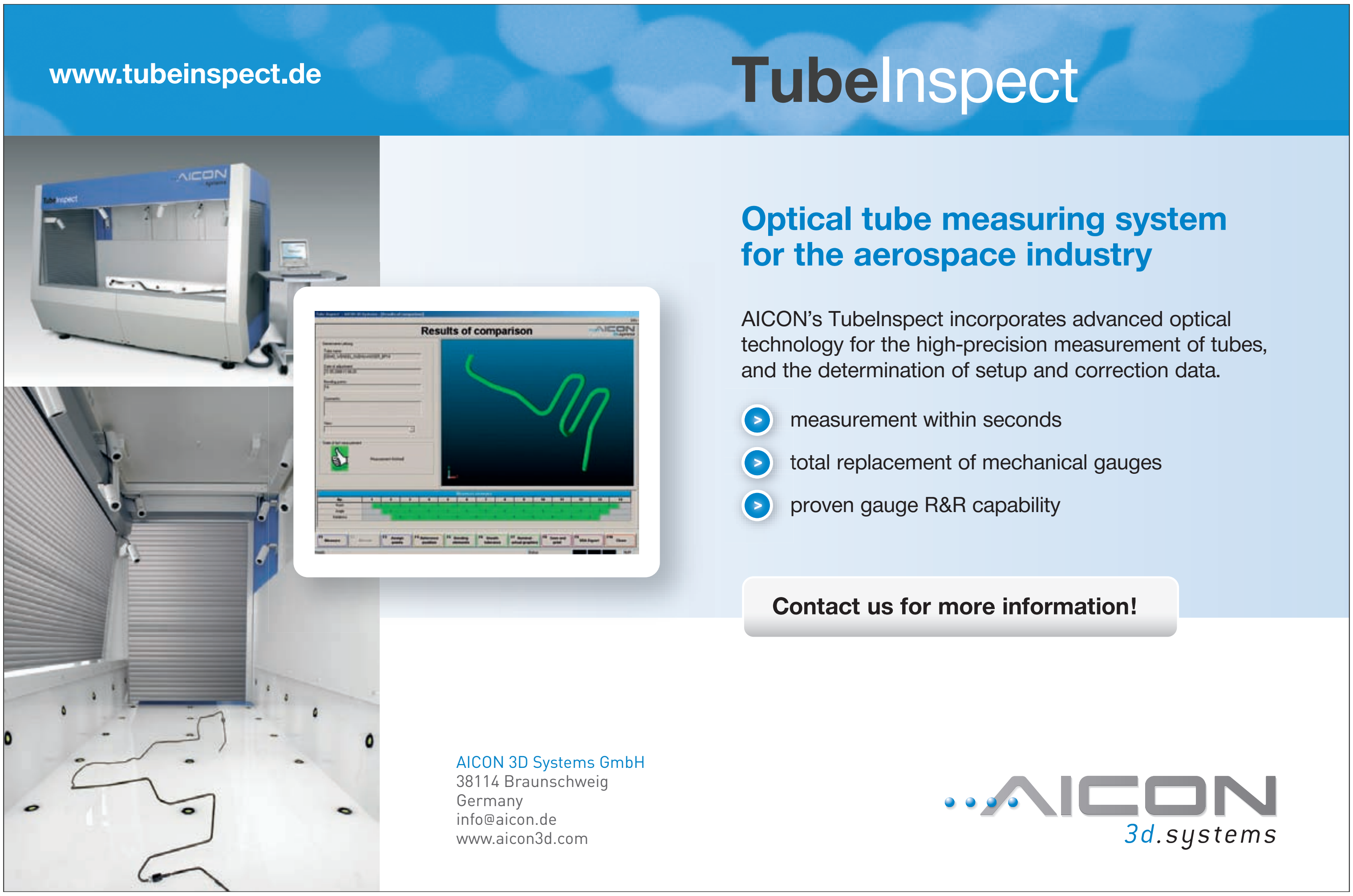
John I. H. Patterson, PhD, director of marketing and product management with Bruker-Elemental

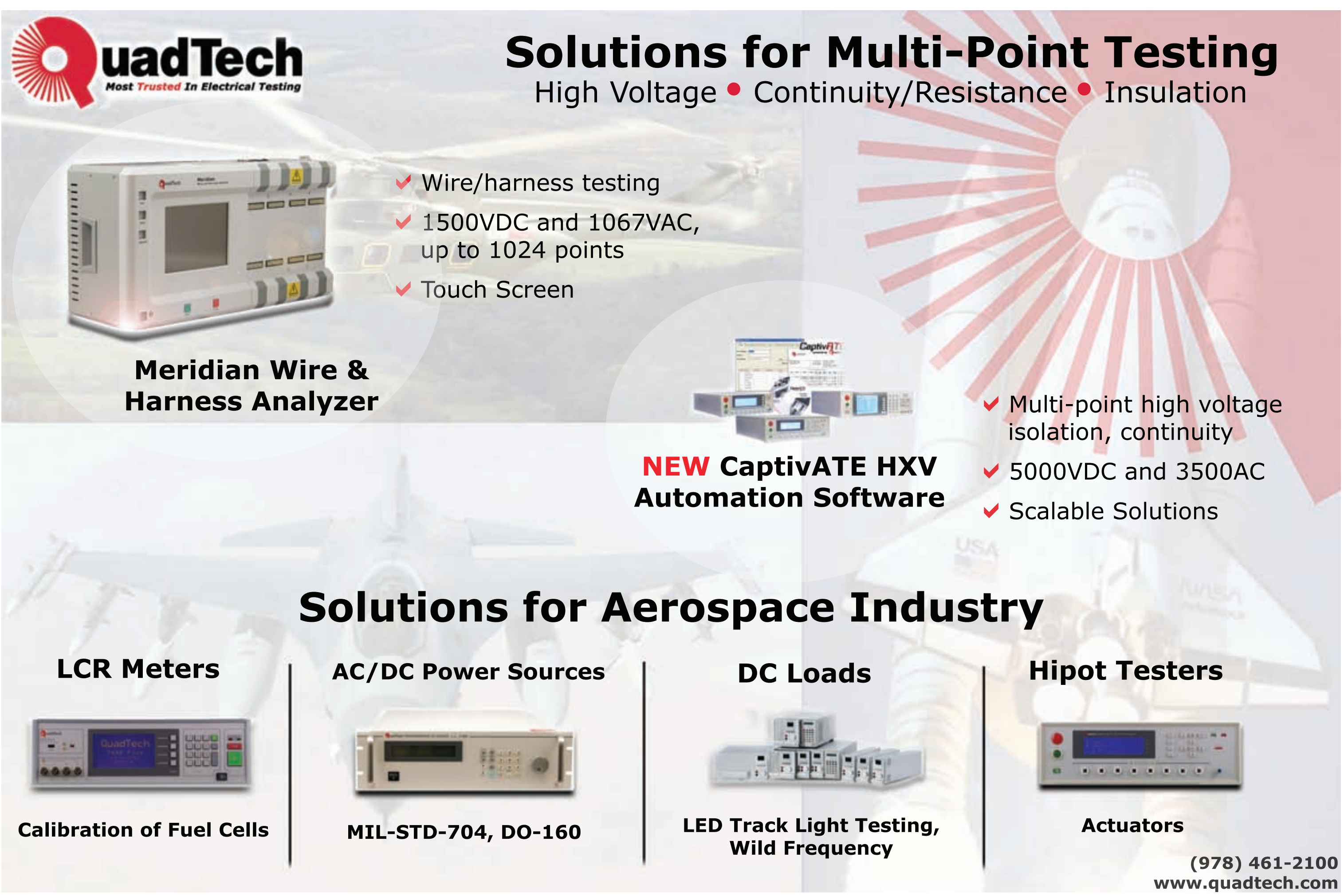


Left: Figure 1, Nickel Alloy Spectrum

Below: Figure 2, Correlation Curve for Magnesium in Aluminum Alloys




www.tubeinspect.de
TubeInspect
Optical tube measuring system
for the aerospace industry
AICON's TubeInspect incorporates advanced optical technology for the high-precision measurement of tubes, and the determination of setup and correction data.
measurement within seconds
total replacement of mechanical gauges
proven gauge R&R capability
Contact us for more information!
Results of comparison
AICON 3D Systems GmbH
38114 Braunschweig
Germany
info@aicon.de
www.aicon3d.com
AICON
3d.systems


QuadTech
Most Trusted In Electrical Testing
Solutions for Multi-Point Testing
High Voltage • Continuity/Resistance • Insulation
Wire/harness testing
1500VDC and 1067VAC, up to 1024 points
Touch Screen
Meridian Wire & Harness Analyzer
NEW CaptivATE HXV Automation Software
Multi-point high voltage isolation, continuity
5000VDC and 3500AC
Scalable Solutions
Solutions for Aerospace Industry
LCR Meters
Calibration of Fuel Cells
AC/DC Power Sources
MIL-STD-704, DO-160
DC Loads
LED Track Light Testing, Wild Frequency
Hipot Testers
Actuators
(978) 461-2100
www.quadtech.com

Simulate all flight conditions

THE FACILITIES RUN BY ARNOLD ENGINEERING DEVELOPMENT CENTER, CAN REPRODUCE JUST ABOUT ANY FLIGHT CONDITION FOR ANY SCENARIO – A WORLD LEADER IN FLIGHT SIMULATION TESTING

> "AEDC offers aerodynamic ground-test capabilities from very low subsonic speeds through to Mach 14"

BY SHAWN JACOBS

Since Arnold Engineering Development Center's (AEDC) inception following World War II, the members of Team AEDC have established a rich heritage of development support to the Department of Defense (DoD), NASA, and commercial aerospace systems. Of the more than 50 test facilities at AEDC, over half provide test capabilities unique to the USA or the world.

Flight systems

The propulsion wind tunnel ground test complex team at AEDC offers aerodynamic ground-test capabilities from very low subsonic speeds through to Mach 14 in various wind tunnels. AEDC operates five active wind tunnels in two primary facilities, the Propulsion Wind Tunnel Facility (PWT) and the Von Kármán Gas Dynamics Facility (VKF). AEDC also manages two wind tunnels at remote operating locations – the Hypervelocity Wind Tunnel 9 in Maryland and the National Full-Scale Aerodynamics Complex (NFAC) in California.

AEDC wind tunnels are used for testing in areas including vehicle aerodynamic performance evaluation and validation, weapons integration, inlet/airframe integration, exhaust jet effects and reaction control systems, code validation, proof-of-concept, large- and full-scale component research and development, system integration, acoustics, thermal protection system evaluation, hypersonic flow physics, space launch vehicles, operational propulsion systems and captive flight.

Propulsion Wind Tunnel 16T provides flight vehicle developers with the aerodynamic, propulsion integration, and weapons integration test capabilities needed for accurate prediction of system performance. Large-scale models can be accommodated in the $16ft^2$ by 40ft-long test section and can be tested at Mach numbers from 0.05-1.60. Pressure in the test section can be varied to simulate unit Reynolds numbers from approximately 0.03-7.2 million feet or altitude conditions from sea level to 86,000ft. Air-breathing engine and rocket testing can also be performed in Tunnel 16T using a scavenging system to remove exhaust from the flow stream.

NASA/Army UH-60 individual blade control test on the Large Rotor Test Apparatus (LRTA)

AEDC's 4ft-transonic wind tunnel (4T) is a versatile, continuous-flow, mid-size test facility that can be used for a variety of aerodynamic test needs. Used primarily in conducting small-scale aerodynamic and store separation testing, the tunnel has a 4 x 4 x 12.5ft test section. The transonic designation indicates its primary use for testing at near-sonic airspeeds; however, its Mach number capability extends from 0.05- 2.46.

The Von Kármán Gas Dynamics Facility (VKF) is comprised of a supersonic wind tunnel (Tunnel A) and two hypersonic wind tunnels (Tunnels B and C). These tunnels provide high-quality flow in the Mach number 1.5-10 flight regime and operate as variable-density, continuous-flow units. The tunnels are used extensively to obtain large aerodynamic and aero-thermodynamic databases to develop supersonic and hypersonic flight vehicles. These facilities conduct testing for static stability, pressure loads, jet interaction, store separation and vehicle staging, heat transfer, inlet integration, material sampling, thermal mapping, and dynamic stability, including forced and free oscillation.

Hypervelocity Wind Tunnel 9, located at White Oak near Silver Spring, Maryland, provides aerodynamic simulation critical to the development of hypersonic systems and hypersonic vehicle technologies. Noteworthy advan-

SHAWN JACOBS

Fully-reusable access to space technology proof-of-concept launch vehicle in Tunnel A

tages of Tunnel 9 over other facilities include a unique storage heater with pressures up to 1,900atm and temperatures up to 3,650°R. Axi-symmetric contoured nozzles for Mach 6.7, 8, 10 and 14 are also available. The 5ft-diameter (1.5m) test cell accommodates large-scale heavily instrumented test articles.

The National Full-Scale Aerodynamics Complex (NFAC) wind tunnel facility, located at NASA's Ames Research Center at Moffett Field, in Mountain View, California, is composed of two large test sections and a common, six-fan drive system. A wide range of available support systems combine with this unique facility to allow the successful completion of aerodynamic experiments that cannot be achieved anywhere else. The 80 x 120ft test section is the world's largest wind tunnel.

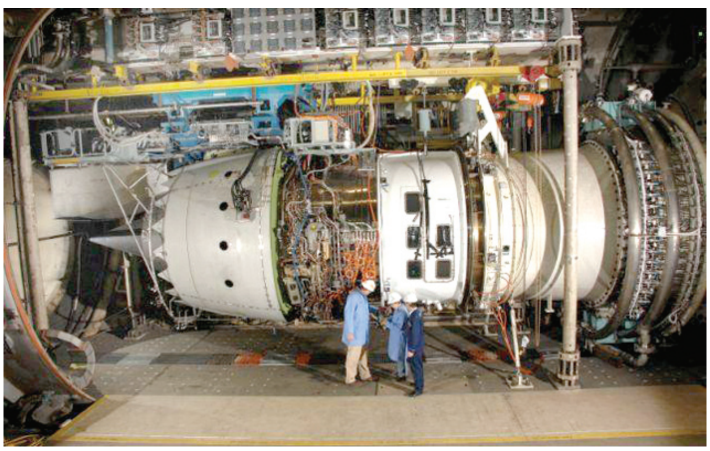
"Test Cells J-1 and J-2 are altitude test cells sized for medium and large turbine engine testing"

Aeropropulsion systems

The turbine engine ground test complex team at AEDC is responsible for propulsion testing in the Engine Test Facility (ETF) test cells, which are used for development and evaluation testing of turbine-based propulsion systems for advanced aircraft. AEDC operates eight active test cells for atmospheric inlet and altitude testing.

Altitude Test Cells C-1 and C-2 comprise the Aeropropulsion Systems Test Facility (ASTF), part of the Engine Test Facility. C-1 and C-2 are each 28ft in diameter and approximately 45ft in length. Either cell can provide engine inlet temperatures of up to 350°F and accommodate engines producing up to 100,000 lb of thrust.

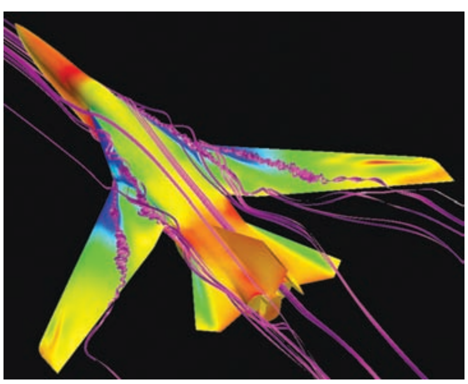
Test Cells J-1 and J-2 are altitude test cells sized for medium and large turbine engine testing. The cells are each approximately 44ft in length, but J-1 is 16ft in diameter and J-2 has a diameter of 20ft. Both J-1 and J-2 are capable of



Above: Arnold AFB, Tennessee, home of Arnold Engineering Development Center

Left: The Trent 1000 engine for the Boeing 787 Installed in C-2

Below: Computed Flow Field About the Standard Check Model Configuration



> **"The Range G launcher is the largest two-stage, light-gas gun system in the USA"**

simulating altitudes up to 75,000ft and testing up to Mach 3.2 and Mach 2.6, respectively. J-1 and J-2 can provide engine inlet temperatures of up to 450°F; however, J-1 can attain 720°F with facility modifications. J-1 can accommodate engines that produce up to 70,000 lb of thrust, while J-2 is sized for engines that produce up to 50,000 lb of thrust.

Sea-Level Test Cells SL-2 and SL-3 provide the capability to economically conduct durability testing on large augmented turbine engines at near-sea-level conditions (1,000ft altitude) by eliminating the cost of running inlet and exhaust plant machinery. In addition to running ambient pressure inlet conditions, they also provide the capability of using the ETF plant to run ram conditions (inlet pressures above ambient), allowing testing at up to Mach 1.2 when necessary to achieve test objectives. Both cells can accommodate engines that produce up to 70,000 lb of thrust.

Altitude Test Cells T-3 and T-4 are diverse cells with multiple applications for testing small and medium turbine engines and cruise missile engines. T-3 is 12ft in diameter and 15ft in length, and T-4 is 12ft in diameter and 47ft in length. T-4 is capable of testing at altitudes of 75,000ft and Mach numbers of 2.5, while T-3 can simulate altitudes up to 100,000ft and Mach numbers of up to 4.0. T-3 and T-4 can accommodate engines producing up to 20,000 and 50,000 lb of thrust, respectively.

Space and missile systems

The space and missile systems ground test complex team at AEDC is responsible for ground testing space and missile weapon systems from subsonic to hypersonic conditions reaching Mach 20. The complex provides hypersonic, rocket propulsion and space environmental T&E services. This branch coordinates testing in over 15 facilities that support the development of defensive ballistic and tactical missile interceptors as well as weapons systems such as theater, cruise missile, high-speed aircraft and launch vehicles.

Hypervelocity Ballistic Range G is used to conduct kinetic energy lethality and impact phenomenology tests. The Range G launcher is the largest two-stage, light-gas gun system in the USA that provides unequalled 'soft launch' (minimized acceleration loading) capability to launch extremely high-fidelity missile simulations at hypervelocity speeds.

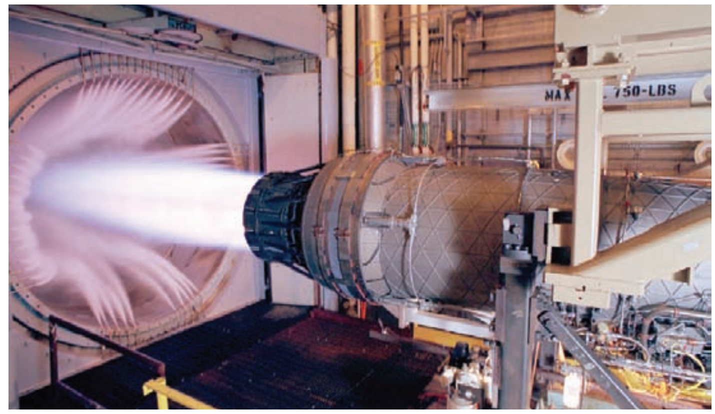
Three other ranges are available at AEDC: Range I is similar to, but smaller than, Range G; Range S1 is a two-stage, 0.75in. lab gun similar to Range G; Range S3 is a 7in., single-stage gun previously used for bird-strike impact testing of aircraft canopies.

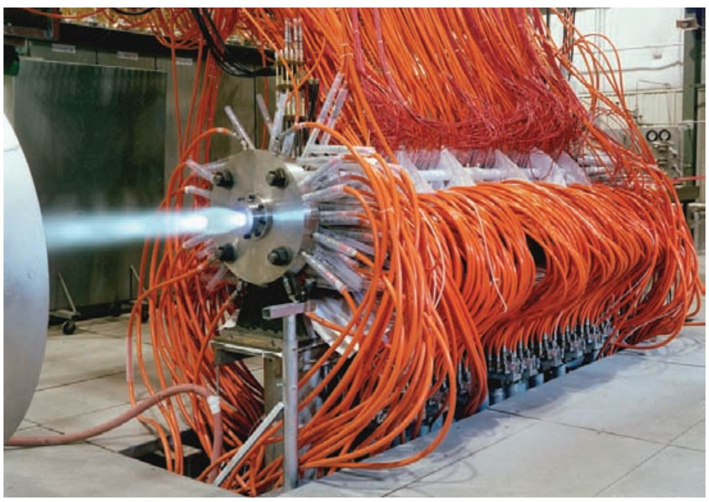
The J-6 Facility provides ground-test simulations for solid-propellant rocket motors. J-6 has been used mainly for aging and surveillance and in testing of stages II and III for both Minuteman and Peacekeeper ICBMs. Additionally, J-6 has supported ORBUS and Castor 30 as well as STAR37 motor qualification testing for the Air Force's Global Positioning Satellite (GPS) constellation. J-6 is the largest of its kind in the world.

The AEDC arc heater facility is used to provide high-enthalpy test environments to test materials and other means of thermal protection. The test facilities include two high-pressure, segmented arc heaters (H1 and H3) and one Huels arc heater (H2). The 70MW H3 arc heater was developed to provide a large, high-pressure arc facility with sufficient size and performance for testing of full- and large-scale missile and reentry samples and structures.

The Aerodynamic and Propulsion Test Unit (APTU) is a blowdown test facility designed for testing true temperature performance of propulsion, material, structures and aerodynamics of supersonic and hypersonic systems and hardware. Under the High-Speed/Hypersonic Air-Breathing Propulsion Test and Evaluation Capability (HAPTEC) program, APTU began a series of major upgrades in 2002 to provide a ground-test capability for supersonic and hypersonic systems up to Mach 8. Upgrades are planned through 2016 that will be implemented with minimal interference to customer test schedules.

The AEDC 7V (7ft diameter by 21ft long) and 10V (10ft diameter by 30ft long) sensor chambers are part of a state-of-the-art space environment simulation test facility designed to test interceptors and surveillance sensors.





Above: The F100 Engine for the F-15 and F-16 being tested in SL-2

Above left: 10V Sensor test chamber

Left: H3 arc heater firing

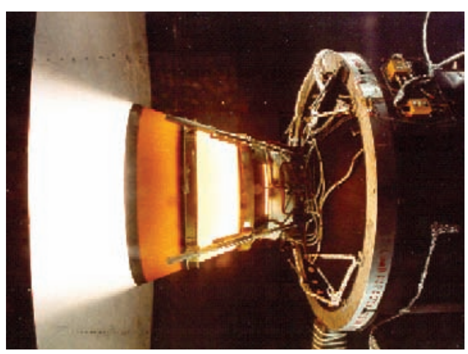
Below: The F100 engine for the F-15 and F-16 being tested in SL-2

These chambers are configured to provide complete characterization and radiometric calibration of a visible and infrared (IR) sensor.

Mark I (42ft diameter by 82ft high) is DoD's largest space chamber and has tested full-scale satellites and space platforms. The 12V Chamber is a 12ft-diameter x 35ft-high thermal vacuum test facility. The facility has its own nitrogen thermal shroud and an optional gaseous helium liner that can be cooled to 10K.

The Space Threat Assessment Testbed (STAT), a ground-test capability, will evaluate space systems and subsystems against realistic threats in realistic environments while simulating various orbits. STAT will provide the ability to evaluate space protection Key Performance Parameters (KPPs) for space hardware, ground control equipment, and software 'left of launch'.

The Advanced Missile Signature Center (AMSC) is a national facility supporting the Missile Defense Agency (MDA), Defense Intelligence Agencies (DIA) and other DoD programs with analysis, modeling, measurement, archival, and distribution services. The AMSC archives include target, threat and battlespace environment signatures for missiles and other vehicles. These capabilities are leveraged to also address signatures associated with missile post-burnout and reentry, celestial and terrestrial backgrounds, scene generation and other battlefield targets such as mortars, small arms fire and fixed and rotary wing aircraft.



Applied technology and analysis

Team AEDC supports a robust and versatile Test Technology Branch focused on three primary disciplines: modeling and simulation (M&S), instrumentation and diagnostics (I&D) and facility and testing technology (F&TT). A team of engineers, scientists, craft and support personnel provides expertise to develop, adapt and apply complex computational models, non-conventional diagnostic systems, advanced facility capabilities, test techniques and engineering-level facility models to address customer testing and AEDC facility infrastructure requirements.

The goal of the M&S focus area is to provide validated, computationally efficient tools that can be transitioned to support all the test engineers in their efforts to optimize test matrices and test facility configurations. Post-test computational fluid dynamic (CFD) aerodynamic simulations do provide insight for diagnosing and correcting data anomalies and extrapolating ground-test data to real flight scenarios.

Test support services

In addition to extensive test and evaluation capabilities, Team AEDC can provide a full range of other services for its customers. Confidentiality of customer test and evaluation information is paramount, so AEDC has an active security program.

The precision machine shop has a full complement of skilled machinists and a complete range of modern machines, from conventional to six-axis computer-numerically controlled (CNC), as well as electrical discharge machine tools. The Metallurgical/Non-Destructive Evaluation Laboratory provides metallurgical test and evaluation services including stress and tensile strength testing, welder certifications, radiographic inspections, and other Non-Destructive test services.

The Chemical Laboratory provides chemical analysis of various components including fuels, oils, soils, liquid-rocket propellants, exhaust gases, water and various other liquids and gases.

Team AEDC maintains the Precision Measurement Equipment Laboratory (PMEL), which is certified by the Air Force Metrology and Calibration (AFMETCAL). The Aerothermodynamic Measurement Laboratory (ATML) provides technical expertise, analytical tools and calibration/characterization facilities for applied research in aerothermal test measurement techniques. High-performance computing (HPC) computational resources are provided to support customers with time-critical mission support via rapid data analysis and the capability to computationally test high-fidelity physics models in a shorter time, saving resources.

All these technical capabilities and more truly make AEDC the most advanced and largest complex of flight-simulation test facilities in the world. ∎

Shawn Jacobs is a public affairs specialist at Arnold Air Force Base

Accessing the aerospace trends

A MAJOR COMPANY SURVEY CONSIDERS HOW AEROSPACE MARKET TRENDS ARE AFFECTING TEST SYSTEMS

"It is the fastest set-up speed of test rigs that will have the most effect on future aerospace testing"

PIM VAN DEN DIJSSEL

BY PIM VAN DEN DIJSSEL

Test-equipment specialist Moog has completed a global project to gauge views from the industry on new trends in the aerospace market and how they will impact on testing in the future. Its intention was to facilitate responses to market changes in the most effective way possible.

Moog is a major supplier of turnkey test solutions for the global aerospace industry, as well as a key producer of components and systems for all types of aircraft. Its customers can reconfigure or expand test rigs easily, increase test productivity while maintaining test accuracy and integrity and without compromising test specimen safety, the last aspect being critical when the specimens may be one-off prototypes costing many millions of dollars or may have accumulated valuable laboratory-induced fatigue damage accrued over a period of years.

Test solutions incorporate the performance of Moog's Test Controllers, Software and Servo Valves. What further sets the company apart is its collaborative approach with its customers, focusing on their ideas and responding to them with new solutions to meet upcoming challenges in the dynamic world of aircraft testing.

Moog put a series of questions to customer OEMs, institutes and Tier 1 suppliers in the Americas, Europe and Asia. Moog asked them how the following trends would affect testing: the development of lighter aircraft; the increasing use of composite materials; the increasing use of safety systems in test equipment; the growing need for damage assessment during test cycles; the focus on ease-of-use of test equipment; faster test speeds; shorter set-up times for test rigs and systems, and testing out-sourcing by OEMs.

