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SHOWCASE 2010

AEROSPACE TESTING INTERNATIONAL

2010 SHOWCASE

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Breaking new ground

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Remaining in the slow lane is the 'overweight' A400M, which is now around four years behind schedule and in a critical design phase. Engines have been tested, but it could still be at least three to four years before it goes into service, and with leasing orders for C-17s and C-130Js increasing to fill the military transport gap, who knows how many customers will fulfill orders?

Sitting just slightly forward of the A400M are a number of civil projects that seem to have stalled. Delays, parts shortages, and last-minute fixes have cost the 787 billions of dollars in extra expenses and lost years. That's on top of weak demand for aircraft as air travel and freight shipments take a hit during the economic downturn. But Boeing's troubles have arisen partly from a new approach to airplane building. In recent years, the company has outsourced manufacturing and engineering work to suppliers around the world, and made ambitious use of carbon composites.

The technological leaps have proved troublesome for the company. "We have experienced a bridge-too-far, leading-edge kind of development, which is what we are trying to recover from right now," Boeing chief executive Jim McNerney said recently, following the company's earnings announcement.

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Christopher Hounsfield, editor

EDITOR Christopher Hounsfield (c.hounsfield@ukipme.com)
CHIEF SUB-EDITOR Alex Bradley
SUB-EDITOR William Baker
PROOFREADERS Christine Velarde, 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 Joanna Coles, Lewis Hopkins, Carol Doran, 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

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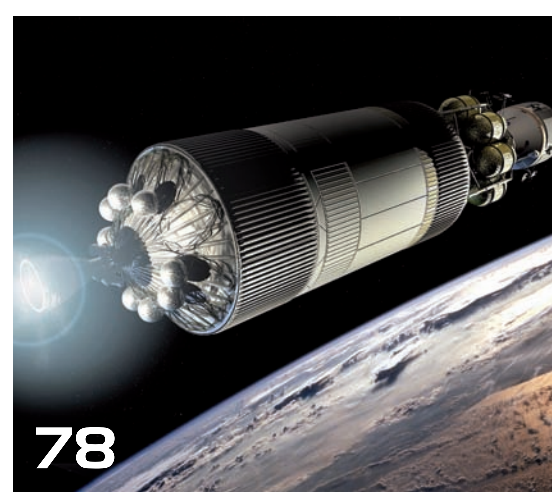

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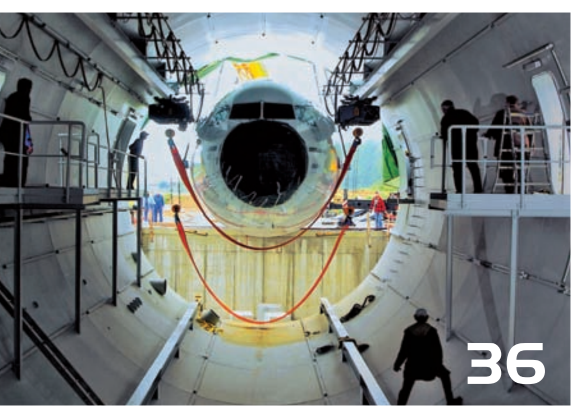
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Introduction: Jaiwon Shin

ASSOCIATE ADMINISTRATOR FOR AERONAUTICS RESEARCH, NASA

Since the first flight of the first powered airplane a little more than a century ago, the human race has realized the amazing feat of making air travel the safest mode of transportation. Today's aviation is truly one of the marvels of engineering. But the industry recognizes that there is still a huge potential for improvement in aviation despite the millions of hours we have logged in airplanes. Although there is a wide range of maturity and capability in the world's vehicle systems, our everyday experiences with fixed-wing aircraft and rotorcraft still leave us with a desire to improve the current configurations to take full advantage of their capabilities. For example, there are numerous military applications for supersonic aircraft, but we have not been able to develop the technologies needed for efficient and practical civilian supersonic transport over land. The state-of-the-art for the supersonic combustion ram jet engine technology required for air breathing hypersonic flight has been demonstrated in an actual flight for only 10 seconds.

This is a time of challenge for the global aviation industry. Accommodating a level of air traffic in 2025 that may be double that of today will require passenger and cargo aircraft that fly much more cleanly and quietly, and consume less fuel. To improve performance, we must expand the flight envelope, increase the reliability and reduce the weight of airframes and engines, and increase the energy efficiency and operability for the entire aircraft package: airframe, engines, and subsystems. Challenge brings opportunity for NASA. Our aeronautics research strategy employs novel test methods and validated prediction tools to improve system trade-offs for advanced concepts that can meet long-term targets for lower noise and emissions and higher performance.

Environmental concerns and system efficiency are at the top of the list of problems for which NASA aeronautics is seeking solutions, and there is a direct correlation between improving fuel efficiency and reducing greenhouse gas emissions related to climate change. Local air quality is a growing concern anywhere there is an airport, so NASA is also investigating cleaner combustion technologies. NASA's environmentally responsible aviation research is not limited to chemical pollutants, however. It is also studying ways to reduce noise in and around airports – the whine of jet engines and the thunder of sonic booms – because these annoyances hinder growth in the aviation system worldwide and the commercial development of supersonic air transportation. Improvements in system efficiency through new approaches to air traffic management, which NASA is researching, will yield considerable economic gains.

We at NASA strive for world-class quality research, drawing on rich talent and expertise from our four key research facilities in California, Ohio, and Virginia, and in partnership with other government agencies, industry, and academia to develop innovative concepts, tools, methods, and technologies with the potential to revolutionize air transportation. If we carry out groundbreaking aeronautics research but do not share what we have learned, there is no benefit. So we work hard to transition the results of our research to the aeronautics community and to leverage our technical capabilities on a global scale through international partnerships.

There was a time just 50 years ago when no one knew if an airplane could fly safely at the edge of space or cruise at hypersonic speeds. The notion of bringing a spacecraft to a pinpoint touchdown on Earth after a fiery re-entry and an hour-long free fall from orbit into and through the atmosphere was appealing, but still science fiction. The fact that all of this seems to be practiced rather routinely today is a testament to the USA's X-15, the most successful experimental aircraft program in history. Its contributions to the development and growth of the aerospace industry around the world cannot be over-emphasized. Powered by a rocket engine, and with stubby wings, a wedge-shaped tail, and skids for landing gear, this titanium-and-inconel rocket plane racked up 199 test flights between 1959 and 1968, flying as fast as 4,520mph and as high as 67 miles. Its speed and altitude records still stand.

Lessons learned from the X-15 enabled the use of exotic materials in air and space vehicle construction, development of computer-controlled flight, advances in training by simulation, the entire landing profile of the Space Shuttle – and much more. The X-15's most important lesson for us, by far, is this: To advance the state-of-the-art in aeronautics, we must be willing to take risks. We must step outside our comfort zones and find out what is possible. Even if we fail to meet our goals, we will succeed if we learn new things and communicate that knowledge to others to enable new capabilities in the future.

Dr Jaiwon Shin is the associate administrator for the Aeronautics Research Mission Directorate. In this position, he manages NASA's aeronautics research portfolio and guides its strategic direction. This portfolio includes research in the fundamental aeronautics of flight, aviation safety, and the nation's airspace system

Missile defense mechanism

A COMPREHENSIVE TEST PROGRAM FOR THE BALLISTIC MISSILE DEFENSE SYSTEM, COMPRISING A COMBINATION OF INTERCEPTOR AND SENSOR SYSTEMS, IS BEING PUT IN PLACE BY THE MDA

> "In 1972, only nine countries possessed ballistic missiles. Today, this has grown to more than two dozen"

LT GEN PATRICK J. O'REILLY

BY PATRICK O'REILLY

The mission of the Missile Defense Agency (MDA) is to develop defenses to protect the US homeland, deployed forces, allies, and friends against ballistic missiles of all ranges and in all phases of flight. President Obama asked the US Department of Defense and the MDA to prove that the missile defense system, initially fielded in 2004, works. The MDA is dedicated to accomplishing this task to build the confidence of US and allied stakeholders in the ballistic missile defense system (BMDS), bolster deterrence against the use of ballistic missiles, and send a powerful message to potential adversaries looking to acquire ballistic missiles.

Ballistic missile defense system

Back in 1972, only nine countries possessed ballistic missiles. Today, this number has grown to more than two dozen, and it includes hostile regimes with ties to terrorist organizations. The ballistic missile threat continues to grow in size and complexity. Potential adversaries are increasing short-range ballistic missile (SRBM), medium-range ballistic missile (MRBM), intermediate-range ballistic missile (IRBM), and intercontinental ballistic missile (ICBM) inventories, even as they are developing more advanced and capable systems. Current trends indicate that adversary ballistic missile systems, with the integration of advanced liquid or solid-propellant propulsion technologies, are becoming more mobile, survivable, reliable, accurate, and capable of flying over longer distances.

Given the unique characteristics of different ballistic missiles, no single missile defense interceptor or sensor system can effectively counter all ballistic missile threats. War fighters are not only faced with the challenge of intercepting relatively small objects at great distances and very high velocities, but they may have to counter large raid sizes involving combinations of SRBMs, MRBMs, IRBMs, and ICBMs and, in the future, countermeasures associated with structured ballistic missile attacks.

Standalone missile defense systems must be integrated into a layered BMDS to achieve cost and operational efficiencies, while improving protection performance with increased defended area and minimizing force-structure costs.

The Aegis BMD-equipped ship, USS Hopper (DDG 70), detected, tracked, fired, and guided a SM-3 Block (Blk) IA

The most operationally effective missile-defense architecture is a layering of endoatmospheric and exoatmospheric missile interceptor systems with ground and space sensors, connected and managed by a robust command and control, battle management, and communication (C2BMC) infrastructure.

The USA is developing and fielding a range of land- and sea-based terminal and midcourse capabilities to counter SRBMs to protect forces deployed abroad, allies, and friends. The SRBM

defense capabilities of the BMDS consist of the Patriot Advanced Capability-3 (PAC-3), THAAD (Terminal High Altitude Area Defense system), and the Aegis Standard Missile (SM)-2 Block IV and a portion of the SM-3 Block IA interceptor battle space with associated fire-control software.

The THAAD and Aegis BMD capabilities are able to counter MRBMs to protect deployed forces, critical assets on allied territory, and population centers. THAAD is a near-term transportable capability that will enhance the ability of combatant commanders to wage theater wars by intercepting SRBM and MRBM threats using hit-to-kill technologies. The THAAD missile is uniquely designed to intercept targets both inside and outside the earth's atmosphere, making it difficult to use countermeasures against THAAD in their terminal phase.

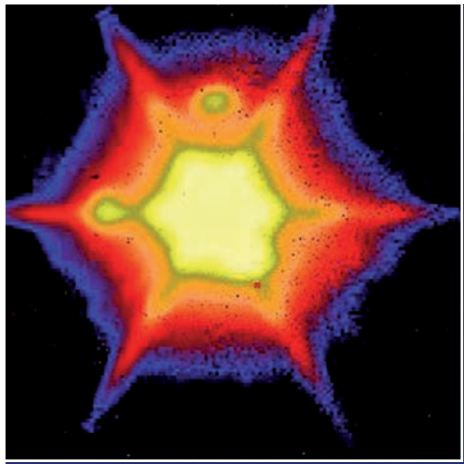
Aegis BMD cruisers and destroyers integrated with SM-3 hit-to-kill interceptors and SM-2 terminal interceptors provide a mobile capability that may be surged to a region to protect deployed forces and allies against SRBMs and MRBMs. The US Navy and MDA are collaborating on plans for a far-term sea-based terminal defensive capability to enhance the commander's ability to protect seaborne forces and complement other regionally deployed missile-defense assets.

Deployment

To counter the long-range ballistic missile threat, the USA has deployed ground-based midcourse defense (GMD) interceptors in silos at Fort Greely in Alaska and Vandenberg Air Force Base in California. Although the ICBM is the least proliferated threat delivery system among rogue states today, it is important to have a system in place to counter it because the blackmail or coercion possibilities stemming from the threat of long-range attack on the USA could have profound and major foreign policy consequences.

Continuously available, transportable, and mobile BMDS sensors provide real-time detection and tracking data to the system and the war fighter through C2BMC. The BMDS relies on space-based (defense support program, space-based infrared satellites, and, in the future, an operational space tracking and surveillance system (STSS) constellation), sea-based mobile (Aegis BMD ships and sea-based X-band radar), and ground-based (Cobra Dane, upgraded early warning radar (UEWR), AN/TPY-2 forward-based X-band radars, and, pending future decisions, European midcourse radars) sensors to provide detection, tracking, classification, and hit-assessment information.

BMDS integration is accomplished through the centralized development of seven common missile defense functions called the BMDS unifying missile defense functions: communications, sensor registration, correlation, system track, system discrimination, battle management, and hit-to-kill assessment. These unifying functions enable combatant commanders to automatically and manually optimize sensor coverage and interceptor inventory to defend against all ranges of ballistic missile threats.



An intercept from a long-range Strategic Targets System (STARS) rocket

Proving missile defense works

The USA's missile defense capability is maturing, as demonstrated by its 17 of 19 successful hit-to-kill tests in a little over three years. All these tests used operationally configured interceptors. Nevertheless, much work remains to be done. A comprehensive test program must not only measure the operational effectiveness of individual sensors and autonomous interceptors, but it must also measure the performance of an integrated BMDS, comprised of a combination of these individual interceptor and sensor systems.

After a comprehensive review of the missile defense test program that took several months and involved the US Services' operational test agencies and the director for operational test and evaluation (OTE), a new integrated master test plan (IMTP) has been created along with a rigorous test program that includes expanding flight tests to demonstrate capability against medium, intermediate, and long-range threats.

The objective is to establish a new convention for setting test objectives that go beyond simply exercising newly delivered elements of the system, and give primary emphasis to demonstrating the specific functions necessary for successful missile-defense operations. This review resulted in an event-oriented plan that extends out as many years as necessary to collect all data required to demonstrate specific missile-defense functions.

Evaluating the BMDS is likely to be one of the most challenging test endeavors ever attempted by the Department of Defense. Ideally, comprehensive and rigorous testing is enabled by a stable configuration of the system being tested, a clearly defined threat, a consistent and mature operational doctrine, sufficient resources to repeat tests under the most stressing conditions, and a well-defined set of criteria of acceptable performance.

Unfortunately, none of these situations applies to the BMDS. The hardware and software configurations of the BMDS frequently change as the system elements are still under development. There are many uncertainties

A Standard Missile-3 (SM-3) is launched from the Aegis cruiser on USS Lake Erie (CG 70)

> “Evaluating the BMDS is likely to be one of the most challenging test endeavors ever attempted by the Department of Defense”

surrounding the nature and specifics of the ballistic missile defense threat. Moreover, the operational doctrine for simultaneous theater, regional, and homeland defense is immature. Finally, costs range from US$40 million to more than US$200 million per BMDS flight test, making the repetition of a complex flight test cost-prohibitive.

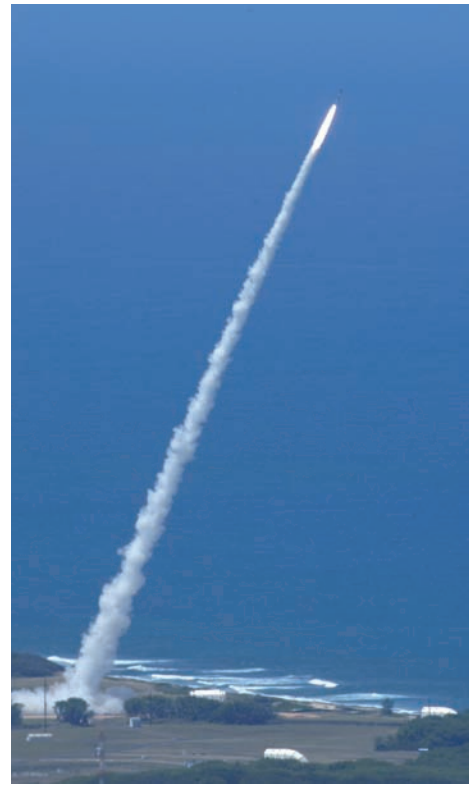
In light of these challenges, the BMDS performance evaluation strategy is to develop models and simulations of the BMDS and compare their predictions to empirical data collected through comprehensive flight and ground testing to validate their accuracy, rather than physically testing all combinations of BMDS configurations, engagement conditions, and target phenomena. The MDA is changing from an architecture-based goal approach to a parameters-based test-objectives approach. The focus of the ongoing BMDS test review has been to determine how to validate the models and simulations so that the US war-fighting commanders have confidence in the predicted performance of the BMDS, especially when those commanders consider employing the BMDS in ways other than originally planned or against threats unknown at this time.

Key factors

In Phase I of the test review, MDA and the multiservice operational test agency (OTA) team studied the BMDS models and simulations and determined the variables (key factors) most sensitive to the predicted results. The OTAs and MDA then combined sets of key factors with test conditions that provide the greatest insight into the BMDS models' predictive capability, when compared to test results, and called them critical engagement conditions (CECs).

However, there are many cases where the only practical way to measure, rather than simulate, performance is by ground or flight testing under operationally realistic conditions. The OTAs and the MDA call these tests empirical measurement events (EMEs). Much of the data needed for the OTAs' critical oper-

> **"Extensive testing between fiscal year 2010 and 2015 will take place, with more than 52 intercept tests"**



ational issues (COIs), such as survivability, reliability, performance in extreme natural environments, and supportability, can be collected only through the conduct of EMEs. MDA then combined the CECs, EMEs, and COIs into test objectives. Phase I identified the need to collect data for 101 CECs and EMEs in order to accredit the BMDS models and simulations and facilitate comprehensive operational assessments.

In Phase II, the OTAs and MDA combined these critical test objectives and selected test scenarios. These test objectives not only addressed data necessary to validate the models of individual missile defense interceptor systems, but also demonstrated the performance of the BMDS working as an integrated system. The OTAs and MDA prioritized the resulting test scenarios according to the need to determine BMDS capabilities and limitations and the combatant commanders' urgency of need for a specific missile defense capability.

In Phase III, the MDA identified the funding and infrastructure (including targets, interceptors, ranges, instrumentation, and personnel) needed to implement the test events designed in the second phase. Available targets and available test infrastructure were a key driver in the revised test schedule. For example, one of our high priority test events is to conduct a ground-based intercept with a high closing velocity, but the target to support that engagement will not be available until fiscal year 2013. In fiscal year 2011 and beyond, the ability to establish an inventory of reliable target configurations to satisfy test objectives over a variety of BMDS flight tests will be a key cost driver.

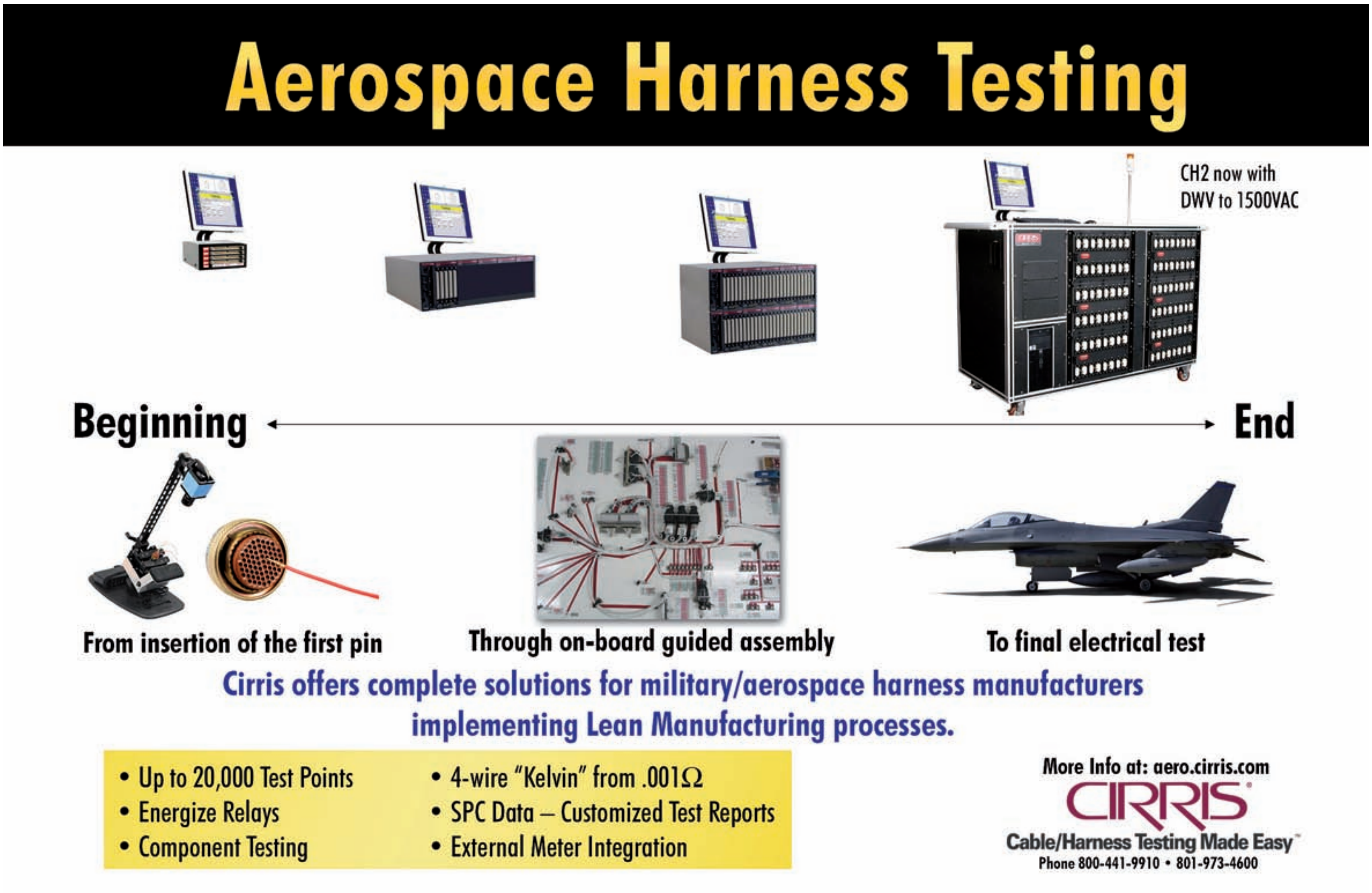
Two Space Tracking and Surveillance System (STSS) satellites were launched by the MDA from Cape Canaveral

At the conclusion of the three-phase test plan review, the OTAs and MDA produced, with full involvement by DOT&E and US Strategic Command, an integrated master test plan that is event-oriented and extends until the collection of all identified data is completed to ensure adequate test investments.

Extensive testing between fiscal year 2010 and 2015 will take place, with more than 52 intercept tests out of 81 flight tests, many involving multiple threat missiles in the air at the same time, carried out across the entire Pacific Ocean. A combination of satellites, unmanned aerial vehicles, ships, radars, and interceptors will be used.