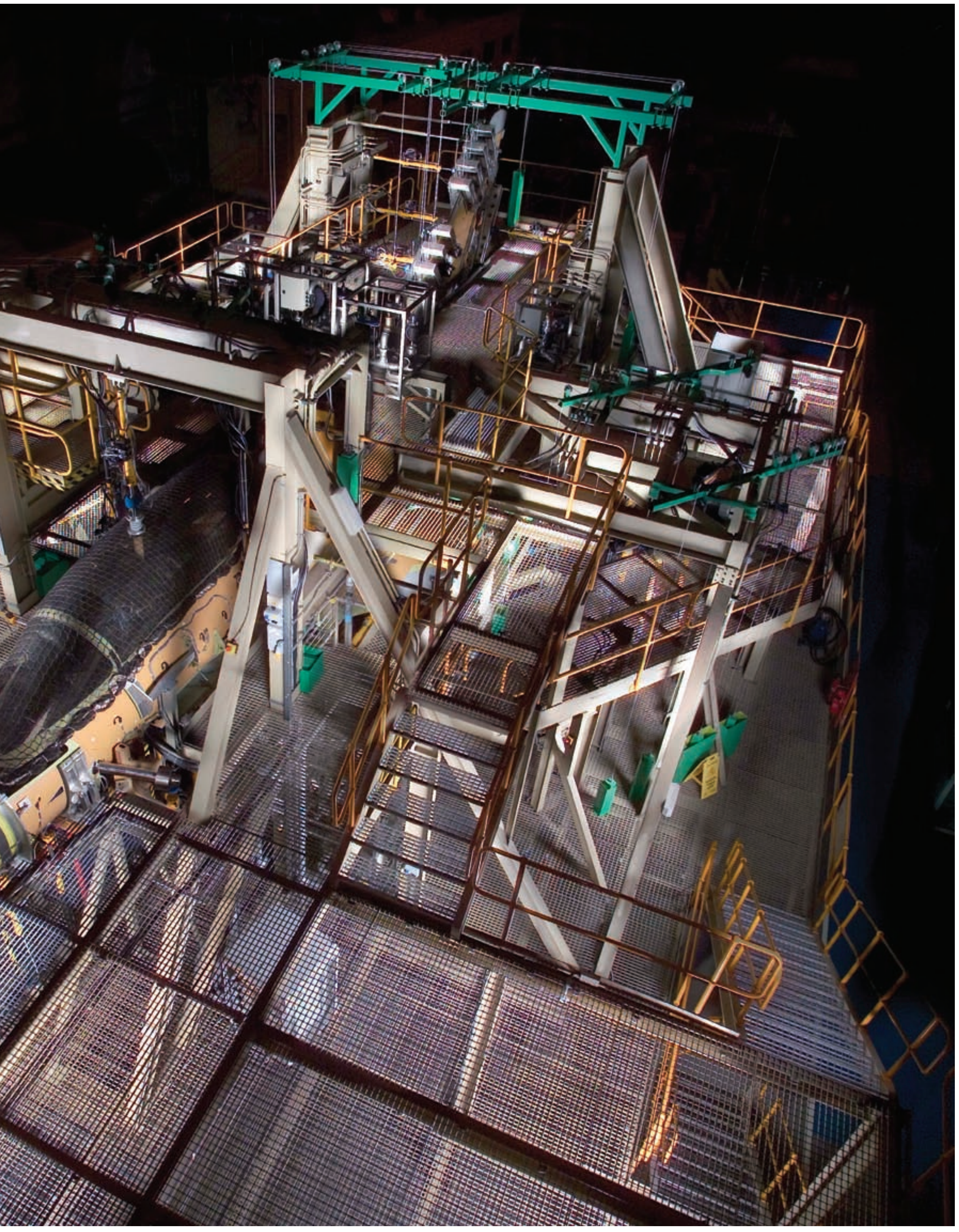
Timing, a major issue

Among the many answers obtained, the clearest message was that it is the faster set-up speed of test rigs and systems that will have the most important effect on future aerospace testing. Over 80% of respondents either agreed or strongly agreed with the assertion that set-up speed would have important effects on aerospace testing (whether that means more tests, better tests, or new tests) in the future, indicating that this is an even more important time and cost issue than the speed of the test itself.

Full scale fatigue testing

Respondents said faster set-up would enable them to better cope with heavy workloads and cut costs. "Customers want everything to be done faster," said one European respondent, and a reply from the USA said, "timing is a major issue." From China and Korea came comment: "We have a very heavy workload currently, if the system can be set up more quickly, it will help us a lot," and, "Project owners are always asking for reduced test time."

One respondent went so far as to say that set-up speed was the reason he bought the



Moog's test system. "I can set up the rig in half the time," he said. "We can fly sooner if set-up is shorter. There is a huge financial penalty if set-up is slow."

The question did however also give rise to doubts about just how much set-up times could be further reduced. "Things are so big, I don't see how set-up can be faster," said one customer.

Some of the trends that Moog is spearheading are designed to allow aircraft manufacturers to run a higher range of test tasks. These are set to reduce set-up time, optimize test running rates, maintain accuracy and test-specimen safety. Faster testing is key to the success of aerospace manufacturers. This is where real operational improvements can be made in the lab. Moog's latest real-time Ethernet communication interfaces increases the functionality of servocontrollers and boosts bandwidth. Operational speed is improved by providing faster graphics, accurate synchronization of more than 500 control channels, reduced latency time and complete management of specific safety procedures. These not only to eliminate any risk on the test specimen. It also enables fast, easy-to-set-up test systems that can be integrated with the users' existing test and laboratory infrastructure.

Recent test-rig installations by Moog already addressed the emphasis on speed, faster setup, faster testing, and is a key aspect of its latest high-end testing systems.

Test Systems: a global reach

In just three days, Moog installed a comprehensive leading-edge test system for a wide range of structural and fatigue tests for helicopters' components for the Korean Aerospace Research Institute (KARI). This system is part of a multi-billion dollar procurement project by the South Korean Ministry of National Defense that involves developing and building 245 utility helicopters over a 16-year period.

The system now runs full-scale structural tests and has potential for 12 independent helicopter tests delivering faster, more efficient analysis and comparison of tests. Because the two systems are connected via Ethernet, KARI can directly cross-check data from the load-control system and the data-acquisition system through full synchronization using time stamps. This enables all data to be stored and archived on a hard disk for post-test analyses. Moog's test controllers incorporate a unique control-loop technology that can handle complex multichannel tests.

Their flexibility and high-performance handling of complex testing formulas, utilizing proprietary software, are particularly suited for advanced aerospace testing. Moog provides servocontrollers that run structural tests (static and dynamic) ranging smoothly from complete aircraft and sub-assemblies across to components.

In Europe, for AgustaWestland, Moog also developed a fatigue-test application system, offering all the functionality needed by the test engineers in one, all-embracing, software suite and including real-time Ethernet interfaces.

The research findings also reflected how downstream requirements and operational cost-cutting needs figured prominently in customers emphasizing the importance of test speeds. Here, 62% of respondents agreed or strongly agreed that the trend would have an important effect.

However, the law of diminishing returns was highlighted.

"Parts are sensitive to speed, so you can start to get erroneous results if you are too aggressive with speed," said one customer. Another suspected there would be a cost trade-off.

Specimen safety also figured prominently as a trend driver. Over 46% of respondents strongly agreed that safety systems would have an important impact on aerospace testing in the future. Respondents emphasized the importance of specimen safety and that they are doing their best to upgrade safety measures. The main reason for this emphasis on safety is the high cost of the specimens.

"Usually there is only one test specimen," said a customer in the Asia-Pacific region. "So we are very particular about the safety of the specimen and also of our engineers. We cannot afford for the test to fail."

Related to this fact, 59% of respondents agreed or strongly agreed that more damage assessment during test cycles was an important trend. Some test labs have, in fact, already experienced changes in test requirements relating to increased damage assessment. "Composite materials are driving this," said one North American respondent.

The statement that increased use of composite materials could have an important impact drew a cautious affirmation from respondents, with 37% agreeing and 29% agreeing strongly, but with some respondents in all regions also believing that there would be little change.

"The testing will not be complex but the interpretation will be," said one customer. "Analyzing data [from tests on composites] is not as straightforward as analyzing data from regular steel."

Another said: "(Users) may not be able to apply the loads they want in the manner they want to see. It's evolving slowly I believe."

The desire for test systems that are easier to use was evident from the survey, with the emphasis on new solutions to increase work efficiency and cut costs rather than on lowering requirements for technical expertise. 48.8% of respondents agreed or strongly agreed with the argument that improved ease of use systems would have an important effect on testing.

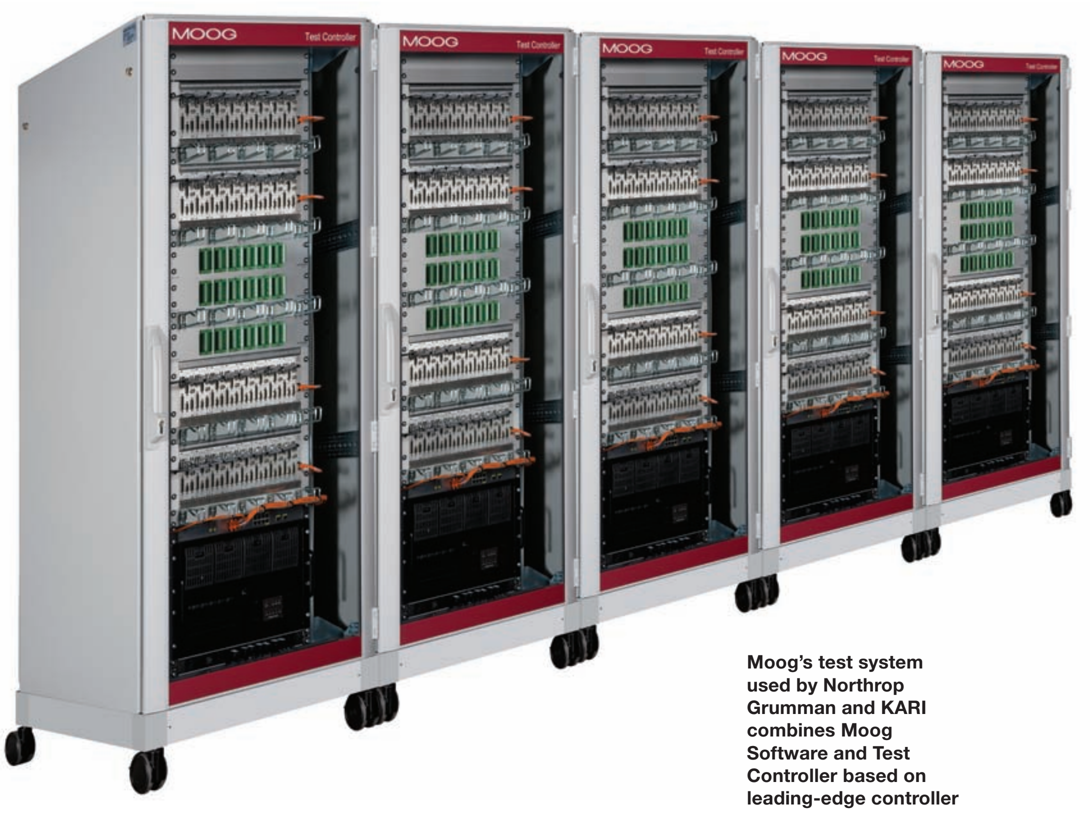
"We are dealing with different components of the aircraft," said one reply. "Each set-up may not be suitable for [every] component. We can save time doing the test if it is easy to use."

However, there were a particularly high percentage of respondents offering a 'neutral' reply. "I think we are doing fine at the moment," said one, and explained that there was firm agreement on the need for qualified operators.

"Operators don't only operate but must know what is happening," said one North American customer. "We definitely need qualified operators, even with ease of use."

The impact of the financial crisis

Finally, on the question of the impact of the global crisis, there was much diversity of opinion, with an almost equal number of respondents agreeing and disagreeing that the crisis had an important effect on test budgets and on internal justification procedures, and a majority saying it had not affected the type of equipment they were using.



Moog's test system used by Northrop Grumman and KARI combines Moog Software and Test Controller based on leading-edge controller platform

"Overall, replies indicated Tier 1s had been hit the most, with cuts in investments"

Static wing testing

Overall, replies indicated that Tier 1s had been hit the most, with cuts in investments, while test institutes had faced fewer budget cuts and OEMs emerging largely unscathed.

"Most likely due to the long-term nature of their development projects" says van den Dijssel. Not surprisingly, investment approval processes have been tightened up across the board. "Management wants to see more cost justifications, more details, better estimates," said one OEM. Moog is committed to meeting these challenges and requirements set by the marketplace.

By using advanced technology, world-class products and application know-how, Moog is able to deliver the complex requirements of faster testing, while ensuring the highest accuracy, repeatability and safety. One of the latest feature development by Moog facilitates higher run rates without experiencing all the usual problems associated with faster testing, such as strain overshoot.

Expertise gained by working in industries such as the aerospace testing industry has enabled Moog to implement advanced solutions in other industries with similar complex requirements for multichannel control and faster throughput. ∎

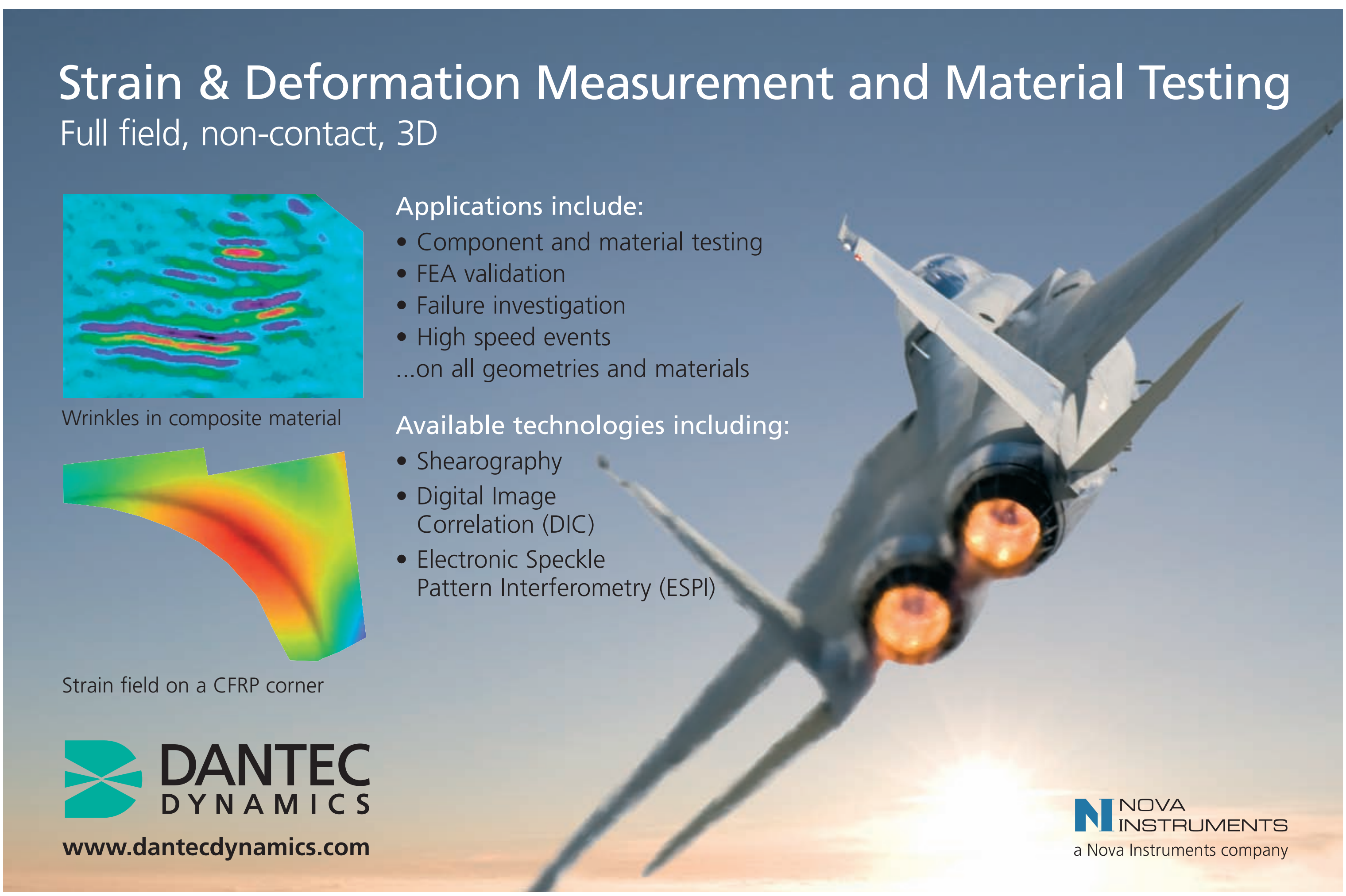
CONTACT

Pim van den Dijssel, is business manager for Europe at Moog

Contact: test@moog.com

Information: www.moog.com/test


Motion Sensors for Aerospace
Long term stability
Low power
Harsh environment
Low vibration rectification error
COLIBRYS MS9010.D 7001 001
High Performance MEMS Accelerometer
To meet the continually increasing needs of Inertial Measurement Unit (IMU) and Attitude-Heading and Reference System (AHRS) products for Civilian and Military applications.
To get more information on our full range of accelerometers for Inertial, Vibration, Seismic and Tilt applications, contact our experts at sales@colibrys.com orvisit www.colibrys.com.
Smart Sensing Solutions
COLIBRYS


Strain & Deformation Measurement and Material Testing
Full field, non-contact, 3D
Wrinkles in composite material
Strain field on a CFRP corner
Applications include:
• Component and material testing
• FEA validation
• Failure investigation
• High speed events
...on all geometries and materials
Available technologies including:
• Shearography
• Digital Image Correlation (DIC)
• Electronic Speckle Pattern Interferometry (ESPI)
DANTEC DYNAMICS
www.dantecdynamics.com
NOVA INSTRUMENTS
a Nova Instruments company

High-speed camera trends

A FOCUS ON THE MARKET TRENDS FOR DIGITAL HIGH-SPEED CAMERAS FOR AIRBORNE APPLICATIONS – THE PROS AND CONS

BY RETO HUBER

Digital high-speed cameras have now replaced film-based high-speed cameras in most applications, either for airborne or any other applications. The benefits of immediate access to the sequences, lower operating costs and integration into the digital workflow are obvious.

Dedicated digital high-speed cameras for airborne applications have been available for a number of years, and the proof of the technology was achieved long ago. Cameras, such as the X-EMA or S-EM, made by AOS Technologies, have been used by air forces and airplane manufacturers for years.

What are the newest trends in the aircraft industry, and what will the high-speed camera of the future look like? What features are truly needed, and which are often requested but actually give minimal benefit to the user?

A trend in recent projects seems to be to go for 'high resolution, high-speed' cameras. More pixels, more frames. Or simplified this means: 'better images at higher frame rates'. But is more always better? What are the trade-offs? What needs to be considered, and how much does the complete camera system change? The latest trends have pros and cons.

A dedicated digital high-speed camera for airborne applications, including the camera, a lens with an image diameter suitable to cover the complete active-sensor area, a lens cage and a mounting plate

> "There is a natural limitation without making the whole camera substantially bigger"

Trend one

The pixel race came to an end some years ago when digital high-speed cameras reached an image resolution of 1,280 x 1,024. Although not impressive compared with modern digital still cameras, which have often sensor resolutions of 10-15 megapixels, the images recorded by digital high-speed cameras offer resolutions enabling fine details to be detected for visual- or software-assisted motion analysis.

Another driver for high-speed cameras with high-sensor resolutions is digital video cameras with HDTV and full HDTV technology. A TV set specified for full HDTV offers impressive image at a resolution of 1,920 x 1,080 pixels. This all led to requests for digital high-speed cameras with substantially higher sensor resolution than those used in the past.

Is more always better'? As with all new technologies, there are pros and cons to be considered. Image sensors with more pixels compared with a given design have either to be larger to accommodate the extra number of pixels, or keep their basic size and the pixels are reduced in their size, so the same sensor area can accommodate the higher number of pixels. Can the sensor be enlarged to any size? It is obvious that there is a natural limitation without making the whole camera substantially bigger. But even if the sensor is just slightly enlarged to accommodate the additional pixels, a substantial problem is created.

What lens can cover the sensors active area? Existing high-speed cameras offer an image sensor with an active sensor area specified as 1in (though, in fact, it is not 25.4mm but approximately 16mm – but that is another story). A wide range of c-mount lenses with an image diameter of 1in are available from many manufacturers, so the choice is quite large when selecting an appropriate lens.

Even bigger sensors with more pixels feature a bigger active area, and therefore need lenses with a larger image diameter. However, lenses with a c-mount lens thread cannot offer an image diameter larger than 1in, so other lens designs have to step in.

A preferred choice of many camera operators is to use manual Nikon lenses, originally designed for still photography. Most of these lenses offer exceptional image quality, a robust

RETO HUBER

"Getting a good set of lenses for a multicamera system is not always easy"

Imaging sequences specialize in missile separation

mechanical design, and an image diameter large enough to cover any high-speed image sensor. However, most lens manufacturers stopped manufacturing manual-focus lenses long ago, or have at least reduced their portfolio to a few lenses – unfortunately not those needed for airborne applications. Second-hand suppliers offer plenty of suitable lenses, but getting a good set of lenses for a multicamera system is not always easy, and who wants to equip a brand new high-speed camera for critical airborne applications with pre-owned lenses, possibly from an unknown vendor?

Using new still photography AF lens are usable in some cases. However, most modern AF lenses for digital photography no longer offer a ring to preset the aperture – digital still cameras step down the aperture electronically and can only be operated with the iris fully open at which point the lens does not give its best performance, and the depth of field is minimal.

Smaller lens manufacturers like Zeiss have designed new manual F-mount lens with exceptional optical and mechanical qualities. Of course they sell at a substantially higher price than the original Nikon lenses. Obviously, mechanical F-mount lenses are a weight and size which needs to be considered for airborne applications.

They often need a custom-made lens cage to support the lens and to fix the focal and iris ring. The camera-mounting bracket also needs to be designed so it can securely hold the camera, lens and lens cage under high-g conditions and vibrations.

Operators requesting such high resolution cameras have to make sure lenses, fitting lens cages and robust camera mounting brackets are available, ideally from the camera manufacturer. Perhaps same size sensors with more pixels are the solution? Yes, and no. Everyone is familiar with the grainy, washed-out pictures made with a 5-megapixel cell phone. The smaller the pixels, the less photons they can accumulate, the higher the gain, resulting in poor image quality. So reducing the pixel size is also not the way to go.

Standard high-speed image sensors have a typical sensor size of 12um (resulting in a pixel area of $144\mu m^2$), and even a slightly smaller pixel of 10µm (-20% compared to 12µm) covers only $100\mu m^2$, a full 44% less. Even consumers have noticed that their latest point-and-shoot cameras with 12, or more, megapixel provide often a lower image quality then their older six or eight megapixel camera – exactly because the newer cameras use a higher gain setting and heavier image processing. Some leading camera manufacturers have understood this, and their newest cameras offer less sensor pixels than the cameras two years ago.

So a compromise between the requested sensor resolution, sensor size, available lens and desired image quality has to be found. A manufacturer of digital high-speed cameras has to carefully weigh and balance these factors to offer customers a camera system with exceptional performance.

X-EMA camera, complete with lens, cage and mounting plate

"Typical high-speed cameras have a built-in image memory with a capacity to store sequences 2-20 seconds"

Trend two

As digital high-speed cameras reduce their original sensor resolution to reach higher framing rates, image quality can drop at higher framing rates. So a camera with the possibility to use a full sensor resolution higher than the usual 500-1,000fps, or even 2,000fps, would apparently be wonderful.

But consider the full system performance. Supposing such image sensors were available, the amount of image data grows at the same rate as camera performance. Image data needs to be processed and stored. Although high-capacity solid-state memory modules get smaller and become less expensive, the data processing takes time. Even without data compression and exporting the image data to a standard image data format, the raw image data needs to processed to create the desired image quality. Fixed-patter-noise reduction and white balancing are just some processes image data has to go through before being visualized.

Trend three

Typical high-speed cameras have a built-in image memory with a capacity to store sequences 2-20 seconds. What if a longer process has to be monitored and recorded from alpha to omega? Manufacturing industry has used high-speed streaming systems for some time to monitor processes as well as for troubleshooting. Such systems do not store the image data in the camera itself, but stream them to a connected mass-storage device. Recording capacities are often between 30 minutes and several hours, with frame rates of 200-300fps.

Cameras or camera modules with the necessary data interfaces, such as Camera Link, are available from some manufacturers, but the design and implementation of a complete, turnkey 'high-speed image streaming system' including the controller, software and airworthy, vibration-proof mass storage devices is a task for specialized integrators or camera-system specialists.

The three trends

Three trends, noticed in the market for digital high-speed cameras for airborne applications are: more sensor pixels, higher framing rates at full resolution, and substantially longer recording times to record complete processes at full length. Technically, most requests can be fulfilled in one way or the other. To avoid disappointment, careful and close communication between the end user, the system operator and the camera-system manufacturer is more important than ever. ∎

CONTACT
AOS Technologies
Tel: +41 56 483 34 88
www.aostechnologies.com
info@aostechnologies.com

Tubeway army – measurement analysis

A TEST REPORT HAS DOCUMENTED THE SUITABILITY OF THE MEASURING SYSTEM 'TUBEINSPECT' FOR DEPLOYMENT IN THE AEROSPACE INDUSTRY

> "Unbent tubes can only be obtained by explicitly qualified suppliers"


JUTTA THIEL

BY JUTTA THIEL

Quality demands on tube manufacturing in the aerospace industry are considerably more stringent than in other industrial sectors. To determine the suitability of the optical tube measuring system 'TubeInspect' for this sector, PFW Aerospace AG carried out an extensive measurement system analysis. During the tests PFW project engineer Martin Seibt identified the high repeatability of the system. Even the reproducibility was five times higher than the one of the competing measuring systems.

The test results have led to Airbus, a major customer of PFW, certifying the suitability of the TubeInspect measuring system for tube bends of over seven degrees and PFW has been given the official approval to deploy TubeInspect in production.

Tube manufacturing in the aerospace industry is much more complex that it appears at first glance. Highly developed systems constructed of bent tubes which are invisible from the outside run like veins through every modern aircraft from the tip of the wing right to the landing gear. There are tube systems for example for fuel, hydraulic liquids, air and oxygen. Today, PFW Aerospace AG, with its headquarters in Speyer, Germany, and over 1,500 employees worldwide, is considered to be a market leader in tube system manufacturing for the aerospace industry. EADS/Airbus, Boeing, Bombardier and Eurocopter are some of their renowned reference customers.

Special requirements

All tube systems are subject to strict quality regulations, as any imprecision could have disastrous consequences. Unbent tubes can only be obtained by explicitly qualified suppliers, who issue single parts with individual certifications. Accordingly, during further processing strict tolerance specifications have to be observed. At PFW Aerospace AG the tube bending process has to fulfil highest demands in regards to perfect geometry.

To remain profitable, however, the company has to be in a position to manufacture tubes in the smallest production batches with a minimal number of rejections.

"It is our aim to be able to manufacture profitably even for a production batch of just one unit as our customers often commission us to produce just one part," Seibt, explains. "Take

Right: Tube bending within precise parameters for the aerospace industry

building a satellite as an example. A tube needed here is very unique and consequently a 'one-off'. So you commission PFW to produce just this one tube."

Even serial parts for aircraft can be ordered in quantities of less than ten pieces. Nearly without exception, production includes costly materials such as titan, stainless steel or Inconel, which is a non-corroding nickel-based alloy, and rejections have to be kept to a minimum.

"Today PFW is in a position to immediately produce 20,000 components with minimal discard," says Seibt. "More than two tubes being rejected before the first good unit would be an unacceptable cost factor for us."