MDA is focused on conducting meaningful ballistic missile testing that rigorously demonstrates the capabilities of the BMDS. Executing a test program in accordance with a test schedule as established in the IMTP is one of the MDA's highest priorities. Missile defenses can play a useful role in supporting the basic objectives of deterrence, broadly defined, and help us to deal smartly with the missile proliferation challenge and the very real threats of blackmail and coercion. The nation, our forward-deployed troops, and our allies and friends are counting on the MDA and the Department of Defense to develop and field the effective, proven capabilities needed to defend against the ballistic missile threat of today and tomorrow. ∎

Lt Gen Patrick J. O'Reilly is the director of the USA's Missile Defense Agency. Parts of this article were used in Lt Gen Patrick O'Reilly's testimony before the US Senate Armed Services Committee and the US House of Representatives Armed Services Committee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Hybrid wing body configuration

NASA IS DEVELOPING NEW TECHNOLOGIES AND AIRCRAFT DESIGNS THAT COULD LEAD TO GREENER AIRLINERS. TO THIS END, ITS EFFICIENT LOW-NOISE HYBRID WING BODY AIRCRAFT IS SOON TO BE TESTED IN ITS SUBSONIC WIND TUNNEL

"The goal is to lay a foundation for the development of new generations of quieter and more efficient airliners"

BY DR FLORENCE HUTCHESON

As part of its effort to be more environmentally friendly, NASA is preparing for high-fidelity wind tunnel testing of a hybrid wing body (HWB) aircraft configuration that has the potential to reduce the noise experienced in the vicinity of airports and to fly further on less fuel. The goal is to lay a technological foundation for the development of new generations of quieter and more efficient airliners.

One objective is to introduce new aircraft concepts by 2020 that would enable the development of unconventional aircraft configurations that are 42dB quieter (cumulatively with respect to current subsonic transport aircraft noise certification levels set by the International Civil Aviation Organization) and burn 40% less fuel than a Boeing 777.

Engine configuration

A team funded by NASA and led by Boeing is developing two HWB aircraft concepts referred to as N2A and N2B. The N2A configuration has twin-podded, high bypass ratio turbofan engines mounted above the HWB airframe. The N2B is an embedded engine version of the HWB concept and will include boundary layer ingestion and advanced engine architecture with a single core driving multiple fans. Both concepts are designed to be all-wing freighters with a payload of 103,000 lb and a range of 6,000 nautical miles.

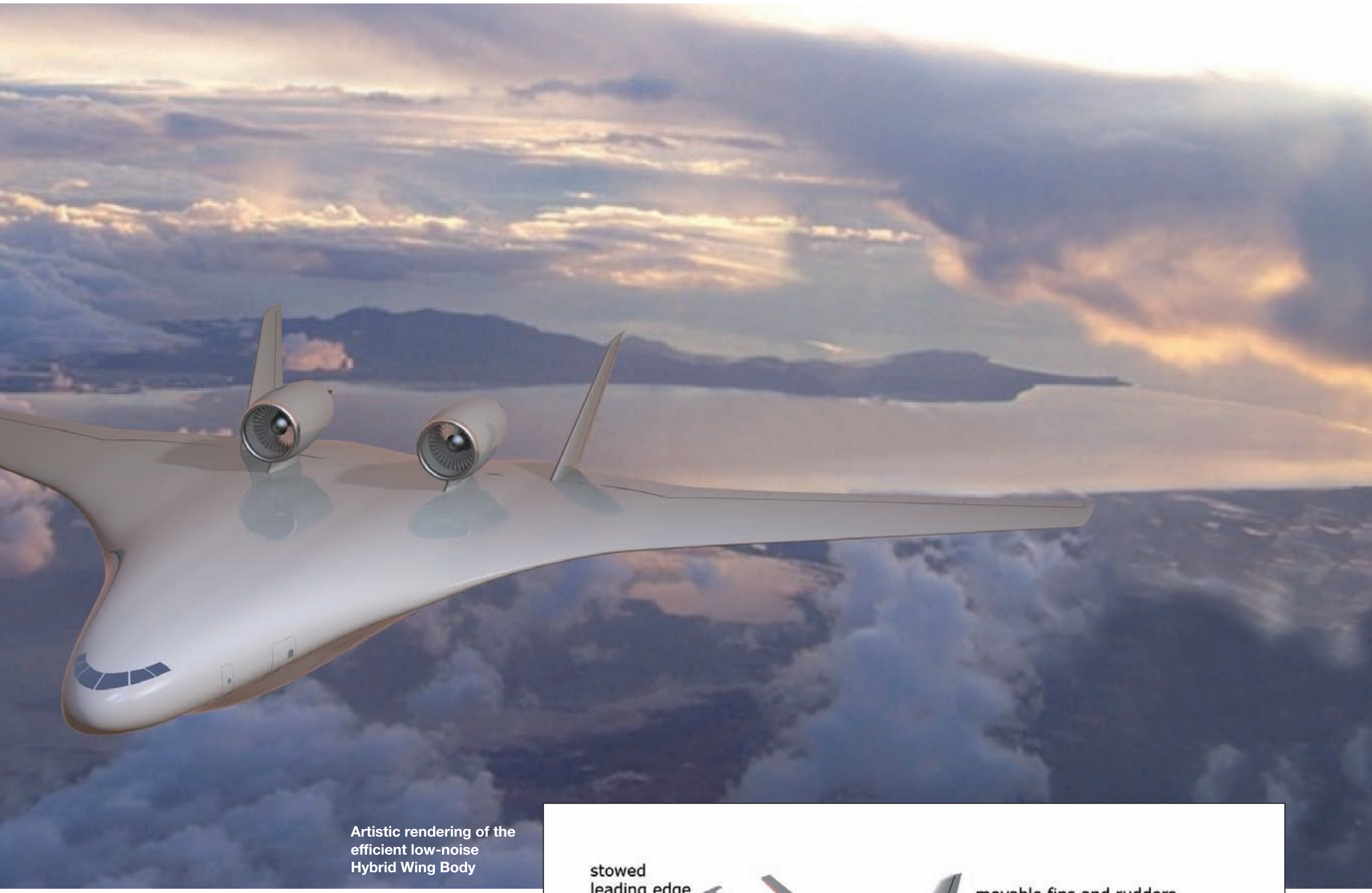
NASA is collaborating with the Boeing team by providing engine-system definition and aircraft noise-prediction expertise. The Boeing team includes the Massachusetts Institute of Technology (MIT), the University of California at Irvine (UCI), and the United Technologies Research Center.

The university teams are focusing much of their efforts on developing new methods to model and predict jet and turbomachinery noise shielding. Once validated, these new prediction methods will be integrated into NASA's aircraft noise prediction program (ANOPP), which is itself being expanded to incorporate prediction capabilities for advanced vehicle designs such as the HWB. At this stage of the research effort, the N2A configuration shows the best potential to meet the noise and fuel consumption goals. It will be the initial focus of the NASA HWB test program, with testing of the N2B configuration to follow in later years. The N2A HWB configuration is being designed to achieve the targeted noise reduction level of 42dB and a fuel burn reduction of at least 25% relative to a conventional aircraft for the equivalent mission. At present, laminar flow control is not included in the N2A design. This will be required to achieve the fuel burn reduction goal of 40%, and will be investigated in future system studies and experiments as a design iteration on N2A.

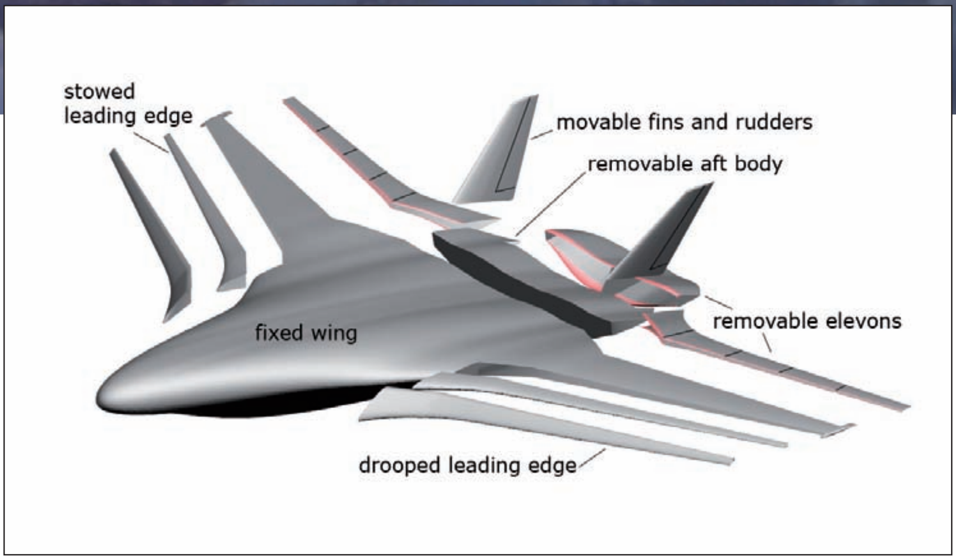
In the N2A configuration, the airplane forebody is used to shield the fan and turbomachinery noise radiating forward from the engine inlet. Aft turbomachinery and jet noise reduction is achieved by moving the engine pods forward so that the airframe trailing surfaces provide aft noise shielding. The vertical tails are also used to shield the sideline noise radiation.

Shielding of jet noise is limited by the distributed nature of the jet noise sources that can stretch approximately 10 nozzle diameters downstream. Several nozzle concepts that will improve jet noise shielding by

DR FLORENCE HUTCHESON



Artistic rendering of the efficient low-noise Hybrid Wing Body



compaction of the jet noise sources are also being evaluated.

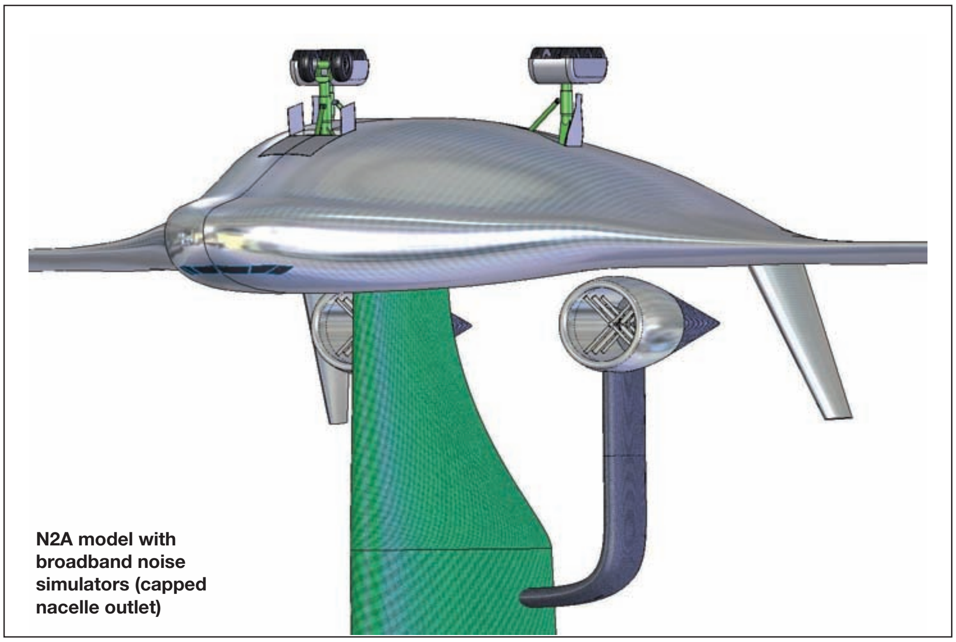
Wind tunnel and acoustics

NASA and the Boeing team are collaborating on the plans for medium-scale wind tunnel aerodynamic and acoustic testing of the N2A HWB configuration. Initial testing in 2011 will examine the basic aerodynamic characteristics. In 2012, detailed aeroacoustic testing will validate the 'low noise' characteristics of the N2A design. Subsequent tests will focus on much more detailed aerodynamic and low-speed flight stability and control characteristics. The objectives of the aeroacoustic test will be to determine the noise spectral levels and directivity of the N2A HWB and its components, and examine noise-shielding parameters such as engine location, vertical tails, and nozzle configurations to determine their effect on noise emissions. Finally, results from this test will be used to validate new acoustic shielding prediction methods being developed by MIT, UCI, and NASA as well as NASA's upgraded predictive capabilities for multiple aircraft noise sources.

The HWB aeroacoustics test will be conducted in the 14 x 22ft subsonic tunnel, commonly referred to as the '14 x 22', at NASA's Langley Research Center in Hampton, Virginia. The wind tunnel test section will be configured for acoustic testing, with its sidewalls removed and the ceiling raised, and will be positioned well above the flow's shear layer. The test section floor will be designed to provide a streamlined surface for the wind tunnel flow while maintaining good aeroacoustic absorption. The floor will be formed by lowering the model cart and mounting embedded acoustic wedges under an acoustically transparent surface.

Surfaces away from the tunnel flow will be covered with standard acoustic treatment. A full-span wind tunnel model of the N2A HWB with engine noise simulators will be positioned inverted in the test section. A traversing overhead phased microphone array as well as stationary microphones will be used to perform the acoustic measurements.

The wind tunnel model will be built by Boeing. It will be a 5.8% scale, resulting in a 12ft-span model. The test model scale was determined by the wind tunnel size and microphone



N2A model with broadband noise simulators (capped nacelle outlet)

"The jet noise will be generated by two dual-stream hot jet engine simulators"

frequency limitations. It will enable acoustic measurements to be performed over the full-scale equivalent range of 230Hz to 4.1kHz (4-70kHz, model scale) that is critical to aircraft noise assessment.

The test model will have a modular design to maximize testing capabilities. It will consist of a fixed wing to which various components such as control surfaces, flow-through nacelles, and landing gear will be attached.

The control surface components will include a drooped and a stowed leading edge to model high lift and 'clean' wing configurations, 12 elevons that will be deflected along the wing trailing edge to match specific flight conditions, and vertical fins of several sizes and dihedral angles with moveable rudders and multiple fuselage positions for the engine noise shielding study.

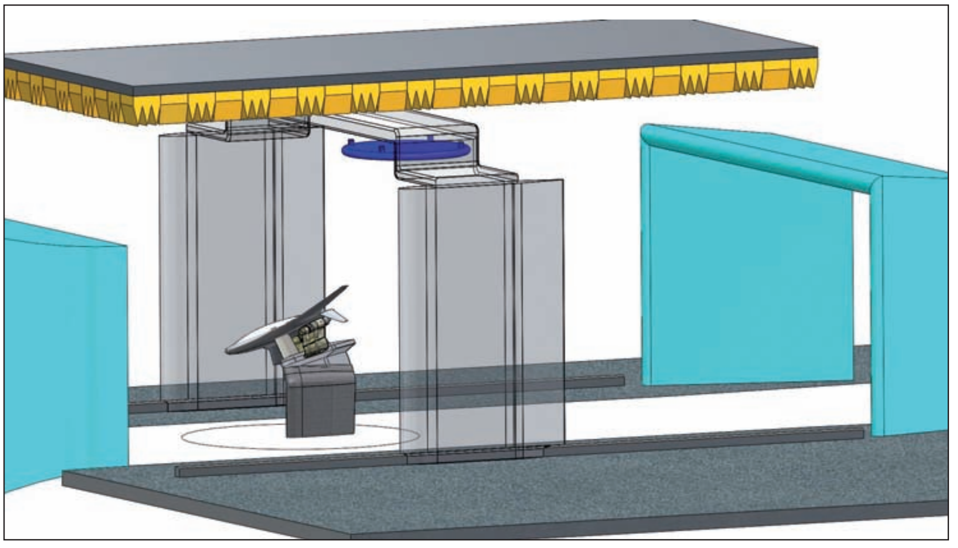
The modularity will also mean the model support strut can be attached to either the top or bottom surface of the model for upright or inverted testing, and the aft body section will be removable to enable testing of other types of exhaust nozzles such as embedded engines. The high fidelity of the geometric details that are important to acoustics, particularly on the landing gear assembly, the trailing edges and control surfaces, will also be emphasized.

Noise simulators

NASA is leading the development of the engine noise simulators and the advanced microphone phased array and traverse systems that will be used to perform the acoustic measurements. These new systems will represent a permanent increase in the capabilities of the 14 x 22.

The jet noise will be generated by two dual-stream hot jet engine simulators. The mid- and rear portion of the simulators will match the 5.8% scale nacelles of the N2A HWB. The front-burner region of the simulators, along with the air and propane supply lines and mounts, will be faired to minimize effect on the HWB fuselage flow field. The simulators will be configured to match the engine bypass ratio and operating cycles of the N2A HWB

14 x 22 wind tunnel test setup with open test section and inverted test model



design. However, the new support infrastructure that will be added to the 14 x 22 will be designed so that it can support a much larger operational envelope.

Provisions in the simulators' design will be made to accommodate different fan and core nozzle configurations. For risk reduction, a prototype of the jet engine simulator burner has been developed to verify flame control over the operating envelope, burner efficiency, and fuel consumption rate, as well as to measure – and if necessary reduce – burner and rig noise levels. This prototype will then be integrated into a full jet engine simulator to develop and test the pressure system hardware and control software prior to installation in the wind tunnel.

Enclosed high-intensity broadband noise generators will be used to determine insertion loss due to shielding by the HWB airframe of the fan and turbomachinery inlet and exhaust noise. The broadband noise will be generated by a series of opposing jet-impingement devices in the open interior of specially designed engine nacelles.

The nacelle's inlet and exhaust will be capped alternately to isolate noise radiation from either the inlet or outlet. The inlets and exhausts will also be instrumented with unsteady surface pressure sensors to monitor the noise source strength. Acoustic characteristics of jet-impingement devices of different sizes and air pressures are being evaluated to determine the most suitable design.

The phased microphone array will consist of 97 0.25in microphones flush-mounted to a lightweight, 8ft-diameter, rigid circular panel. Integrated inclinometers and accelerometers will be used to monitor tilt and vibration of the panel. The position of the microphone array will also be verified using known compact noise sources embedded along the surface of the test model. A two-dimensional traverse system will be used to position the array at different locations above the test model.

A specialist team from NASA is evaluating a gantry concept that will provide lateral and longitudinal motion as well as a stable platform for the array. The gantry would be mounted onto rails positioned on the test chamber floor and would traverse longitudinally from the nozzle exit to the collector. The array would traverse laterally along the top section of the gantry.

The array and the gantry structure will remain positioned outside of the test section flow and shear layer. The gantry, as well as the model stand and the engine simulators' support hardware, will be streamlined, faired, and acoustically treated where possible to minimize noise and acoustic reflection.

Data acquisition

A data acquisition system with a capacity of more than 144 channels will be used to record all the microphone signals simultaneously, along with surface pressure sensor signals. The data will be pre-processed as it is acquired to obtain initial noise spectra. At the same time, the data will be forwarded to a processing cluster for more detailed analysis. This system will be integrated fully with the 14 x 22 data acquisition system.

DAMAS

The acoustic phased array data will be processed using NASA's advanced array processing method, DAMAS (deconvolution approach for the mapping of acoustic sources).

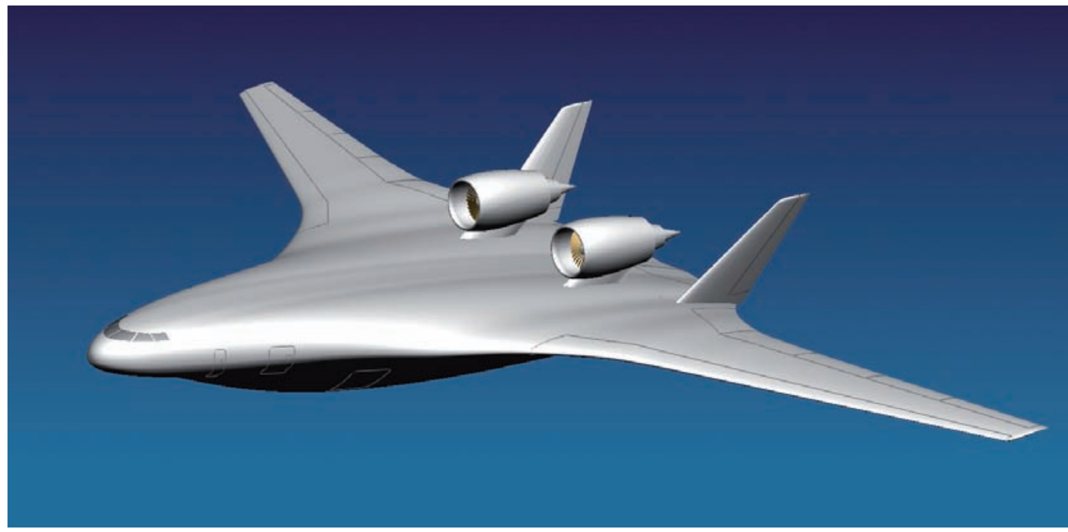
This highly technical method is used to accurately quantify position and strength of the noise sources. The first step of the DAMAS analysis consists of the application of a beam-forming process, which is used to 'steer' the microphone array electronically over chosen regions of the test model while discriminating against background noise, very much like an acoustic antenna. With this process, all the array microphones act as a single point sensor that can focus on distinct spatial locations.

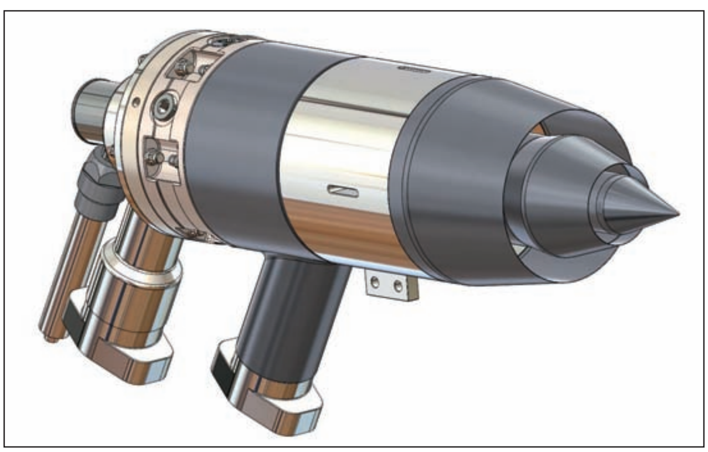
In the next step of the DAMAS processing, a deconvolution algorithm is used to decouple the array design influence from the beamformed output obtained in step one. The resulting deconvolved array output is explicit and used to generate high spatial resolution noise source localization maps. The phased microphone array will be able to measure exactly noise sources that are well below the wind tunnel background noise level.