In the aerospace industry, where product diversity and the manufacturing of a large number of prototypes are required, a measuring system which can be employed universally is the ideal choice. Production methods such as manual gauges which have to be adjusted to fit each change of a tube and which have in addition to be stored for several years, no longer present an economic solution. To achieve more efficiency PFW analyzed for the first time the potential of an optical measuring system and compared this with the tactile system which had been used to date for inspecting manufactured tubes.

Optical measurement

For the analysis, PFW chose Aicon's measuring system TubeInspect as this system is the only fully-optical measuring system on the market today which is specialized in bent tubes. TubeInspect carries out highly precise measurements of tube geometries by using high resolution digital cameras. Moreover it calculates the set-up and correction data and transfers these to the bending machines. The time needed for a tube inspection is short: For a fuel tube measuring data is available within three seconds, controlling a complex brake line with more than 40 bends can be carried out in less than 20 seconds. TubeInspect is capable of completely replacing cost-intensive mechanical gauges.

Analysis using two procedures

First procedure: to carry out the measurement system analysis PFW used two procedures representing latest technological standards. In the first test, which is the measurement capability test, the bias and the variance of the measuring system without any operator influence are evaluated according to a calibration master. An average, a standard deviation and a bias can be calculated from the measuring test sequence.

Carrying out a suitability test of a measuring system which represents the requirements of tube bending in the aerospace industry, PFW used the DKD-calibrated tube as a reference standard. This was measured 50 times, the tube was taken out of the measuring cell and replaced there for each following measuring. With these results Seibt evaluated whether the measured values matched the established reference values of the calibrated tube and how the measurement results related to each other, and how much the measuring results deviated.

The result was convincing: TubeInspect is suitable for the aerospace industry as a measuring system, as 99.7% of all the measured bending points differed less than 0.36mm (target value: 0.50mm) from the actual value. The repeatability was significantly better. The random error was ±0.09mm (3 Sigma), which is considerably less than the variance detected for the measuring method which was formerly used.

"TubeInspect excels in optimal conditions due to its extremely low deviation, " says Seibt. "Compared with the competing system the precision is very good."

Second procedure

The second procedure is entitled Gage R&R-Study (Gage Repeatability and Reproducibility). This measuring procedure determines the repeatability and reproducibility of the measuring process in production conditions taking into account the influence of the operator. Depending on the results the decision is made whether the measuring process is suitable for the measuring task.

During the analysis both TubeInspect and the tactile system were used to measure four completely different tubes from four different machine setters with three different fixturing systems. In total 48 measurements per system were documented.

"We were surprised at the excellent performance of the TubeInspect system with regards to repeatability," comments Seibt on the result of this examination. "Aicon's system performed five times better than the tactile measuring system. We realized that the set-up of the tactile measurement based on a fixturing system manipulates the tube's geometry - and this constitutes an enormous error source. TubeInspect works with an optical positioning assistant and every tube is measured in two positions. Due to this the system achieves significantly improved repeatability."

PFW presented these measurement results to Airbus, one of its most important customers. Due to the convincing results, PFW received from Airbus the official approval to deploy TubeInspect in production. The system is now implemented in the factory in Speyer and is used on a daily basis.

"Aicon's measuring system is the most contemporary technical method to fulfil the growing demands of the aerospace industry," says Seibt. "Other manufacturers of measuring systems are encountering their technological limits. We are very satisfied with this purchase." ∎

CONTACT

Jutta Thiel
Tel: +49 531 58 000 70
www.aicon.de

NDT and laser ultrasonics

WORKING TOWARD A NEW STANDARD IN QA FOR COMPOSITES MANUFACTURING USING LASER ULTRASONICS (LUS)

"By the end of 2010, Airbus will have the world's most advanced LUS to inspect composites"

ANTONIO TANARRO

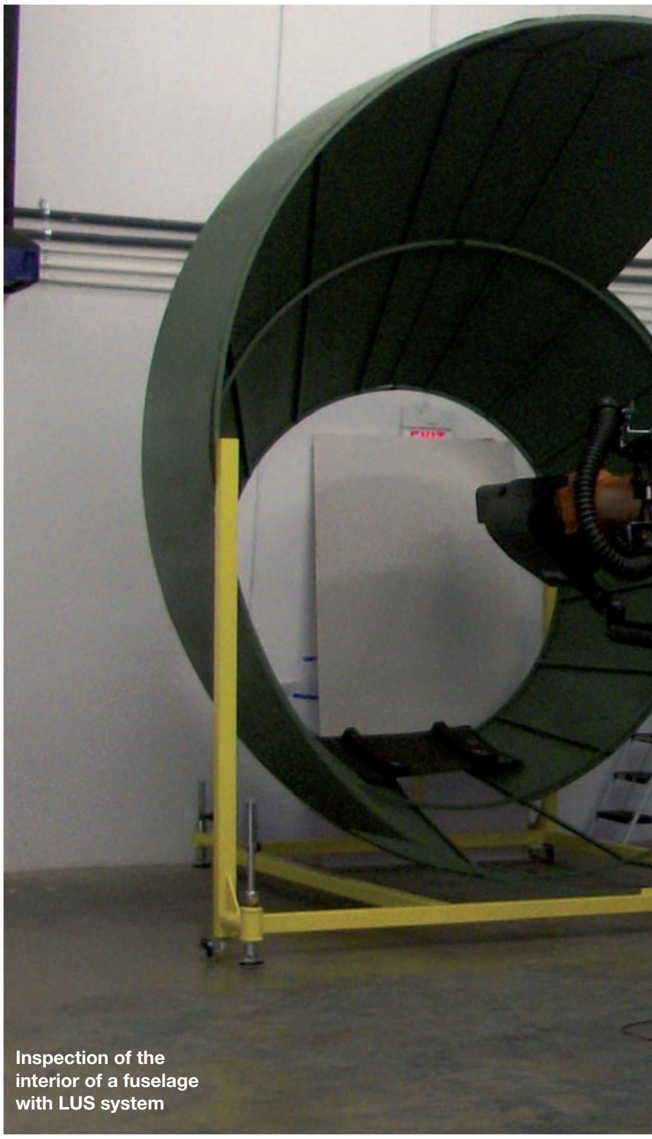
BY ANTONIO TANARRO

Advanced laser ultrasonic systems (LUS) deliver big technical advantages for the automatic inspection of composites in aerospace manufacturing. Current trends in the aerospace industry are focused on saving as much weight as possible in the manufacturing process. Greener transportation and lower CO_2 emissions are behind the driver. Aerospace component manufacturers are including composite materials, mainly carbon fiber, on the production line, and new aircraft projects have up to 70% carbon fiber in the aircraft structure.

This use of composites is generating new demands for the non-destructive testing (NDT) industry. For years, NDT has been improving the applied technology, as the specific characteristics of the new components are its everyday challenge. More complicated shapes, more integrated elements, bigger sizes and more difficult access to the component require new NDT techniques. An ultrasonic inspection that avoids contact between probe and inspected area, and does not need couplant and specific beam focusing, is seen as increasingly necessary.

By the end of 2010, Airbus will have the world's most advanced LUS to inspect composites. The equipment will be installed at Technocampus EMC2, Nantes, France, the technology center for the development of industrial applications of composite materials created jointly by Airbus, EADS-IW and CETIM. Tecnatom, with important experience in the supply of inspection systems for aerospace components, has been selected by Airbus as the main supplier, with its North American technology partner, iPhoton Solutions LLC, which has a long record in the use of this technology.

This new testing technology offers important technical advantages over conventional techniques. Ultrasounds in charge of defect detection are generated directly in the component material, so the angle of incidence of the laser beam on the complex surfaces of aerospace components may be varied by a value 45 times higher than conventional probes; and no ultrasonic coupling is required. This means the probe can be located at a much greater distance from the part surface.



Inspection of the interior of a fuselage with LUS system

A well-known technology

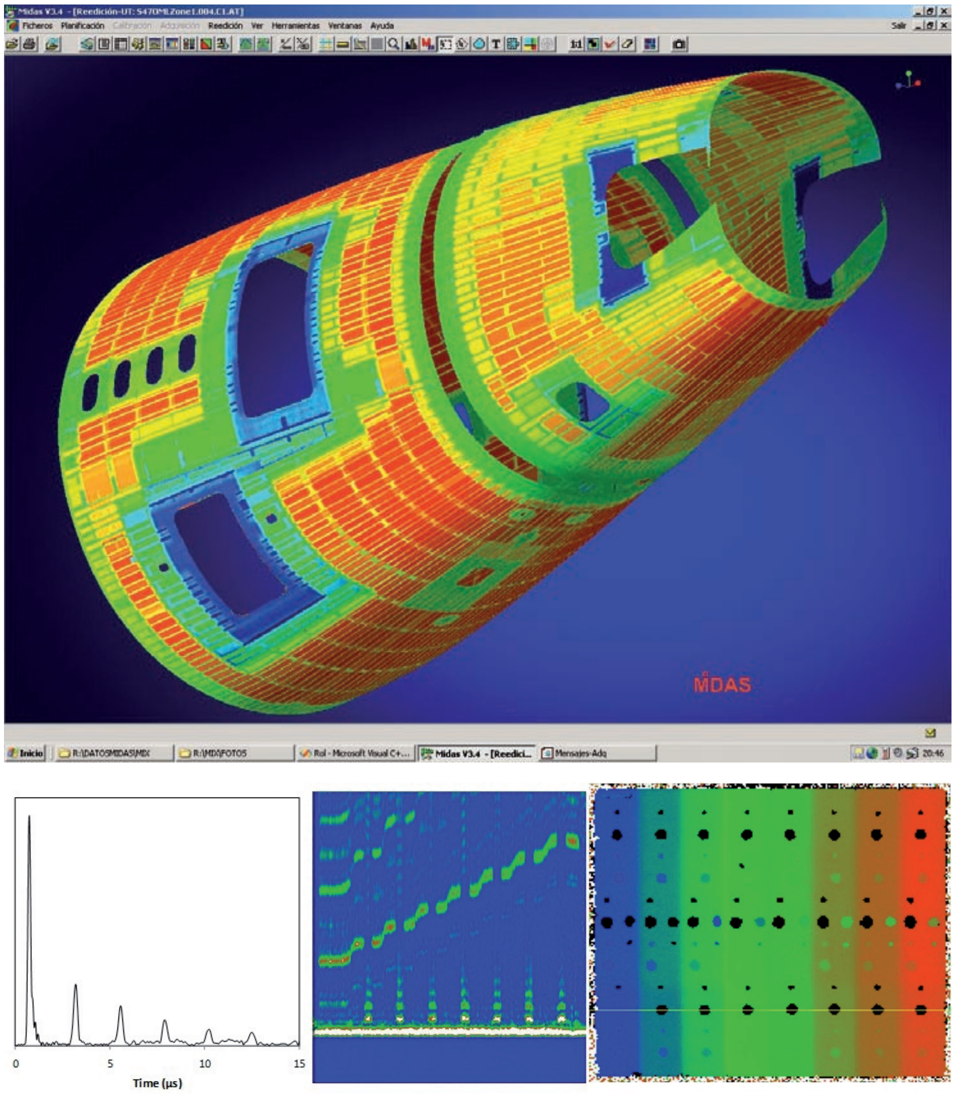
LUS is generally defined as a technology in which one laser generates ultrasonic waves and another laser, coupled to a detection system, detects the associated ultrasonic displacements. White in 1963 discovered the phenomenon of ultrasonic generation by a pulsed laser. In 1980 Calder and Wilcox suggested the use of one laser for generation and one laser, coupled to an interferometer, for detection, creating a first LUS system. In 1983, Krautkramer-Branson carried out a scan of a composite part for a division of General Dynamics (later part of Lockheed Martin) using a LUS system, based on a Mach-Zender or Michelson type interferometer for detection, and on an ultraviolet laser for generation.

These interferometers were not compatible with industrial applications and the ultraviolet laser created visual damage at the surface of the composite part. These limitations were solved by General Dynamics and the National Research Council of Canada, which independently developed the CO_2 laser for ultrasound generation in composites and the confocal Fabry-Perot interferometer for ultrasonic detection. The CO_2 laser and the confocal Fabry-Perot interferometer have become stan-

dard elements for LUS inspection of composites. Between 1994 and 2000, Dassault Systems, with Aerospatiale (now Airbus) and the US Air Force, explored LUS; but did not follow-up with any industrial implementation.

In 1998, Lockheed Martin built the first LUS facility for the Joint Strike Fighter proposal. Two additional facilities were subsequently built for the F-22 and F-35 programs, resulting in the first large-scale implementation of LUS for the inspection of composites in the aerospace industry.

LUS uses one laser to generate ultrasonic waves and another laser, coupled to an interferometer, to detect the corresponding ultrasonic displacements. The CO_2 laser is the recognized choice for generation in composite materials because its wavelength (10.6µm) is strongly absorbed in most organic materials. The CO_2 laser is absorbed in a very thin layer (10-200µm deep) at the surface of the composite, typically in the polymer matrix material or the peel ply. This absorption produces a local temperature elevation which, in turn, creates a local thermal expansion, launching longitudinal ultrasonic waves in a direction normal to the surface, independent from the angle of incidence of the CO_2 laser beam. This charac-



teristic constitutes the main benefit of LUS for the inspection of composites – parts can be inspected with a very high tolerance relative to the angle of incidence.

The detection of the ultrasonic waves is accomplished by a long-pulse single-frequency laser combined with an interferometer. The detection laser beam illuminates the area where the generation laser hits the part. The detection laser light is collected and sent to a confocal Fabry-Perot interferometer. The mechanical displacements created by the ultrasonic waves induce small changes in the optical frequency of the detection laser, that are demodulated by the Fabry-Perot interferometer, resulting in signals very similar to the signals obtained by conventional piezoelectric transducers. The generation and detection laser beams are aligned on top of each other and sent to an optical scanner, such as a two-dimensional galvanometer system. The two laser beams are indexed over the sample surface while firing the lasers.

Despite this long development period, LUS has not yet been implemented in the aerospace industry on a large scale. Two main reasons have limited the spread of LUS for the inspection of composites: the lack of systems specifically developed for industrial application and the high acquisition cost of the LUS equipment. The new approach from Tecnatom and iPhoton Solutions overcomes these two limitations. The strategy consists of adopting technologies from high-volume industries to address cost and reliability issues. The same basic elements of LUS are used but various elements are borrowed from the telecommunication, automobile, and laser machining industries to produce a reliable, flexible, and affordable LUS system.

Above: UT plot of color-coded amplitude signal versus linear position (B-scan) and color-coded time arrival of UT echo

> **"Optical fibers cannot be used in an industrial environment to transmit the CO_2 laser beam"**

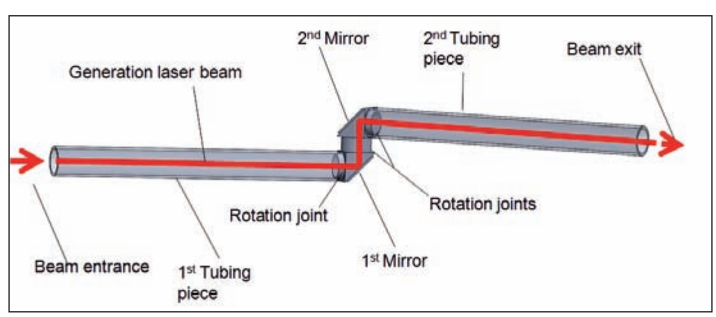
Robotic approach for ultrasonics

Typical optical scanners and laser powers limit the scanning area to approximately 1m^2 and to incidence angles below 45°. For the inspection of composite parts that have complex shapes or large sizes, or both, the optical scanner or the part needs to be repositioned to completely inspect the part. This repositioning can be done automatically by putting the optical scanner on a robot.

The first LUS systems mounted on robots used gantry-type robots. Optical alignment of the CO_2 laser beam in the optical scanner must be precisely maintained to obtain valid ultrasonic results. Optical fibers cannot be used in an industrial environment to transmit the CO_2 laser beam. Therefore, the most obvious solution is to move the CO_2 laser along with the optical scanner. Only this type of robot can move equipment as large and heavy as an industrial CO_2 laser. However, gantry robots present several disadvantages, the most important being cost. It is typically the single most expensive element of such a LUS system.

The auto industry has been using articulated robots in very large numbers for several years. Those robots are consequently very reliable, readily available from several manufacturers, and reasonably priced. LUS technology will benefit from leveraging the robotic experience from the auto industry and adopting articulated robots instead of gantry configurations. In addition to the acquisition-cost advantages, articulated robots have short delivery lead times, are easy and inexpensive to install, do not require as large a footprint, and benefit from a very large base of resources in terms of accessories, vendors, software and qualified labour.

The problem of the optical alignment of the CO_2 laser beam with the optical scanner is solved by exploring the large number of resources available for articulated robots. The laser-processing industry has been using CO_2 lasers and articulated robots for several years. A beam delivery system was developed to use CO_2 lasers with articulated robots for material processing. The beam delivery system concept consists of rigid tubes, coupled together by rotation joints in



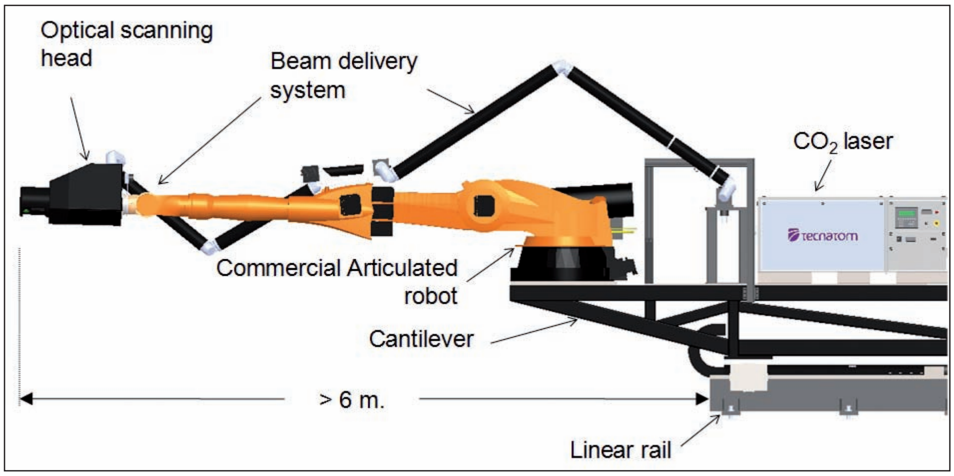
Right: Section of the beam delivery system

which two mirrors are mounted. The CO_2 laser propagates along the centre of the tubes. With near perfect alignment at the entrance of the beam delivery system, the CO_2 laser beam will transmit from the entrance to the exit of the beam delivery system through reflection on the mirrors in the joints as illustrated in the Figure at bottom of page 89.

Industrial solution

A LUS concept, focused on its industrial application, has been developed by Tecnatom and iPhoton Solutions, using a beam-delivery system, mounted on an articulated robot. To increase the working envelope, the robot, the beam-delivery system and the CO_2 laser are mounted on a linear rail. The beam-delivery system requires a support and a tool balancer, as shown in Figure 3. The linear rail provides an almost unlimited working envelope in one direction. The total working envelope is approximately defined by the travel range of the linear rail, 3m in the direction perpendicular to the linear rail and 5m in height.

Some applications require the inspection of composite substructures inside larger structures, such as stringers inside a fuselage. These restricted-access applications are not compatible with this beam-delivery system. Therefore, Tecnatom and iPhoton Solutions have developed a different configuration to cover inner inspection. In this configuration the beam delivery system is made of two standard beam-delivery systems joined together on axis 3 of the robot. This approach, combined with a cantilevered linear rail, provides over 6m of penetration inside a structure, such as a fuselage, in addition to the working envelope of the previous one. This concept is shown in the figure above and an application is shown in the figure below.



A cantilevered linear rail, provides over 6m of penetration inside an aircraft structure

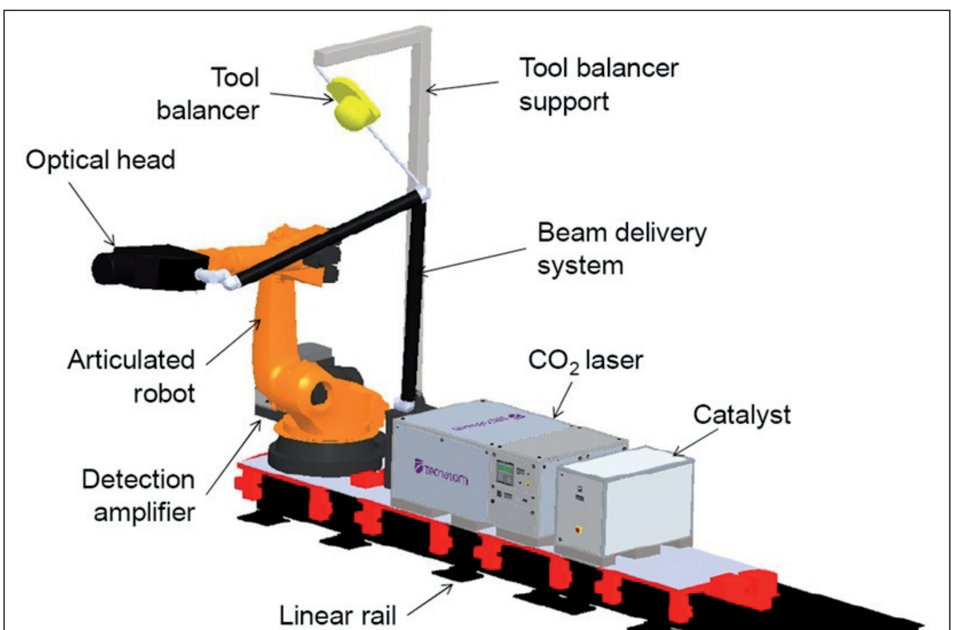
Although gaining working envelope is important, for industrial application it is incomplete without the addition of sophisticated ultrasonic data processing and system control to maximize the benefits of the robot-LUS systems. To save time on the production line, the high-speed inspection requirement has to be met by using an advanced data-acquisition system (DAS), based on state-of-the-art electronics, proven software for mechanical control, and UT-signal recording for evaluation.

These two elements, electronics and software, assure the high productivity and the reliability that industrial-manufacturing processes require. The data-acquisition and evaluation system that is part of the Tecnatom-iPhoton Solutions' approach has the capability to exchange ultrasonic data with other current and future formats. Other productivity tools have been also considered in the data-acquisition and evaluation software: an automated trajectories generator, and an automatic defect-analysis and evaluation module. Figure 6 shows an example of the processing results of a full fuselage inspection.

The new concept for UT inspection represents an important advance toward the widespread adoption of LUS by aircraft manufacturers. The significant reduction in cost, compatibility with current robotic systems, ease of installation, and small-plant footprint are among the advantages that make the difference. The flexibility and tolerance of LUS to the morphology of parts and its simplicity of operation make it a productive and competitive option compared with traditional alternatives.

The addition of a tool like DAS, developed with years of experience in conventional ultrasonic inspection, will contribute to the success of the LUS technique in aerospace manufacturing. Proven electronics, data-acquisition, and evaluation software will help to facilitate the transition from conventional ultrasonic technology to LUS. New advances, such as automated generation of inspection trajectories and an automatic evaluation module can be included in the inspection process, further increasing the productivity of LUS. ∎

> **“The high-speed inspection requirement has to be met by using an advanced data-acquisition system (DAS)”**



An application using the cantilever system

CONTACT

Antonio Tanarro is the manager of diversification and aerospace business development, Tecnatom, Madrid, Spain, www.tecnatom.es

Advanced RVI to improve quality control

ADVANCES IN REMOTE VISUAL INSPECTION – FROM SIMPLE ENDOSCOPY TO 3D PHASE MEASUREMENT

> "Using inspection ports built into aero engines, video borescopes now account for most of the RVI tasks"

THIERRY LAFFONT

BY THIERRY LAFFONT

What cannot be seen by the naked eye is the basis of all non-destructive testing techniques. Ultrasound is used to identify flaws and corrosion in metals and especially in welds. Radiography is used to examine castings and pipes for inclusions, delaminations and other defects. Eddy current is used to examine laminar surfaces for hidden cracking. Remote visual inspection (RVI) is widely used throughout the aerospace industry for examining the insides of a wide range of aircraft components and structures, from engines to airframes. Recent advances in RVI have seen big improvements in the imaging and measurement capabilities of the technique.

RVI is a long-established inspection and non-destructive testing technique in the aerospace sector. Although conventional rigid borescopes are still widely used in the industry, using inspection ports built into aero engines, video borescopes now account for most of the RVI tasks. They find application in the military and civil sectors inspecting airframes, APUs, and engines. They are used as part of MRO routines, as well as by OEMs during engine build. They can be used to inspect for leaks, corrosion, and surface cracking and to check internal gaps, as well as identifying the reasons for blockages and detecting foreign objects. With such a wide range of potential uses and requirements, it is not surprising that video borescopes have developed considerably over recent years.

The evolution of RVI

Industrial endoscopy has its origins in the medical sector; the very first endoscope was developed in Austria in 1806 'for the examination of the canals and cavities of the human body'. But the medical authorities of the time disapproved of the procedure, and it wasn't until 1822 that an endoscope was first introduced into a human body.

Industrial endoscopy only began in earnest after World War II. Early instruments consisted of a lens and illuminating light source, connected to a light-transmitting extension, which ended in a viewing eyepiece. These basic borescopes were used solely for visual

3D phase measurement in action

An XLG3 with onboard PC

inspection, with no means for measuring. As such, they found application in inspecting inaccessible locations or in locations where normal access was denied because of interfering structures or components.

Image capture and measurement capability were introduced into industrial endoscopy in the 1960s, when 35mm still cameras complemented eyepieces; these developments were followed by the introduction of fiber optics as the light-transmitting mechanism and the adoption of video cameras as the preferred method of image capture. There have also been important improvements in the functionality of video borescopes with the introduction of onboard computing power. This has allowed borescopes to offer the capability to save and store video images in digital format. The capturing and storage of digital data was formerly achieved by floppy disc and video tape. This technology then advanced to include CD, DVD, flash media and solid-state memory cards, so that files could be transferred to a PC for further assessment or storage.

Sharing of inspection information is a vital part of any inspection procedure, especially in the aerospace sector, where safety and economics often require expert assessments of engine fitness for purpose. Consequently, the ability to share information is a feature that has been particularly addressed in the latest generation of RVI instruments.

Handling the data

Introducing onboard PCs to RVI has also allowed the introduction of application software to ensure that the vast amount of generated data is efficiently managed. Such software tags images and arranges them in logical files to allow quick and easy access. Instruments such as the XLG3 from GE's Inspection Technologies business use the DICONDE (Digital Imaging and Communication in NDE) format. This is a non-proprietary format, developed from DICOM used throughout the medical sector in radiography, but incorporating many features that are purely NDE-focused.

This protocol forms the basis of GE's Rhythm software platform, which can acquire, report, review, and archive data. It also features important application tools, including image enhancement, manipulation, and zoom.

In the aerospace sector, which often struggles to cope with ever-increasing amounts of inspection information, the archive feature is especially relevant. It accepts images from any number of LAN-connected, remote Rhythm Review workstations and stores these using various compression techniques to save storage space without sacrificing image quality. Input and retrieval of information is quick and easy, by virtue of the simple DICONDE tagging system. Furthermore, Rhythm Archive stores not only the raw inspection data but also any enhanced images developed at a Rhythm Review workstation. It also offers other user benefits, allowing more efficient data searching, as all information from all workstations in the network is available at one central repository. The system can control image information workflow so that data can be routed to other Rhythm Review workstations for further analysis. It can enable productivity improvements by as much as 50%, because pre-inspection plans can now be formulated more efficiently by taking actual inspection history into account. A similar order of productivity improvement can also be achieved in post-inspection, as only relevant inspection data needs to be sent for further analysis.

Making it simple

Software is also available to standardize inspection procedures to ensure consistency of inspection and presentation of inspection results. Menu Directed Inspection (MDI) is a software solution that provides a guided inspection, where context is added automatically. For example, when inspecting an engine a drop-down menu will first allow an inspector to select the relevant manufacturer and specific engine. All the identification data relevant to the task (inspector, site, date, etc) is then input before the inspector carries out the inspection in the manner specified for that engine and component. The data image file is then tagged with annotations and filed within the

Right: remote analysis of inspection data

Below: A rigid borescope

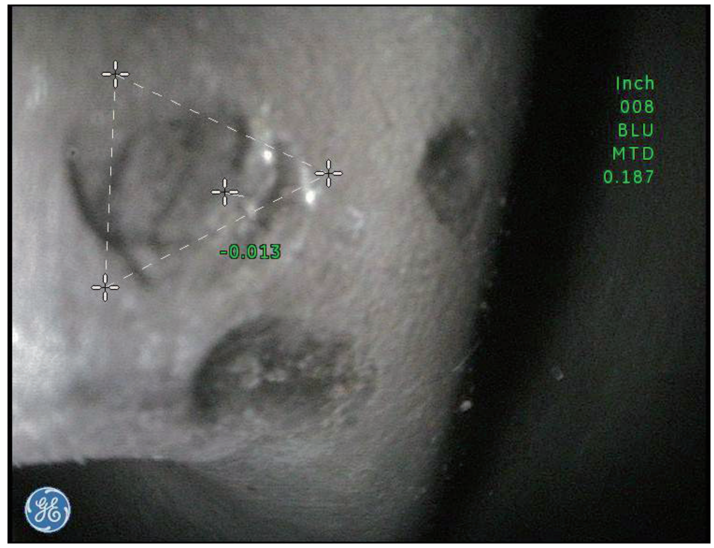
borescope's data capture system. Finally, a hardcopy report is produced with a convenient click-to-report feature.

The measurement of flaws, discrepancies and clearances is often just as important as their detection and identification. To date there have been three major measurement systems: comparison measurement, stereo probe measurement, and shadow probe measurement.

Comparison measurement is based on a known reference dimension in the inspection image, which is used to measure other objects in the same view and plane. The reference dimension is often set in place by the instrument manufacturer or otherwise introduced with the probe.

Stereo probe measurement uses a prism to split images, allowing the camera to capture left and right views with a precise angle of separation. The position of user-place cursors is then analyzed using a computer algorithm, and a triangulation geometry is applied to obtain accurate measurements.

Shadow probe measurement relies on a shadow triangulation of tip-to-target distance. A shadow probe projects a shadow across an inspection image, and the position of the shadow in the image indicates the distance to the object. With this information the shadow probe system can accurately calculate the size of user-selected features or defects. Typical measurements afforded by these measurement



Cursor positioning with phase measurement

methods are depth, length, area, point-to-line, multi-segment length and circle gauge.

Phase measurement

Even with the current range of measurement techniques, measurement remains the most difficult aspect of using video borescopes. Operators must be highly trained and practiced to obtain reliable and repeatable results. This expertise level has been addressed, because RVI is now professionalized as an official NDT discipline and is a module within ASNT's TC1A Level-III testing and certification process.

However, significant advances have been made recently in improving the accuracy, repeatability and ease of use of video borescopes with the development of phase measurement, which is now available with GE's XLG3 instruments.

Phase measurement is based on an existing optical metrology technique and involves projecting line patterns onto a surface, capturing the patterns in a video camera with high-quality viewing optics, and processing the images using proprietary algorithms to produce a point cloud, 3D map of the entire surface. This is then used in conjunction with measurement to obtain more precise information of the defect or object being viewed. Measurement itself simply involves the placing of cursors on the full-screen image, with no need for the point matching, shadow identification or dot selection steps that can be challenging with other techniques.

An innovative feature of this new measurement system is that the 3D scan can be rotated and zoomed to provide enhanced indication of the part's size and shape. Further assistance in assessing a part's size and shape is provided by the system's profile view feature. This is achieved when the user positions cursors on either side of an area of interest and the phase measurement system draws a line between them. Profile view is then selected and a cross-section of the part along that line is displayed, helping to visualize the shape of a pit or crack or corrosion area. At the same time, profile view can also be used to measure depth at points along the cross-section.

Measurement using stereo and shadow can be time consuming as well as requiring expertise. For example, with stereo measurement it is first necessary to spot the defect using a non-measuring optical tip. This tip must then be replaced with a stereo tip, the defect must be relocated, the image is frozen, the cursors are matched and the measurement is taken. With phase measurement, the defect is located, the image is frozen and measurement is carried out. There is no need to change the tip.

As there is no need for the point matching, shadow identification, cursor matching or dot selection steps associated with other measurement techniques, 3D phase measurement offers greater ease of use. This means fewer operator mistakes and more repeatable and accurate results.

Potential applications

An important application of the new technology is the measurement of aircraft engine tip to shroud clearance. Aircraft engines and other axial flow turbo-machinery are typically designed to minimize the radial gaps between the blade tips and the blade housing or shroud. Gaps between tips and shrouds can reduce efficiency by allowing gas or air to leak into the downstream stages. Consequently it is very important to check this clearance, both during manufacture and also during service as the gap changes during engine operation. (High operational rotating speeds and high temperatures can cause radial elastic growth of blades, as well as thermal expansion of the shroud.)

Historically, one method of measuring tip/shroud clearance has involved inserting a thin metal rod into an axially drilled bolt, and attaching this assembly to the fan case so that the end of the rod is positioned where the blade tips should be. After the engine has been operated, the amount of wear on the rod is measured. Obviously this is not a high-accuracy technique and its execution often generates problems such as the liberation of metal from the rod, which can cause damage to the engine.

There have been many advances in RVI since the early days. Imaging quality has greatly improved as a result of fully digital data streams and improved optical and illumination technology. The integration of onboard processing has expanded RVI's versatility and greatly facilitated data sharing though connectivity. Application-specific software such as MDI has helped improve probability of detection, while reducing the occurrence of false calls. Sophisticated data acquisition, review, reporting and archiving software platforms allow the accumulated data to be organized efficiently and utilized to best advantage. Now easy-to-implement, innovative RVI measurement techniques can provide fast, accurate results with more comprehensive imaging to improve quality control during manufacture and to allow smarter, more efficient in-service inspection. ∎

Thierry Laffont is global key account manager, Aerospace at GE Sensing & Inspection Technologies

Wire identification system

A SYSTEM TO ASSURE CORRECT PLACEMENT OF LABELED AND COLORED WIRES IN HARNESS AIRCRAFT ASSEMBLIES

> "If you swap the misplaced wires on the end where the error occurred, all is well"

BRENT STRINGHAM

BY BRENT STRINGHAM

When building wire harnesses it is imperative that they are wired electrically correct so that there are no opens, shorts or mis-wires. But what about harnesses that have wires with unique wire IDs on each wire, or different color wires, or wires of the same color but different lengths and or gauge?

Many times wiring harnesses are built with all the same color wire with no markings. In this case it is critical that they are wired correctly, but it doesn't matter which wire goes into which cavity, assuming that all wires are of the same length, gauge and insulation.

In some cases assuring electrical correctness is not enough. If harnesses contain wires with unique labels, wire IDs, or different colored wires, or wires of mixed length/gauge, it is essential that all of the unique wires are in the correct cavities of the correct connectors on both ends.

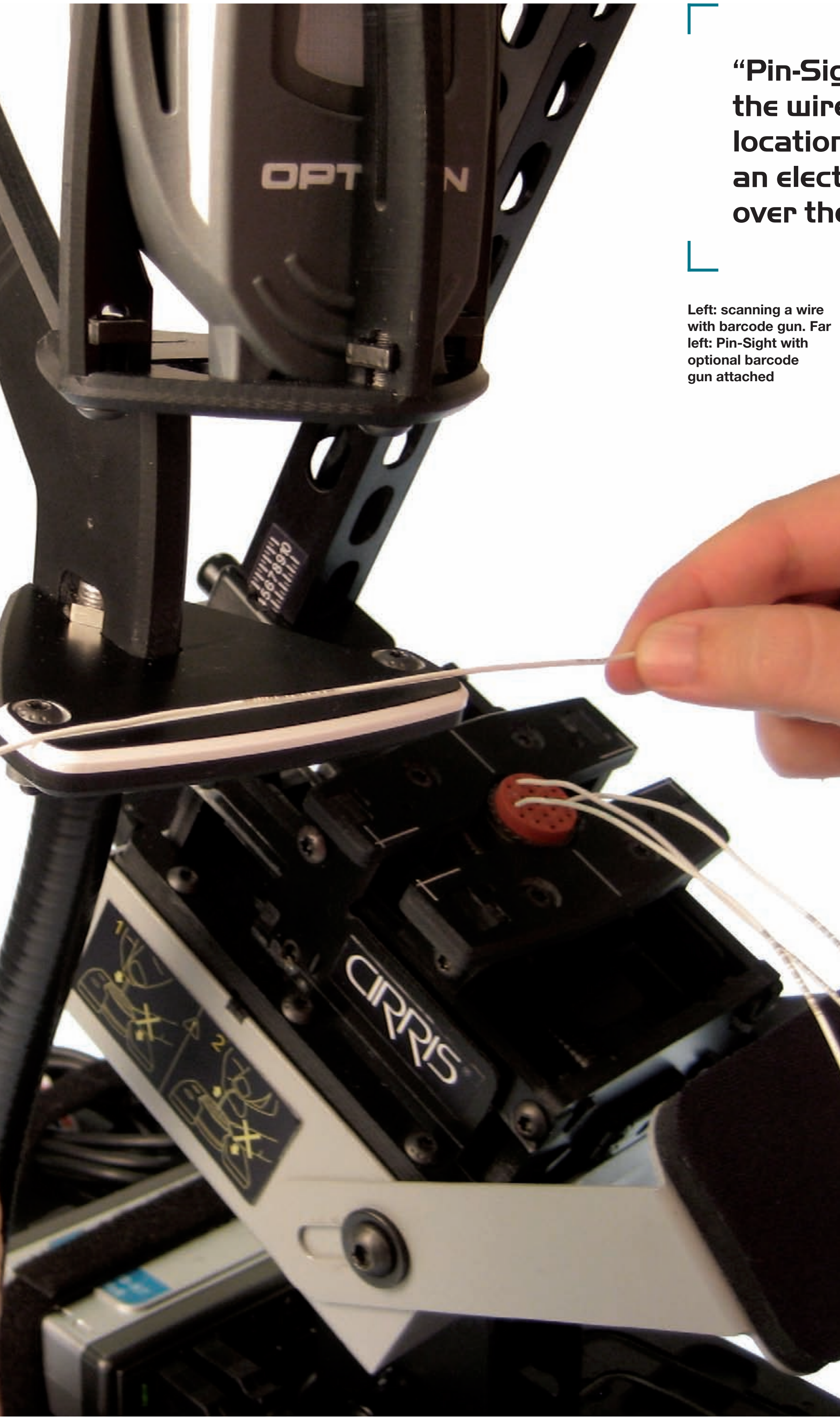
Two key examples of wiring errors that can happen that may pass electrical testing, but will result in a defective harness include: electrically correct, but wrong labels or colors, and during assembly, two wires are swapped in one connector of a harness. The crossed wires are detected during the final electrical test, the error showing up as a 'mis-wire'. You now have a 50/50 chance of fixing the error on the correct end. If you swap the misplaced wires on the end where the error occurred, all is well. If, however, you fix it at the opposite end, you now have a correct path for electricity, but you have two wires that have been swapped, so you have the wrong labels, or colors, in two connectors. This doesn't matter as far as the electrical properties of the cable are concerned, but sometime in the future, a repair technician who is troubleshooting a wiring problem, with only a schematic wiring diagram in hand, may be fooled into thinking he's found a crossed wire, when in fact, it is a wrongly labeled (colored) wire. He then 'fixes' the mis-wire, not only not correcting the problem he's troubleshooting, but introducing an entirely new error!

The second wiring error can be described as, correct wiring pattern but wrong length or gauge wires used. If a harness has different lengths/gauges of wires, it is possible to use a wire of the wrong length or gauge yet still get a harness that 'passes' electrical testing. Depending on the amount of resistance variation due to length/gauge differences, and the sensitivity of the tester being used, if the wiring pattern is correct it will likely pass testing. If the variation is great enough, and highly sensitive (usually 4-wire Kelvin) test methods are used, it is possible to catch these errors with electrical testing, but in practice, it is unlikely. Physical inspection can catch these types of errors, but often they get into the field, where they are found by the customer when trying to fit the harness into its intended application (doesn't fit due to wrong wire lengths) or when equipment doesn't function properly (due to mismatched impedance or other electrical issues caused by wrong gauge wires).

Tool places correct colored wires

At the request of several key customers seeking a solution to these wiring problems, Cirris Systems Corp, a leading manufacturer of cable and wire harness testing equipment, recently introduced a new production tool designed to help eliminate such errors. Pin-Sight, is a new guided pinning tool that enables operators to quickly and easily identify unique wires, whether colored or labeled, and be confident that they are placed in the correct cavity.

The common existing method for inserting labeled wires into connectors goes something like this. An operator picks up a wire, reads the label, searches a paper list to find which cavity that wire goes into, looks at a printed template



> "Pin-Sight instantly 'speaks' the wire color and cavity location. It also places an electronic target circle over the cavity"

Left: scanning a wire with barcode gun. Far left: Pin-Sight with optional barcode gun attached

of the connector to find the location of the cavity, then inserts the wire. Depending on the experience and skill set of the operator, this process can take anywhere from 10-30 seconds, or more, before the operator even begins to insert the wire. Using Pin-Sight the operator picks up a wire and enters the label. Pin-Sight instantly 'speaks' the wire color and cavity location. It also places an electronic target circle over the cavity that the operator can clearly see on the monitor. A real-time video camera allows the operator to 'see' him/herself inserting the wire, making it clear that it is in the correct cavity. Actual time studies have shown that this process cuts the average time down to as little as five seconds for the operator to identify where the wire goes.

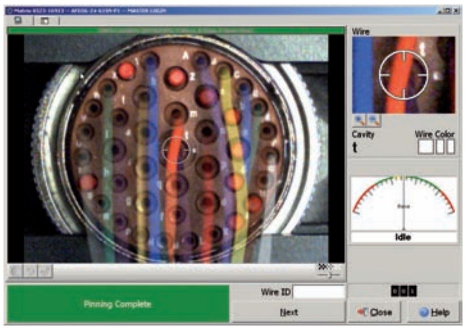
Transparency feature

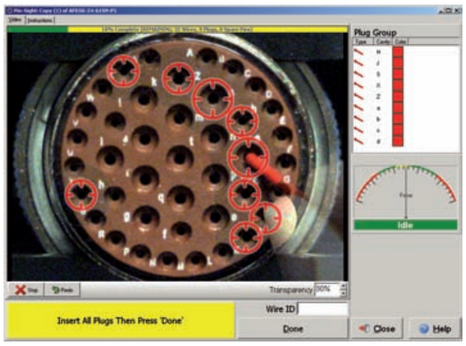
After the operator loads the connector into Pin-Sight, he/she aligns it using two target cavities as specified by the software. Pin-Sight then takes a digital picture of the connector. With this as the background, a transparency level can be selected which portrays the real-time video at less than 100%. This 'ghosting' image gives the effect of being able to 'see through' your hands and wires as they are installed. This is especially useful on large pin-count connectors. As the wires are loaded, the operator can still clearly see the target cavity for the current wire to be inserted.

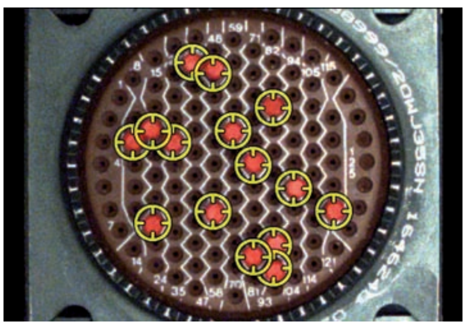
Cirris has further improved the throughput capability of Pin-Sight by developing several methods for the operator to quickly and accurately input the wire ID into the machine. For wires with printed barcodes, a barcode reader option is quick and accurate. For wires without barcode IDs, the operator can quickly enter the wire ID using a 10-key keypad, or computer keyboard. Another effective method is for the operator to speak the wire ID into a headset microphone. This technique is especially effective using Microsoft Window's new version 7 with enhanced text-to-speech capability. Also, based on the wire IDs of the connector being pinned, the Pin-sight software determines how many characters are needed to get a unique ID. In many cases only the last two or four characters are needed to assure uniqueness, so the operator doesn't have to speak or key in an entire long number in these instances.

Fast set up times

For Pin-sight to be practical, users require fast set up and changeover times. This is accomplished through several key features of the







Above: guided insertion of sealing plugs. Quick and easy inspection that all seal plugs are inserted correctly. Transparency setting lets you "see through" installed wires

Left: harness with colored wires

Operator installing labeled wires using Pin-Sight

Pin-Sight. There are no mating connectors required. An important usability feature of Pin-Sight is that it does not require any kind of wired mating interface. The connector to be pinned is inserted directly into the connector holder and held tightly in place via a clamping device. This is particularly key for users who have low volumes and a high mix of connectors to be pinned.

Users can create and add their own connector images into the Pin-Sight database, although Cirris now has an optional connector library with over 10,000 mil-spec connectors available instantly, simply by entering in the connector part number.

Pinning data for connector-build programs can be imported from .csv file formats. In addition, optional software can track real-time engineering changes, alerting operators on the floor of changes required in connectors currently in the assembly process. Wiring change information includes unpinning and re-pinning instructions for partially completed assemblies and this can be provided.

Many Mil-Aero wiring shops use a 'first-end second-end' process where connectors are fully populated on the 'first-end' side, then routed on a harness board and populated on the 'second-end' side. If the accuracy of the first-end process is ensured using a tool like Pin-sight, then guided-assembly/test equipment can be used to help the operator quickly and accurately populate the second-end side. This also enables final electrical test on the harness board, eliminating the need to take completed harnesses off the board to be tested.

In addition to assuring correct placement of labeled/colored wires, Pin-Sight performs a contact retention test, forcing the operator to pull-back on the wire with sufficient force to guarantee it is truly locked in. This task is accomplished through a force sense gauge built into the Pin-Sight base.

Pin-Sight is also an ideal tool for quickly and accurately placing spare pins and seal plugs into connectors. Generally, these are inserted prior to inserting wires. Spare pin and plugs are programmed in groups, so the operator sees a set of target circles, one around each cavity to receive a pin/plug. Again, through the real-time video feed the operator sees herself entering the pins/plugs into each of the circled cavities. When finished it is very obvious if a pin/plug has been missed, or placed into a wrong cavity. By assuring that all spare pins/seal plugs are correctly placed, it eliminates the possibility of them being in a cavity that should receive a wire later in the assembly process.

Results reported

There are now more than 100 machines in the field and Cirris reports impressive results from early users, which include high and low volume wire-harness manufacturers and repair and maintenance depots. Data shows increased productivity from 20-50%, with corresponding reductions in errors. Other noted benefits are decreased operator eye-strain and fatigue, and significant improvements in training time and the accuracy of new assemblers. ∎

A short video demonstration of Pin-sight can be seen at: http://www.cirris.com/testing/guidelines/pin-sight-video.html

CONTACT

Brent Stringham, director of global sales and marketing Cirris Systems Corp, Salt Lake City, UT, USA
Tel: +1 801 973 4600
www.cirris.com

Hydraulic test benches

A MODULAR CONCEPT ESTABLISHED FOR HYDRAULIC AND GENERATOR TEST BENCHES

BY MICHAEL SCHILLING

"Clustering of single aircraft components brings a significant scale effect to an MRO company"

MICHAEL SCHILLING

Low lifecycle costs, excellent reliability, optimized turnaround times for component testing and top quality are the requirements of the company's worldwide customers. These values were the design targets for the new modular concept for all hydraulic and power generating components.

The pressure on price and the necessity of reducing lead times (time to market) no longer allows special customized solutions to be made with their one-off development costs, longer lead time and the risks being borne by one customer. The target of developing modular test benches is to test various aircraft components more cheaply, rapidly and in an environmentally friendly manner. An affordable price can only be achieved by off-the-shelf designs and components. The modular design of the test bench enables testing a combination of different components according to requirements.

A solution for complete hydraulic testing involves the new modular hydraulic concept, which covers all aspects within the field of hydraulic components. The concept is based on two elements: hydraulic power generation and test benches. The combination of these elements enables Test-Fuchs to offer the whole range of hydraulic applications for 3,000 and 5,000psi technology.

Hydrualic components

The PU-module is designed to supply Skydrol or other oils (MIL-Standard) to the test benches and is available with different performance parameters. Test-Fuchs can offer the best economic solution to the customers. Due to the integrated regulation system, the PU-module impresses with a continuous supply of pressure and flow in a very small tolerance band. All parameters can be controlled via an optional tablet PC. On request the PU-module is available with sound-absorbing elements to fulfill all health and safety regulations.

With the test bench modules customers are able to cover all hydraulic components within the airline industry. Components from the general business aviation and the newest civil aircraft like B787, A380 and A350 are easily adaptable. Additional components from all military programs, such as the A400M, the Typhoon, and the Rafale are adaptable for tests without additional effort.

The development of the test benches is based on four pillars. First, testing according to CMMs or other OEM documents is the guideline for all activities. Second, is the optimization and minimization of changeover- and test times. Ergonomic and safety elements for staff operating the test bench are the third pillar. To guarantee best lifecycle costs, the fourth pillar is the focus on reliability and maintainability.

Modular hydraulic test stand for non-rotating components

Clustering of single aircraft components brings a significant scale effect to an MRO company. Different components can be tested on one single test bench. As a result a maximum usability of the test equipment is given. To cover all hydraulic parts within the airline industry, two modules, the MP-module (motors and pumps) and the NR-module (non-rotating units) were developed. To support the OEM customers the test-bench modules can be customized for single component groups. Pooling of similar components combined with a high automation rate result in minimized test-times for the OEM.

Due to the experienced and well-trained personnel, highly complex aircraft components like flight-control units, power-transfer units, engine-driven pumps, brake servo valves and hydraulic-control units are no longer a difficult and expensive undertaking. Test-Fuchs is in the position to support the operating staff, establishing the best practice solution in the aircraft industry.

Small details of the modular-test concept support production and optimize processes. For example, the adapter plate for up to 9,000psi hydraulic pressure enables the test engineers to prepare the component outside of the test bench and reduces usability time of the test bench. As a result, more units can be tested in a shorter time making a higher contribution to financial production figures.

Power-generation components

The success of the modular hydraulic-test bench concept confirmed the company's decision to apply the new philosophy to other technologies. The first modular test bench for aircraft power-generation components is already in production and will be delivered to a well-known MRO player this year.

Undertaken in consultation with the customer, the development of the LMP300 will be the most comprehensive version of the company's aircraft-power generation components-testing equipment. This test bench is capable of testing all power-generation components (IDG, generators, CSD) installed on various aircraft types from the Embraer and Q400 up to the A380 and B787.

In the field of aircraft power-generation test equipment, the focus is on low lifecycle costs, excellent reliability, optimized turnaround times for the component tests, and Test-Fuchs quality. The customer can choose between different modules to customize the test bench according to the requirements of the aircraft and the component portfolio.

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

With the different size of power compensation systems the best economic solution to the customer is available. Adaptations to specific environmental impacts are easily possible. The proven cooling system is capable of dealing with the different climatic zones worldwide and guarantees stable and reliable operation.

The newest technology for the drive- and compensation unit causes a competitive advantage to the customers. Duration between maintenance increases and shut down time of the test equipment is reduced.

The concept supports a high degree of automation and optimizes test times. Easy and fast adaptation of the unit under test was one of the key elements during the development process. The easy and fast coupling system reduces the installation time of the units under test significantly.

Base for success

With the modular approach, the company is in the position to offer a concept which fits exactly the needs and requirements of each organization. Based on manual testing, automation is extendable to fully automated test runs. The data-acquisition system guarantees stable, accurate, and repeatable measurements. All measurement and control elements are visualized on a user interface. According to customer requirements, this can be realized as a touchscreen, dual-screen system, or a fully integrated screen solution. All parameters are stored. Protocols in hardcopy and the traceability of all measurement results is standard.

The measurement- and data-acquisition system is significantly improved. During intensive testing performance, EMC conformity and temperature influence was evaluated. The new platform offers 64 measurement channels with a read time below 30µs. A special focus during the development phase was reliable operation in different climate zones. Tests showed that temperature changes have no impact to the performance of the measurement system. The system is able to regulate complex functions within 200µs.

Complex universal electrical control loops for different components, such as flight-control actuators, are available and can easily be implemented to different test applications. All test equipment is designed according to OEM requirements. If alternative test setups are suggested by Test-Fuchs, the development process is documented and fully traceable. By customer request, documentation to the ARINC 665 standard is available.

Test center and showroom

The company has invested in a customer test center because future developments are only possible if customer and supplier work closely together – development and product improvement never stops. The company welcomes technicians to the Austrian customer test center and is ready to work with them on the test benches, to gain the best results, specific aircraft components are highly appreciated.

With the company's experience in the aircraft industry, Test-Fuchs is able to offer a complete package beginning with expertise for defining the best technical solution, dealing with infrastructure and regulation issues, followed by production, commissioning, and installation of the equipment. After handover of the equipment, our support department takes care of everything.

The modular test benches are already in service and an international team is a guarantee for a successful project with experienced and motivated engineering teams supporting ideas and further developments. All processes are ISO 9001 certified. ▮

CONTACT

Test-Fuchs GmbH

Test-Fuchs Strasse 1-5, A-3812 Gross-Siegharts

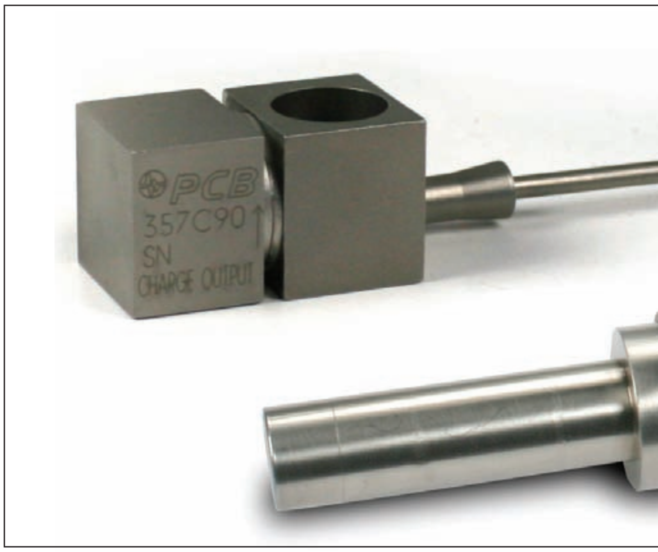
Tel: +43 2847 9001 125

c.fuchs@test-fuchs.com

www.test-fuchs.com

Sensing a change in temperature

RECENT DESIGN UPDATES AND SELECTION CONSIDERATIONS FOR HIGH-TEMPERATURE AND CRYOGENIC AEROSPACE SENSORS



> **"Ferroelectric ceramics exhibit higher sensitivity or charge output per imposed unit of force"**

BY MARGIE MATTINGLY

Accelerometers and pressure sensors for measuring in extreme environments need special consideration during the design and manufacturing process. Specialized applications frequently require the use of a single sensor model, which must be capable of operating over temperature ranges from -420 to +1,200°F (-251 to +649°C), and of giving high accuracy, stability, and reliability.