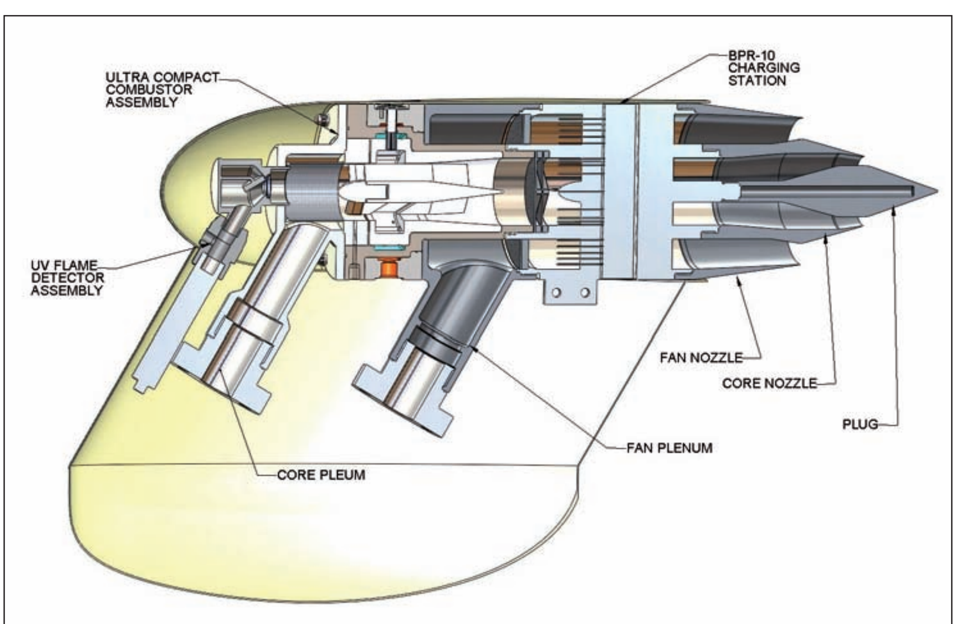
The new jet engine noise simulators and the advanced phased microphone array acquisition, traversing and processing system, together with the installation of new acoustic wall treatment, will result in a major capability upgrade to the 14 x 22 wind tunnel. This upgrade is necessary to meet the unique acoustic challenges of measuring such a low-noise aircraft model.

When completed, this aeroacoustic test will have produced the first detailed noise mapping of an Hybrid Wing Body aircraft design using new advanced acoustic measurement capability, as well as a benchmark acoustic database for HWB that is applicable to full-scale vehicles. ∎

"A data acquisition system with a capacity of over 144 channels will be used to record all the microphone signals simultaneously"







N2A Hybrid Wing Body (above). Cross section of jet engine noise simulator (below)

Dr Florence Hutcheson is a NASA research engineer. Contributors to this article include Dr Thomas Brooks (NASA senior research scientist and HWB test-team lead) and Dr Russell Thomas and Henry Haskin (NASA engineers)

Revival of Australian test range

AUSTRALIA'S WOOMERA, THE LARGEST LAND-BASED DEFENSE AND AEROSPACE RANGE IN THE WORLD, IS CURRENTLY EXPERIENCING A REVIVAL

> "The Woomera Prohibited Area (WPA) is a massive land area covering 127,000km²"

LINDSAY CAMPBELL

BY LINDSAY CAMPBELL

A woomera is an Australian aboriginal spear-throwing device described as 'the most efficient spear-throwing device ever'. It is a device that enables a spear to travel much further than with arm strength alone. The woomera is still used today in some remote areas of Australia.

The name woomera comes from the Eora people, who were the original inhabitants of the Sydney metropolitan area, and is an apt name for Australia's national air, space, and land experimental and test range. The Woomera Test Range's motto – 'sharpen the spear' – alludes to both its namesake heritage, and its strategic mission: to support and enhance Australian Defence Force warfighter capability through effective operational management of the Woomera Capability.

For those making their first visit to Woomera, many say that their lasting impression of this unique, remote, and famous region of Australia's arid Outback is of a constant and colorful landscape: red from the deep, rich ochre-colored dirt that is the color of the very heart of Australia; arid green from the huge array of sparse rain-fed emerald grasses, desert saltbush, gum trees, and native shrubs that survive in the most extraordinary places; and, all wrapped under a cloud-free sky of clean, endless dazzling cobalt blue.

Many are also surprised by the sense of 'emptiness' about Woomera, borne of a stillness and quiet that, to some, can be overwhelming or spiritual, and sometimes both. Woomera is a place that can grow on you as 'a special place'. Still others marvel at the abundance of native wildlife to be found everywhere in this arid region – even in the streets of Woomera Village! Kangaroos, emus, wedgetail eagles, and many native Australian birds, reptiles, insects, and other fauna are to be found all over the range, and many a range visitor has taken home a snap of emus walking around the village, or the odd kangaroo hopping around the vacant areas behind the Eldo Hotel.

Of course, Woomera's climate is far from benign. In the summer (December to February), daytime temperatures can reach well over 113°F. The occasional dust storms and heavy rain showers can wreak havoc on the plans of an otherwise nice day, and in the winter, the wind can be bitingly cold. However, the mean daytime temperature in winter (June to August) is about 61°F. Although it can rain torrentially at times, it can just as likely go without any appreciable rain for many months. But Woomera is an environment well adapted to its climate.

The Tiger ARH is the version ordered by the Australian Army to replace its OH-58 Kiowas and UH-1 Iroquois-based Bushranger gunship

The prohibited area

Within this beautiful and uniquely Australian landscape are to be found 27 pastoralist stations, four major mining activities, and Australia's specialized defense test and evaluation range. The Woomera Prohibited Area (WPA) is a massive land area covering 127,000km² (49,000 square miles) – virtually a county in itself when you consider it is roughly the size of England or the US state of Florida. The WPA also includes all the airspace over the WPA, otherwise known as the Woomera Restricted Airspace (WRX). Together, the WPA and WRX are synonymous with the capability that is the Woomera Test Range (WTR).

The pastoralists within the WPA have been here for around 150-170 years, but Australia's indigenous people have roamed this area for prob-

ably more than 30,000 years. There are no indigenous settlements within the WPA but about one-third of the WPA is traditional lands while the remaining two-thirds are under pastoral leases from the South Australia state government.

Mining has been conducted in the region for many years, but more recently, it has become the driving force of development in this remote part of outback Australia. Although the huge BHP Olympic Dam mine is outside the WPA, it is indicative of the mining potential of the area. Mining co-exists with defense activities in the WPA and generally does not or will not affect range activities.

Defense came here because the Woomera region presented a unique set of conditions that are perfectly suited to the testing of long-range air and space weapons, including: vast open space, clear air, a climate that permits year-round testing, very sparse population (less than one person per 1,000km^2), and special legislative powers to permit the primacy of 'the testing of war materials' over all other activities.

Early operations

Initially established in 1947 under the Anglo-Australian Project, Woomera became an Australian- and world-recognized icon during the 1950s and 1960s, synonymous with long-range rocket and missile testing during the Cold War. For over 35 years, it was one of the western world's most secret defense research and testing facilities.

At the height of the Anglo-Australian Project, which lasted nearly 30 years, Woomera was second only to the USA's Cape Canaveral in terms of the rate and number of rocket launches. Woomera's launch sites and tracking systems also played a crucial role in the development of the launch and tracking of spacecraft in the pioneering years of the space age.

Lake Hart, Red Lake, Mirikata, Koolymilka, Nurrungar, and Island Lagoon (also known as Deep Space Station 41 or DSS-41) are all Woomera sites of great historical significance to the early development of ballistic missile systems, spacecraft, and space travel. However, with the end of the Gemini program, and the winding down of the Anglo-Australian Project, T&E activities related to in-service weapon systems, and some ongoing weapons systems development work by DSTO became the range's principal activities as the 1980s approached and the Cold War waned.

Cold War to next generation

From the late 1970s through to the late 1990s investment in the range's principal instrumentation systems amounted mostly to 'care and maintenance'. But, in the mid-1990s, as the ADF began considering its future weapons systems requirements, it was also becoming apparent that the costs associated with introducing this next generation of weaponry, and in particular the T&E component, was going to be a major challenge for the ADF.

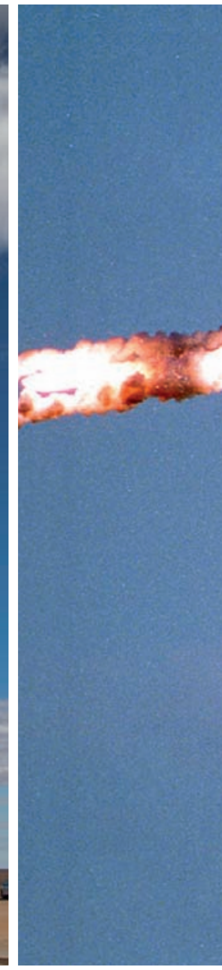
The Royal Australian Air Force (RAAF) assumed operational control of the Woomera Capability in 1999, with a long-term plan to rebuild the capability to support the ADF's significant aerospace T&E requirements planned to enter service through to 2030. That decision proved to have great foresight, as the T&E needs of these new systems became better understood, it also quickly emerged that Woomera was really the only range left in the western world still big enough to test these new weapons within its land borders. Additionally, as various fighting systems become more closely integrated in every aspect of their operations in the battlespace, the need for a vast and open airspace to simulate, test, and evaluate the operational effectiveness of new systems has focused a new era of interest on Woomera's unique operational T&E environment.

Although Woomera has a strong focus on supporting aerospace T&E activities for the ADF, the range also hosts a wide range of defense-related research and experimentation (R&E) activities. These activities, in general, are conducted by, or under the control of, Australia's Defence Science and Technology Organisation (DSTO).

The Australian Defence's Defence Material Organisation (DMO) and the ADF's Capability Development Group (CDG) are also great users of Woomera's specialist T&E capabilities, conducting a wide range of operational test and evaluation (OT&E) activities for new defense systems reaching in-service operational capability. Force Element Groups (FEGs) of the ADF, and particularly those directly involved in aerospace activities, are major users of Woomera.

There has been a recognized increase in inquiries involving public/private partnerships (PPP) and other defense industry teaming-type activities between organizations such as DSTO and commercial defense industries, as all sectors of defense continue to work together in an effort to find effective ways to rationalize their R&E and T&E costs – now generally accepted as about 25% of the entire in-service cost of a new system.

Hyshot Rocket Trial on Launcher 1, Woomera, South Australia



"The Woomera Test Range was finally listed for reinvestment in the 09-19 Defence Capability Plan (DCP)"

Woomera is also seeing a modest growth in joint activities being conducted in conjunction with the ADF under a number of long-standing allied agreements, and the WTR is once again becoming a much favored site with the broader defense industry community for its unique and specialized test enabling environment. In particular, Woomera is now the destination of choice for a number of UAV flight-test programs and the new generation of beyond visual range (BVR) weapons testing due to its huge, empty, and very 'electromagnetically clean' airspace – and the fact that Woomera is one of the only ranges where BVR weapons can be fully tested within land borders.

Reconfiguring for the future

In 2003, under the command of the RAAF's aerospace operational support group (AOSG), the Woomera Test Range was re-established as an independent wing-level unit of AOSG, with a clear new operational mission: "To support and enhance Australian Defence Force warfighter capability through effective operational management of the Woomera Capability." This mission is designed to take it to 2035 and beyond.

Under the current director, Dr Doug Gerrie, the Woomera's capability has been reassessed, replanned, and redefined with the aim to redevelop Woomera into a state-of-the-art aerospace T&E range. Achieving that aim will have considerable cost benefits for the ADF over the next 30 years. So the balance between the systems needed, and how best to deliver them, is a crucial part of Woomera that is expected to emerge over the next 7-10 years.

The remediation plans for Woomera are being endorsed by the command chain right through to the Australian government as the importance of Woomera as a strategic national T&E asset continues to emerge and gather momentum.

With new systems such as the Super Hornet, JSF (F-35), and new beyond-visual-range weapons due to enter service with the ADF over the next 20 years, a resurgent Woomera Test Range will play a critical role in testing these systems as well as giving Australia greater control over the T&E cost challenge, not to mention the gain in knowledge and technology that will naturally flow with an indigenous T&E capability of the Woomera dimension.

Within that climate of review, the Air Force vision defined for Woomera back in 1999 has begun to mature. In May 2009, the Australian federal government included the Woomera Capability in its white paper on defense business and budget priorities to 2030. In July 2009, the Woomera Test Range was finally listed for reinvestment in the 09-19 Defence Capability Plan (DCP) under Joint Project 3024 (JP3024). Around A$250 million (US$225 million) is to be invested in new tracking systems and infrastructure for the Woomera Capability, and it seems fairly assured that the range will be ready to meet its redefined role and mission for the next 30-50 years.

2015 and beyond

More than 60 years ago, Woomera's combination of environmental attributes such as its vast, flat groundspace, clear airspace, and lack of population, coupled with its remoteness and ideal hot/dry climate, resulted in the selection of this huge arid region for the creation of a capability that is likely to become as relevant to Australia's role in helping to maintain peace in the next 30 years as it was in its first 30.

The future focus of the WTR support to T&E activities is intended to include: air

Australian Army Aviation has 34 Blackhawk S-70s currently in service

is already receiving a A$2-5 million (US$1.8-4.5 million) internal systems upgrade as a first step toward its eventual fuller upgrade. But some of the more crucial elements, such as installation of fiber cable to replace the old copper wire network, have been ongoing for several years already.

In terms of operational tempo, over the past two years the number of trials requested and conducted at Woomera has soared. Trial request lead time now needs to be not less than 12 months – but even that level of forward planning cannot guarantee a range slot. Missile and other air weapons testing is often back-to-back. Supported instrumented range time is in high demand, with bookings now stretching well into the foreseeable future. Strong programs around rocket-based activities, electronic warfare testing, and weapons and ordnance testing from all platforms, round out a full annual schedule of activities.

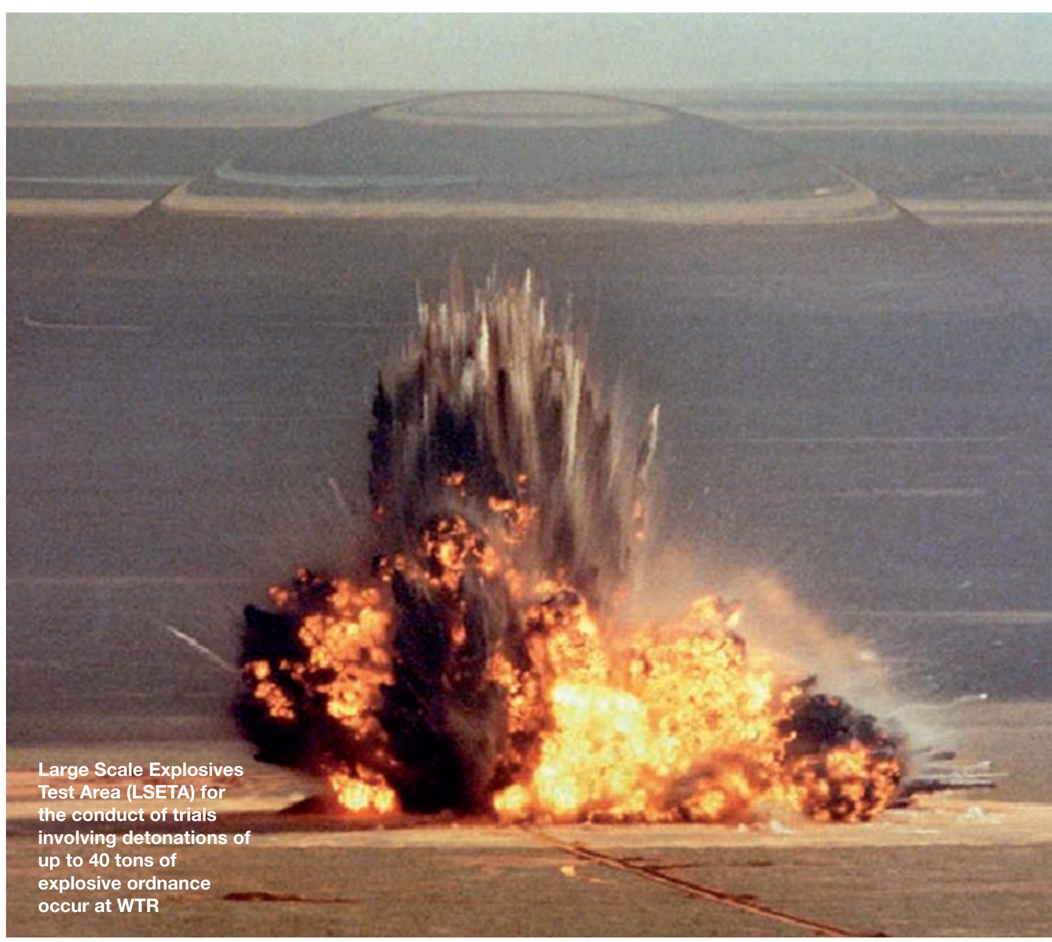
Around 2015, Woomera intends to be well on the way to being a completely refreshed T&E range, and be ready to meet its longer-term mission. With new technologies in place supporting data acquisition and reporting, and with appropriate upgrades of the supporting operational infrastructure, Australia will be able to realize the huge operational knowledge and technology benefits that will flow from the T&E programs slated for Woomera. ∎

Lindsay Campbell is head of external relations at WTR. woomera.enquiries@defence.gov.au; WTR open source website: www.woomera.com.au

weapons and platforms R&E and T&E, electronic warfare R&E and T&E, demolition testing (large and small scale), space vehicle R&E and T&E launch and recovery, ground-based weapons and platforms R&E and T&E, emerging technologies R&E, CIED and desert warfare tactics R&E and T&E, and simulation and training (force preparation) for the integrated battlespace.

One of the critical resources for the future success of the range is Woomera Village itself. When trial team members from all over Australia and the world assemble in Woomera, the support of the village is critical to them as their immediate support base to operations on the range. Adelaide, the nearest major city (and home to the Headquarters, Woomera Test Range at RAAF Base Edinburgh – just 30km north of the center of Adelaide city) is over 460km southeast of the range. The nearest major population center, Port Augusta, is 180km south of Woomera. But for more than 60 years, the challenge of traveling this distance has always been met by trials teams who have come from all over the globe to work at Woomera.

The core technologies supporting the key deliverables of the Woomera Test Range's capability are planned to be brought into the 21st century digital age over the next 10 years. Key deliverable services such as coarse and precision time and spatial positional information (TSPI) using a mix of radar and optical instrumentation remain at the core of the operational systems plan. The range control center



Large Scale Explosives Test Area (LSETA) for the conduct of trials involving detonations of up to 40 tons of explosive ordnance occur at WTR

The future for Phantom Works

A CHALLENGING TEST PROGRAM IS YIELDING CUTTING-EDGE SYSTEMS FOR MANY AREAS OF THE INDUSTRY, FROM HIGH-FLYING HYPERSONIC AIR BREATHERS TO SURFACE-SKIMMING SEACRAFT

"The air-breathing, jet-fueled engine powers the vehicle to a flight speed of approximately Mach 6+"

MARC SKLAR

BY MARC SKLAR

With primary development responsibilities for Boeing Integrated Defense Systems' (IDS), Phantom Works supports the main production divisions and works closely with Boeing Research & Technology (BR&T), which leads company-wide technology research, development, and innovation. Phantom Works' goal is to develop programs that transition to the production divisions as programs of record.

Phantom Works divisions include: Advanced Boeing Military Aircraft; Advanced Global Services & Support; Advanced Network & Space Systems and Analysis; and Modeling, Simulation & Experimentation. This means the group's work covers many area, including the X-51A WaveRider hypersonics demonstrator, energy management, cyber security, the SkyHook Heavy Lift Vehicle, the High Altitude Long Endurance aircraft, and nanosatellites.

"Given what we do, our test programs are always challenging," says Darryl Davis, Phantom Works president. "At the component, subsystem, system integration, and flight test levels, we are almost always dealing with items that are new, or things that haven't been done before. Therefore our test programs must be rigorous, and we need to focus on areas such as risk reduction."

Rapid prototyping

In 2009, Davis unveiled the Phantom Ray unmanned technology demonstrator, which builds on Boeing's successful Unmanned Combat Aircraft Systems (UCAS) programs. "Our goals for Phantom Ray clearly demonstrate our commitment to rapid prototyping, and are an important part of the company's efforts to remain a leader in the unmanned aircraft business," explains Davis.

Phantom Ray picks up where the UCAS program left off in 2006 by further demonstrating Boeing's unmanned systems development capabilities in a fighter-sized system. The Boeing UCAS program began with the X-45A, which successfully flew 64 times from 2002 to 2005. Those flights included a demonstration with two X-45A aircraft that marked the first unmanned, autonomous multivehicle flight under the control of a single pilot. Boeing also designed a larger UCAS aircraft, the X-45C1, which serves as the basis for the Phantom Ray.

Lab testing for the Phantom Ray air vehicle is scheduled for mid-2010, followed by ground testing and a first flight in December 2010. The program calls for 10 test flights over six months.

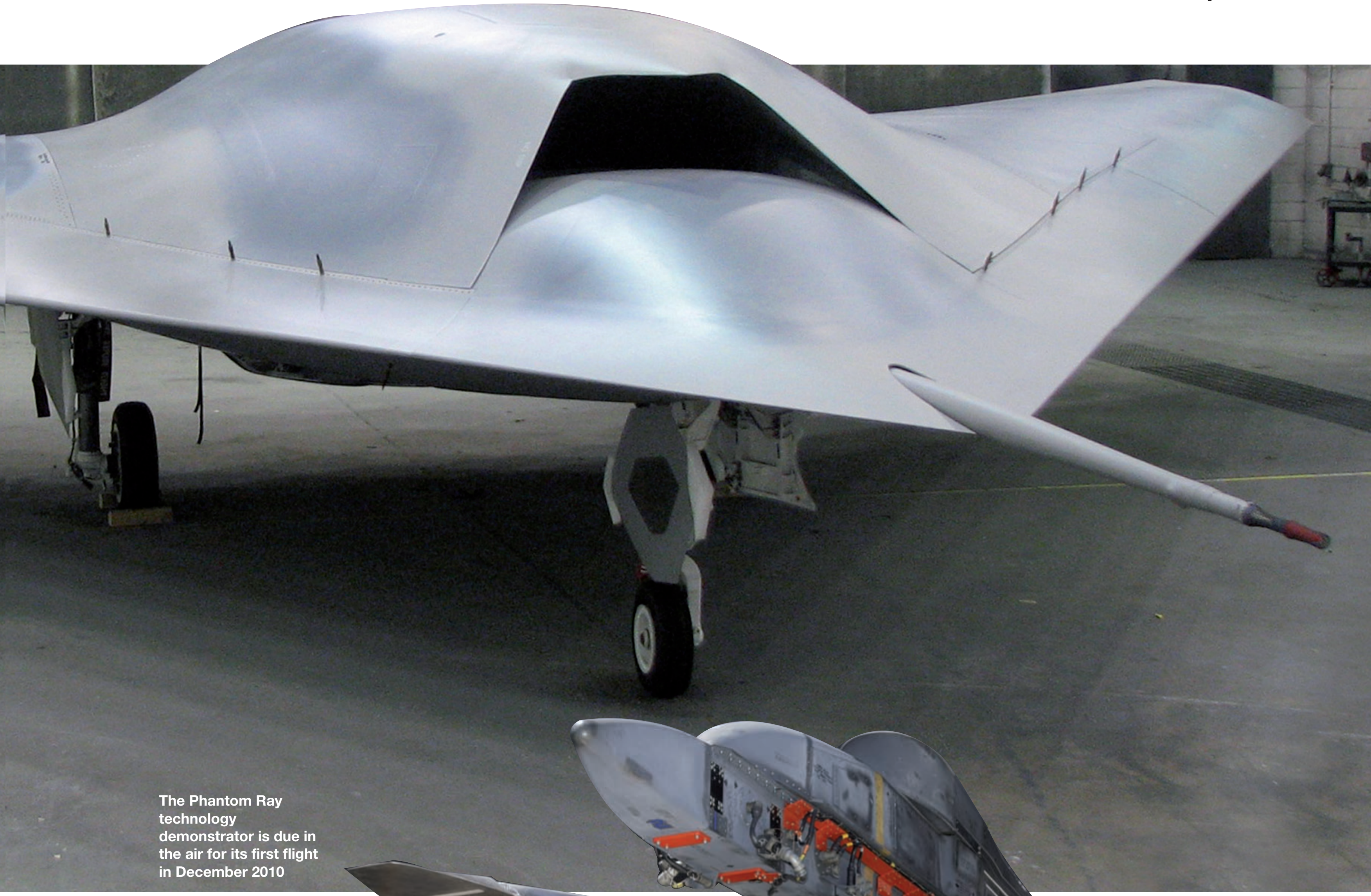
Future possible experiments using the testbed are autonomous aerial refueling; strike/suppression; electronic attack/directed energy; intelligence, surveillance and reconnaissance; and hunter/killer missions.