Typical applications for high-temperature aerospace sensors include measuring gas turbine engines in-flight and in test cells, as well as rocket motors and thruster assemblies. The same sensor might be required to withstand radiation and be used to monitor the vibrations inside a nuclear power plant or on a space vehicle, or the cryogenic properties of liquid propellants. These environments present many challenges. Materials and construction must be optimized, not only to enhance high-temperature performance, but also to allow operation in the presence of gamma and neutron radiation without degradation.

Material selection

Piezoelectric sensors are made from both natural and ferroelectric ceramic crystals. The choice of crystal depends on environmental and performance requirements. Each material has unique features and advantages, which characterize its performance in various applications. Natural crystals tend to provide the highest temperature ranges and the lowest pyroelectric outputs. However, ferroelectric ceramics offer extended frequency ranges and smaller sizes for equivalent charge outputs.

Single, natural crystals, such as quartz or tourmaline are inherently piezoelectric. Most natural materials are single crystals grown in laboratories rather than mined, which results in consistent quality with a reduced risk of supply. In addition, the man-made aspect of a natural crystal enables development of new, higher performance variations.

Ferroelectric ceramic materials on the other hand are not inherently piezoelectric. A ceramic is composed of many crystals in random orientation. For the ceramic to become piezoelectric the dipoles must be aligned. The alignment/polarization process involves applying a high voltage to the material to align polar-regions within the ferroelectric ceramic element. This process is known as poling.

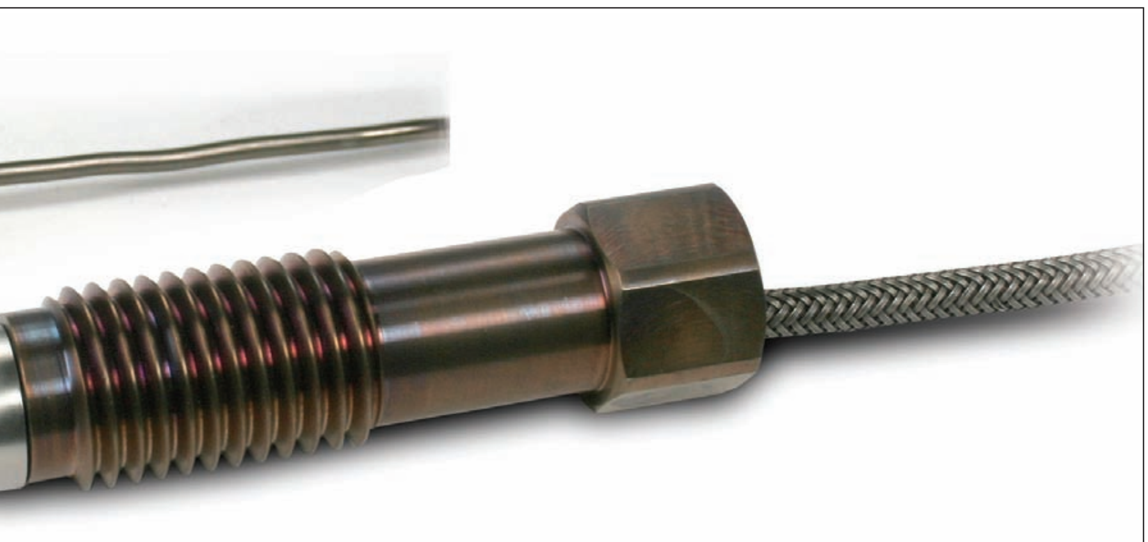
Ferroelectric ceramics exhibit higher sensitivity or charge output per imposed unit of force. The most common material, bismuth titanate, has an output ten times that of the most common high-temperature natural crystal, tourmaline. Bismuth titanate can be used up to 950°F (510°C). Various compounds may be added to the ceramic material to alter sensor characteristics but high temperature ranges come at the expense of sensitivity.

A natural single-crystal material can be employed in either shear or compression mode. In compression mode, the material creates an electric charge in the same direction as the applied force. Lead zirconate titanate (PZT) is a ceramic material that is widely used in temperature environments as high as 550°F (288°C). In shear mode, the material creates a charge in the direction perpendicular to the applied force. PZT can be designed into sensors using both shear and compression mode, but is most efficient in the shear mode since it has a

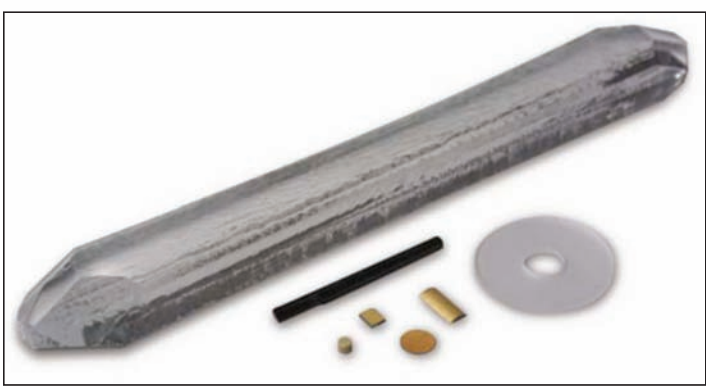

BY MARGIE MATTINGLY

Left: 900°F (482°C) accelerometer and pressure sensor with removable cable

Right: Differential 900°F (482°C) accelerometer for turbine engine monitoring



Above: 1200°F (649°C) accelerometer and pressure sensor with attached cable



Left: Examples of quartz, tourmaline, and ceramics

higher charge output and upper temperature range. Typically, shear mode configurations are more efficient than compression because there is greater bandwidth and higher output with smaller size. In addition, since the required preload force that holds the crystal in place is perpendicular to the polarization axis, a shear design has extremely stable output over time. This enables extensive design flexibility and performance optimization.

There are numerous temperatures, bandwidths, mounting, and other trade-offs that must be considered in high-temperature applications. Temperature effects exist beyond the limitation of the operating environment. Temperature changes may produce extraneous outputs and may change the sensitivity and other parameters. Piezoelectric sensors cannot produce an output in response to a constant temperature because they cannot produce an output in response to a constant input: they are self-generating. They can, however, produce an output in response to a change in temperature.

The piezoelectric element itself is often pyroelectric; that is it generates an output in response to temperature. In addition, temperature or temperature gradients may change the preload stress on the element because of thermal expansion. Temperature change inside a sensor, where output would be affected is relatively slow due to the thermal transfer. Therefore, thermal outputs are at low frequencies where they are attenuated by the low frequency of the system. For this reason, thermal output is not usually a problem. Sometimes piezoelectric sensors can show sharp spikes in their output after a large temperature change; this can be related to electrostatic surface discharges in the pyroelectric fields. Spikes that continue after a pyroelectric discharge can be related to both the piezoelectric material and the design of the individual components and the processing of the sensor.

A design that utilizes ferroelectric ceramics materials in compression mode will have a greater pyroelectric output than that of a piezoelectric shear design or one using a separate natural crystal.

This is because of two effects: in compression mode accelerometers, piezoelectric material is directly coupled to the environment through the base of the sensor. Also, the ferroelectric material is sensitive to uniform temperature changes on those surfaces perpendicular to the axis of polarization.

However, pyroelectric output is a very low frequency phenomenon that is typically well below the frequency ranges of interest and can be avoided by the use of high-pass filtering within measurement system electronics.

Challenges

The maximum operating temperature of these sensors is controlled by two design challenges: the first is a property of the piezoelectric material known as the Curie temperature in piezoceramics, or the twinning temperature in natural materials. This is the temperature at which the material loses its piezoelectric properties.

The second design challenge is a sensor's insulation resistance, which decreases rapidly with temperature. A low insulation resistance charge amplifier and charge converters must be specifically designed to operate with sensors having low insulation resistance values. If the charge output is being measured, the frequency response will not be affected, but the low frequency noise will tend to increase. And some charge measuring equipment will not tolerate low input resistance and will clip the output signal. Ordinarily, the leakage resistance of a sensor is understood and the appropriate signal conditioning is used so there will be no noticeable effects.

Whenever a sensor is exposed to temperature changes, other parameters such as sensitivity and sensor capacitance also change. Changes should be predictable and repeatable but every component and process associated with building the sensor are influenced by the crystal material. Manufacturers should test every high-temperature sensor at its maximum operating temperature to be sure of consistency and quality.

Successful measurements

Successful high-temperature measurements require more than just good sensor design. Cabling and electrical connections are critical to the acquisition of good quality data. A loose connector can result in the generation of a high-level, low frequency signal that is not related to the measurement. Over time, the reliability of connectors can degrade at temperatures above 900°F (482°C) due to oxide formation on the pin-to-socket contacts and potential loss of pin retention. The result can show up as a roll-off in the output of the sensor at higher frequencies.

Sensors designed for temperatures up to 1,200°F (649°C) are therefore fitted with integral cables, which are mechanically isolated from the seismic system to avoid base and cable strain effects. Cables provided might use magnesium oxide or silicone dioxide insulation. The latter is preferred since it is non-hydroscopic and exhibits excellent high-temperature electrical characteristics.

Careful selection of the cable material and use of protective over-braid facilitates handling and allows bend forming during installation while maintaining cable integrity. The braid provides flex to rigid cables and protects it from getting nicked or damaged. Cables should not be bent under two-and-a-half times the diameter of the cable as it may damage internal insulation or affect dielectric properties. Cables on accelerometers should be clamped at approximately 8in (20 cm) intervals to prevent excessive flexing during vibration. It's important to provide clearance between cables and other components on the structure to prevent abrasion during vibration.

An accelerometer must be coupled with the surface it is measuring. As a result, bending of the structure or mounting bracket can cause distortion, producing unwanted output called base-strain sensitivity. If brackets have to be used, care must be taken to avoid introducing dynamic response problems due to bracket resonances within or near the operational frequency range. A thorough understanding of the modes of mounting brackets and adaptors is important for good data and it must be verified that engine resonance, bracket resonances, and sensor resonances do not overlap.

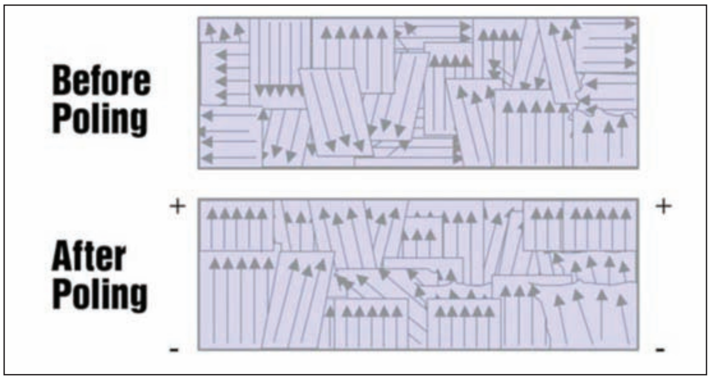
Piezoelectric sensors will operate normally when subjected to radiation-rich environments. Pyroelectric outputs will be produced when transient radiation produces significant temperature changes, but this is no greater than that produced within the standard temperature range. The magnitude of pyroelectric output depends on the type of piezoelectric ceramic used as well as the design. There should only be small errors produced as a result of temperature changes present in nuclear shock, with typical vibration applications resulting from Gamma radiation. Neutron radiation could cause changes in the molecular structure but only at extraordinary levels. Adverse reactions to radiation include a reduction of piezoelectric material output and the deterioration of various materials that are intolerant to radiation such as Teflon. Generally, higher temperature crystals are more resistant to the effects of radiation.

High-temperature sensor design is driven by their possible applications. In test and measurement applications, single-ended designs are used to minimize mass and size. Because of the wide array of test and measurement environments and associated conditions, high-temperature sensors feature numerous mounting and cable/connector configurations. With a single-ended system, the accelerometer has an inherent capacitance between the case and the signal side of the crystal. It would normally be susceptible to electrostatic pick-up without the use of an insulating base.

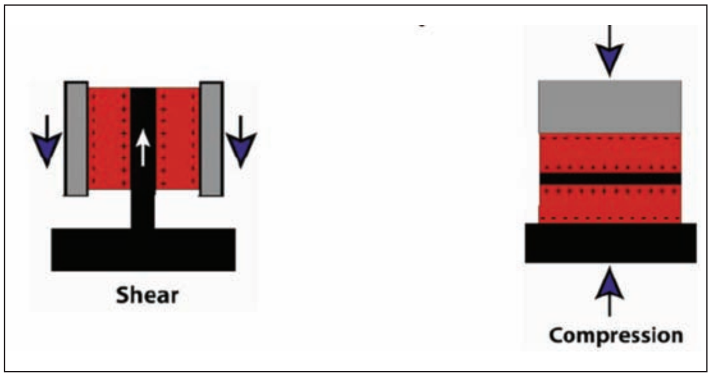
A general high-temperature category is used in permanently-mounted monitoring applications. This type of accelerometer is often referred to as a bill of material or OEM sensor because it is integrated into a customer's product line. These accelerometers are almost exclusively designed for each application. Unlike their test and measurement counterparts, the housings for these sensors are almost always electrically isolated from the measurement circuit and the charge output of the sensor is differential. Differential signal output is used where the capacitance balance between signals is important because the structure on which it is mounted is used as an electrical ground return. Capacitance balance allows differential charge amplifiers to distinguish between common mode signal (noise) and differential signal, which is the true measure of dynamic acceleration. Differential output is preferred when signals must be routed through multipin connectors where the individual shielding of conductors is not feasible.

Whether they are used in aircraft engines, space vehicles, or power generation stations, these sensors must provide high levels of accuracy, stability, and reliability. Therefore, the instruments used in extreme environments such as cryogens and high-temperature sensors require special consideration during the design and manufacturing process. ∎

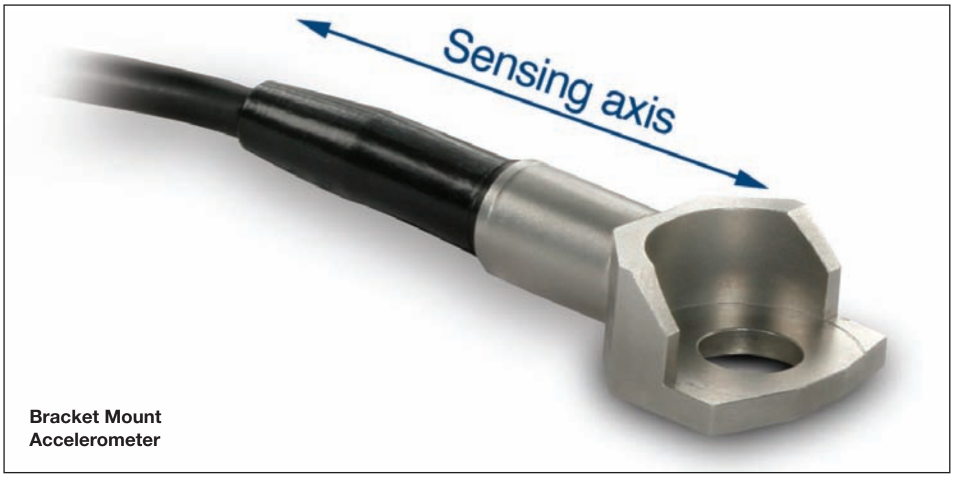
Margie Mattingly is a senior program manager with PCB Piezotronics



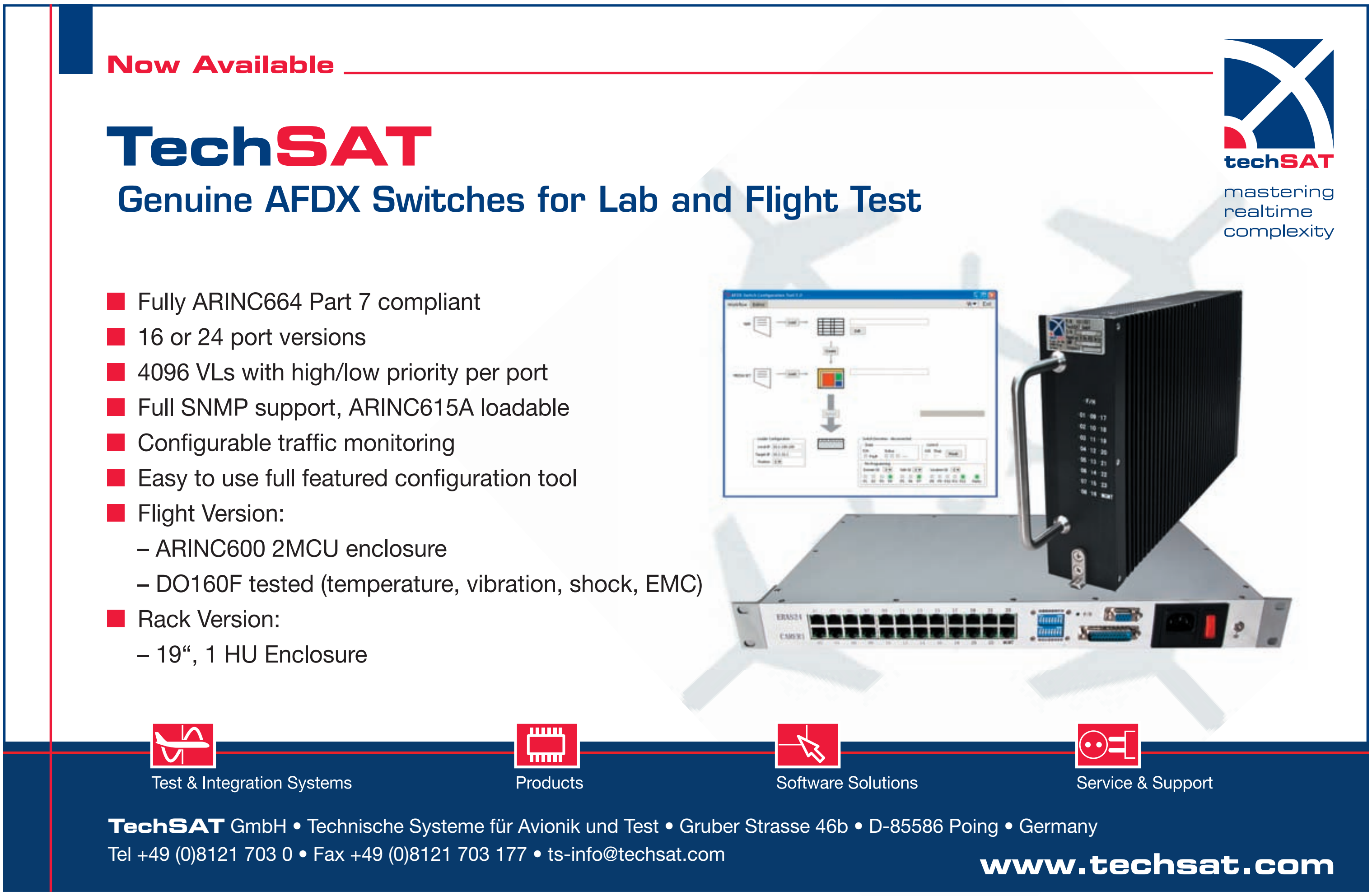
Left: Poling process - aligns polar-regions within the ceramic material



Right: Shear versus compression sensor design



Bracket Mount Accelerometer


Now Available
TechSAT
Genuine AFDX Switches for Lab and Flight Test
techSAT
mastering realtime complexity
Fully ARINC664 Part 7 compliant
16 or 24 port versions
4096 VLs with high/low priority per port
Full SNMP support, ARINC615A loadable
Configurable traffic monitoring
Easy to use full featured configuration tool
Flight Version:
– ARINC600 2MCU enclosure
– DO160F tested (temperature, vibration, shock, EMC)
Rack Version:
– 19“, 1 HU Enclosure
Test & Integration Systems
Products
Software Solutions
Service & Support
TechSAT GmbH • Technische Systeme für Avionik und Test • Gruber Strasse 46b • D-85586 Poing • Germany
Tel +49 (0)8121 703 0 • Fax +49 (0)8121 703 177 • ts-info@techsat.com
www.techsat.com


TEST-FUCHS
safety in test - safety in flight
HYDRAULIC
Test Bench for Fuel Components
PNEUMATIC
Modular Hydraulic Test Bench
Mobile and fixed test benches for all kinds of civil and military aircraft components. Everything from one source from concept to comissioning and lifelong after sales support.
FUEL
Hydraulic Ground Power Unit
Moveable Turbine Cleaning Equipment
ELECTRIC
ELECTRONIC
Generator Test Bench
TEST-FUCHS GmbH
Test-Fuchs Strasse 1-5
A-3812 Gross-Sieghart
www.test-fuchs.com
Tel: +43 (0) 2847 9001-0
Fax: + 43 (0) 2847 9001-299
mail: office@test-fuchs.com

Bus interfaces for ground systems

HOW A SWISS-BASED COMPANY SET UP ELECTRONIC BUILDING BLOCKS FOR AIRCRAFT TEST SYSTEMS

"With modern FPGA technology, virtually any interface functionality can be implemented on the same platform"

AKOS CSILLING

BY AKOS CSILLING

The requirements for test equipment are very diverse. They vary from one aircraft to the next, and also depend on the specific use of the equipment. It is also important to have a similar structure and compatible interfaces, to simplify the integration, use and maintenance of the system.

It is therefore logical to build modular systems, based on a limited number of hardware building blocks, flexible programmable devices, and coherent and stable software interfaces.

Partnership for success

Creative Electronic System (CES) has worked with the business division Military Air Systems (MAS) of EADS Defence & Security (at the time DASA – Daimler Benz Aerospace Aktiengesellschaft) for many years to develop building blocks for ground test systems. This collaboration dates back to the late 1980s when CES built the FIC-832x, a Motorola 68k-based VME processor board. Nowadays, the advanced integrated data acquisition and stimulation system (AIDASS) is the core product of all EADS MAS test systems, and CES CPU boards and interface boards are standard components of every test bench built on this foundation.

When CES designed the first multifunction computing core (MFCC), a combination of a PowerPC CPU and a user-programmable FPGA in a PMC form-factor, EADS decided to base a new generation of bus interfaces for aircraft ground-test systems on a combination of MFCCs and RIOs (PowerPC-based VME processors). The first successful interface board of this new family was a MIL-1553 interface built as a 'bundle' of a RIO2-8062 and two MFCC-8441. With this architecture, a wide range of bus interfaces could be built with the same hardware, simply by modifying firmware and software (an enormous advantage for test benches that require a wide variety of interface boards).

In the following years, the catalogue of interfaces supported expanded to cover essentially all standard avionic interfaces. Many new features were added, to support specific requirements for one customer application or another, including error detection and error injection. Currently, CES solutions are available for MIL-1553, EFAbus, EFAbus Express, PanLink, CCDL, ARINC-429, CANbus, IRIG-B, RS-232/422/485, AFDX, Gigabit Ethernet, digital video (SDI), as well as discrete and analogue I/O.

The international collaboration to define the common modelling and test environment (MaTE) for all Eurofighter ground test benches brought CES in contact with other partner nations such as Italy, Spain and the UK, and CES equipment was introduced not only in the implementations of MaTE systems, but also into the test-system designs of these other partner nations, bringing new ideas and requirements into the overall design.

To improve performance and to handle obsolescence, newer generation devices have replaced the underlying hardware platform. Nevertheless, the overall architecture and the application-specific software and firmware interfaces have remained the same. In fact, CES makes a strong commitment to handle obsolescence by providing functionally equivalent solutions at comparable costs when older system elements can no longer be produced. This commitment also affects software development, because it is the task of CES software packages

predefined block, with stable interfaces to the rest of the board. The infrastructure of the board, such as memory controllers, PCI bridges, and CPU interface is provided by CES, hiding the complexity of the particular platform.

In terms of software support, CES maintains a generic VxWorks BSP that is compatible with most VxWorks variants and versions, and at the same time supports all variants and versions of several generations of CES boards. Thus, the application software can be ported from one CES platform to another with minimal effort.

In addition, the generic VxWorks BSP has been extended with additional functionalities, to provide several general-purpose utilities that are widely used in test systems:

BP-Net is a channel-based communications library over VME and PCI, with auto-configuration features. Each node can be a VME or PMC processor, and BP-Net provides a transparent communication facility between any two nodes in the system. It also implements IP emulation, thus standard applications using network sockets can communicate over the BP-Net channels.

VmeQuick is a high-level data transfer abstraction library, which supports at the same time VME, PCI, and local memory for read and write transactions. It manages dynamic address mapping, DMA chaining, notification, and so on.

The uAccess library provides a further abstraction layer for the access to each component of the system, using a database of all the building blocks of the system, so that it can take into account specific information both about the source and about the destination of the data transfer.

The microTimer library provides multiple high-resolution timers based on the PowerPC time base by multiplexing decrementer interrupts, and provides multiple single-shot, cyclic and sleep timers.

TrueTime is an FPGA-based service that provides synchronized time-stamps and interrupts on all processors connected in a system. The TrueTime master may receive an external synchronization input via IRIG-B or other synchronization methods, and transmits synchronization data to all participants internally over

to hide inevitable hardware changes from the user application. Innovative software packages, such as a timer library and a VME access library have their origin in this collaboration with EADS. They form part of the hardware abstraction layer, which helps to keep applications constant across changing hardware platforms.

Building blocks

The building blocks CES proposes for test systems are themselves composed of other smaller building blocks. This modularity applies at the same time to the hardware, FPGA and software design, leading to a very modular architecture.

A typical interface board consists of a 6U VME single board computer (SBC), with one or two PMC boards (according to the type and number of channels required), and an electrical or optical signal-conditioning unit. The PMC itself may be a SBC with a PowerPC processor and an FPGA that is customized to implement the specific interface, as well as a separate customized front-end electrical adapter.

The electrical interface, located on the signal-conditioning unit, is developed for each interface, as a standard VME or rear-I/O board. This interface translates electrical signals to appropriate levels for direct connection to the FPGA. Common electronics required for the FPGA implementation, such as oscillators, and LEDs for status display are located on the front-end adapter, which is the same for all boards within one family of interfaces.

In addition to interface boards, the same SBCs can be used as generic real-time processors, whether in VME or PMC form-factor. These can run scaling or simulation, or act as a communications relay to the user interface and data recording.

With modern FPGA technology, virtually any interface functionality can be implemented on the same platform. To support the implementation of the application logic in the FPGA, CES provides a stable environment, where the infrastructure of the board is isolated from the application logic by well-defined interfaces.

In early hardware designs, the board infrastructure was implemented in a separate FPGA, and CES provided simply a back-end interface with a template application for the user-logic. Today, CES provides an FPGA board support package (FBSP), which implements the same conceptual functionality for the user-logic in the FPGA, as the BSP for the application software. The application logic is implemented in a a dedicated line in the VME backplane, or externally through a front-panel connector and a simple cable.

The CPU management server provides remote access to board monitoring and maintenance functions through an XML interface.

Putting the blocks together

With the increase in the amount and complexity of embedded electronic systems, larger and larger ground-test systems are needed to test complete aircraft systems, or to simulate a realistic environment for individual components. Therefore, test systems become larger, and scalability becomes critical.

The connection between components of large test systems presents an important challenge. As long as the entire system can be housed in a single VME enclosure, each CPU can access every other CPU, including the PMC boards through simple memory mapping, established by the SBC carrier.

When the entire system can no longer be housed in a single VME enclosure, connecting VME systems transparently becomes an issue. This introduces the requirement to connect VME systems with minimum latency and maximum throughput, yet at the same time being compatible with previous software. CES PVIC boards achieve this by establishing a transparent connection between VME enclosures, presenting a common address space in both subsystems. Thus, controller boards in a central enclosure can access I/O boards distributed over several enclosures, without worry for their physical location.

Above: Large test system, comprised of several racks of equipment, for integration testing of aircraft electronics

Left: Ruggedized portable aircraft ground equipment for on-aircraft diagnostics

At the same time, in a drive to reduce costs, smaller, portable and reconfigurable systems are also increasingly popular. These can be easily moved and configured to address the specific needs of the moment. Currently, these are small VME-based systems, with 3-12 slots, and a laptop that provides the user interface and mass storage.