Going hypersonic

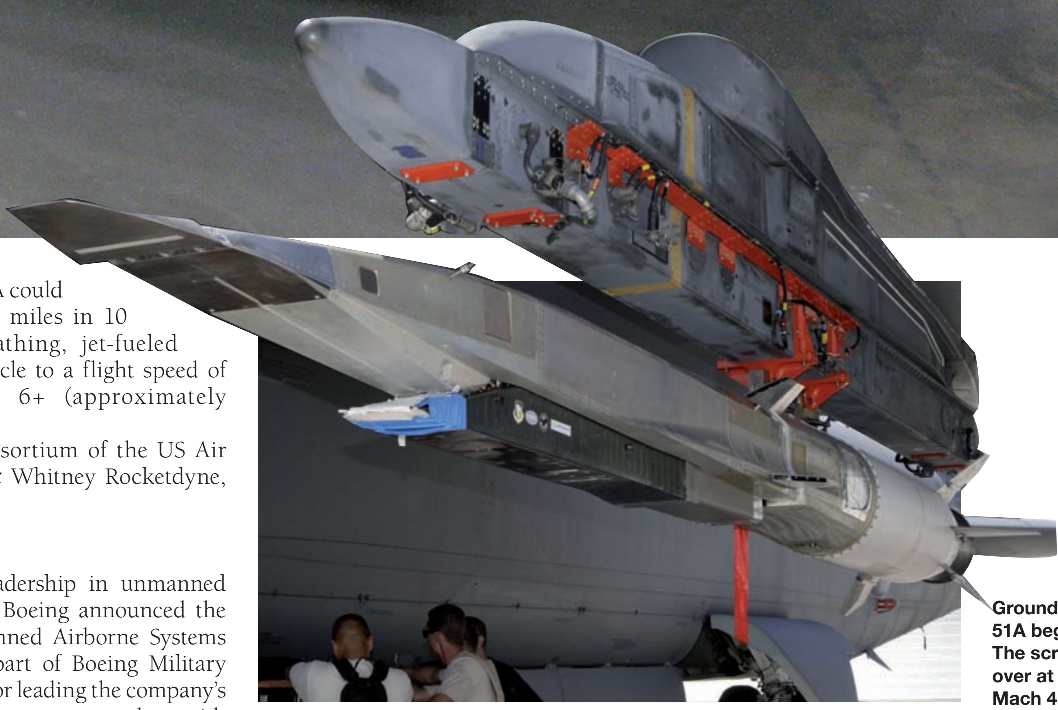
The X-51A WaveRider is due to take to the air in early 2010. The four flight test vehicles have been undergoing systems integration and testing including the integration of the flight engine – a Pratt & Whitney Rocketdyne SJY61-1 scramjet propulsion system – and a fit test on the B-52 that will carry the X-51A to its launch point.

"The X-51A's flight under scramjet propulsion will last about 300 seconds," says Joe Vogel, Boeing X-51A program manager. "That's substantially longer than a lot of the other hypersonic vehicles that have been flying (such as the X-43A, which flew for 10 seconds). It's a pretty cool vehicle."

During the test, the X-51A is expected to travel about 350 nautical miles. If the system were optimized for a missile application, a mod-



The Phantom Ray technology demonstrator is due in the air for its first flight in December 2010



Ground tests of the X-51A began in late 2006. The scramjet will take over at approximately Mach 4.5

ular version of the X-51A could fly about 600 nautical miles in 10 minutes. The air-breathing, jet-fueled engine powers the vehicle to a flight speed of approximately Mach 6+ (approximately 4,567mph at sea level).

The X-51A is a consortium of the US Air Force, DARPA, Pratt & Whitney Rocketdyne, and Boeing.

Humming along

To help solidify its leadership in unmanned vehicles, in June 2009 Boeing announced the formation of its Unmanned Airborne Systems (UAS) division. UAS, part of Boeing Military Aircraft, is responsible for leading the company's unmanned airborne systems strategy, along with executing and transitioning product to market.

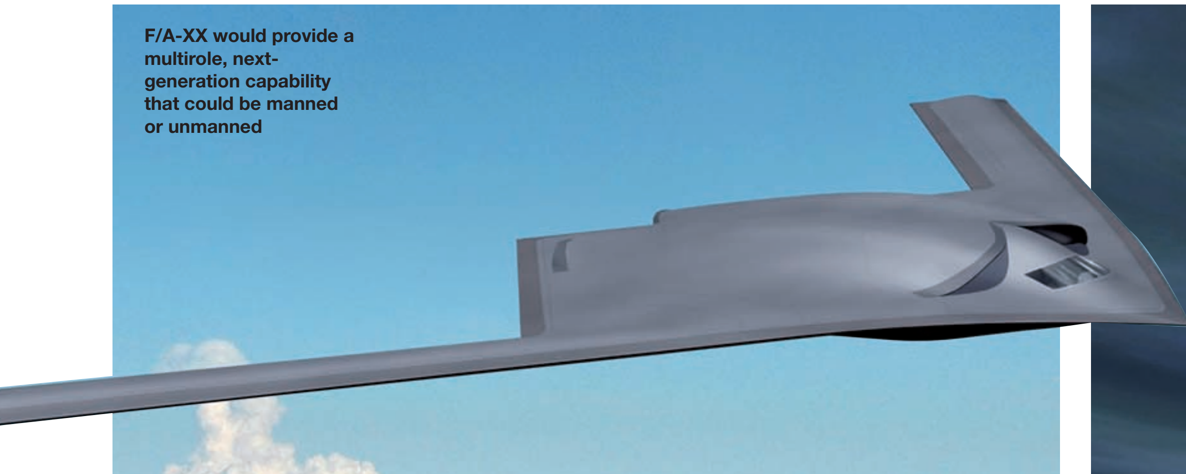
Shortly after UAS was established, Phantom Works transitioned the A160T Hummingbird unmanned rotorcraft to UAS. That followed several years of successful development and testing by Phantom Works. Capable of operating in fully autonomous, semi-autonomous or manual modes, in 2008 the Hummingbird set an endurance record flying for 18.7 hours without refueling, demonstrated gear shifts in its rotor transmission, and flew with an external pod for DARPA's FORESTER foliage-penetrating radar.

The test program continued this year to expand Hummingbird's flight envelope and focus on payload testing and experimentation. This included A160T's first flights with pylons and inert Hellfire missiles in January 2009. Over the US summer of 2009, the aircraft performed a long-range persistent surveillance demonstration of targets under foliage at a US military base.

"The past three years have seen a considerable advance in the A160 from a technology demonstrator to a fully capable multimission surveillance and weapon system," says Mary Jayne Cribbs, senior flight test manager and deputy chief engineer on the A160. "We have also carried payloads including EO/IR, signal relay and resupply pods. The technology has proven itself, now our challenge is to further expand the envelope and mature the platform through continued flight testing of both the vehicle and various payloads."

A160T's successes led to Boeing winning a US$500,000 contract on August 5, 2009 from the US Marine Corps Warfighting Laboratory to demonstrate the Hummingbird (designated the YMQ-18A) for the Marines' Immediate Cargo Unmanned Aerial System (UAS) Demonstration Program.

Hummingbird's patented optimum speed rotor helps give it unmatched endurance by



F/A-XX would provide a multirole, next-generation capability that could be manned or unmanned

enabling it to operate efficiently throughout the flight envelope The aircraft also features a hingeless rigid rotor that avoids damaging resonance problems.

The A160T's potential missions include precision resupply, C4ISR, direct attack, and anti-submarine warfare/undersea warfare.

Blended wing benefits

Boeing Research & Technology's X-48B Blended Wing Body research vehicle passed the 66 total test flights mark as of mid-September 2009 (28 flights in 2009), and has 10 to 15 more flights planned through to the year end.

"In general, we are extremely pleased with the flight behavior and handling qualities of the X-48B," says Michael Kisska, Boeing X-48B project manager. "In short, we have learned that this Blended Wing Body configuration flies just like a conventional aircraft, which is a testament to the skill of the engineers who wrote the flight control software developed for the vehicle.

"Once the team's current block of test maneuvers are completed – those designed to define the Alpha (angle of attack) and Beta (angle of sideslip) axes of the vehicle – we will perform Departure Limiter Assault maneuvers to verify that the flight computer can recognize and anticipate the maneuver being performed, and allocate the surfaces accordingly as to not allow the pilot to exceed previously tested limits. This final, robust set of flight control laws is the end product of the current phase of testing, which will be used as the base platform for future X-48C flight testing in 2010."

"The X-48C will be used to examine BWB noise levels"

The tests Kisska cites include aerodynamic wing stall testing of forward and aft center-of-gravity loading configurations with slats extended and retracted.

Test flights in 2010 will include the start of Single Surface Parameter Identification (PID) experiments to validate the effectiveness of each individual flight control surface.

The group just completed 420 hours of wind tunnel tests of the X-48C, a modified version of the current X-48B demonstrator, in the large-scale wind tunnel at the NASA Langley Research Center in Virginia. Test data will help the team refine flight control software, which will be used when the X-48C is taken to the NASA Dryden Flight Research Center at Edwards Air Force Base on the west coast, for planned flight testing next year.

Configured with two turbofan engines instead of three, and with twin canted fins mounted on the aft body section, the X-48C will be used to examine BWB noise levels.

"The greatest challenge our X-48B test team continually faces relates to the logistics of conducting unmanned flight operations and the multiple variables that must align perfectly in order for the team to conduct a test flight," says Kisska. "These include: favorable atmospherics, access to both range and flight termination frequencies, availability of the Test Range and Dry Lakebed runways, flight crew, chase plane and pilot and lastly, total absence of any GPS jamming activities in the High Desert. Any one of these variables can keep the team grounded."

With a 21ft wingspan, the 500 lb X-48 airplanes are 8.5% scale models of a heavy-lift, subsonic airplane with a 240ft wingspan that Boeing Phantom Works believes could be developed in the next 15 to 20 years for military cargo applications. Because of the X-48B's efficient

The JHL-40 is environmentally acceptable because it mitigates the impact of building new roadways in remote areas

Boeing will design and build a larger retractable-rotor test rig that will be installed in a 20ft wind tunnel

aerodynamics, researchers believe the BWB configuration offers the potential for reduced fuel burn over conventional, similar-sized tube-and-wing transports. In addition, because of the way the engines are integrated into the vehicle – on top of instead of underneath of the wings – they believe the BWB concept offers the potential to be quieter.

Heavy lifter

With all this activity in current and near future test, Phantom Works has numerous programs and projects moving through earlier stages of development.

On the large side of the spectrum is the SkyHook Heavy Lift Vehicle. Under development by Boeing and SkyHook International Inc, SkyHook measures 410ft long, 205ft wide and 141ft high. It will combine the best features of an airship and a helicopter. Lighter-than-air helium neutralizes the aircraft's weight. Four helicopter rotors generate the power needed to lift payloads up to 40 tons. Ducted propellers maneuver and propel the aircraft, at maximum payload, horizontally up to 200 nautical miles (230 miles) without refueling.

The next major milestone will be 'Detailed Design' in 2011, which centers on the design, analysis and specification of all hardware, software and related aircraft and ground support systems interfaces. SkyHook is designed to transport heavy equipment and supplies to remote locations supporting the energy and extractive industries among others.

Further developments

Meeting customer operational needs for extreme endurance in the stratosphere is the goal of the High Altitude Long Endurance (HALE) aircraft. With a liquid-hydrogen propulsion system, highly reliable subsystems, lightweight structures and careful thermal management, HALE could provide a breakthrough capability of seven-plus days of endurance carrying a multisensor payload weighing up to 2,000 lb.

HALE missions could include persistent ISR, border reconnaissance, port security, and telecommunications.

Mid-2009, Boeing began development studies for DARPA's DiscRotor. The 30-month contract is to validate capabilities for the aircraft that would convert from vertical lift to fixed-wing flight. Taking off like a helicopter, the DiscRotor would then retract its rotor blades into a disc above the fuselage as it gained forward speed and transitioned to swept-wing flight.

"Boeing Rotorcraft has a wealth of history in technology-challenging concepts," says Adam Petruszka, DiscRotor program manager. "This concept has new and different challenges, but advanced technologies, tools, and control systems allow us to do things we were unable to do in the past." DiscRotor is expected to be able to fly at speeds in excess of 350kts. Current tiltrotors fly at about 250kts.

Under the contract, Phantom Works' Advanced Rotorcraft will build a small-scale model for wind tunnel test including lift-to-drag and stability studies. The team will also build a model of the rotor system to examine the transition from rotary to fixed-wing flight, and later the program will build a larger retractable-rotor


The A160T has now completed 20 test flights with the foliage penetration reconnaissance, surveillance, tracking and engagement radar

test rig for additional wind tunnel tests.

Teamed with Lockheed Martin, Phantom Works is continuing development work concepts for the Next Generation Bomber. With no current bombers in development, NGB is envisioned as a subsonic aircraft with possible manned or unmanned configurations. It would have a 2,000 nautical mile (2,300-mile, or 3,700km) unrefueled radius with a payload of 14,000-28,000 lb. The bomber would provide the capability to ensure penetration of projected air defenses.

On the fighter side of capabilities, Phantom Works is working on the F/A-XX – a concept to recapitalize the F/A-18E/F Super Hornet in the mid 2020s. So far, the Navy has not issued any formal requirements for F/A-XX. Boeing is providing the Navy with technology assessments. F/A-XX would provide a multirole, next-generation capability, and could fly manned or unmanned, depending on the missions assigned and technology maturity.

Space, energy, security

Phantom Works is not limited to things that fly in the atmosphere. Programs in space from exploration to tiny satellites, and in fields such as energy management and security, are also in various stages of development.

In early 2009, the demonstration picosatellite CubeSat TestBed 1 (CSTB1) surpassed 10,000 Earth orbits. It was launched on April 17, 2007. After completing its original mission goals of operating for six months in space and supporting three months of tests, the spacecraft, which is smaller than a standard toaster, continues to operate and provide engineers with data.

> "The bomber would provide the capability to ensure penetration of projected air defenses"

Boeing is exploring new ways to reduce the size, weight, and power of satellite technologies needed for operational nanosats – spacecraft weighing less than 22 lb. Picosatellites such as CSTB1 weigh less than 2.2 lb.

"We've downloaded more than 1 million datapoints to date, including dozens of photographs by CSTB1's small camera with a lens the size of a pencil's eraser head," says Scott MacGillivray, program manager for Boeing Nano-Satellite Programs and CSTB1.


FAST will form the foundation to perform ultra-high-power communications, radar, satellite transfer and servicing missions

Boeing's next CubeSat demonstration, CSTB3, will be the first of a family of spacecraft designs representative of Boeing's new Tensor small-spacecraft avionics architecture, which will be the core of an array of missions.

CSTB3 is larger (approximately 8.8 lb and 4in x 4in x 12in) than CSTB1 and will demonstrate larger spacecraft capabilities, such as higher communications bandwidth, three-axis control, onboard autonomy, and advanced dynamic power management. CSTB3 could be flight-ready by spring 2010.

In June, a Phantom Works-led industry team was awarded a US$15.5 million contract for Phase 2 of the Fast Access Spacecraft Testbed (FAST) program. This DARPA program is an effort to develop a new ultra-lightweight high power generation system (HPGS) that can generate up to 175kW of power for spacecraft – more power than is currently available to the International Space Station.

When combined with electric propulsion, FAST will form the foundation for future self-deployed, high-mobility spacecraft to perform ultra-high-power communications and space radar missions as well as satellite transfer and servicing missions.

The contract includes designing, fabricating and integrating test articles, performing a series of component-level tests, and two full-scale tests – a mechanical deployment demonstration and an integrated performance demonstration. On-orbit demos are expected in the fourth quarter 2011.

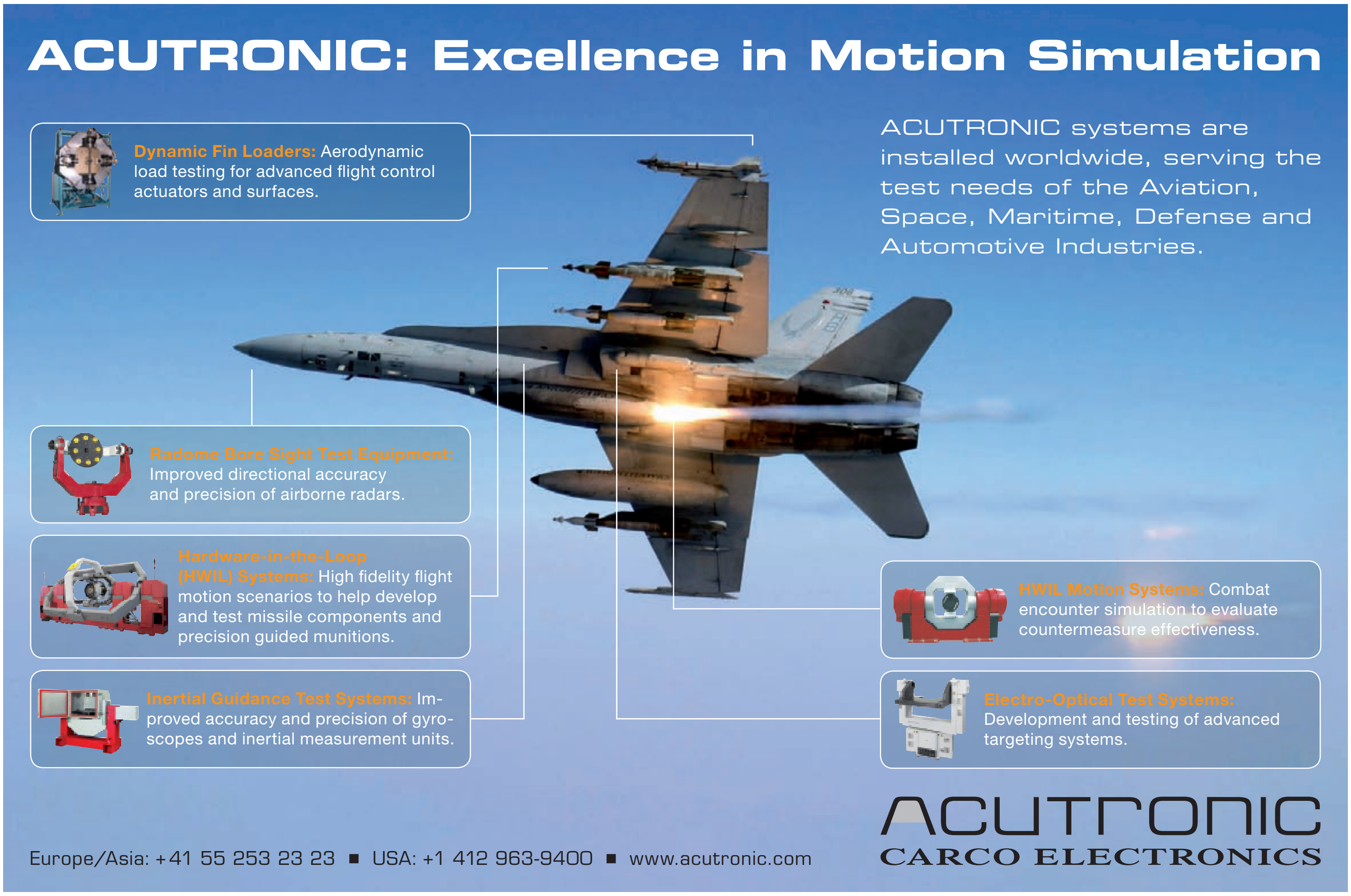
Making testing better

One key to Phantom Works' testing success is its Analysis, Modeling, Simulation and Experimentation division. AMSE facilities and staff allow Boeing and its customers to use live, virtual, and constructive simulation to examine new concepts of operations, explore options, analyze performance, refine requirements, enable rapid development and testing of capabilities, and reduce risk. "AMSE is an important partner to all of our programs," says Davis. "Our networked facilities, with the ability to tie in real and virtual assets, play a vital role in nearly all of our development programs, ensuring we focus on the right capabilities and we maximize the use of resources from concept through testing to delivery."

AMSE facilities include the Virtual Warfare Center in St Louis, large engagement centers on both US coasts, The Portal (operated with partner QinetiQ) in the UK, the Systems Analysis Lab in Brisbane, Australia, and a growing list of US centers and international locations.

In short, Phantom Works has about 2,500 employees and test engineers and staff across Boeing, who are engaged in dozens of development programs. This includes upgrades to ongoing programs as well as the near- and long-term programs that will be soaring in the decades to come. ∎

Marc Sklar is the senior communications specialist with Phantom Works, The Boeing Company



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PSP and PIV in wind tunnels

ADVANCED OPTICAL MEASUREMENT TECHNOLOGIES ARE JUST ONE OF THE CUTTING-EDGE APPROACHES USED AT THE JAXA WIND TUNNELS

"JAXA not only has practical measurement techniques, but also some of the world's cutting-edge technologies"

KAZUYUKI NAKAKITA

BY KAZUYUKI NAKAKITA

Japan Aerospace Exploration Agency (JAXA) is a Japanese governmental agency for aerospace research and development. JAXA Wind Tunnel Technology Center (WINTEC) operates its own large-scale wind tunnels, ranging from low-speed to hypersonic, at the Chofu Aerospace Center, Chofu, Tokyo. These wind tunnels have contributed to many domestic aerospace developments for civil and defense purposes.

Aerodynamic measurement technologies, which include aerodynamic force and moment, pressure, heat flux, flow visualization, etc. have also evolved to meet the requirements of vehicle designers. As electronic devices such as computers and cameras have advanced rapidly, various advanced optical measurement technologies have also been widely developed.

In terms of aerodynamic measurement, pressure-sensitive paint (PSP) measurement, which can acquire a surface pressure distribution, and particle image velocimetry (PIV), which can acquire a velocity vector around a model, have evolved from small laboratory setups to being conducted in large industrial facilities. JAXA is also developing PSP and PIV systems for large industrial wind tunnels, and is now preparing to make them available for JAXA wind-tunnel users.

JAXA not only has practical measurement techniques, but also some of the world's cutting-edge technologies. Unsteady flow fields are one area for advanced optical measurements to provide innovative information that has been difficult to acquire until now. Unsteady flow fields also continue to be difficult problems for computational fluid dynamics (CFD). However, unsteady measurement results are valuable validation data for unsteady CFD. Targets of JAXA's unsteady measurement are flutter and buffeting, aeroacoustic flow field, helicopter blades, and so on.

In this article, JAXA's activities to develop advanced optical measurement for large-scale wind tunnels, including practical and cutting-edge PSP and PIV techniques, are introduced.

PSP measurement

PSP has been used for pressure distribution measurements in wind-tunnel tests since the early 1990s, and is a non-intrusive optical pressure measurement technique. PSP can not only acquire global surface pressure distribution by using a PSP-painted model and CCD camera, but can also produce global, high spatial resolution and quantitative pressure distribution. JAXA has constructed a practical PSP measurement system for its large industrial wind tunnels, and has conducted several industrial wind-tunnel tests since.

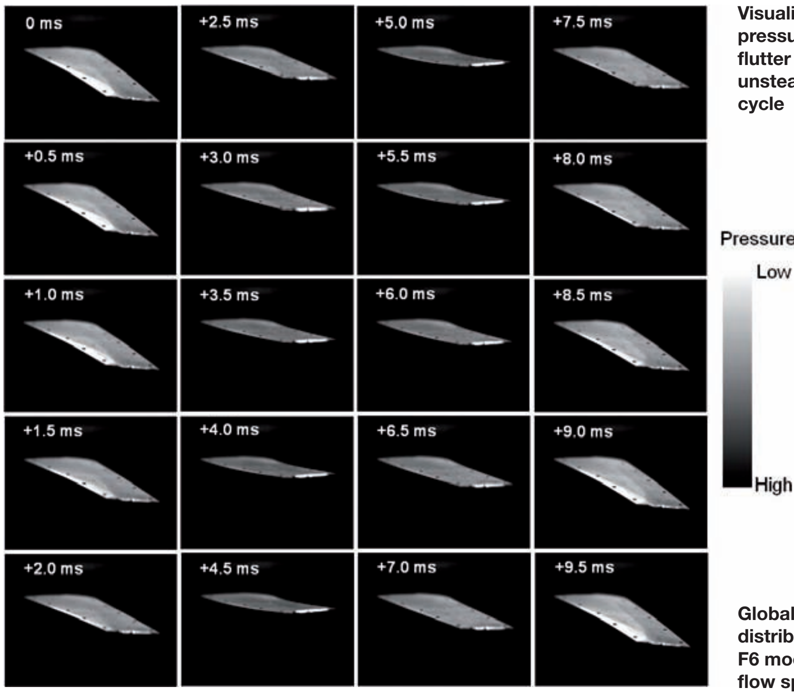
In addition to the practical PSP system, JAXA is also trying to develop an unsteady PSP measurement technique in order to detect unsteady flow phenomena such as flutter, aeroacoustic fields, and so on.

Here is an example of practical PSP measurement for industrial applications. It is a conventional PSP measurement that has already been established as a quantitative pressure measurement technique, and has been installed in the large-scale industrial wind tunnels at NASA, DLR, ONERA, etc. JAXA has also introduced it to its large-scale wind tunnels, mainly to the JAXA 2 x 2m transonic wind tunnel. Important requirements for the JAXA practical PSP system were sufficient data accuracy and productivity for productive industrial wind-tunnel tests.

The system needs three key components: pressure-sensitive paint, a CCD camera, and an illumination light source for PSP. Pressure-sensitive paint is a polymer-based paint, and its PSP dye is PtTFPP. The CCD camera is a cooled-CCD camera with high-quantum efficiency, and its spatial resolution is 1k x 1k pixels. The illumination light source to excite PSP dyes is xenon light for transonic wind tunnels, or violet LED for low-speed wind tunnels.

The figure on the next page shows a PSP test result of the DLR F6 model at the JAXA 2 x 2m transonic wind tunnel. Test conditions were M=0.75 and P0=80kPa. The model angle of attack was +1.0°. The entire model surface was measured using four cameras simultaneously. Global pressure distribution on the model was measured quantitatively. PSP global pressure image also helps the designers intuitively understand the flow field around test vehicles. Quantitative pressure data is provided with the 3D grid data, so that the designers can also calculate the structural load for every location on the body. The PSP was bi-luminophore PSP, which is now under development.

Here is an example of unsteady PSP technology. As an extension of the practical PSP technique, the unsteady PSP technique is now



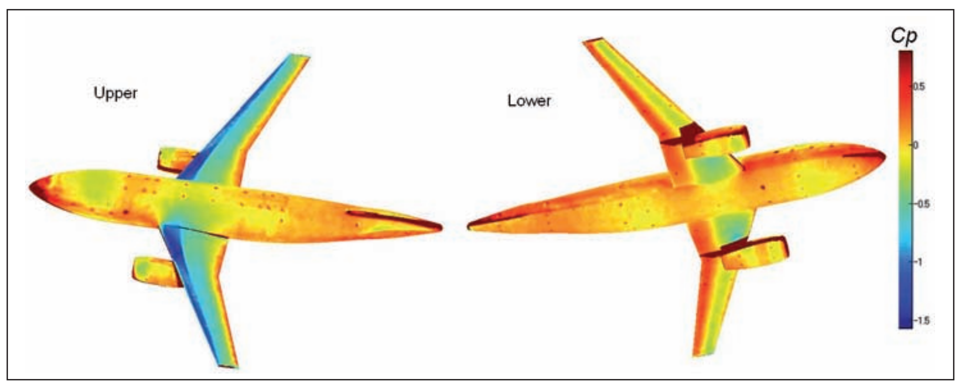
Visualization of pressure behavior of flutter measured by the unsteady PSP over one cycle

under development to measure unsteady flow phenomena. CFD has recently become capable of calculating various kinds of steady flow fields; however, it still has much difficulty with calculating unsteady flow fields. The pressure distribution image produced by unsteady PSP measurement could become a powerful tool for global understanding of unsteady flow fields.

Unsteady PSP uses the same three key components as practical PSP; however, they have to have the following capabilities: PSP needs to be fast-response PSP to cover the frequency of the phenomena; the camera needs to be a high-speed video camera to cover the frequency of the phenomena; and the illumination light source should be a high-power one to compensate for the short exposure due to the high frame rate of the high-speed video camera.

The figure at the top of the next page shows an example of unsteady PSP measurement applied to transonic flutter. Flutter is an important phenomenon when designing the aerodynamics and structure of aerospace vehicles. Prediction tools using CFD and FEM have recently been developed to estimate non-linear behavior such as transonic dip. However, they are still under development and vehicle designers need to confirm the prediction results using actual wind-tunnel test data. Typical kinds of acquired data from conventional flutter tests are time-series and frequency information using strain gauges and steady/unsteady pressure transducers. The numbers of those measurement points over the test model are limited, which causes difficulties when validating or improving the prediction tools.

On the other hand, no shock waves were observed on higher-location cases, which corresponds to negative angle of attack. It can be observed at the lower location of model deformation that there were two kinds of shock waves, which were located at the near leading edge and 50-60% at local code. Continuous time-series images help to understand the unsteady behavior of shock waves and pressure distribution over one cycle of flutter. The unsteady flutter phenomena was visualized and understood as the global flow field information by unsteady PSP measurement.



Global surface pressure distribution around DLR F6 model at transonic flow speed

PIV in practice

A stereoscopic PIV technique is the instantaneous three-component velocity vectors measurement in the volume around a test model. It is applied to some practical flow fields in industrial large-scale low-speed and transonic wind tunnels in JAXA. The stereoscopic PIV system consists of a high-power Nd:YAG laser, two high-resolution CCD cameras, commercial PIV software on a PC, and a calibration target traverse system. Also, average velocity and turbulent quantities are obtained based on the instantaneous velocity data.

The wind-tunnel applications include a tip vortex generated from a rectangular wing, jet-engine exhaust/external flow interactions for transport-type airplane, helicopter blade-vortex interactions (BVI), and leeward flow of cranked-arrow-type wing. The results indicate that the stereoscopic PIV is suitable and effective to investigate practical, complex velocity fields in large-scale low-speed wind tunnels. Some comparisons of the PIV results with seven-hole probe results show good agreements and prove quantitative validity of the PIV measurements.

The advanced design of high-lift devices has a great impact on improving take-off and landing performance of an aircraft, weight reduction, shortening of the design/manufacture period, and reduction of maintenance costs. However, the flow field around high-lift devices contains complicated flow phenomena, so higher reliability of performance prediction for advanced aerodynamic design is required. In order to demonstrate the applicability and capability of the stereoscopic PIV to the high-lift system, a stereoscopic PIV test of the JAXA High-Lift Configuration Standard Model (JSM) was conducted to measure the flow around a three-dimensional wing-flap configuration in the JAXA 6.5 x 5.5m low-speed wind tunnel.

Development of time-resolved PIV

Time-resolved particle image velocimetry (TR-PIV) is the powerful tool recently developed to help understand unsteady phenomena, which are aeroacoustic noise, flutter, buffeting, helicopter blade, etc. A TR-PIV technique that can be applied to industrial wind tunnels has been developed at JAXA, and will be able to measure unsteady phenomena up to 1KHz. Now a prototype TR-PIV system is being constructed. Preliminary wind-tunnel tests were conducted as a feasibility study for TR-PIV. Its target was the flow field associated with the trailing-edge noise around a 2D NACA0012 model. The sampling rate of vector maps was 5KHz in these results. It is clearly observed that vortices generated by the wing were traveling downstream.

As practical techniques there are several applications for advanced optical measurement, PSP and PIV in industrial wind-tunnel tests; however, most of them still need to be improved for actual industry-wide application. For unsteady technologies, the techniques are now on the feasibility study level and have much potential to become measurement tools used in practical wind-tunnel tests that produce useful unsteady CFD validation data. JAXA continues to develop both systems and increase their performance sufficiently so that the JAXA wind tunnel can be open to users as soon as possible. ∎

Kazuyuki Nakakita is the department leader for Wind Tunnel Technology Center, Aerospace Research and Development Directorate, JAXA. Contributors include researchers Hiroyuki Kato, Kazunori Mitsuo, Mitsuru Kurita, and Shunsuke Koike

HIFEX sled train

THE HOLLOMAN HIGH SPEED TEST TRACK HAS BEEN TESTING A SUPERSONIC WEAPON RELEASE PROGRAM USING ACTIVE FLOW CONTROL. THE ROCKET TEST SLED REPRESENTS A GLOBAL STRIKE AIRCRAFT WEAPONS BAY

BY LT MATT LAWRENCE

A Mach 2 rocket sled demonstration of weapon release with active flow control: '5… 4… 3… 2… 1… 0… Fire!' This was the last sound heard before the ignition of the rocket-powered high-frequency excitation (HIFEX) active flow control for supersonic weapon release sled at the Holloman High Speed Test Track (HHSTT). The HHSTT is a state-of-the-art aerospace ground test facility operated by the US Air Force, 846th Test Squadron at Holloman Air Force Base, New Mexico.

Holloman's test track is the world's premier rocket sled test facility, boasting the longest, fastest, and straightest rocket sled test track on earth. To ensure the smoothest ride possible, the track has an unequaled alignment standard, enabling test velocities up to Mach 10. In 2003, the HHSTT set the world land speed record at 6,453mph (10,385km/h) on its nearly 10-mile (16km) track.

The HHSTT is situated in the Tularosa Basin in southern New Mexico on Holloman Air Force Base, which is on the eastern edge of the White Sands Missile Range (WSMR). This remote and secure location gives the test track many advantages. One of these is reduced or eliminated safety and environmental risks that would otherwise be present in populated areas where rocket exhaust, sonic booms, and high explosive detonations would encroach upon the local population's quality of life.

US government agencies and their respective contractors, allied foreign governments, and commercial customers use the track. Rocket sled testing is performed to evaluate many types of weapons systems and to provide simulated flight dynamics in closely controlled and highly instrumented test environments. Sled testing provides debugging and developmental shakedown for all types of weapons systems including missile defense lethality, hard target and earth penetrators, kinetic energy kill vehicles, weapon dispensing munitions, seekers, and fuzes. The track is also frequently used to evaluate aircraft crew escape systems and parachutes, inertial guidance and GPS navigation systems, infrared countermeasures systems, and survivability through blasts and aerothermal, rain, ice, and dust environments.

HIFEX

The track is currently involved in the developmental testing of supersonic weapon release using active flow control. The sled test program, HIFEX, started in 2003 using a rocket test sled representative of a global strike aircraft weapons bay. The HIFEX sled test that demonstrated the full-scale dispense at supersonic speed was conducted on August 29, 2007. The HIFEX sled train set a record as the heaviest that had been launched near Mach 2 in the 56-year history of the Holloman track, and was the first to demonstrate dispense from a representative global strike aircraft weapons bay at high supersonic speed using a traditional ejector.

The HIFEX program is under development by the Defense Advanced Research Projects Agency (DARPA), the Air Force Research Laboratory (AFRL), and The Boeing Company. The objective of the HIFEX program is to develop an active flow control system representative of the internal bay of an aircraft to assist in a weapon's release during travel in excess of Mach 2.

Historically, releasing a weapon at high subsonic or supersonic speeds was a dangerous venture. Shockwaves that formed around the aircraft or weapons bay could cause the munition to have an unpredictable and dangerous trajectory. This was the cause of some accidents with the General Dynamics F-111 and the Convair B-58 Hustler. Occasionally, when these aircraft released a munition, fuel tank, or pod, the article would rebound off the shockwave and make contact with the aircraft. When using an internal weapons bay it became standard practice to have spoilers modify the shear layer while the bay doors were open. The modified shear layer enabled a munition to pass through with less risk of rebounding back into the bay. This was an effective method for a narrow range of flight

> "In 2003, the HHSTT set the world land speed record at 6,453mph"

The 10 mile (16km) sled track at Holloman AFB (above). The first-ever test release of an MK-82 Joint Direct Attack Munition on a rocket sled traveling at supersonic speed (right)

conditions, such as high subsonic and low supersonic weapons release. A faster aircraft might have been required to slow down to a subsonic speed to deploy a weapon safely. This approach places the aircraft at risk as its exposure time to enemy weapons is longer. Because the spoilers used in the past would not be feasible at the speeds in which the HIFEX program was interested (above Mach 2), an alternative method for modifying the shear layer would need to be developed.

Polysonic wind tunnel

Between the year 2000 and 2003, the first two phases of the HIFEX program were conducted. These phases were concerned with defining active flow control approaches. Many different actuators were tested in the Boeing Polysonic Wind Tunnel (BPWT) including powered resonance tubes, splash actuator, flow-powered actuator, jet screens, and supersonic microjets.

A one-tenth scale weapons bay was constructed for testing in the BPWT. Initial testing showed that all the actuators greatly reduced the resonance tones and sound pressure levels in the bay. In order to select the best actuator, a traversing arm was mounted in the bay and a model of a MK-82 munition was attached. This arm moved to various positions of the bay and recorded the forces, moments, and pressures placed upon the model. The data was evaluated to analyze the best weapon separation characteristics.

The next phase was to use an ejector to eject the subscale munition into the supersonic flow of the BPWT. Based on the previous tests, it was decided that a tandem array of microjets would provide the best weapon separation characteristics using the least amount of airflow necessary for dispense.

In the tandem microjet arrangement, two arrays of microjets were used. The first array was placed at the leading edge of the weapons bay to modify the shear layer over the bay. These were called the shear actuators. The second array was placed further upstream from the weapons bay to modify the shockwave. These were called the 'shock' actuators. This configuration suppressed the acoustic resonance of the bay and sufficiently turned the airflow to give the MK-82 model a pitching moment away from the weapons bay instead of toward (back into) the bay.

After successful testing of the subscale models, Boeing (with the agreement of DARPA) contacted the 846th Test Squadron to plan for full-scale testing. Through rocket sled testing at the HHSTT, a full-scale demonstration of the high-speed weapon release would be possible. Due

"The sled has knife blades that cut through the screen, completing a circuit that activates an event such as igniting rocket motors"

to the size and aerodynamic requirements of the HIFEX test project, a customized test sled had to be designed and fabricated. Although the initial focus of the program was to provide a full-scale demonstration of the active flow control system, the focus of the track team quickly shifted to the design of the forebody sled and its fabrication. The HIFEX sled marked many firsts for the HHSTT. It was the first sled to be designed by computational fluid dynamics rather than empirical correlations and simplified design tools. It was also the first to be constructed using lean fabrication methods resulting in great savings in fabrication cost. The HIFEX rocket sled became the fastest sled in its weight class, being the first to achieve near Mach 2.0 (previous tests of sleds in this weight class reached just above Mach 1).

The HIFEX forebody sled's design reproduced the elements of the subscale model of the active flow control system during wind tunnel testing. This ensured that the wind tunnel data was relevant to the full-scale configuration. Once the 846th Test Squadron was given the test objectives, preliminary design work for a Mach 2 sled test began. The bay was 200in (508cm) long, 40in (102cm) wide, and 40in (102cm) deep.

The initial sled design produced by the HHSTT had a total sled width of 60in (152cm). Boeing's review of the design concluded that this width would produce three-dimensional flow effects not consistent with prior wind tunnel testing. Boeing began computational fluid dynamics studies to examine flow characteristics. Their study showed that increasing the width of the sled to 90in (229cm) was suitable for the full-scale test without aerodynamic and g loading becoming unreasonable. This expanded size with its added weight posed technical challenges to the track for getting the huge sled up to the desired Mach 2 velocity.

Two models

Once the basic configuration was defined, the 846th Test Squadron design engineers developed two different sled models. The major difference between these models was the internal support structure and construction method. The first model used a traditional frame construction method; the second model was based on an aircraft fabrication approach of a load-bearing skin.

Weight, strength, and cost of manufacturing were the criteria by which the models were evaluated. Based on these criteria, the aircraft fabrication method was selected. With a design selected, FE analysis was carried out. Excessive stress regions were discovered and modifications were made to reduce or eliminate them. An aeroelasticity analysis was performed by Boeing, exploring 40 flutter modes, and it was determined that all primary flutter modes should be damped.

The HIFEX sled train consisted of three sleds. The forebody sled contained the simulated weapons bay, which dispensed the full-scale weapon. The two trailing sleds were pusher sleds whose sole purpose was to accelerate the forebody using solid-propellant rocket motors. The track executes the desired velocity profile through precise staging of rocket motor ignition along the track. Ignition while the sled is moving is handled through the use of trackside screenboxes (a C-channel covered with a metal mesh, or screen, which is attached to a voltage source, usually a battery). The sled has knife blades that cut through this screen, thereby completing a circuit that activates an event such as igniting rocket motors, enabling the microjets, or activating the ejector. Three thrust stages were used to reach the desired velocity for the HIFEX sled. The first stage consisted of six Super-Terrier rocket motors. These were ignited simultaneously, by

The sled obtained a velocity of 9,465 feet per second or 6,453 miles per hour, delivering a 192 lb. payload into a target

The HHSTT exists for the analysis and simulation of hypervelocity penetrator munitions on hard targets. The HIFEX consists of three sleds (right and below)

hardwire, produced 438,000 lb (1,948,321N) of thrust and burned for almost six seconds. Once the motors burned out, the first-stage sled coasted behind as the second stage ignited. The second-stage sled contained six Improved Honest John rocket motors. Five of the motors were ignited simultaneously, providing 575,000 lb (2,557,727N) of thrust and burned for approximately three seconds. The sixth motor was fired to sustain the sled velocity and acceleration profile necessary to provide the conditions for release of the weapon.

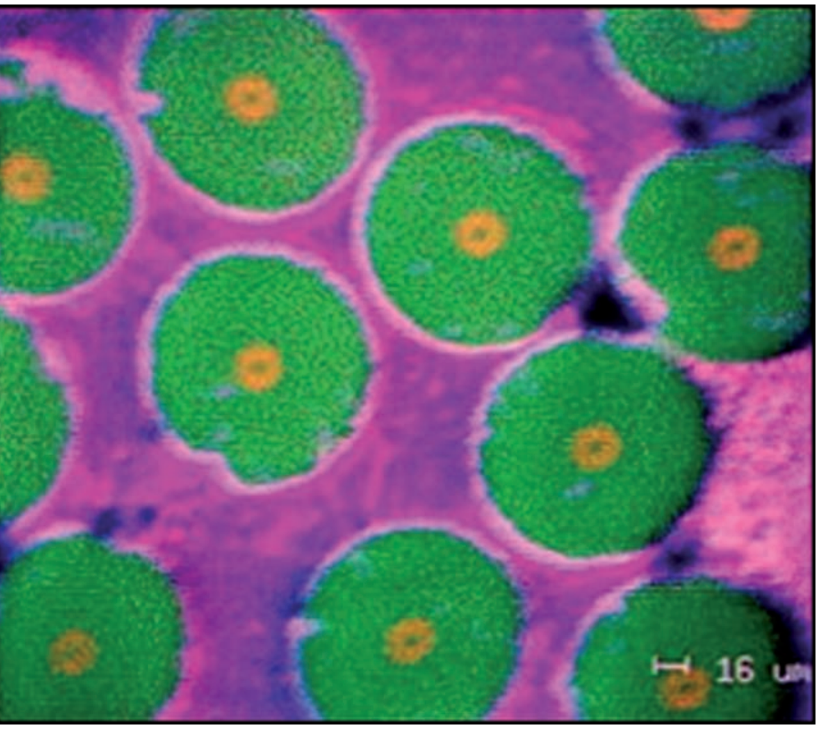
First mission

On August 18, 2006, the first mission of HIFEX was conducted. This test demonstrated the sled's performance at supersonic speeds without releasing the MK-82 munition. On August 29, 2007, a second mission was conducted during which the MK-82 was released. This was the first mission to demonstrate the dispensing of a munition from a weapons bay at supersonic speeds using a traditional ejector. The sled's predicted speed was 2,256ft/s (688m/s). Once this velocity was reached, it was sustained for two seconds while the test munition was released.