New development is aimed at reducing the size and cost of the test systems by increasing integration of the interfaces, for example by replacing a VME carrier plus two PMCs with a single PMC, which will use embedded processors in the FPGA for the time-critical control loop. The electrical interface will be implemented on the front-end adapter, instead of a separate rear-IO board, thus further reducing the size of the interface.

The new hardware platform, a PMC with a PowerPC processor and two embedded processors in the FPGA, is already available. This reduction in size will also allow more flexibility to build small systems, by putting the interfaces directly into a PC, instead of a separate VME enclosure.

Another new development area aims at improving the connectivity, by using PCI Express to connect several systems together. The link will be implemented as a carrier, so that instead of taking up a PMC slot on a carrier, it would actually provide two PMC or XMC slots. The same link will also enable a more direct connection to a PC, thus part of the real-time application could also run there. The possibility to use optical cables for PCI Express will enable larger distances to be covered, which is useful for very large systems, and will also provide easier connectivity to the aircraft.

Component set-up

As we have seen, the modular approach used by CES to build components for ground-test systems offers a very flexible architecture, which scales easily from small to very large systems. It also simplifies the development of new interfaces by reducing the effort needed to manage the underlying hardware, so that the interface designer can concentrate on the actual functionality, instead of platform details.

Existing solutions cover a very wide range of avionic interfaces, with virtually no limits on the number of channels and the size of the system that can be built. A powerful hardware abstraction layer provides a uniform interface for the software, which is kept stable over the evolution of the underlying hardware platform.

Future requirements drive the development towards more integration and even better connectivity. New products are in development to address these key issues, ensuring continued success for years to come. ∎

Akos Csilling PhD is a senior systems engineer with Creative Electronic System (CES) based in Switzerland

Data measurement applications

THE CONVERGENCE OF ANALOG DATA, BUS DATA, AND POWER ANALYSIS INSTRUMENTATION FOR FLIGHT TEST APPLICATIONS

> **"Perhaps the most intractable problem arises once testing is complete"**

GRANT M. SMITH

BY GRANT M. SMITH

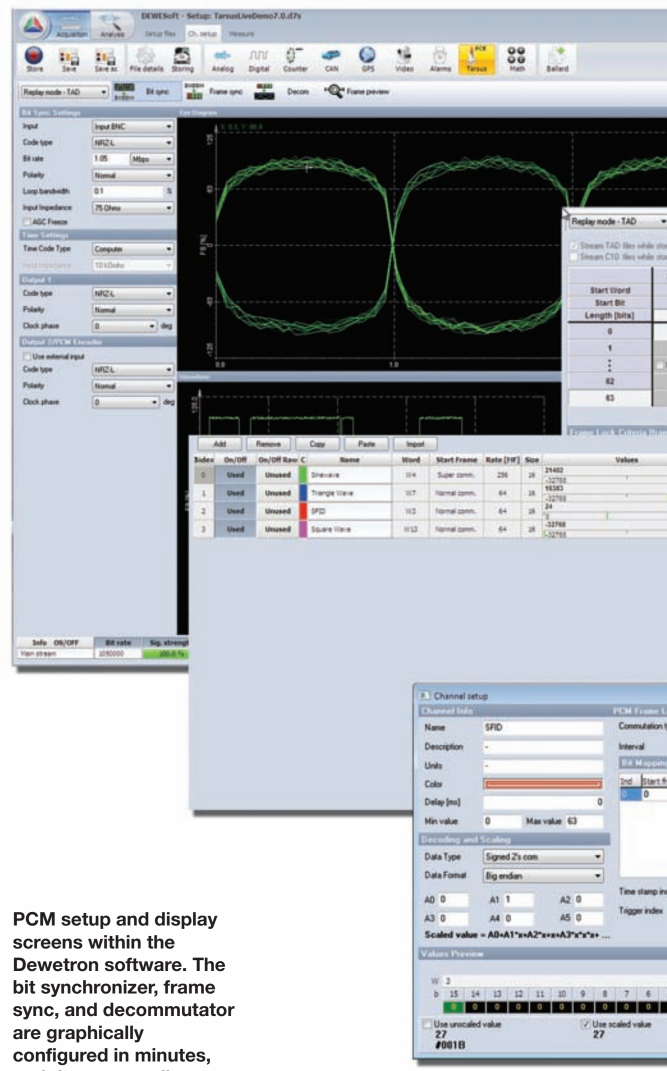
For flight test engineers, one of the biggest challenges in recent years has been mastering the sheer number of different test instruments needed to perform comprehensive testing on today's aircraft.

Traditional analog data acquisition systems and recorders are needed to record analog signals from a wide variety of sensors, including strain gauges, accelerometers, force sensors, pressure and load sensors, and thermocouples, as well as voltages and currents from power systems. Now other recorders are needed to acquire and display data from the aircraft bus itself, including ARINC and MIL-STD-1553 data buses.

Furthermore, since the power bus of the aircraft is also mission critical, power analyzers are needed. Unfortunately, the systems that work well at a power utility are of little use in aircraft, many of which use 400Hz and not the 50-60Hz used in the rest of the world.

Finally, dynamic testing also requires the synchronous acquisition of video feeds from onboard cameras in NTSC and PAL formats, or the addition of higher-speed videography to analyze actuators and other fast-moving events. Assuming that the aircraft has the physical space to accommodate four or five different data recorders, the use of disparate instruments can lead to additional problems. It can be daunting trying to master one system and this is only magnified by adding four more, each with their own power requirements and user interfaces. Secondly, simultaneously testing, operating, or simply monitoring the results from these instruments is virtually impossible for one person. Engineers know that they have a finite amount of time to get the results that are needed. It is very expensive to conduct aircraft tests either on the ground or in flight, and there's nothing worse than having to repeat a test because the data was not properly captured the first time.

But perhaps the most intractable problem arises once testing is complete and the data needs to be analyzed. If you have ever tried to align a home movie shot with non-synchronized cameras then you will understand the problem. This is compounded by the fact that



PCM setup and display screens within the Dewetron software. The bit synchronizer, frame sync, and decommutator are graphically configured in minutes, and data are easily displayed in a wide variety of formats during acquisition to disk

different systems have different sample rates, that time bases can drift, that some instruments may be capable of alignment to an external time reference while others are not, and, finally, while most systems acquire time domain data, others, such as spectral analyzers, measure in the frequency domain (rotary systems such as torsion analyzers operate in the angle domain). Even power quality analyzers align their calculations in phase with the base power frequency. So while it is imperative to align the time codes to be able to analyze test data, for the above reasons it is not easy. Engineers often end up with no alternative but to spend many hours in post-test analysis in third party analysis programs that are capable of importing data from all these instruments. These programs enable

them to align the time axes manually until they appear to be correct.

Data acquisition

Set against this backdrop, the amalgamation of these separate instruments into a single unit would seem an obvious development but it has taken many years to get this far. Today, Dewetron makes data acquisition instruments that can perform all of the different testing paradigms simultaneously (and in sync with each other) as well as synchronizing to an external time reference such as IRIG time-code or the UTC code from GPS.

In addition to their data ingest and synchronization capabilities, these systems must be ruggedized, portable, and run from a wide range of AC and DC power supplies. If not, they cannot be used in the aircraft environment. Therefore, the company makes systems in several form factors, from handheld instruments to portable, bench-top, and 19in rack mounting.

ARINC 429 and MIL-STD-1553

One of the most compelling additions to these systems in 2010 is the integration of ARINC 429 and MIL-STD-1553 bus interfaces with all of the other data input types.

ARINC 429 is an interface employed on many commercial and military aircraft. ARINC essentially constitutes an avionics LAN. The ARINC 429 bus runs at either 12.5Kps or 100Kps. The data is 32 bits long, which includes the label among other parameters. A two-wire interface, ARINC 429 is self-clocking on the receiver end, making it easier to implement than alternate protocols.

The hardware that Dewetron uses to handle ARINC is typically provided in the form factor of a PCI card installed within the instrument itself. However, in the case of handheld and other small instruments, it can be supplied as a USB device. ARINC interface cards are available with up to 32 channels, each of which can transmit many parameters. The software within the data acquisition system provides all of the setup for both send and receive ARINC 429 channels as well as scaling.

Military aircraft commonly utilize a different bus called MIL-STD-1553 in lieu of ARINC for the same purpose.

MIL-STD-1553 has been a military avionics standard serial databus since the 1970s. Today it is also used in spacecraft for onboard data handling (OBDH) subsystems. Although ostensibly military in nature, applications for MIL-STD-1553 encompass both the military and commercial sectors.

MIL-STD-1553 is a bus controller responsible for multiple receiver terminals. The messages are 16 bits wide and can be command, status, or data words.

The hardware that Dewetron uses to handle MIL-STD-1553 can also be configured to handle ARINC 429 because one card can provide two interfaces. Multiple 1553 ports are available. PCI cards are also available with only MIL-STD-1553, while a handheld USB MIL-STD-1553 interface is also available for extremely small systems.

Synchronizing the Asynchronous

Dewetron systems uses an innovative approach to keeping all of these disparate data sources in sync with each other. They must also be referenced to external time from IRIG or GPS UTC. At the center of each system is an ORION card,

Dewetron systems record ARINC 429 and MIL-STD-1553 bus data from both commercial and military aircraft. Data are recorded in sync with analog data, video streams, and more

which utilizes a high-resolution clock to stamp samples as they arrive from each device. These could be frames from video cameras, GPS sensors, inertial/gyro sensors, low-speed data from DC, temperature measurement signal conditioners and transmitters, and, of course, the parameters from the ARINC 429 and MIL-STD-1553 interface cards.

All of the analog sensor data is synchronized because it is sampled by an ORION card using a separate ADC chip for each dynamic input channel. Importantly, the clock on the ORION card itself can be hardware synchronized to an external time reference such as the highly precise PPS signal from GPS, or one of the popular IRIG time codes.

In this way, the ORION card serves as the timing backbone of every Dewetron system, permitting the synchronization to within 25µs based on its 40MHz clock.

Acquiring PCM data

In conjunction with NASA and the United Space Alliance, Dewetron has developed a comprehensive interface to an FGPA-based bit-synchronizer interface card. This PCI form factor card can be added to virtually any Dewetron instrument, from portable battery-powered units to larger rack-mounted systems.

The bit sync and frame sync are handled by hardware in the graphical user interface within the DEWESoft software platform common to all Dewetron acquisition systems, whereas the decommutator is implemented entirely in the software. This gives maximum system flexibility, including the ability to handle one or more embedded asynchronous data streams.

"Each instrument can be configured as a standalone device within a networked system"

The hardware can handle PCM data in most common formats at up to 33Mps. This hardware and software combination is used by NASA's Kennedy Space Center and at the US Army's White Sands Missile Range.

Network systems together

A networking extension enables the user to control several Dewetron instruments as if they were a single system. These systems can be physically connected if they are in the same room but they could be on different continents. And some may be in the air while others are on the ground. As long as a wired or wireless TCP/IP interface can be established, this networking paradigm works.

Networked systems are ideal when the test engineer has several locations requiring instrumentation, and yet the data needs to be synchronized as if it were recorded by the same instrument. In this way, Dewetron's powerful synchronization can be extended to dozens of devices so location is not an issue.

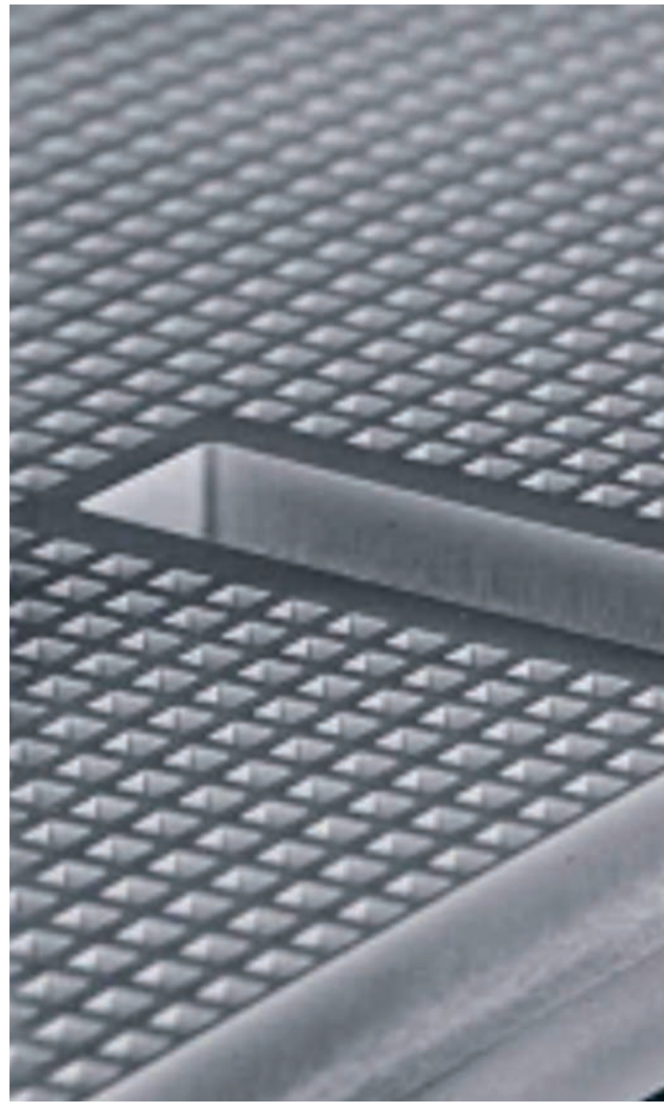
Within a networked system, each instrument can be configured as a standalone device, a master controller (which controls but does not directly measure), a master instrument (which measures data and controls the other devices), or a slave measurement instrument, which is simply a measuring device operated by the master.

Even in those cases when a TCP/IP network cannot be established, the use of time codes within each instrument allows the data files to be precisely aligned on the time axis and combined.

The end result is that today's flight test engineers are afforded a new approach to making a wide range of measurements. They need less equipment, have an easier setup, and create smaller physical and carbon footprints. Perhaps most important is that all of these disparate measurands from analog, digital, PCM, ARINC, MIL-STD-1553, power bus and angle-based sensors are recorded in sync and referenced to external time from the beginning, thereby eliminating the laborious need to align files from many different instruments later. This gives a better look-in to the data during measuring – which can prevent the need for expensive re-testing – as well as better overall test results. ∎

Grant M. Smith is president of Dewetron Inc based in Rhode Island, USA

Ultrasonic Instruments
For Every Application
..For ANY Budget!!
..over 35 Years!!
AvengerEZ
Miniature Handheld Flaw Detector
Featuring:
3.9" LCD with Hard Coat Display Lens
SplitScan, SplitView & AutoTrack
Weld Trig Functions
Amplitude & Thickness Gating
Size: 7.5"x3.5"x1.5" @ 1.8Lbs
Operates on 3 or 6 'AA' Batteries
for Up to 10+ Hours.
THE Price Performance Leader
A New Range of HIGHLY Affordable Single, Dual
and Multi-Mode Bond Testers...
The BondaScope 300, 350 & 3100
Featuring: Resonance (Flying Dot & RF)
Pitch-Catch (Single Frequency & Swept
Mechanical Impedance Analysis (MIA)
And Much More....
NEW Ultrasonic Bond Testers
You Now Have Choices... Several! in fact!!
Introducing... BondaScope 300, 350 & 3100
Performance and Features... Industry Leading
Prices... Highly Affordable!!
TG900 Series
High Precision Thickness Gage
0.004" - 50" Range • 0.0001" Resolution
Scrolling 'B' Scan • 50,000 Point Logger
Ultra High Speed Alarms • Auto or Dual Point Cal
Introducing.........
The All New RAPTOR
Imaging Flaw Detector
Use as conventional Flaw Detector OR
connect DIRECTLY to any manual, semi-automated
or fully automated scanner for full
C-Scan imaging and archive capability!
At Standard Flaw Detector Pricing!!!
ALL NEW
TG210 & TG410
3.9" A-Trace Display 320x240 Display
300Hz PRF • SplitView AutoTrack
Scrolling B-Scan Display
Single & Multi-Point Cal
IP-1st, 1st-2nd
Through Paint Capable
0.020" - 50" Range
7.25"H x 3.5"W x 1.375"D
StringScan
Manual
MMS2
Available Standard Scanners
CA-12
Battery Powered
NDT Systems
Worldwide Excellence in Ultrasonics
17811 Georgetown Lane • Huntington Beach, CA • 92647 • PH: 714.893.2438 • FX: 714.897.3840
Web: www.ndtsystems.com • email: info@ndtsystems.com
WANTED: Reps, Dealers & Distributors



Microsensors take-off

MEMS ACCELEROMETERS ARE REPLACING ELECTROMECHANICAL DEVICES AND ARE BEING UTILIZED MORE AND MORE IN MILITARY AEROSPACE APPLICATIONS

BY JEAN-MICHAEL STAUFFER

> **"Stability performance relies on the quality of the raw material"**

JEAN-MICHAEL STAUFFER

MEMS accelerometers are replacing established, expensive, and fragile high-end electromechanical devices in the military aerospace market. The driving forces for this revolution are the need for devices offering the same or even better performance at lower cost, lower power consumption, a smaller size, and greater strength.

The success of MEMS accelerometers started in the early 1990s with the airbag application in the automotive industry. Today, MEMS accelerometers and gyros are used successfully in numerous automotive and consumer applications. In the beginning, MEMS accelerometers replaced existing devices. They have now enabled previously impossible functionalities such as camera stabilization, human body control, cell phones, and toys. The key factors in the success of these applications were: extremely low cost, reliability, and a low power consumption for moderate performance (4- to 12-bit resolution). The market for automotive and consumer motion sensors is expanding rapidly, with estimated growth of 22.9% in 2010. It is expected to surpass today's most popular MEMS applications (inkjet printing and projectors) by 2014.

A similar process has begun for high-end MEMS accelerometers. High-performance products already on the market are becoming popular in various military aerospace applications, such as testing, instrumentation, and the energy markets. The first barrier to entering these fields is technical, with the issues of stability (1-100ppm of the full scale) and resolution (16-24bits) needing to be addressed. Factors such as cost and performance are now considered more important than robustness, power, and size.

To address these requirements, some people try upgrading versions of automotive sensors but they have relatively little success. It turns out that the basic technologies developed for automotive and consumer applications, which are driven by cost, can not reach the required performance. This limitation is exposed by a different business model. The volumes and qualifications for long-term commitments are radically different for automotive/consumer and high-end markets. In the world of motion sensors, Colibrys has a unique position in the market. It focuses on the high-end markets with an appropriate business model and with technologies specifically designed for performance.

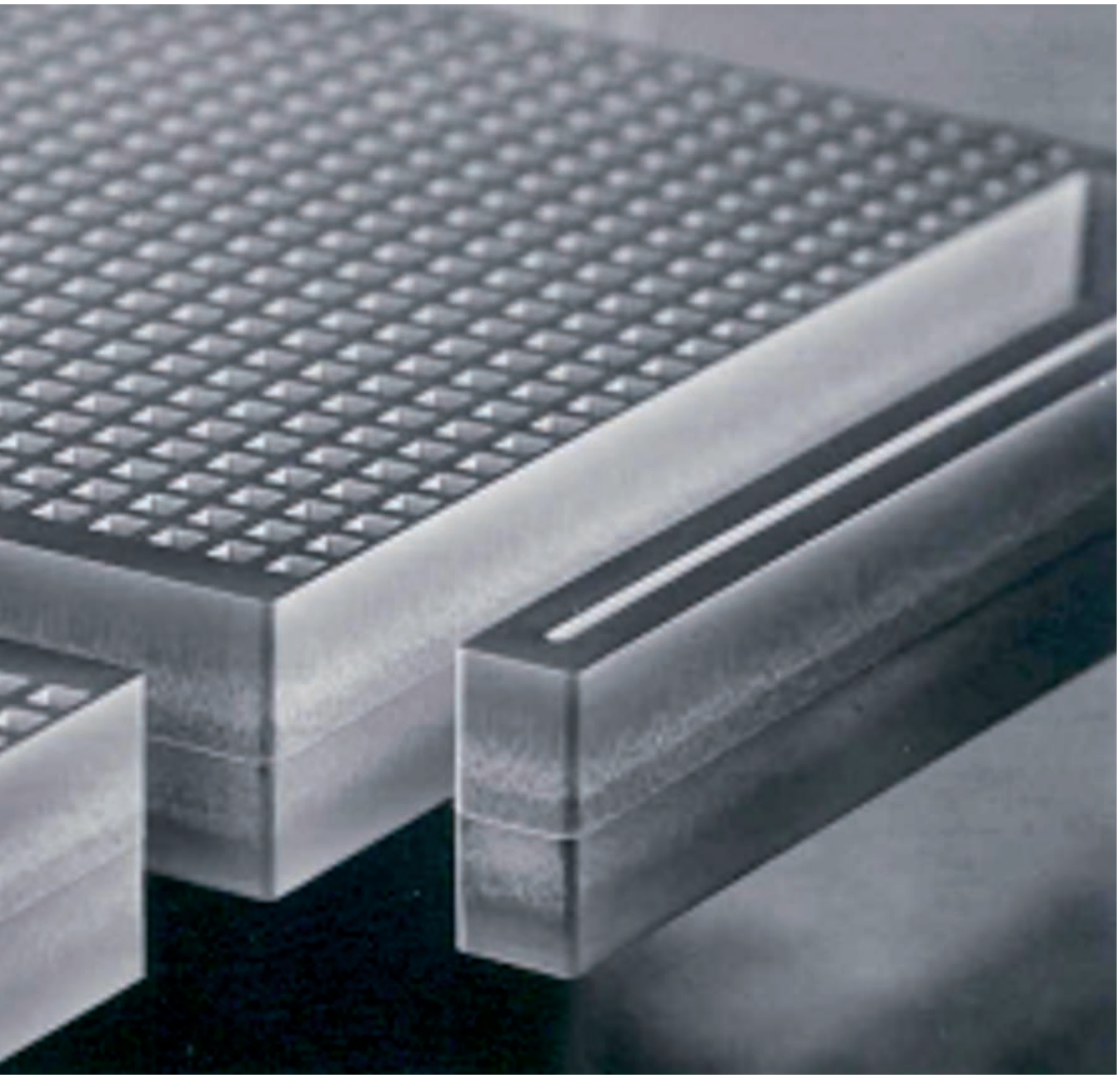
The three key ingredients needed to make a high-performance accelerometer are a stable MEMS sensor, state-of-the-art assembly and packaging technology, and high-quality electronics. The advantage of this technology over traditional electromechanical solutions comes from the lower manufacturing cost of MEMS devices.

Stability performance relies on the quality of the raw material (silicon wafers) and capability of the design in meeting performance with manageable manufacturing tolerances and manufacturing processes, thereby avoiding lengthy and expensive burn-in and selection procedures. High-end MEMS accelerometers need a few hours at most for testing whereas electromechanical devices can sit on test benches for days.

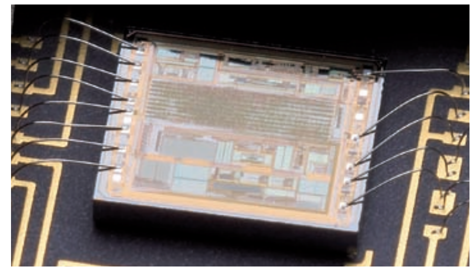
Colibrys has developed innovative proprietary solutions for the three key constituents of MEMS accelerometers over the years.

MEMS Sensor

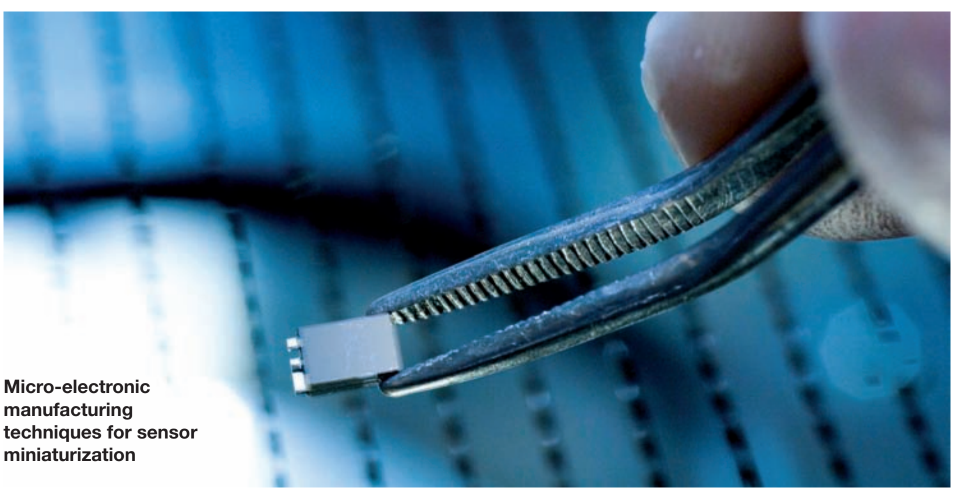
The basic structure of the MEMS sensor is shown in the figure next page. A proof mass with a surface of a few square millimeters and a thickness of



Left: Scanning electronic microscope (SEM) picture of a Silicon MEMS structure realized by deep reaction etching (DRIE)



Below: Custom electronic designed for advanced applications under harsh environments



Micro-electronic manufacturing techniques for sensor miniaturization

several hundred microns is attached by a silicon spring to a frame, which constitutes the basic acceleration detector. Acceleration is electrically determined by the movement of the proof mass and the corresponding variation of the capacitance formed by the proof mass and detection plates separated by a narrow gap (typically 2μm). This structure is realized by the so-called bulk micromachining MEMS process. The three wafers are manufactured independently and are then hermetically bonded in a vacuum at high temperatures to form a wafer stack of hundreds of accelerometers. Compared with automotive/consumer technologies that operate with the thin proof mass moving in the plane, this technology is somewhat more expensive (thicker plates and larger surfaces) but it boasts considerably better performance.

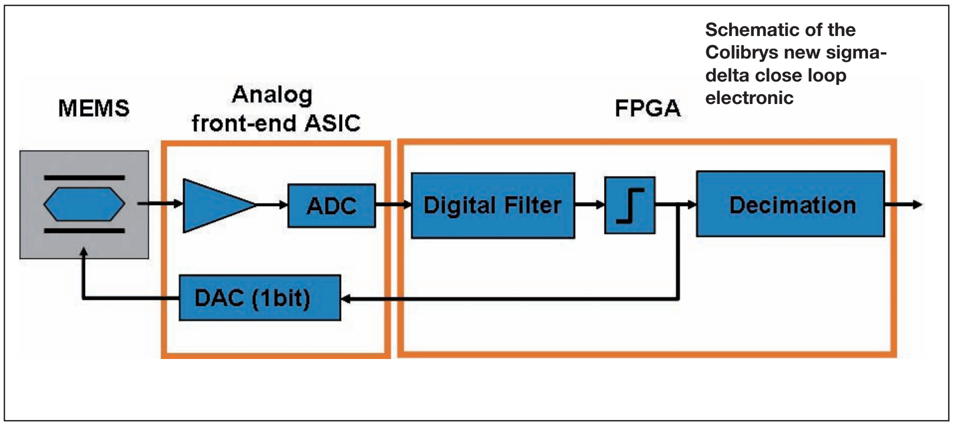
Recently, the design and technology for high-end accelerometers have been refined, increasing the performance of Colibrys accelerometers. The basic stability of the sensor is representative of the repeatability of the proof mass position at zero g. For a fully assembled sensor, the proof mass returns to an initial position within 0.03Nm or 1/30 of the radius of a silicon atom even after extensive temperature and environmental testing. With regard to resolution, extremely low mechanical noise is vital for devices designed for seismic applications. A noise floor of 20ng/√Hz and lower, which is 5,000 times quieter than the noise of quality automotive-grade devices, is maintained during production. This enables the machine to detect the seismic waves from earthquakes tens of thousands of kilometers away. Finally, the gas damping used to induce squeezed film effects leads to non-linear behavior generating vibration rectification errors (or bias shift induced by vibrations). The latest designs have virtually eliminated these effects.

In spite of their fine performance parameters, these devices are extremely robust. Inertial grade accelerometers, for example, can be used in smart munitions where data needs to be collected immediately after the device has been shot from a six-inch cannon with initial accelerations of more than 20,000g. At the same time, high-sensitivity devices need to remain intact and continue functioning after being dropped thousands of times from various heights. This is a major improvement over traditional electromechanical devices that have shock limits of 1,000g.

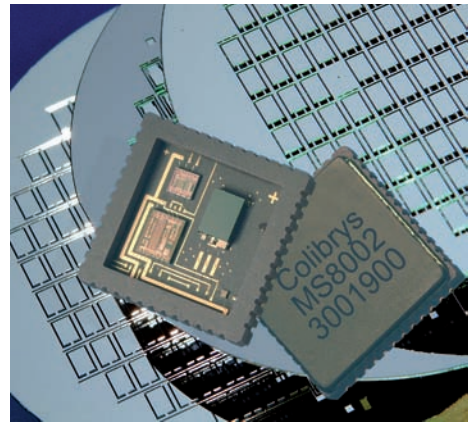
Assembly and packaging

The sensor assembly is critical for precision in harsh environments. Colibrys has chosen a multichip module (MCM) approach that combines the MEMS device and its electronics in a hermetically sealed ceramic package. The MEMS die is attached during a low-stress process to prevent the performance of the MEMS from degrading during assembly.

The package has to protect the sensor and related electronics from external perturbations such as humidity. The MCM modules are qualified against MIL standards, insuring long-term stability and reliability. With a plastic packaging approach that by definition is non-hermetic, and which is commonly used in automotive/consumer devices, performance and long-term stability will suffer.



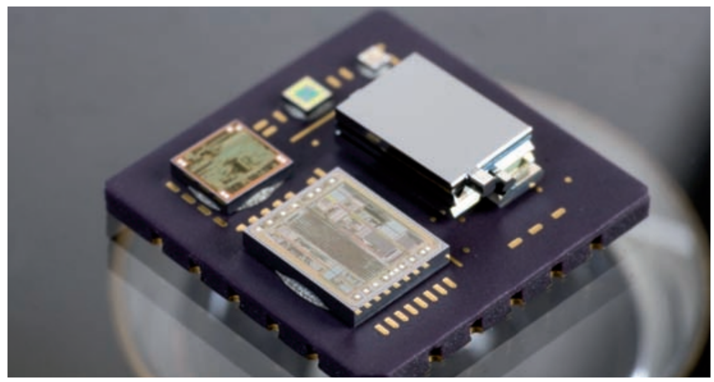
Schematic of the Colibrys new sigma-delta close loop electronic



Above right: Combination of three different structured silicon wafers to produce capacitive MEMS accelerometers

Right: Close view of a Colibrys hybrid MEMS accelerometer assembly (MS9000)

left: Advanced manufacturing clean room for MEMS accelerometer production



Electronics with MEMS Sensors

The electronics associated with the MEMS Sensor are crucial for performance. There are two ways to operate a capacitive MEMS Sensor. For the open-loop approach, mechanical plate deflection is measured via a change in associated capacitance.

This concept provides excellent results for its size and power. However, the system has limitations in terms of noise and linearity. Typically, open-loop sensors work at their best when 16- to 20-bit resolution is required. For closed-loop (or servo) accelerometers, the proof mass is held in a fixed position and the inertia is compensated for by electrostatic forces. With this concept, the limits of MEMS Sensors can be further explored in terms of stability, noise, and linearity. In the future, closed-loop sensors will work in the 20- to 24-bit resolution range and beyond. For these open-loop sensors, a patented, self-balancing bridge concept was implemented in an ASIC. This allows for stable, low noise, and highly linear analog output with low power consumption (~1mW).

With traditional closed-loop accelerometers, Colibrys uses a servo concept based on analog voltage force feedback. This concept is used for the SiFlex family of seismic sensors.

The best performance can be achieved by placing the MEMS Sensor in a Sigma Delta servo loop and applying electrostatic force pulses to rebalance the position of the proof mass. This concept was initially developed for sensors used in seismic imaging but Colibrys is adapting this concept into its navigation-grade accelerometers.

The Sigma Delta servo loop gives exceptional performance in terms of bias stability, noise (20- to 24-bit resolution), and linearity, and it also provides a direct digital output signal. This concept is implemented in a small front-end ASIC and combined with digital signal processing in a FPGA.

This concept uses somewhat more power than the open-loop sensors but it's still only a quarter of comparable traditional electromechanical devices.

Products and applications

For several years Colibrys inertial and vibration open-loop product families – MS8000, MS9000, and VS9000 – have been gaining worldwide acceptance. Colibrys is about to launch its new RS9000 series, which boasts better performance in terms of bias stability, linearity, and vibration rectification.

These inertial products are used in a broad range of applications. Accelerometers are fitted to Inertial Measurement Units (IMU) such as aircraft, UAVs, short-range missiles, and guided munitions. Guided munitions applications usually require the products to be hardened (HS8000) so they can survive the acceleration when fired from a six-inch gun (20,000*g*) and still send a precise and reliable signal.

Inertial sensors are also used for attitude, heading, and reference systems (AHRS) in aircraft, as well as for land navigation. Accelerometers can also be used to measure vibrations and monitor the structural health of airplanes, helicopters, and trains, reducing maintenance downtime. Finally, accelerometers can be used as tilt sensors to aid platform stabilization for cameras, antennas, turrets, and weapons stations. Measuring tilt angles when drilling boreholes in temperatures of over 150°C is also vital. Experimentation with higher temperatures is ongoing.

The SF2006 and SF1600 Colibrys seismic sensors are used as part of the earthquake monitoring network to assess the structural stability of dams, bridges, and nuclear plants. Due to their extremely high resolution, they can also be used for seismic imaging (this is a customer-specific product) or perimeter security.

New products based on closed-loop technology will address demanding inertial applications such as precision navigation and north-finding systems. Their smaller size, lower cost, and higher strength are expected to lead to new applications. It is being investigated, for example, whether accelerometers can be used to assess aircraft wing dynamics and control systems.

For several decades, electromechanical accelerometers such as the Q-flex family from Honeywell and its counterparts from other suppliers were the undisputed leaders when it came to high-end accelerometers.

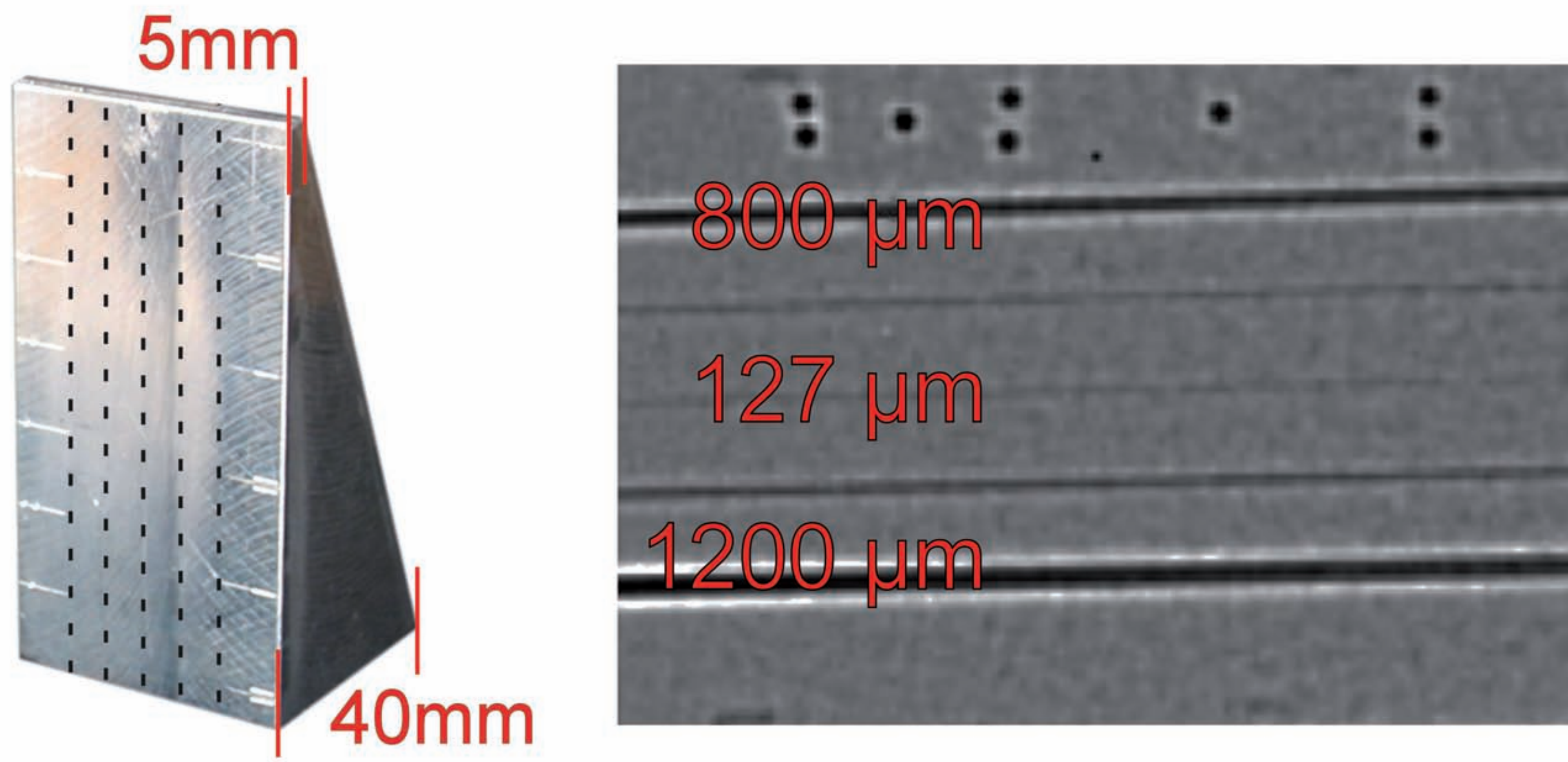
Since the early 1980s when MEMS accelerometers were being developed, they have revolutionized the automotive and consumer sensor markets, replacing existing technologies and enabling a wealth of new applications. In the high-end sector evolution was slower.

Vibrating beam MEMS accelerometers have proven to be a solution for some specific applications but they did not meet expectation in terms of cost and performance. Recent incarnations of capacitive open- and closed-loop sensors will gradually replace established electromechanical accelerometers as this new technology enters the mainstream. ■

CONTACT
Jean-Michael Stauffer is VP marketing & sales, Colibrys SA based in Switzerland
Tel: +41 32 720 58 11

Wealth of contrast

HIGHLY DYNAMIC RADIOSCOPY, WITH FAST DIGITAL FLAT-PANEL DETECTORS AND IMAGE PROCESSING, DETECTS CASTING FLAWS FASTER




PETER KRAMM

BY PETER KRAMM

When inspecting lightweight metal-cast parts, visual x-ray inspection is standard to assess the inevitable porosities, blowholes, or other imperfections that arise during production. The newest technology involving highly dynamic radioscopy (HDR) combines fast digital flat-panel detectors with image processing capable of generating live images. As a result, flaws can be detected with certainty, despite a high inspection-item throughput.

The image intensifier systems still being utilized for imaging have been a reliable source of images for five decades. Lately, these systems were upgraded by introducing digital cameras. Even so, many factors were unable to be overcome due to the excessive sensitivity of image-intensifier tubes. As soon as slight differences in material thicknesses arise, thin areas quickly become overbright, while thick areas remain insufficiently irradiated.

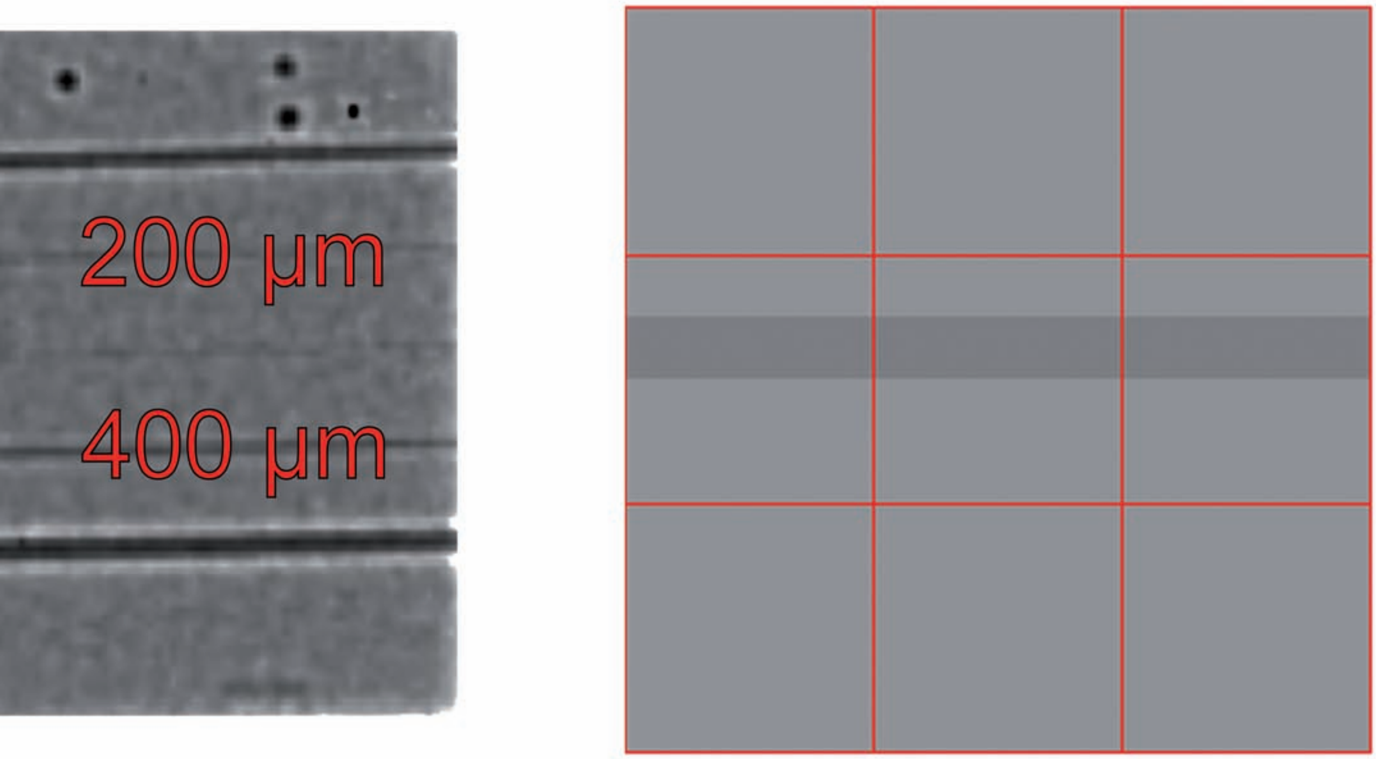
This is why the x-ray inspection operator frequently has to readjust the x-ray voltage in order to guarantee an assured inspection of all material thickness sectors. In the case of manual inspection, this costs time. Prefilters are nearly always employed for beam hardening to increase the range of depictable material thicknesses, but this reduces contrast and increases image noise.

Digital flat-panel detectors

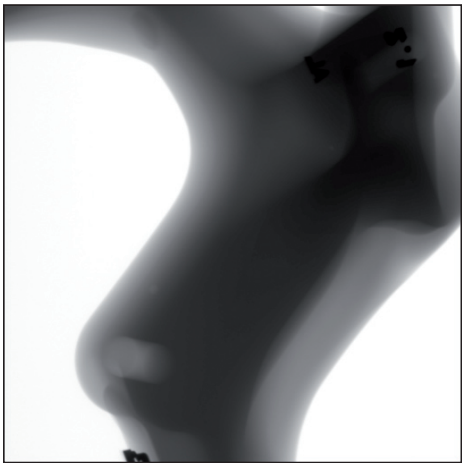
Once the digital flat-panel detector had been optimized to suit the requirements for industrial usage, it began to be incorporated rapidly into industrial inspection. This technology has now successfully asserted itself in the fully automatic inspection of cast parts for the automotive industry. Ever since refresh rates of respectively 15-30Hz were achieved, flat-panel detectors have been deployable in practice for visual inspection in motion, too.

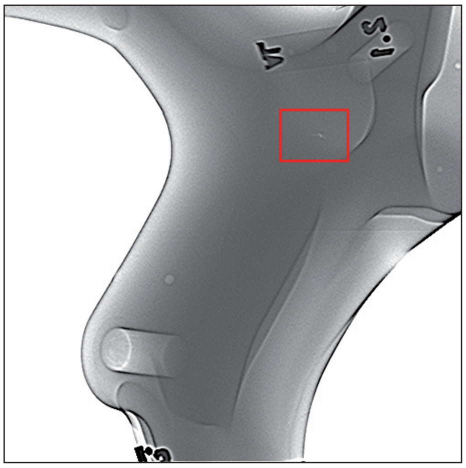
Using digital flat-panel detectors with a dose up to 400 times as high as with other systems, the signal-to-noise ratio (SNR) can be distinctly increased, therefore significantly improving detail detectability. In the case of x-ray images, experiments have shown that contrast and noise have a close correlation to each other. Besides this, detecting details in an x-ray image depends much more on the noise present than on 'blur'. When using flat-panel detectors, this has a positive effect because, on the one hand, x-ray tubes with a larger focus generate a comparatively higher dose, and on

"The problematic facts of this situation are solved by optimizing contrast locally within a live image"



Aluminum wedge with a material thickness of 5-40mm and five different slotted holes. The one with a diameter of 127µm is clearly identifiable in the filtered image using a 400µm flat-panel detector without magnification





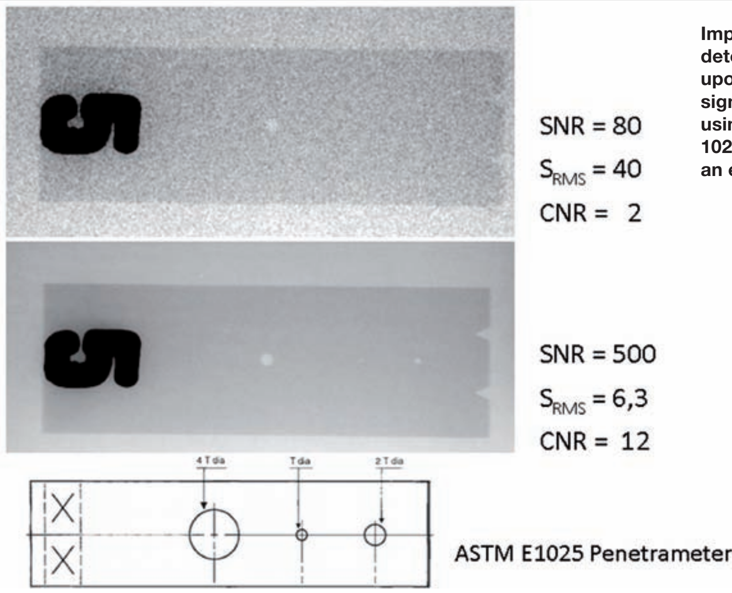
Castings often have a big range in material thickness. The live image filtering Y.HDR-Inspect enables the inspection of all areas without changing the contrast and brightness scaling or the x-ray parameters

the other, larger detector pixels are able to detect greater quanta.

In practice, a digital flat-panel detector can resolve over 20,000 shades of gray, enabling radiography of a material thickness area ranging from 3-76mm in the case of aluminum and a voltage of 120kV. At 160kV, a contrast resolution of less than 1% can be attained in a material thickness area ranging from 10-110mm.

As good as that may sound, when the situation involves visual inspection without any further measures taken, these advantages, due to high gray-scale resolution, benefit the x-ray inspection operator to only a limited degree. This is because the human eye is merely able to differentiate between about 60 shades of gray.

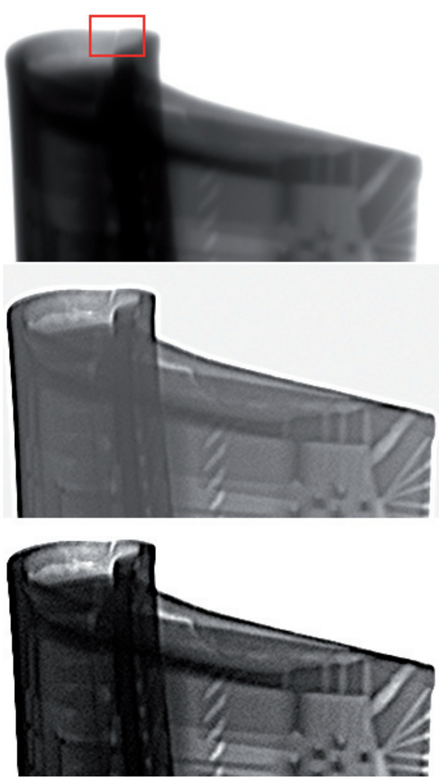
The problematic facts of this situation are solved by optimizing contrast locally within a live image. From a technical point of view, a software filter with an intense high-pass effect serves to accomplish this, although that same filter now accentuates noise due to the principle involved, and despite additional noise-suppressing low-pass components. On the other hand, the large scope of dynamics displayed by digital flat-panel detectors enables inspection using levels of energy that are greater than would be possible if image intensifiers with their excessive sensitivity were used. With this greater energy, the relative contrast for 30mm of base material is reduced as if 1mm of material had been added; by increasing the x-ray voltage from 90kV to 160kV, a diminishing in relative contrast of approximately 30%. However, in this case it follows that the signal-to-noise ratio rises disproportionately because substantially more quanta penetrate the mate-



Impacts on defect detectability depend upon the SNR, the signal-to-noise ratio, using an ASTM E 1025 penetrameter as an example

> **"Even small differences in contrast caused by small casting flaws become clearly visible"**

Live image filtering with Y.HDR-Inspect helps to see even small details at a glance, like the 1-1T hole of this ASTM penetrameter



Some cracks can only be recognized by inspection in motion. Y.HDR-Inspect points them out for a reliable inspection

rial due to the increased energy. In the example stated the SNR increases from 36 to 250. In other words, at 160kV around seven times as many quanta penetrate the inspection item than would occur at an x-ray voltage of 90kV.

The two quality parameters contrast and noise now enter into the so-called CNR, the contrast-to-noise ratio (Figure 1), a correlation stipulated in the ASTM standard E 2597-07. The CNR is therefore viewed as the most important parameter for quality. In the above-mentioned example, and despite slightly diminished contrast, the CNR increases by 500%.

Using qualified inspection personnel it was determined on an empirical basis that flaws in an inspection item are able to be ascertained with a probability of >99% at a CNR of >2.5. This reproducible numerical value for the CNR can be validated and logged using appropriate system-qualification tools for flaw detectability of a given x-ray inspection system.

At a high-contrast resolution, even flaws distinctly smaller than the pixel size are detectable. What is more, work can be performed using a lower geometrical magnification. As a result, not only 'more' of the inspection item is depicted, there is less focal-spot blur, too.

In all probability, future inspection standards are going to enable a lower local resolution to be compensated for by a higher contrast resolution.

Differences in contrast

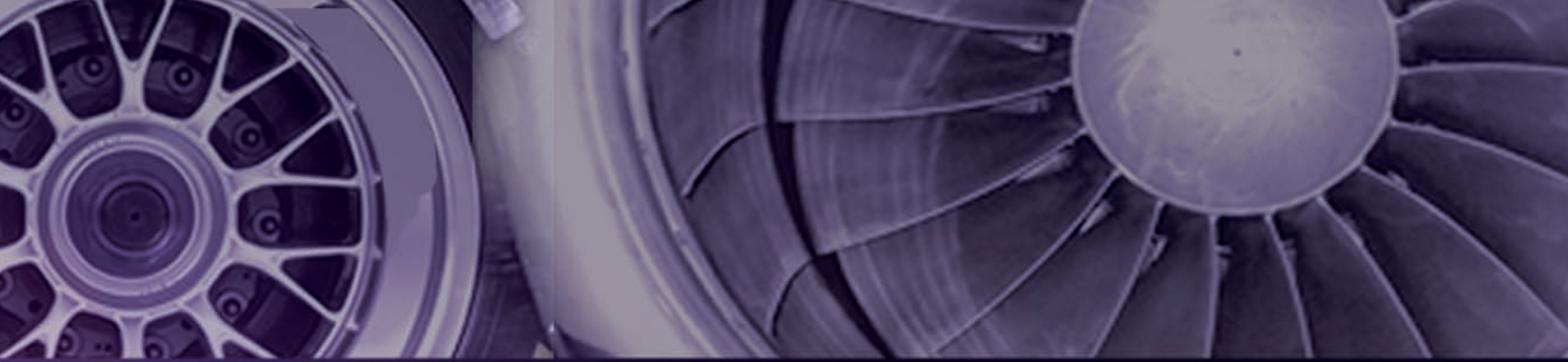
The combination of fast digital flat-panel detectors with a pixel size that is not too small (recommended in practice are pixel sizes from 200-400µm) together with high-output x-ray tubes permits low-noise live images, with a high contrast resolution.

Through the skilled selection of image processing and optimized programming, local contrasts can be accentuated in that live image as well. As a result, even small differences in contrast caused by small casting flaws become clearly visible. Inspection in motion has the major advantage that the optimum radiation angle (angle of incidence) is used that displays the flaw best. That way inspection can be performed faster and with greater certainty, and even smaller imperfections can be detected reliably. Furthermore, the highly dynamic radioscopy (HDR) procedure allows the filtered image to be superimposed onto the original x-ray image. This, in turn, enables an impression of the inspection item as if it were made of glass, and enables an assessment of flaw depths in the moving inspection item.

Users who have modernized their inspection system from image intensifiers to HDR report that the inspection system is now considerably easier to operate. With an image intensifier system, until then it had been necessary to optimize the image in a relatively time-consuming manner by resetting the x-ray parameters to achieve the desired defect detectability. With the HDR procedure, quick, simple and assured inspection decisions are now possible. ∎

CONTACT

Peter Kramm, product manager, YXLON International GmbH, Hamburg, Germany
Tel: +49 40 527 29 406
peter.kramm@hbg.yxlon.com



Net value

LARGE ETHERNET/LXI-BASED, SYNCHRONIZED DATA ACQUISITION AND TEST AND MEASUREMENT SYSTEMS REDUCE THE AMOUNT OF SPACE AND CABLING NEEDED AND THEREFORE CUT COSTS TOO

BY DR FRED BLÖNNIGEN

"Currently missing from normal Ethernet is the possibility to synchronize all data channels"

In the aerospace industry, one can identify an obvious trend for the standardization of data acquisition systems. Lifecycles of such systems tend to be five to eight years and obsolescence problems in the past made support very difficult and hence very expensive.

As Ethernet is becoming the backbone of internal infrastructure in more and more places and even aircraft, it was only logical to try to use Ethernet for data acquisition and test and measurement needs as well. One major obstacle to widespread use was the need to synchronize all data in large data acquisition systems with high or moderate sample rates, such as turbine or wind tunnel test stands. The IEEE 1588 protocol now enables the industry to do this and brings data acquisition to an Ethernet standard. Bustec demonstrated successfully to NASA, the synchronization via IEEE 1588 to 25nsec in a large, 3,600-channel system.