The test munition was to be released within the very tight acceleration envelope of +0.5 to -1.8g. Event data was captured using photographic methods provided by Newtec contractor personnel at the HHSTT and data-acquisition systems placed on board the sled. The mission on August 29, 2007, was launched at 11:44 Mountain Daylight Time. All motors fired as intended and pushed the sled to a maximum ground speed of 2,050ft/s (625m/s). Given the temperature and pressure at the HHSTT, this speed equates to approximately Mach 1.8. The MK-82 ejected as planned, however the peak height of the munition was greater than expected.

The HIFEX project is one of many that demonstrate cutting-edge technology developed at the Holloman High Speed Test Track. ∎

1st Lt Matthew L. Lawrence is a graduate of the University of Kansas, School of Engineering. He is currently working on strategic development at the Holloman High Speed Test Track, New Mexico



Analysis of composite functionality

SURFACE CHARACTERIZATION PLAYS A KEY ROLE IN COMPOSITE AND COATING EVALUATION FOR AEROSPACE APPLICATIONS

"In composite manufacture it is increasingly common for the fiber component to be surface modified"


DR CHRIS PICKLES

BY CHRIS PICKLES

The aerospace industry and manufacturers are continually in pursuit of new or improved high-performance structural materials. In addition to metals, polymers, and ceramics, composites is one such category of materials that plays an important role in aerospace components. The outstanding strength, stiffness: density ratios and superior physical properties make composites ideal for aviation and aerospace applications.

A composite material generally consists of fairly strong, stiff fibers such as carbon, glass, or boron in a durable resin matrix polymer. By combining materials with complementary properties, a composite material aims to combine all the benefits of the individual component materials with few or none of the weaknesses. Another advantage of composite materials is that generally they can be formed into more complex shapes than their metallic counterparts. This not only reduces the number of parts making up a component but also reduces the requirement for fasteners and joints.

With composites, the interface between one material and another is critical to the performance of the product in operation, as is the strength of the bond between the fiber and the matrix. Any disruption to this interface will affect the adhesion and can lead to resin-fiber disbondment. Similarly, coating adhesion to composite structures is dependent on the physical and chemical nature of the composite substrate and of the coating. Although the substrate surface roughness has an optimum value related to the keying of the coating, in the aviation and aerospace industry the coating outer surface needs to be as smooth as possible to reduce drag. The machining of composites is also an area of potential concern in terms of fiber breakout and edge finish, whether the structure is machined or water-jet cut.

Interfacial functions

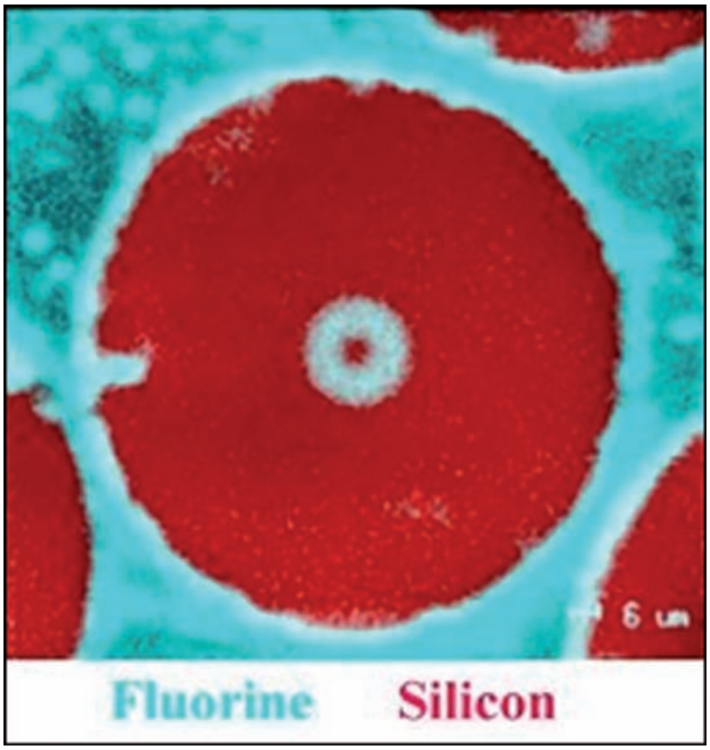
A number of key surface analytical techniques are playing a crucial role in testing the functionality of composite material interfacial interactions in terms of their composition and shape. This is particularly useful during manufacture, as well as in the initial development of composite materials, which relies heavily on experimental designs during their development, and in failure investigations.

Certain surface analysis techniques can map materials chemically and detect which chemical is present, where it is, and how much is present. This is possible with high sensitivity for all the elements and molecular fragments as large as 10,000 mass units. However, machined composites often behave quite differently to monolithic materials because of movement between the different components and, therefore, it is important to analyze the physical appearance of the composite. Where this movement affects the surface form (such as after machining) the character and magnitude of the effect can be measured in three dimensions by surface profiling.

Here, three primary techniques used for the chemical analysis of the surface of materials are outlined: x-ray photoelectron spectroscopy (XPS); time of flight secondary ion mass spectrometry (ToFSIMS); dynamic secondary ion mass spectrometry (DSIMS); and one physical profiling method – non-contact 3D profilometry (3DP), which uses white light interferometry. All techniques are critical to the testing and characterization of various composite materials in aviation applications.

Photoelectron spectroscopy

XPS is quantitative to an accuracy of 0.1 atomic % and samples the top 10Nm of the composite sample surface. It can also be applied in high resolution mode to unravel the nature of elemental bonding (for example, C-O, C-C) or the



oxidation state of metallic elements. The technique can also be used to construct 2D chemical maps for particular elements of interest and for quantitative elemental depth profiling of either the top 10Nm or more deeply by using argon ion-beam sputtering.

In composite manufacture it is increasingly common for the fiber component to be surface-modified in some way either by physical etching or chemical treatment in order to improve the fiber-matrix bond strength. XPS can be used to measure the level and distribution of such treatments.

The surface specificity of the technique can be seen on a polyethylene oxide (PEO) coated polypropylene (PP) mesh, where the quantitative spatial distribution of the coating is tagged using the C-O signal from the spectrum and the substrate is tagged using the C-C signal (see figure next page).

ToFSIMS

Static secondary ion mass spectrometry uses a primary ion beam to sputter material from the composite sample surface. The sputter cascade contains neutral and ionic species and the secondary ions are focused using ion optics toward a charge detector. Mass detection is achieved by the use of an extended flight path so that the lighter ions arrive at the detector in advance of the heavier ions, giving 'time-of-flight' spectral separation. In contrast to the XPS output, this generates a mass spectrum that can extend to molecular fragments as large as 10,000 mass units.

ToFSIMS is a highly sensitive qualitative method that samples the top 3Nm of the composite surface and is sensitive to ppm levels. It is routinely used to investigate organic material at surfaces and interfaces. Adhesion-failure analysis is a common application where the presence of a very wide range of contaminants can be confirmed. The technique can also be used to examine cross-sections to determine bulk distribution in complex systems.

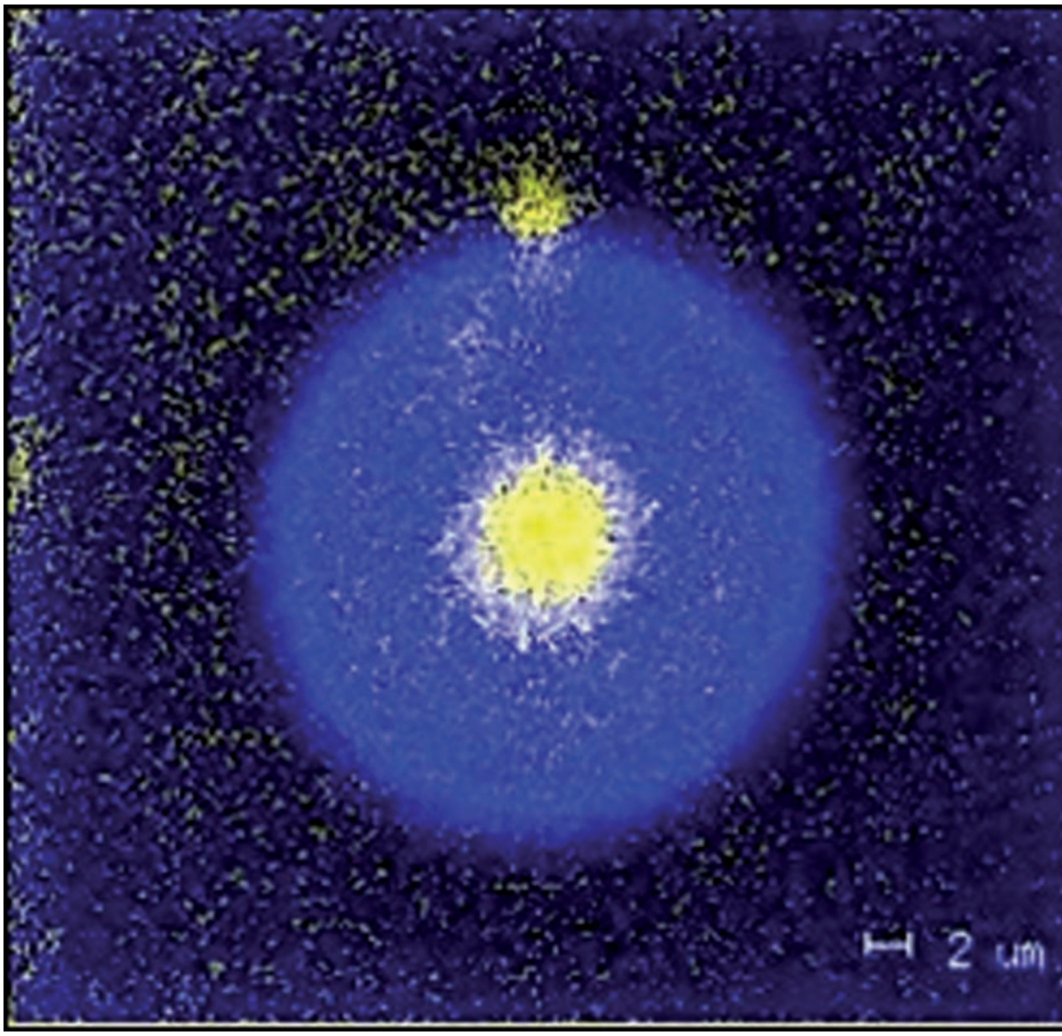
DSIMS

For many applications the region of interest is not only the surface or interfacial condition of a composite but also the immediate subsurface. This is particularly the case where multilayer coatings are concerned, or where embedded material distribution with depth is of interest. For these applications DSIMS is the technique of choice. In these situations the primary ion beam is used to continuously sputter the area of interest with sufficient energy to generate a crater in the material under investigation. The secondary ions that are generated are continuously detected and plotted against the sputter rate, which is subsequently calibrated against the crater depth (see both figures on this page and opposite).

Unlike the three previous techniques, which generate chemical information at surfaces, subsurfaces, and interfaces, 3D profilometry (3DP) uses white-light interferometry to measure surface topography and generate quantitative information on the physical nature of surfaces and subsurfaces.

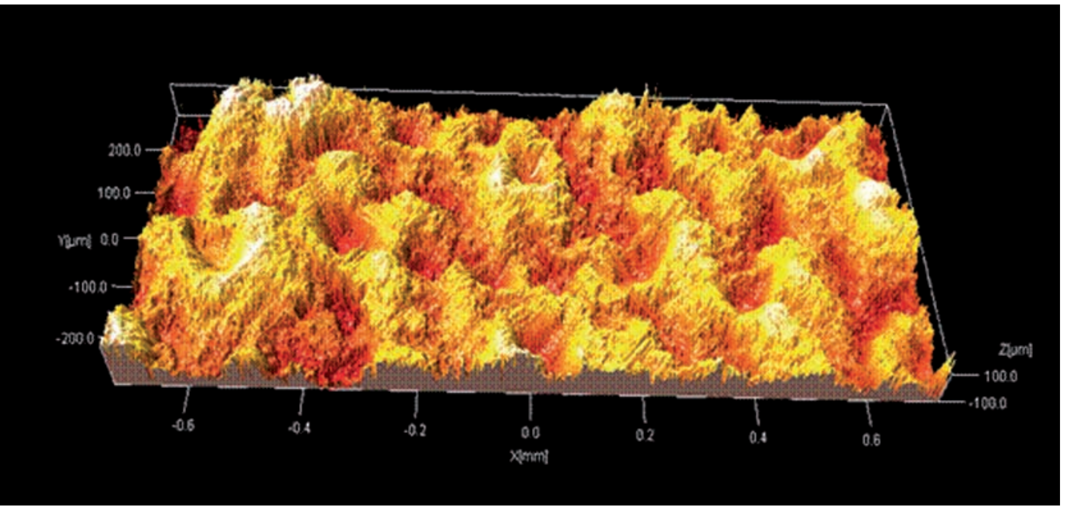
A microscope illuminates the composite sample surface and also a reference plane within the instrument. The interference pattern generated by the recombination of the reflected light from both surfaces enables the construction of

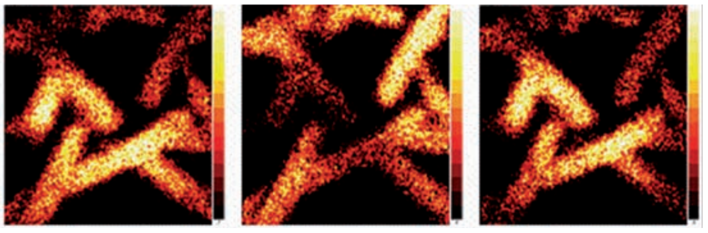
DSIMS chemical map images of an optical fiber bundle at three resolutions (below and left)



Solution provider

CERAM is a leading independent materials testing, analysis, and consultancy organization, whose materials expertise in the aerospace sector includes: advanced ceramics, metals, alloys, super alloys, composites, processing, fabrication, joining, welding and bonding know-how and capabilities, surface and coating characterization, and corrosion analysis. From initial concept, material selection, and design and prototyping through to verification, validation, and manufacturing support and performance/failure evaluation, CERAM works to provide integrated solutions to materials innovation, development, and improvement challenges.





3D topographic profile of turbine blade with line scan and statistical data (above and below). XPS heat scale chemical map images of PEO coating on PP mesh (left))

a 3D image of the composite surface. This image is half-micron pixelated in the x-y plane, but nanometer resolved in the vertical (z) axis. 3DP can be used to specify the composite surface condition where adhesion between different materials is critical (Figure 3).

In composite manufacture for aerospace applications, surface roughness measurement is important for the raw material and finished product. Surface deterioration measurement (for example, on a turbine blade leading edge) can be accurately quantified by the 3DP technique as an in-service monitoring method.

Surface techniques

Surface analysis techniques can be used to diagnose changes in composites – for example, in the analysis of a multilayer printed circuit board in which the glass fiber/filled epoxy pre-pregnated layer is delaminated. Surface mass spectrometry provided chemical analysis of the fiber surfaces and the resin residues and when compared with conforming material, showed that insufficient adhesion promoter had been used in the pre-treatment of the glass fibers prior to curing.

In another example, a multilayer acrylic/metal laminate had suffered a different form of delamination due to compound formation at the interface. This condition was characterized by quantitative 3D surface profiling, giving nanometer resolved topographical images of the surface discontinuity together with quantitative, elemental surface spectroscopy to identify the chemical species present. Surface chemical characterization has also been applied successfully to release paper analysis to investigate potential material transfer.

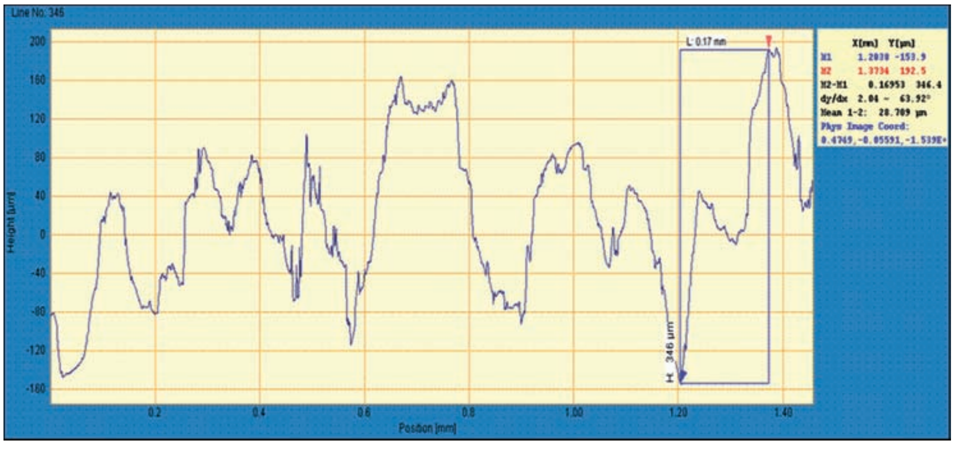
Coatings and substrates

The adhesion of coatings is paramount in delivering in-service performance. The causes of delamination or the adhesive failure of coatings on composites can be investigated using surface characterization techniques. For example, surface molecular mass spectrometry together with quantitative surface elemental spectroscopy investigations of a two layer coating that was exhibiting adhesive failure showed that ingredient segregation from one of the layers was affecting the inter-layer bond strength.

The occurrence of extraneous surface contamination, often of silicon-based materials, is the most common cause of adhesive failure for coated composites. Aerospace manufacturers routinely operate multistage cleaning procedures to ensure substrates are adequately cleaned prior to the coating process. The quality of cleaning is commonly monitored by a rinse/filter/particle count procedure with various limit values. This does not, however, reveal what potential contamination may remain on the cleaned component. Surface characterization can measure part cleanliness directly and quantitatively. Cleaning processes can be routinely monitored using pre-qualified coupons, which are passed through the process with the components. These can then be analyzed by surface elemental spectroscopy and, by the use of a bespoke chemical combinatorial algorithm, a percentage cleanliness measure can be generated. This enables an unequivocal cleanliness specification to be set and an ongoing quality control procedure to be implemented.

Composites used as to make aircraft structures and components lighter and for development of new material continues to hold the key to maintaining, or improving essential product performance requirements in the aviation/aerospace industry. Underpinning many areas of these technological advances is a need to understand surface and interface functionality from a chemical and physical standpoint.

When XPS, ToFSIMS, and DSIMS are used in combination, they provide highly sensitive (ppm) quantitative information on the elemental, molecular, and oxidation state of composite surfaces and subsurfaces and their coatings. This data can be presented as spectra, chemical maps, and depth profiles. In contrast, 3DP generates three-dimensional images of the surface with nanometer resolution on the vertical axis and a quantitative statistical measure of area surface roughness. In many cases it is possible to overlay the chemical information onto the physical profile, giving highly informative details about composites, and providing a powerful tool for failure analysis, standard tests during manufacture, and in the design and development of new materials. ∎



CONTACT

Dr Chris Pickles
chris.pickles@ceram.com
www.ceram.com

Clean sky initiative

THE RADICAL REDUCTION OF POLLUTANTS AND NOISE ARE IMPORTANT FIELDS OF ACTIVITY FOR THE FRAUNHOFER SCIENTISTS WORKING AS PART OF THE EUROPEAN CLEAN SKY PROJECT

> "The aim of the Clean Sky Initiative is to reduce CO_2 by 50%"


MARTIN LEHMANN

BY MARTIN LEHMANN

The Clean Sky Joint Technology Initiative (JTI) is an innovative program with an endowment of €1.6 billion. It is the largest European project for the sustainability and competitiveness of aviation in Europe, and will radically improve the impact of air transport on the environment while strengthening and securing the European aeronautics industry's competitiveness.

The program's purpose is to demonstrate and validate the technological breakthroughs that are necessary to reach the environmental goals set by the Advisory Council for Aeronautics Research in Europe (ACARE: the European Technology Platform for Aeronautics & Air Transport). Together with Agusta Westland, Airbus, Alenia Aeronautica, Dassault Aviation, EADS-CASA, Eurocopter, Liebherr-Aerospace, Rolls-Royce, Saab AB, Safran, and Thales, Fraunhofer-Gesellschaft is one of the platform leaders and a member of the Clean Sky JTI governing board. The Fraunhofer Institute for Structural Durability and System Reliability LBF is coordinating the efforts of Fraunhofer within the JTI.

What are the goals?

The aim of the Clean Sky Initiative is to reduce CO_2 by 50%, NOx by 80%, and noise emissions by 50% by 2020, as well as to introduce sustainable lifecycles for all aircraft components. Researchers are working on an intelligent early-warning and monitoring system that makes the lightweight construction of wings and other components safer. This solution incorporates optical fibers and piezoceramic patches. By interlinking experimental and numerical test procedures, the work performed becomes unique. This approach increases component safety while shortening the development cycle.