Data acquisition systems are built as distributed systems with input/output points distributed between large distances, as for example in the structural test of large airplanes. Up to now, each sensor was connected with long wires to signal conditioning units, which in turn were connected to central data acquisition units and computers. These classical setups had two major problems. First and quite obviously, the high cost of cabling would normally use a third of the total system budget. Second, there was the problem of deterioration of signal quality, due to these long cable lengths. Signals from sensors are normally in the µV range and are sensitive to electromagnetic noise. Induced errors resulted in the order of 2% of the measured values. Considering the cost of actual data acquisition systems and the measurement accuracy of better than 0.01% that can be easily achieved with modern data acquisition systems, these older solutions are really no longer very effective.

Therefore, a logical choice would be to use distributed systems with integrated signal conditioning based on standard Ethernet (IEEE 802.3). In contrary to the myriad of short-lived PC buses with new and incompatible versions every three to four years, Ethernet has been commercially available for 30 years. Every revision is always backward-compatible to the former ones. Obsolescence problems such as those in the world of different PC buses and their derivatives such as PXI never existed. Furthermore, the TCP/IP protocol is well established and in use in every company in the world.

DR FRED BLÖNNIGEN

Data throughput

Another important factor in modern data acquisition systems is data throughput. With the standard 1G or 10G ports sustaining 100MB/sec or 1GB/sec, even very large systems with thousands of channels can be handled easily. For even larger applications, multiple ports can be put into one PC or server. In the above-mentioned example at NASA, a four-port 1G interface card was used and up to 400MB/sec throughput to the PC was achieved. The 3,600 channels were running at 10kHz per channel with 24bit resolution.

The total data volume was 144MB/sec. This proved to be no challenge for the system. Should a system require more than 1GB/sec data throughput, the number of PCs can be scaled up to achieve the desired throughput.

Currently missing from normal Ethernet is the possibility to synchronize all data channels in a distributed environment. This synchronization could be achieved through external cables, but then two problems would be faced – the first is that trigger/timer distribution boxes would be needed and the second is that there would again be specialized and expensive cables. It would be much better to be able to synchronize over the normal Ethernet cable. This brings LXI into the picture.

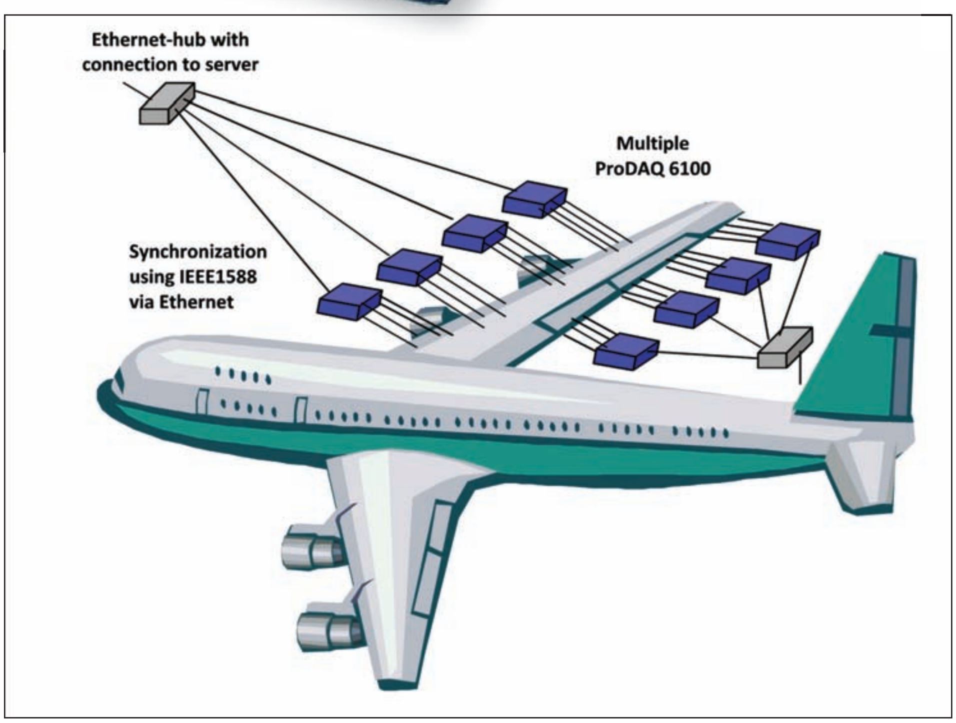
LXI stands for LAN eXtension for Instrumentation. As the name suggests, it is based on standard Ethernet (IEEE 802.3) and the well established TCP/IP protocol. It has some very useful additions and comes in three classes with different additions for measurement applications.

LXI advantages: Class C

The standard Class C consists of a normal Ethernet device with a built-in web server. All instruments can be discovered with the 'discovery protocol' and the web interface allows the units to be configured. An additional prime

Main image: ProDAQ 6100's width is half of 19in and height is 1U with different function cards fitted

Below: Multiple ProDAQ 6100 located around the aircraft and wired to different strain gauge sensors



advantage is the serviceability of the units via the web server from any location.

Class B

Class B adds IEEE 1588 and brings the clock synchronization to distributed data acquisition systems via the standard Ethernet cable. The quality of the synchronization depends on the quality of the implementation. Bustec is offering the best clock synchronization with a clock uncertainty of only 25nsec in fully distributed systems. This time was achieved by using a standard 1GB Ethernet switch. In all environmental measurements such as temperature, pressure, vibration or strain measurements, acquisition is normally run between 100Hz and 100kHz per channel and in wind tunnels up to 200kHz; 200kHz corresponds to clock intervals of 50µsec. This is a factor 2,000 times smaller than the speed at which data can be sampled and even in turbine tests with an angular error of less than 0.1°, it is really negligible.

Class A

Should the needs of synchronization be even more demanding, a user could choose a Class A device with an external synchronization cable. This brings the synchronization down to a couple of psec. Bustec offers all its devices with the option to be Class A, although the aerospace user normally does not need this precision.

Typical applications

It comes as no surprise that companies such as Rolls-Royce, Boeing and Airbus are asking for their next-generation test systems to be based on Ethernet with IEEE 1588.

Boeing has already installed the first large stress test system based on LXI. The figure below left shows how a system like this would look. Airbus is even asking to bring all onboard data acquisition and test systems to the new LXI Class B standard. As described above, even in large systems such as those at NASA with more than 3,000 distributed channels, ProDAQ 6100s can work successfully. Applications ranging from turbine and engine testing, structural analysis, wind tunnel measurement to inflight data acquisition and monitoring are ideal candidates for Ethernet with IEEE 1588 or LXI Class B.

Bustec's ProDAQ 6100 is a small LXI carrier box. The unit is 1U high and half of 19in wide, which is about the size of a normal laptop. The user can install in each of these ProDAQ carriers up to four different or the same input and output cards called 'function cards'.

In the aerospace industry, Ethernet with IEEE 1588 or LXI Class B is the logical choice for data acquisition or test and measurement systems. All measurement and test applications in the industry can be handled. Obsolescence problems are no longer of concern as backward compatibility of more than 30 years is assured.

The distribution of data sources is handled by Ethernet, which by definition gives a distributed environment. Synchronization via IEEE 1588 solves even demanding clock synchronization needs. The measurement accuracy, such as in the case of Bustec systems, is on a level never seen before. The data throughput to the PC or server can scale with the user's needs and is virtually unlimited, such as in the NASA system described above. The maximization of channels per measurement card, such as in the case of Bustec's ProDAQ 3416, brings down the total volume of measurement systems considerably.

This translates into lower system cost, as the space needed for the systems also minimizes. Last but not least, the cost of cabling will be reduced considerably, as expensive signal conditioning and data cables are mostly replaced by inexpensive Ethernet cables. As a result, costs are lowered but performance is improved. ∎

Dr Fred Blönnigen has a PhD in physics. In 1998, he founded Bustec in Ireland and opened a branch in 2000 in the USA. He is still working as CEO of Bustec

Fuel measurement in aircraft

OPTICAL MEASUREMENT OF THE QUANTITY OF FUEL IN AIRCRAFT PROVIDES ADVANTAGES COMPARED TO THE ESTABLISHED MEASUREMENT METHODS

"Fuel-level measurement in today's aircraft is mainly done by two different methods"

INGO BEBERMEIER

BY INGO BEBERMEIER AND SVEN CIERULLIES

Measuring the exact quantity of fuel remaining in the tanks of an aircraft is an important task to determine the remaining hours or minutes that the aircraft can stay airborne. In addition, exact measurement of the fuel mass during refueling reduces the need to take surplus fuel, reducing the aircraft's weight and enabling extra payload to be transported. For this purpose, both fuel level and fuel density have to be measured to accurately calculate the fuel mass.

Fuel-level measurement in today's aircraft is mainly done by two different methods, capacitive or ultrasonic measurement. Both methods, however, require electrical power inside, or at least, close to the fuel tanks. This introduces the risk of fuel-vapor ignition. In addition, the electronic components have to withstand the environmental conditions in the fuel tanks, mainly located in the aircraft's wings and thus subject to extreme temperatures, vibrations, stress, humidity, and electromagnetic disturbances.

A general design guideline for the optical measurement systems was to reduce the number of components, especially those sensitive to such things as temperature and vibration in the fuel tank area. The light sources and sensors are thus located inside the aircraft, in the fuselage or electronics bay, and the sensors in the fuel tanks are merely optical devices which direct the measurement light through, or along, the kerosene. Two measurement methods are under development – one for measuring the fuel level and one for measuring the fuel density. Together, they enable the calculation of the fuel mass.

Differential absorption

The differential-absorption method utilizes the absorption properties of kerosene fuel, which shows an absorption peak at a wavelength of about 915nm, and exhibits considerably lower absorption at shorter wavelengths (Figure 1).

The fuel level can easily be calculated by measuring the power of light transmitted through the fuel at a higher absorption wavelength, using a wavelength with lower absorption for a reference measurement to eliminate errors through additional system losses.

The measurement can be carried out, for example, at a wavelength of 905nm while a reference measurement is performed at 850nm, which are wavelengths where reasonably priced commercial pulsed- and continuous-wave laser diodes are available. The wavelength of a laser diode is influenced by temperature and manufacturing conditions. An online reference measurement has to be carried out to determine the exact absorption coefficients. This is done by using a reference cell located at the bottom of the tank. Variations of the absorption properties of different fuels or at different temperatures are also corrected by this method.

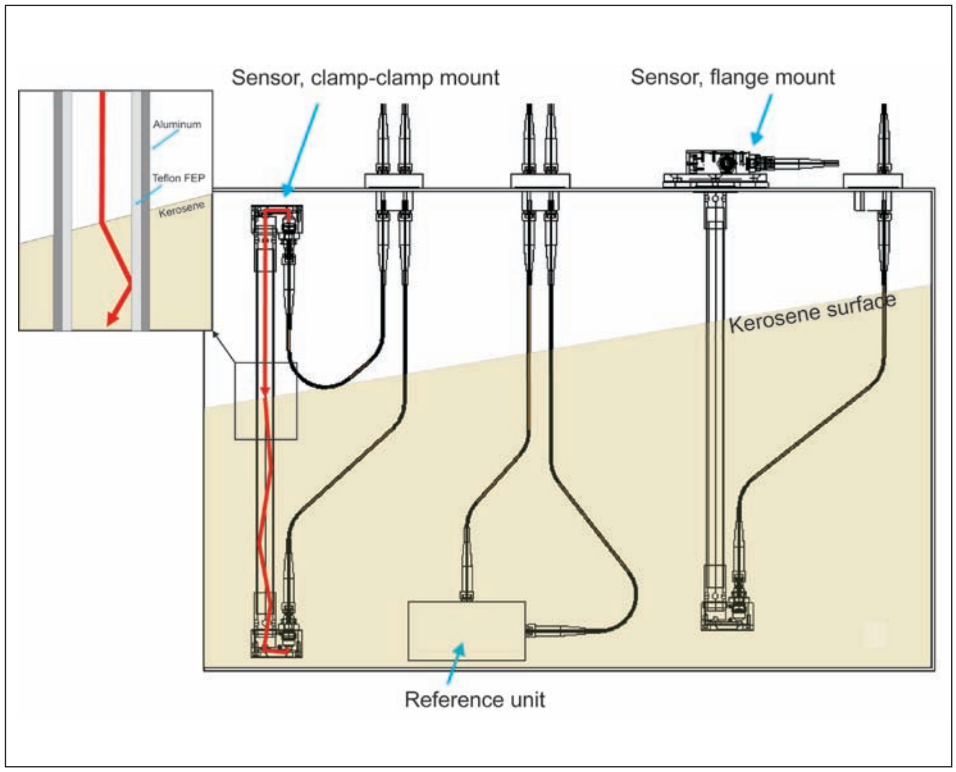
The sensor inside the tank is kept very simple because the most important design guideline for the optical fuel-measurement system was to keep sensitive equipment out of the fuel tanks. The sensor's tasks are to collimate the light from the optical fiber into a collimated beam, direct the beam through the fuel, and focus the light into the second fiber, which directs it back to the measurement unit.

These tasks are performed by a patented sensor, which consists of two fiber collimators, two dove prisms for beam-steering, and an aluminum tube, coated on the inside by Teflon FEP, which has a refractive index considerably lower than that of kerosene. Because of this, the kerosene-filled part of the fuel sensor acts as a liquid light-guide by utilizing the principle of total internal reflection, which improves the overall transmission of the system and reduces the optical power needed for appropriate power levels at the detector. This light-guiding property is especially important when the kerosene surface is not perpendicular with respect to the incident beam, and thus the refraction directs the light toward the wall of the sensor tube. This issue is also illustrated for the sensor at the left-hand side in Figure 2.

Using this method, a simple measurement system can be set up, which uses large-core multimode optical fibers to get light to the tank and back to the measurement system. To avoid errors and signal fluctuations due to interference-effects, multimode pulsed laser diodes with short coherence lengths were used as light sources.

Two pulsed laser modules are combined with a polarization beam splitter and the light is distributed to the measurement, reference and monitoring. After having passed the sensor (the kerosene), the measurement light is transmitted back to the controller in an optical fiber and detected by a photo diode. The pulse energy is measured then by integrating the pulse power.

A first setup of the measurement system has been tested for fuel levels between zero and 50cm. In Figure 3, the result shows the good accuracy of the measurement system throughout the whole measurement range.



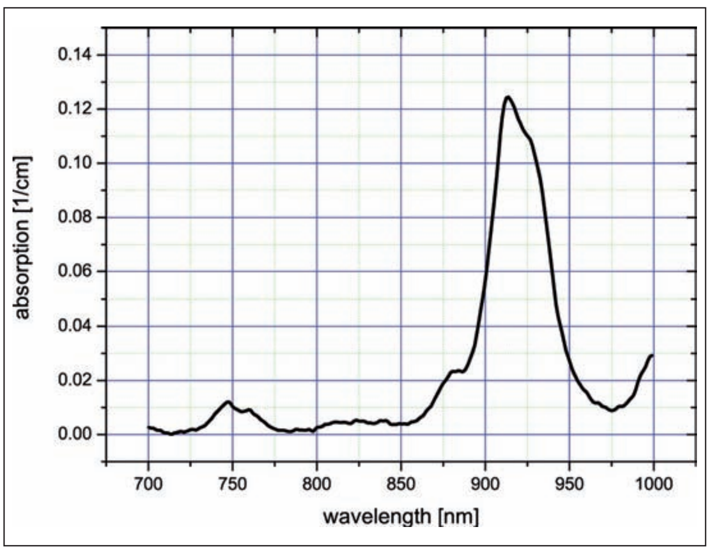


Figure 2 (above): fuel level gauging system setup, showing two types of level sensors for different mounting types

Figure 1 (left): absorption characteristic of Jet-A1 kerosene fuel

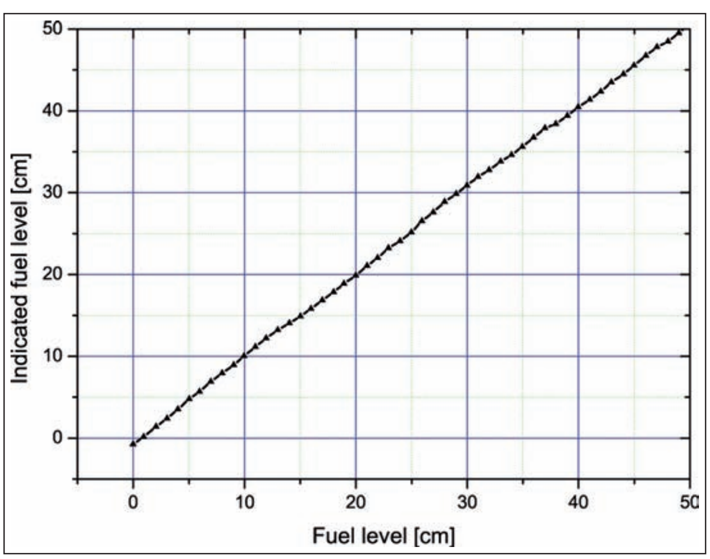
Figure 3 (below left): measurement results of the differential-absorption level gauging system

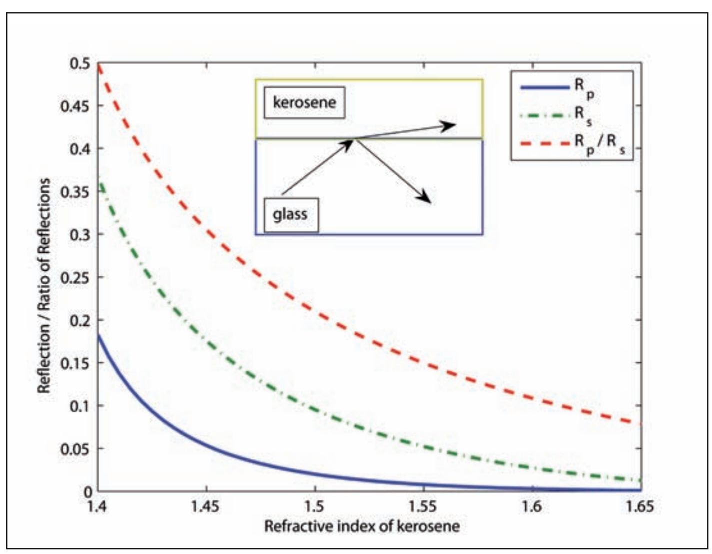
Figure 4 (below right): reflection coefficients for s- and p-polarized light and the ratio of those as a function of the refractive index of kerosene

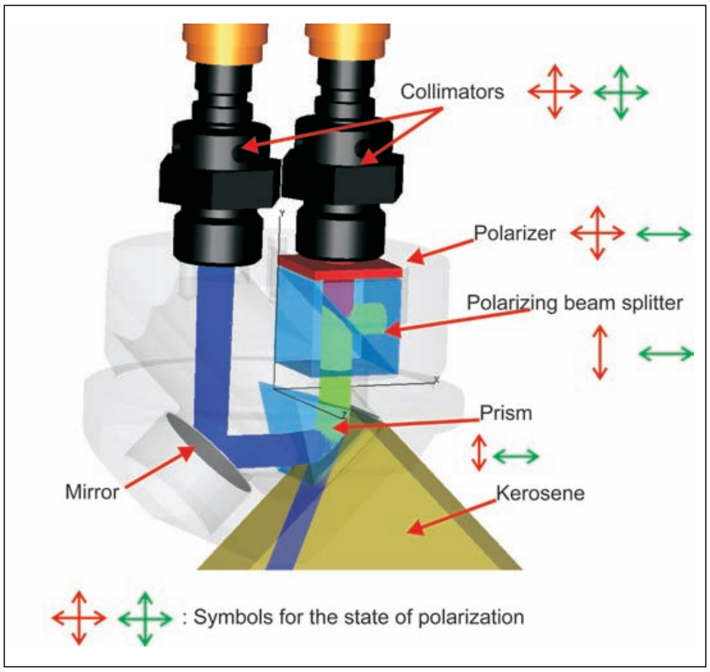
Polarization-based measurement

Measurement of the density of kerosene can be performed with sufficient accuracy by measuring the optical refractive index. A well-known method for remotely measuring the refractive index is ellipsometry. Using two different states of polarization, the refractive index of a sample can be calculated by measuring the ratio of the respective reflection coefficients. However, for standard ellipsometry, expensive small-core polarization-maintaining fibers or delicate moving mechanics would be necessary, so a method is used where two different wavelengths are polarized orthogonally. Therefore, for the density measurement large-core multimode fibers can be used, too, which increases the coupling efficiency of the sources and reduces the necessary alignment precision.

The measuring principle of the refractive index sensor is based on the fact that the







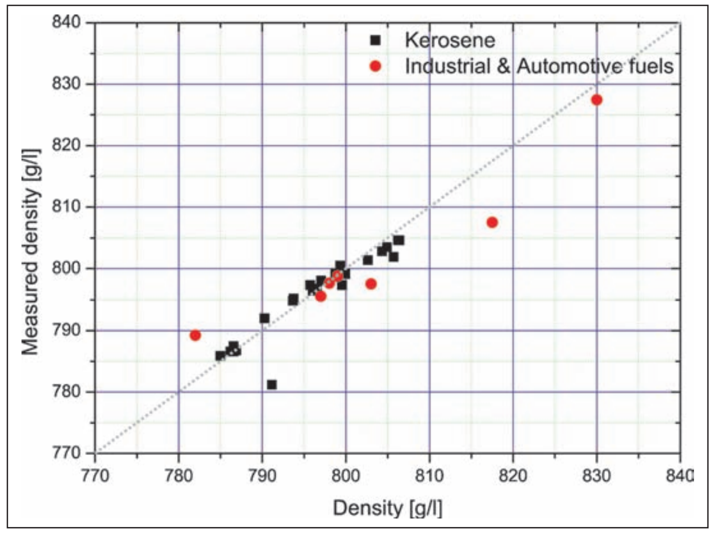


Figure 5 (left): mechanical set-up of the refractometer head, including collimators, two polarizers, and the glass-kerosene interface

Figure 6 (above): density measured by the optical refractometer compared with actual density

two materials with different refractive indices does not only depend on the refractive index difference and the angle of incidence, but also on the state of polarization of the incident light. In Figure 4, the reflection coefficient for s-polarized light, p-polarized light and the ratio of both is shown for a configuration with an angle of incidence of 50° and a refractive index of glass of 1.79. By measuring the ratio of the polarization-dependent reflection coefficients, the refractive index of kerosene can be determined.

The remaining task is to generate light polarized in two orthogonal states at the interface between glass and kerosene without having to use expensive polarization-maintaining fibers. This is accomplished by a setup which uses the wavelength-dependent polarizing properties of a polarization beam splitter and a sheet polarizer. These elements usually offer a very good separation of the polarization states in a certain wavelength interval, and show a much less polarizing effect at wavelengths outside of that interval. Combining two devices which polarize in adjacent spectral regions, one can create two light beams at two different wavelengths which are orthogonally polarized. Since this results in a ratiometric measurement method, losses due to such things as fiber bends, connector, and dirt have no influence on the measurement results as long as they affect both measurement wavelengths in the same manner. This can be achieved by selecting two wavelengths which are spectrally as close as possible.

The setup of the sampling head is illustrated in Figure 5. The light, collimated by the first collimator, passes the polarizer sheet, which polarizes the green light while not changing the state of polarization of the red light. The polarizing beam splitter then polarizes the red light orthogonally with respect to the green light. Light at both wavelengths is reflected at the interface between the prism and the kerosene, and afterwards coupled back into the second fiber, where it will be guided toward the detector. The wavelengths are separated there, the power is measured, and the refractive index of the kerosene can be calculated. Depending on the specific wavelengths, a numerical correction for dispersion of glass and kerosene has to be applied.

Measurement results

To test for the accuracy of this method for determination of the density of fuel, several types of kerosene from refineries all over the world were tested. In addition, military jet fuels, automotive fuels and industrial petroleum products were examined. The results, plotted in Figure 6, show that this method provides a good accuracy for jet fuels, but is also applicable to other fuel types.

Optical measurement of the level and density of kerosene in aircraft tanks offers advantages compared to standard methods. However, several issues have to be addressed to make an optical measurement system airworthy. It has been shown that the technical and environmental challenges have been addressed with a method for optical measurement of the fuel level and for measuring the fuel density. Both methods have in common that they neither need electrical energy nor environment–sensitive devices inside or near the fuel tanks. In addition, standard components, such as laser diodes and LEDs can be used, which considerably reduces the cost.

Both measurement methods showed good accuracy, and both are robust and relatively, simple technologies, suitable for use in harsh environments. This also implies reduced maintenance costs. The measurement systems are also suitable for the measurement and characterization of other liquids, such as water, lubricants, or cooling agents. ∎

CONTACT
Dr Sven Cierullies & Ingo Bebermeier
m-u-t Aviation-Technology GmbH, Rissener Landstraße 252, 22559 Hamburg, Germany,
+49(0) 4026344401,
info@mut-aviation.com

Index to advertisers

Tunnel vision

AN OLD HIGH-SPEED WIND TUNNEL IN THE UK HAS BEEN TOTALLY REFURBISHED. IT WAS FINISHED EARLIER THAN EXPECTED AND UNDER BUDGET

"The facility was built and commissioned in the late 1950s and has been in almost continuous operation since"

BY PHIL LISTON-SMITH

The High-Speed Wind Tunnel (HSWT) at Engineering Integrated Solutions, BAE Systems, Warton, UK, is a tri-sonic blow-down tunnel with a Mach number range of 0.4 to 3.8. The facility was built and commissioned in the late 1950s and has been in almost continuous operation ever since. It has seen over 38,000 runs in the last 60 years and a major refurbishment of the facility has now been completed.

The supersonic Mach number is controlled by the precise positioning of 72 hydraulic actuators that allow the adjustment of flexible nozzle walls. Subsonic and transonic velocity is controlled by the formation of a second throat behind the model test section.

In March 2009, BAE Systems engaged Jacobs Technology Inc to manage the refurbishment of the High-Speed Wind Tunnel facility. This US$7.2 million (£4.5 million) task will be complete by the end of December 2010, ten weeks earlier than expected and within budget.

The refurbishment has centered on replacing the 5,500 lb (2,500kg) Monel 400 plates which form the flexible nozzle walls, and the precise realignment of critical components. The geometric conformances of the flexible nozzle walls are key in optimizing Mach-number governance and tunnel flow quality. Each 30ft plate has been machined to a tolerance of +/-0.001in (0.025mm) with an into-wind surface finish of approximately 16 microns.

The refurbishment meant almost complete stripping the main tunnel carcass.

Operational improvements

The refurbishment included installing safety measures to protect the flexible nozzle. A linear encoder-based system deployed at each jack station monitors plate deformation and plate stress during all nozzle movement operations. In the event of an over-stress warning, hydraulic systems are shut down so that nozzle stresses are relieved.

As part of the final commissioning phase, BAE Systems will conduct a flow calibration in the supersonic working section of the tunnel. A hydraulically actuated, multiprobe flow calibration rake capable of withstanding the high start/stop loads has been built to allow the quantitative evaluation of flow quality and tunnel characteristics.

To support the refurbishment program BAE Systems has developed a mathematical model of the control mechanism to enable nozzle profiles to be predicted for further analysis with nozzle design methods. The ability to predict these profiles provides a sound basis for calibrating the HSWT control mechanism as well as optimizing nozzle profiles.

Operational capability and efficiency improvements have been carried out concurrently with the refurbishment. The model carriage system has been upgraded and refurbished, and a new HD video system will be installed. High-maintenance mechanical systems have been redesigned to extend service life and lengthen maintenance intervals.

The return to service of the High-Speed Wind Tunnel in December 2010 will fulfil the needs of the aerodynamic community in supporting a new generation of high-speed airframe and missile concepts and systems for several decades. ∎

Phil Liston-Smith is engineering manager at Project Ventus, Aerodynamic and Flight Systems Test, BAE Systems, Warton Aerodrome, UK. Tel: +44 1772 852828; Email: phil.liston-smith@baesystems.com

PHIL LISTON SMITH