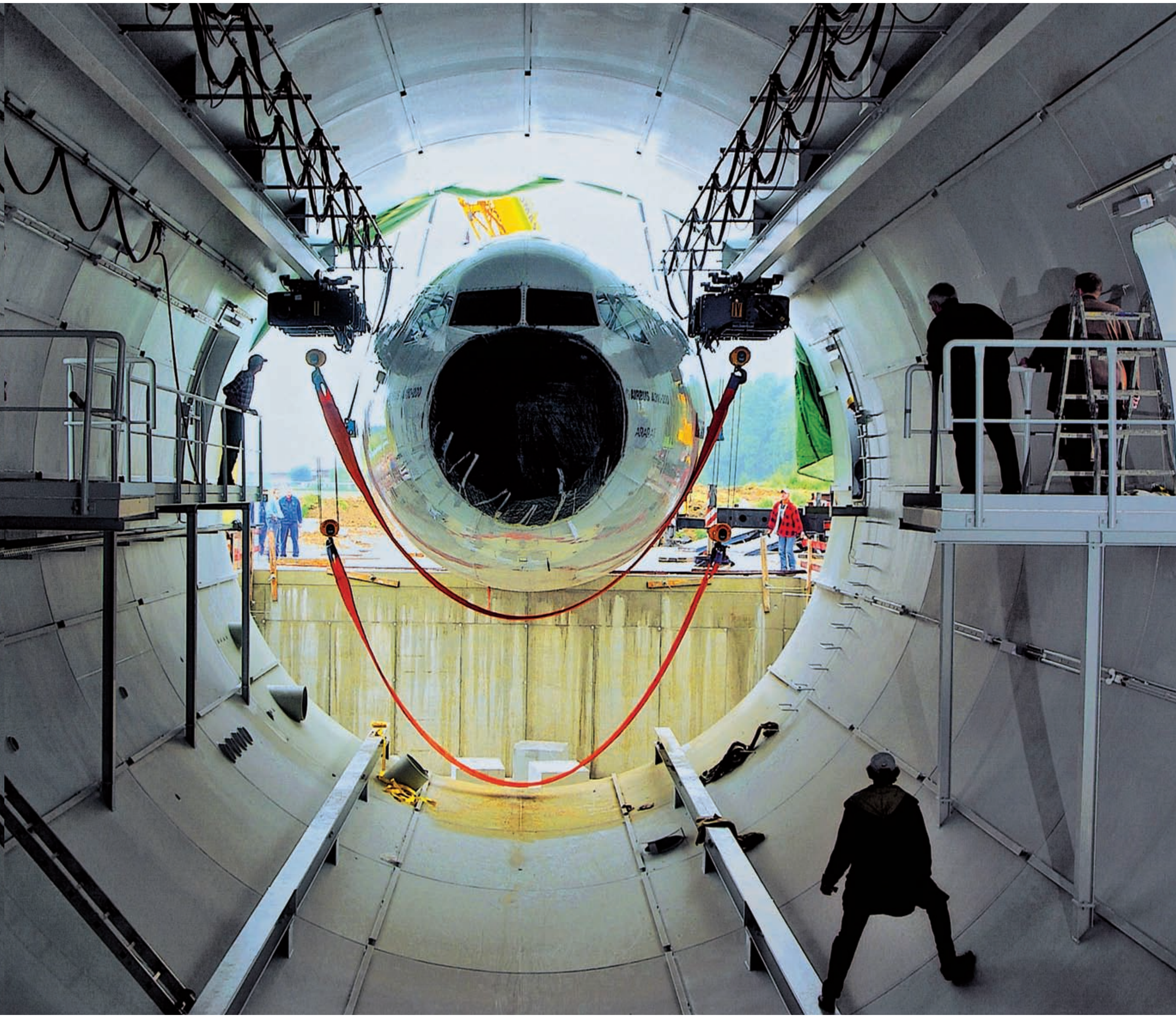
At Aerospace Testing Expo 2009 Fraunhofer demonstrated its competencies in simulation, processing, assembly, testing, and improvement. Two major exhibits were presented at the Fraunhofer booth, showing some of the company's activities for the aviation industry. One is a full-scale wing mock-up standing more than 4m tall, which demonstrates future Structural Health Monitoring (SHM) concepts. Four kinds of sensors – sensitive coatings, piezo transducers, optical, and electrical strain gauges – are applied on the wing skin. Load monitoring of structural strain and impacts will allow users to


Assembly of the Fraunhofer Flight Test Facility near Munich, Germany ©Fraunhofer IBP

estimate the residual lifetime of a structure in the future. Therefore the knowledge of the actual loading helps estimate individual (and therefore longer) maintenance intervals, as well as exploiting the full lightweight potential of a permanently monitored configuration.

The other exhibit showed different innovative bonding and repair methods for aviation structures.

In addition to these technologies, visitors to the expo could learn about the Fraunhofer flight-test facility located near Munich, which houses an actual cabin from a passenger jet, allowing researchers to expose it to a range of



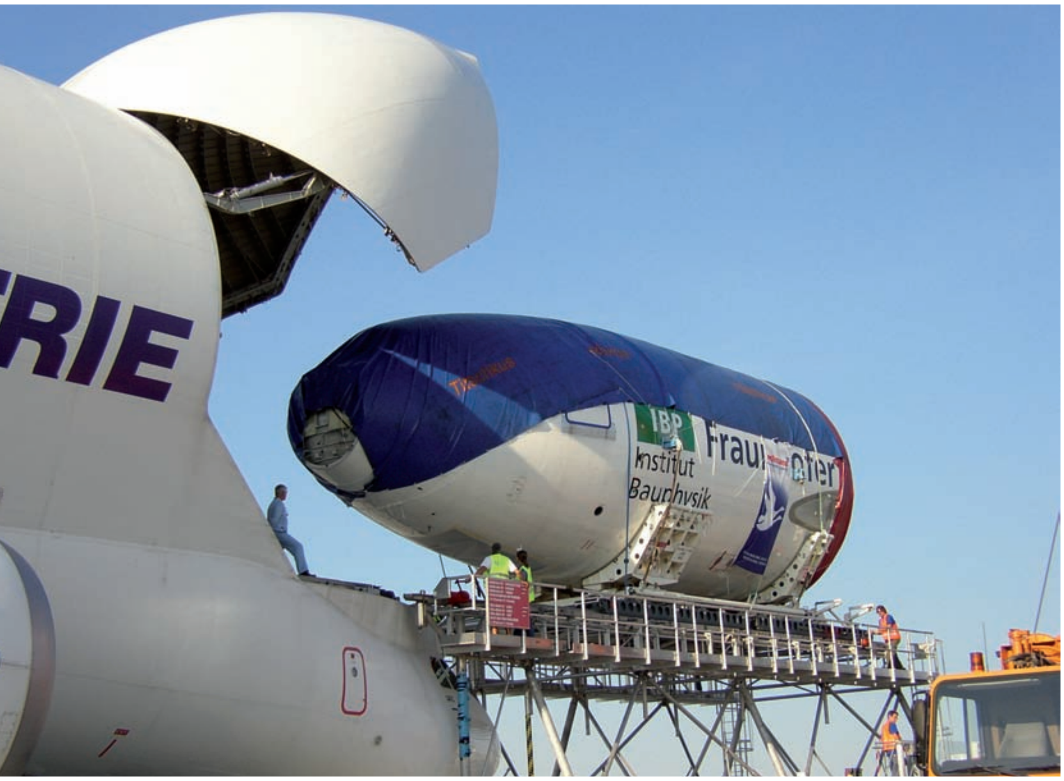
pressure and interior climate conditions, and thereby analyze the wellbeing of up to 80 passengers at a time. Together with aircraft manufacturers, the researchers are making improvements to the cabin climate. They are analyzing air quality, hygiene, thermal comfort, acoustics, and lighting, as well as looking for solutions to improve the transport of heat and moisture in the fuselage.

Green technologies for aviation

In cooperation with the other integrated technology demonstrators (ITD), Fraunhofer is committed to developing environmentally friendly methods and materials for the design and operation of aircraft. Applied high-level physics are needed by the aeronautics business to keep it on an excellent footing in the present ecological and economic challenge – Fraunhofer works as part of the ITD to support the Clean Sky JTI.

The ITD SMART Fixed Wing Aircraft (SFWA) project will work toward the goal of reducing medium- and long-range aircraft fuel burn and noise emissions. It aims to develop an all new 'smart wing' design that makes use of passive and active flow and load control technologies, which will help reduce the drag of the wing in cruise mode. Fraunhofer will contribute to the functionalization of the surface, general bonding, and application of durability driven loads control strategies. This assumes a high integration standard, supporting smart wing adaptabilities to industrial qualification.

The ITD Eco-Design (ED) focuses on environmentally sound aircraft production, as well as on aircraft recycling technologies. Clean, resource-efficient technologies for aircraft structures and equipment will be created and matured, along with a quantification of environmental improvements using a focused life-cycle assessment approach. 'Green', pre- and



Fraunhofer offers

- Application-oriented adhesive bonding solutions for the industry;
- Smart systems integration using micro and nano technologies;
- Integration of nano materials as well as printed functionalities;
- Development of SMC semi-finished products, processing technology, and material development;
- RTM technology with microwave-assisted accelerated curing and one step in-situ polymerization;
- A wide range of methods and special equipment for testing and improvement;
- Low-pressure flight test facility;
- Large-scale structural testing for several aspects such as material properties, design and manufacturing issues, and various application scenarios;
- Testing, analyzing, and optimization of properties and the lifecycle of lightweight structures made of plastics or fiber-reinforced plastics (FRP);
- R&D of real-time solutions in the fields of simulation, adaptive transfer, visualization, and efficient rendering of 3D data.

post-use-phase technologies along with aircraft Eco-Design guidelines will be presented.

A second pillar of ED is the systems domain, which tackles the generics and validation of eco-friendly aircraft systems. These substantiate systems architectures that prominently de-implement hydraulic fluids in liaison with the 'all-electric' philosophy. This will be pioneered on the business, regional, and rotorcraft scale flight vehicles.

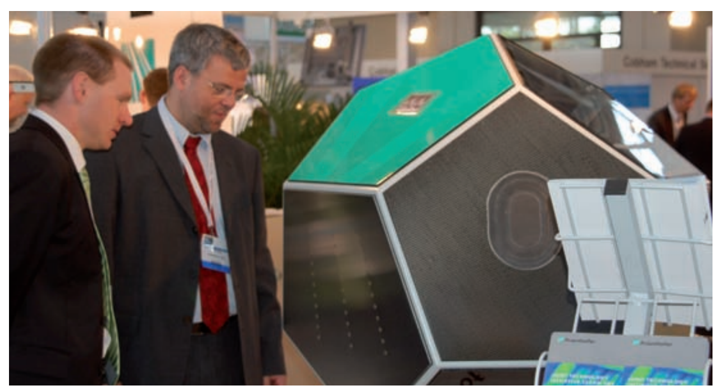
The ITD System for Green Operations (SGO) will improve aircraft operation through the management of aircraft energy and the management of mission and trajectory. Technologies from this ITD are enablers for further improvements in environmental impacts at the vehicle level. Fraunhofer will address sensorics within A/C main and auxiliary energy generation and will contribute to environmental testing campaigns.

The ITD Green Regional Aircraft (GRA) plays a key role in the enhancement, validation, and demonstration of the technologies and also contributes to novel high-lift devices and landing gear design in the ITD GRA. SHM concepts based on FOBG, acoustic emission and ultrasonics, wireless communication, thermoset, and nano-reinforced composite materials as well as laser beam welding represent the core of the involvement in LWC. Advanced leading-edge design, landing gear geometry and kinematics will be developed and tested in the wind tunnel for low-noise purposes in LNC.

The Technology Evaluator (TE) monitors the progress of the ITDs' outputs as part of the Clean Sky Initiative, for JU stakeholders and internal and external entities. The TE consistently assesses the merit of complementary R&D activities performed in ITDs with regard to ACARE environmental objectives, bringing a global ATS view. The TE also helps identify interdependencies of impacts and provides elements of guidance and justification for decision making within Clean Sky, to maximize JTI synergy effects. Fraunhofer leads the global assessment of ecolonomic impacts in Clean Sky.

Aircraft fuselage ready to be transported to the Fraunhofer Flight Test Facility

Aerospace Testing Expo 2009: Composite aircraft wing with integrated sensors for measuring strain in flight ©Fraunhofer LBF



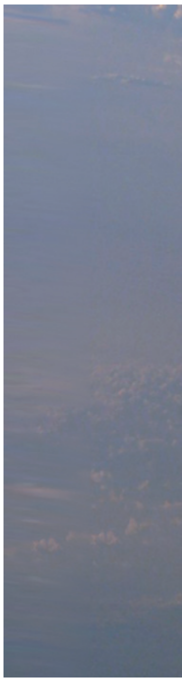
> **"Fraunhofer employs a staff of around 15,000, who work with an annual research budget totalling €1.4 billion"**

About Fraunhofer

Fraunhofer is the leading organization for applied research in Europe. Its research activities are conducted by 57 Fraunhofer Institutes at over 40 different locations throughout Germany. Fraunhofer employs a staff of around 15,000, who work with an annual research budget totalling €1.4 billion. Roughly two-thirds of this sum is generated through contract research on behalf of industry and publicly funded research projects. Branches in the USA and Asia serve to promote international cooperation. The practical application of the results is always the goal for all contract research, initial research, consulting, and studies. Fraunhofer's tasks therefore mostly lie within the sphere of cooperation between public authorities and private companies.

Companies of all sizes and industries use Fraunhofer Institutes as external high-tech laboratories for almost all types of development projects and special services, and as a competent advisor for organizational and strategic issues. ∎

Martin Lehmann is a project engineer with Fraunhofer Institute. Co-contributor Anke Zeidler-Finsel is the institute's press officer. www.lbf.fraunhofer.de/cleansky and cleanskypress@lbf.fraunhofer.de



Hypersonic engine demonstrator

A US MILITARY PROJECT LOOKING INTO HIGH-SPEED, HIGH-TEMPERATURE HYPERSONIC ENGINE DEMONSTRATORS HAS ENDED IN SUCCESS

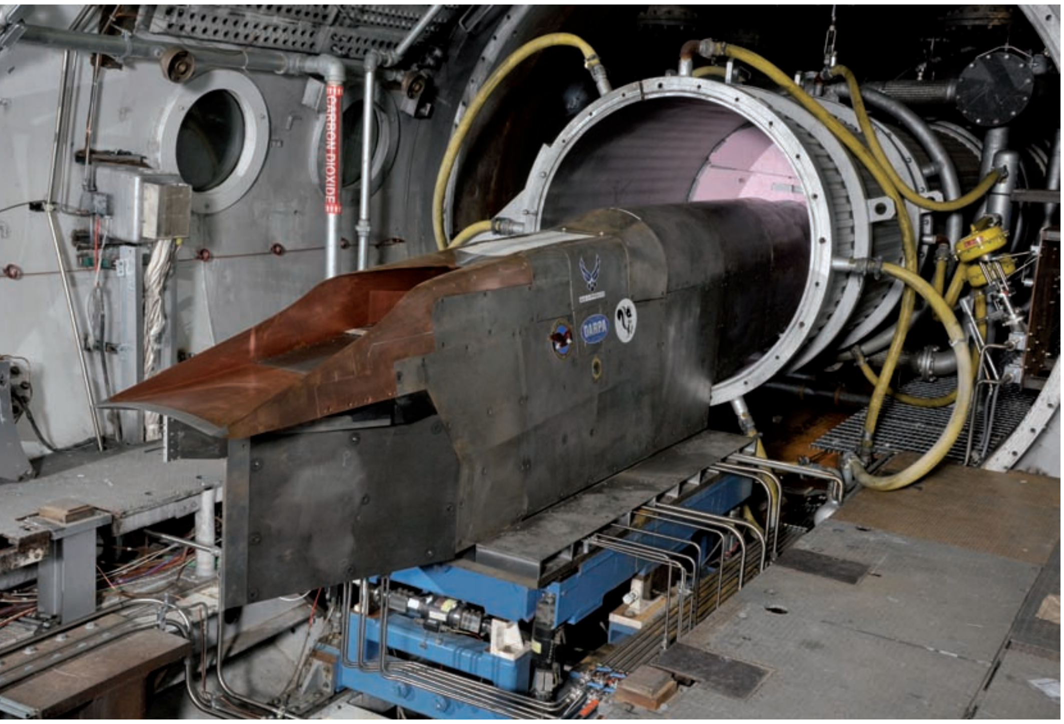
> **"What is unique about this test article is that it combines two propulsion systems into a single package"**

BY AEDC PERSONNEL

The craftsmen, engineers, and managers in the aerodynamic and propulsion test unit (APTU) at the US Air Force's Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee, have recently witnessed the fruits of their long and hard labor.

AEDC's 10-year effort to upgrade a high-speed, high-temperature, blow-down ground test facility culminated in successfully planning and executing a major test for the Defense Advanced Research Projects Agency (DARPA) on a Falcon Combined-cycle Engine Technology (FaCET) demonstrator, dual mode ramjet/scramjet hypersonic engine.

"Not only was it a successful freejet test on DARPA's FaCET article, but this test also represented our first entry for a customer since APTU underwent its extensive multi-year facility upgrade," says the current AEDC manager for APTU, Matthew Bond.



"The main purpose of the FaCET program was to test this combined-cycle engine and its common flow path at Mach 3, 4, and 6," he explains. "What is unique about this test article is that it combines two propulsion systems into a single package, which could be used to power a flight vehicle from zero to hypersonic flight and back.

"The test was to verify that the flow paths are designed correctly," recounts Bond. "The most critical issue in a turbine engine, or a ramjet, is making sure you can manage the airflow. Each propulsion mode has different requirements. For example, with a ramjet, even though the vehicle is going Mach 3 or Mach 4, it actually gets choked down to subsonic flow when the air enters the inlet."

The challenge to getting a combined-cycle propulsion system to function is to properly manage the flow transition between supersonic and subsonic.

"APTU is a fixed Mach facility in which you install a nozzle and run one Mach number," explains Bond. "You can't vary the Mach number during the run. So, you try to run a set of test points that capture the different modes of the test article.

"The original test plan called for us running several Mach 3 conditions first. These conditions had the bypass door to the turbine partially open, to divide the incoming flow. Next, we'd run the test article at Mach 4 conditions, representing its ramjet mode, and finally at Mach 6 conditions for its scramjet mode, distinguished by supersonic combustion.

"We tested at these different modes and our customer verified their airflow calculations. The correct amount of airflow into the engine is very important to actually light the fuel/air mixture in the combustor and maintain that combustion," he says. "Our primary objective was to deliver as much data as we could with the FaCET test article to support future combined-cycle engine developments."

Scramjet technology will lead to an aircraft like the one above. AEDC officials are heralding a successful first test on the DARPA FaCET in APTU (left), a major milestone on two fronts. (Photo by Rick Goodfriend)

Facility upgrade

Chris Smith, technical director for the 718th Test Squadron, thinks it helps to understand what took place beforehand to bring APTU to its present capability in order to appreciate this milestone.

"Perhaps the biggest facility upgrade in APTU during the last decade was replacing our old vitiated air heater (VAH) with the new combustion air heater (CAH)," he explains. "The CAH increased our capability to generate greater Mach numbers and dynamic pressures while providing greater facility reliability. However, the CAH wasn't part of the original plan.

"In the 1990s, we acquired the Sudden Expansion (SUE) burner and fixed nozzles from the canceled national aerospace plane (NASP) program with the intent to take APTU from a high-supersonic test facility at Mach 4 to a truly hypersonic one up to Mach 8."

Smith describes the SUE burner as "crucial" to providing APTU with the necessary pressures and temperatures to reach hypersonic

> "The CAH increased our capability to generate greater Mach numbers"

The APTU

APTU is an air blow-down test facility designed for true temperature aerodynamic testing of propulsion systems, materials, and structures of supersonic and hypersonic flight vehicles. For 25 years, APTU used its vitiated air heater (VAH) to conduct many successful tests. From 1981 to 2005, AEDC made more than 275 program runs.

Under AEDC's high-speed/hypersonic air-breathing propulsion test and evaluation capability (HAPTEC) program, APTU began a series of major upgrades in 2002 to provide a national ground test capability for air-breathing simulated flight up to Mach 8. Upgrades are planned through 2016 and will be implemented customer test schedules.

Phase I of HAPTEC was completed in 2004. It modified the APTU utility supply systems (high-pressure air, isobutane, liquid oxygen, and water) and replaced the air ejector system to increase the facility's Mach/altitude simulation capability. AEDC used this interim capability to successfully test the dual combustor ramjet (DCR) in 2005.

Phase II completed in 2008. It replaced the VAH with a high-pressure, high-temperature combustion air heater (CAH) and characterized the flow quality of its fixed Mach nozzles. During this time, the APTU team also made improvements to its test productivity, resulting in multiple runs per day with multiple test conditions per run.

The CAH reached its initial operational capability (IOC) of Mach 6.75 and can operate over a range of total pressures from 200-2,800psia (14-190atm) and a range of total temperatures from 1,000-4,700R (670-2,600K). AEDC successfully completed its first hypersonic propulsion test in 2009 using the CAH and three of its characterized nozzles.

Phase III is currently adding a 'fly the mission' test capability. The expected variable Mach/altitude test range will be from Mach 3 to approximately Mach 6 with fixed Mach nozzles above that. When completed, AEDC and HAPTEC will provide customers with a much-needed ground test capability for the research, development, and acquisition of high-speed and hypersonic flight vehicles.

Outside Machinist Everett Fulmer inspects the Defense Advanced Research Projects Agency's Falcon Combined-cycle Engine Technology scramjet test article

flight conditions. External funding issues stalled the upgrade.

"In 2001, we regrouped our efforts and made another push for the upgrade as we knew the nation sorely needed this ground test capability," Smith continues. "One of the reasons the USA canceled NASP was the lack of a ground test facility to support development of its propulsion system and buy-down risk prior to flight testing. Hypersonic propulsion is the pacing technology hurdle for these types of flight vehicles."

AEDC initiated a new military construction (MILCON) program in 2002, again with the goal of integrating the SUE burner into the facility and checking out the improved utility systems.

"However, the SUE burner turned out to be unusable," he recalls. "Limited checkout was conducted in 2004 and the MILCON was closed. That same year, we initiated an AEDC-funded procurement of a SUE-burner replacement and also received Department of Defense approval for our 'fly the mission' variable Mach capability under the auspices of the central test and evaluation investment program. We took delivery of our CAH in March 2007 and awarded our design contract for a flexible wall nozzle in September of that same year. The rest, as they say, is history."

And what a history it was.

"The June 24 FaCET test was extremely important for APTU," says Bond. "This Mach 6 run was our first-ever scramjet propulsion test. It brought together FaCET with our recently acquired CAH, Mach 6 nozzle, and JP-7 fuel heater."

"High-pressure air is a very scarce commodity, shared among all three test squadrons on base"

Lt Col James Colebank, the 718th Test Squadron commander, says the Mach 6 run was more than a first for APTU.

"This was also a milestone for AEDC because this was the first near-flight scale test of a hypersonic engine here," he says. "There have been earlier experiments conducted on considerably smaller scale engines in our ballistic range, but you'd acquire only 300m/sec of data."

All three men agree the availability of high-pressure air provided considerable challenges for the FaCET test program.

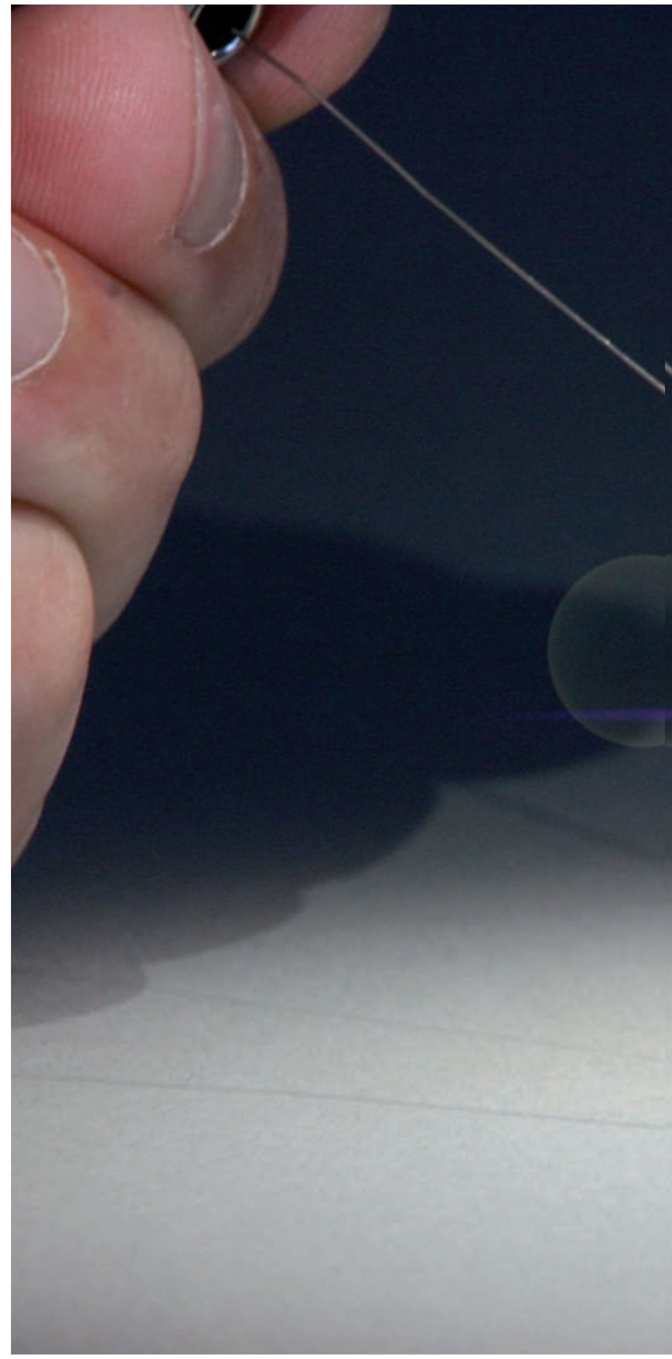
"High-pressure air is a very scarce commodity, shared among all three test squadrons on base," Colebank acknowledges. "Scheduling APTU with other testing at AEDC has been, and will continue to be, a great challenge."

Fly the mission

For decades, hypersonic engine developers have had to rely on a few discrete data points to evaluate their designs on the ground before even considering the move to riskier and more costly flight tests. From these ground test points, they would infer what their engines were doing 'in-between'. Not very comforting when the slightest miscalculation could mean, at best, degraded engine performance in hypersonic flight to, at worst, a failed engine light, a smoking hole or watery grave, and no hardware to examine for cause of failure. This risk 'wall' has been rather impenetrable with only a few willing to scale it for even fewer successful flight demonstrations.

AEDC is ushering in a new era for these engines. With its APTU variable Mach test capability, the developers will be able to 'fly' their engines over their entire flight trajectories on the ground, repeatedly, and know exactly what is happening 'in-between'. Due to a flexible wall nozzle that can withstand the tremendous temperatures and pressures being generated by the CAH, APTU will be able to vary those temperatures and pressures in real time and create the Mach/altitude combinations of the engines in flight.

If all goes according to plan, AEDC should have its variable Mach hypersonic propulsion test capability fully functional and in operation by the middle of the coming decade. So instead of accepting the unacceptable to scale the wall, this new test capability will give the developers a lower risk path and a gateway to flight. ∎



Electronic connection research

ELECTRONIC AND ELECTRIC CONNECTIONS PLAY A LEADING ROLE IN ALL TECHNICAL SYSTEMS. TO ENSURE THEIR RELIABILITY, A RANGE OF TESTS HAS BEEN DEVELOPED FOR ELECTRONIC CONNECTORS DESIGNED SPECIFICALLY FOR THE AEROSPACE INDUSTRY

“Many connectors have been designed for mass production and low stress levels”

LUTZ BRUDERRECK

BY LUTZ BRUDERRECK

Electronic and electric connections play a leading role in all technical systems. In general, pin-and-socket connectors are used for detachable connections. As widely varied as the circuitry requirements may be, the range of connectors is equally broad, much the same as the root causes of defects or malfunctions. TechnoLab has all the necessary experience and technical equipment to perform qualifications and analyses.

On the one hand, the aerospace industry has been using electronic connectors that have been developed over many years. They have been extensively tested and comply with very strict requirements concerning material and processing quality. This wiring is up to a very high operational standard, and malfunction or failure is an exception.

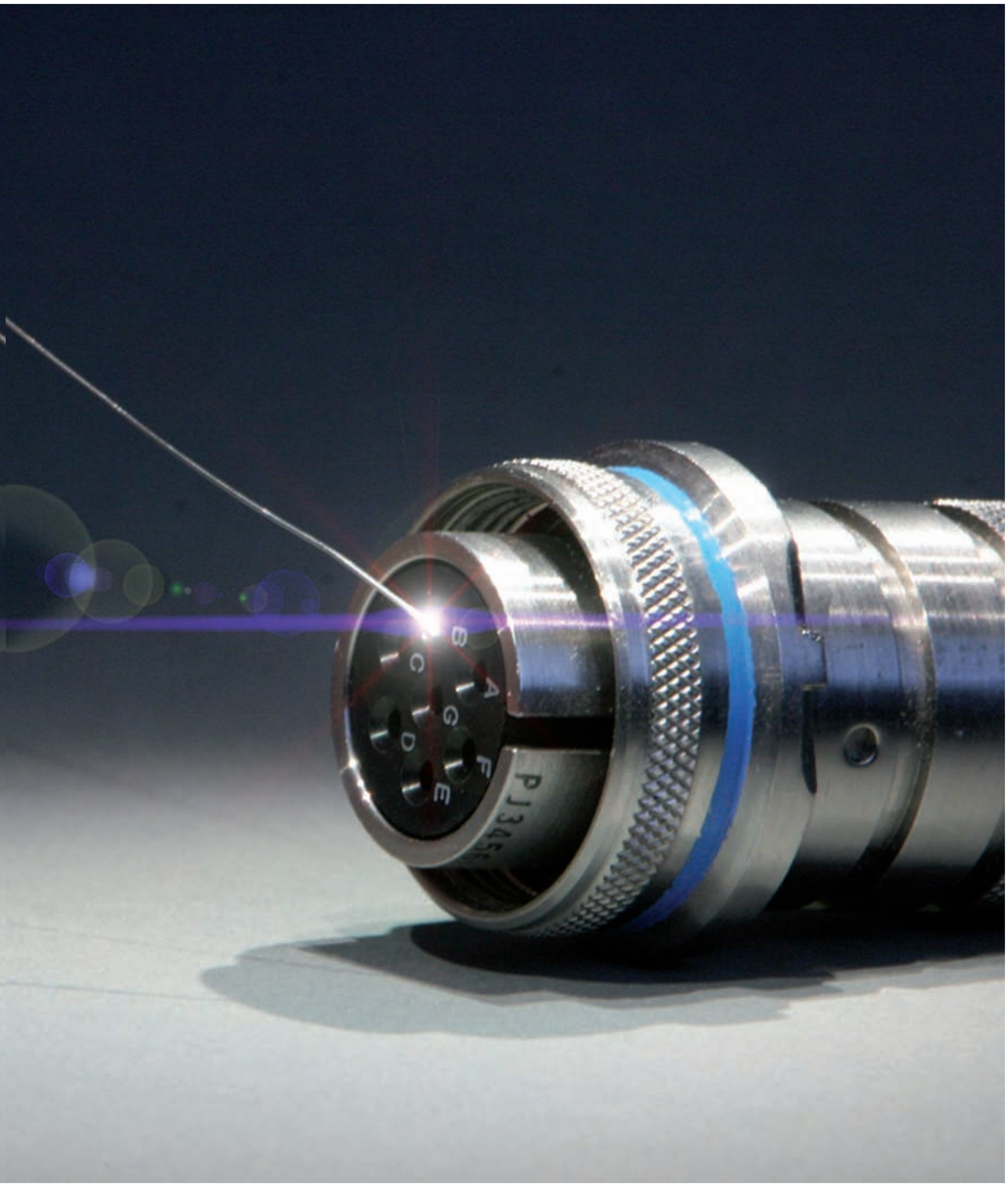
However, an increasing number of connectors are being used that were originally designed for other areas of industry. This applies to telecommunication, general computer, and mechanical engineering parts. This is especially common in the commercial aircraft sector, which has been steadily increasing the number of ‘comfort’ functions in aircraft such as entertainment and passenger leisure.

As far as military avionics is concerned, the situation is similar. But here the cost issue is not as critical. Military aircraft normally have a reduced number of comfort functions, but the requirements are disproportionately high because of environmental and operational stress.

Frequent causes of malfunctions and defects of connectors can be stress due to operational and environmental influence, disturbed contact due to contamination or abrasion of functional layers, temporary soft shorting due to whiskers, poor connections between connecting pin and printed circuit board (PCB), and damage to PCB structure by the connecting pin.

Reliability can be optimized with the help of preventive measures. Tests and analytical methods provide reliable results to ensure reliability in service. Connections between an electronic unit and the circuit periphery are of particular importance here. Environmental simulation and analytical methods are used to assess how good the connections are.

Many connectors have been designed for mass production and low stress levels. If their use in aircraft is intended, tests to prove reliability for this field of operation are necessary. In many cases these tests cannot be carried out by the supplier. The end user or module supplier carries the duty to guarantee and prove the suitability of systems.



Inspection with a flexible endoscope (diameters down to 0.3mm) for organic contamination, abrasion or corrosion

A great number of the usual tests are carried out in accordance with:

MIL-DTL-38999 L Detail Specification Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For

EIA-710-Guide of Space Grade Requirements for Electrical Connectors

EIA-364-D Electrical Connector/Socket Test Procedures Including Environmental Classifications

SAE-AS-39029- Contacts, Electrical Connector, General Specification For

TechnoLab, based in Germany, offers a variety of environmental tests, among which the following are particularly relevant for aviation and aerospace.

Noxious gas test

Humidity and noxious gases, such as H_2S, SO_2, Cl_2, NO_X and O_3, have a corrosive effect on contact materials and structural parts and may lead to failure. They equally influence the 'wettability', adhesive force, and basic structure of surfaces.

The noxious gas test ascertains the tightness of galvanic structures of areas where the basic material of the contact lies open or where the contact material does not show the required composition (thin, damaged layers).

It makes sense to perform comparative tests of different conditions: unmated, mated, after several mating processes. The test layout eventually depends upon the objects to be tested, their prospective place and purpose of operation. This system requires fine-tuning with the customer.

The test is also important to assess whether the contacts are suitable for automatic soldering processes. Noxious gases may vitally harm the first-pass-yield, especially on Ni and Ag surfaces, and therefore impair long-term quality and reliability.

Damp heat

Depending on the location, humidity in combination with changing temperature may have a rapid and recognizable, but sometimes far-reaching influence on the various parts of connectors. The tendency toward miniaturization of assemblies for cost reasons leads to reduced insulation distances and increases the risk of creepage path formation.

The respective tests concern the tightness of bodies, processing quality, and suitability and composition of the materials in use.

The damp heat test is carried out in accordance with IEC 60068-2-30 or IEC 60068-2-56. The tightness test is carried out in accordance with IEC 60529 degrees of protection against intrusion (IP code).

Whiskers

These are defined as very fine single crystals with a diameter of approximately 0.3-10µm, and they may be up to several millimeters long. Whiskers are dangerous for connectors, if the material has been deformed by crimping or clinching, because they appear spontaneously on surfaces and may grow over a prolonged period of time.

The test of semi-finished products or complete connectors is carried out in accordance with JESD-22-A121 standard, Measuring Whisker Growth on Tin and Tin Alloys, including exposure to dry heat, damp heat, and temperature change.

Sand and dust

At an ambient temperature of up to 194°F, 18-50m/s is the speed at which abrasive test media (sand, dust) with a particle (grain) size of 500-3000µm, hit the test object in the sand and dust test. The test helps to assess the tightness of bodies and the intrusion of particles. The stress for the test objects (and abrasion) can be increased by superimposing a vibration test in accordance with MIL-STD-810F Method 510.4 Sand and Dust.

Abrasive media are also used to test their influence on surfaces, such as coatings (protective coatings, varnish) of plastic or aluminum, or any other material. Inspection win-

Fastening an object in the chamber for sand and dust testing

> "Repeated vibration,sometimes coupled with profound resonance, enhances the stress"

dows and window panes are tested for scratches and also the loss of transparency. In extreme cases, panes may even shatter.

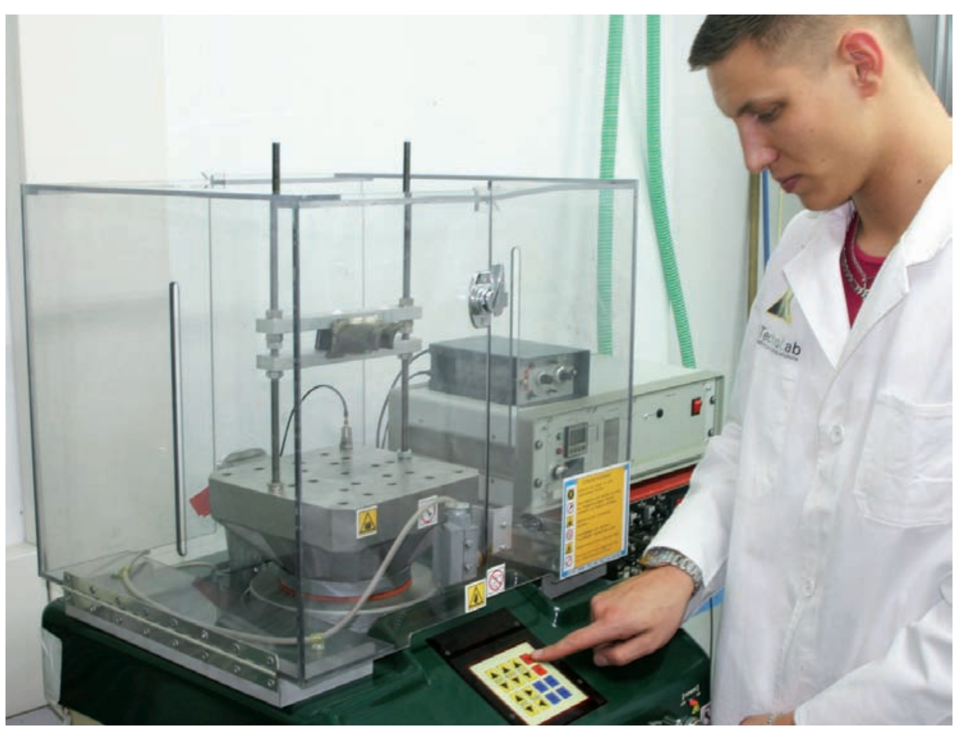
Shock and vibration

The operation of any aircraft implies vibration (turbines) and shock (turbulences, landing). For the small connectors this means that they must not only withstand temperature changes or shocks, but a multitude of climatic and mechanical stress factors (ambient pressure, vacuum). The electronic assemblies in their various designs (through-hole, surface-mount technology) face an enormous challenge if they are to survive the various conditions. On the one hand, the actual electric function must be guaranteed; on the other, the structure must also be able to bear the mechanical load that derives from operational position, dead load, and mechanical stress in the assembly and the solder joints.

Changing conditions are particularly critical. The higher the temperature differences and the frequency of these differences, the greater the stress in the assembly. Connectors and electronic assemblies in places with frequently changing thermomechanical conditions are endangered.

Repeated vibration, sometimes coupled with profound resonance, enhances the stress. Preventive tests and analyses are therefore vital for high-reliability systems.

Inputting parameters and factors for shock and vibration tests



Environmental special tests

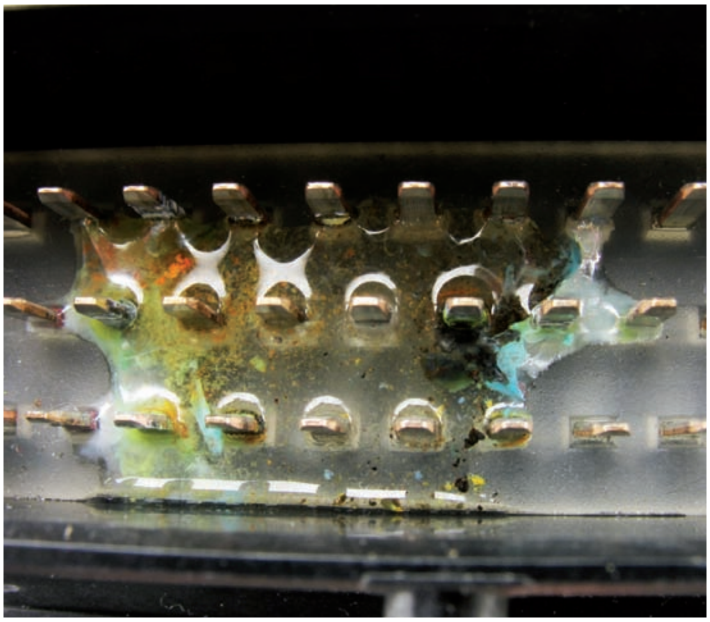
Within the framework of environmental simulation, TechnoLab also performs tests to determine the suitability of the processing procedure of connectors, such as EIA-JEDEC-22-B-106-C – resistance to soldering temperature, or EIA-364-TP71B – connector solder wicking test.

Objects that have failed or malfunctioned are subjected to technical analysis in order to find which mechanism caused the failure. Moreover, technical analysis can check existing quality levels and verify an even quality. Technical analysis is applied for either assessment of connectors from lifecycle tests, assessment of connectors from defective systems – field returns or qualification of connectors, or comparison of connectors from different manufacturers for compliance with standards.

Samples from lifecycle tests are assessed before and after the test. Signs of wear and tear are taken to evaluate the robustness of the samples against the chosen environmental simulation test.

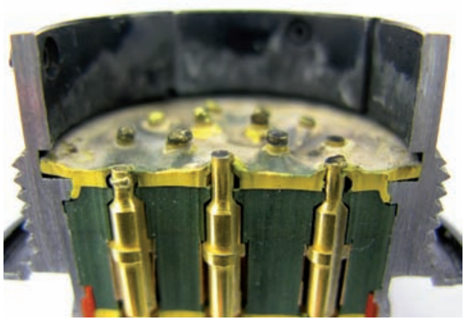
Samples from defective systems frequently lack documentation of the condition on arrival. Analysis must recognize the failure-relevant stress and find evidence for the failure mechanism. Samples to be qualified or compared are subjected to a check of the individual criteria of the chosen standard.

The connectors play a major role. The actual contact-giving system is one focus of attention; the connection between the connector and the PCB is the other. The latter must fulfill the highest requirements regarding the vertical solder fill and the adhesive strength between solder joint and PCB. For PCBs in the aerospace industry, ENIG (electroless nickel/immersion gold) is one of the favorite surface finishes. This finish is well suited for long-term stable solder connections. It becomes problematic only if



Capsuled connector in optical inspection, after environmental simulation

"Technical analysis also deals with assessing solder connections and the layer system of PCBs"



Cross-section of typical connector

difficulties occur during the precipitation of layers. After wetting with solder, this may lead to an effect that has become known as 'black pad'.

Technical analysis also deals with assessing solder connections and the layer system of PCBs. Evaluation is done in accordance with IPC-A-610 or ECSS-Q-70-08A – Raumfahrt-Produktsicherung: Handlöten elektrischer Verbindungen hoher Zuverlässigkeit (Aerospace Product Safety: Manual Soldering of High-Reliability Electrical Connections).

PCBs are assessed in accordance with IPC-A-600 acceptability of printed boards, or IPC-4552 specification for ENIG plating for printed circuit boards.

Third-party qualifications

As an independent test house, TechnoLab offers a multitude of in-house services in various fields where electronic and mechanical assemblies are in common use.

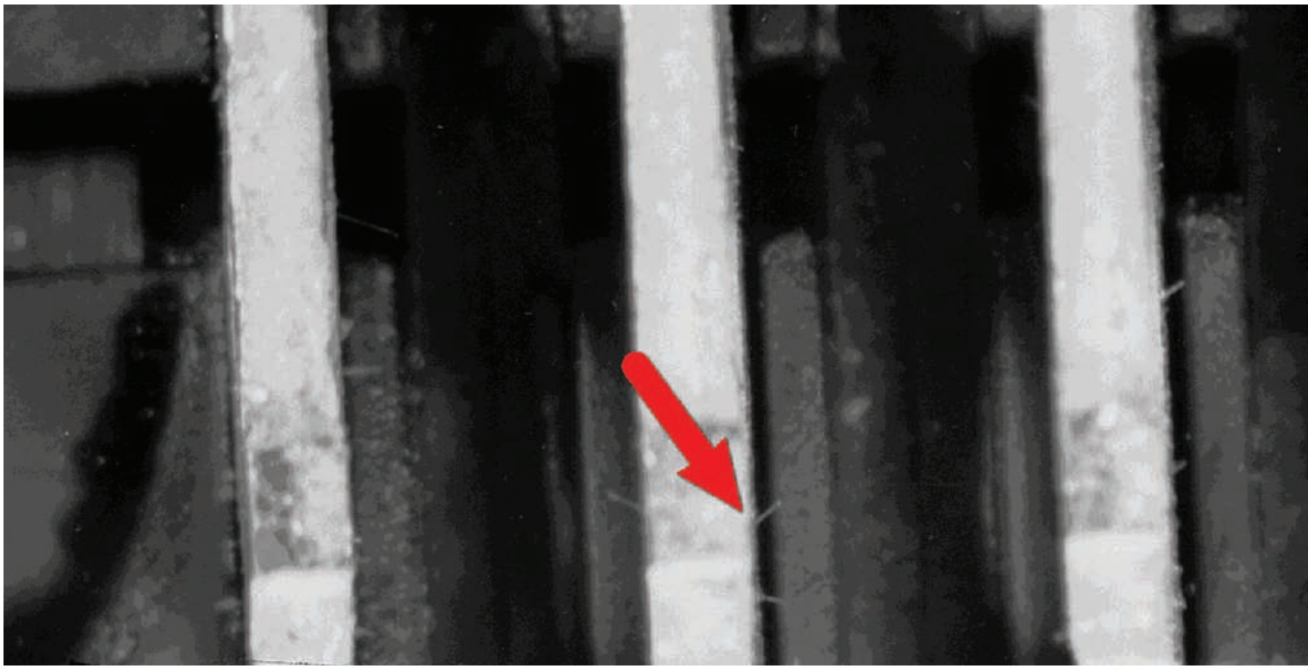
For aviation systems in particular, TechnoLab offers the customer comprehensive answers to 'how' (by tests and inspections), 'why' (by technical analysis), and 'how to prevent' (by inspections). In addition to standard tests the company offers customized tests and develops them in cooperation with customers. Specialized tests concern various fields of application.

Sometimes there is a yawning gap between a customer's idea of a suitable test and the actual load to which an object is subjected in real life. As a consequence, the results of such a test would be disproved by reality. TechnoLab helps the customer choose the appropriate test and qualification method; if necessary, they modify and/or develop customized methods.

To fulfill this self-imposed engagement, TechnoLab has been developing and constructing new test equipment and new test methods. The demand by the in-house analytical staff for sophisticated optical inspection systems prompted the TechnoLab engineers to develop specialized high-precision inspection equipment. The innovative systems range from flexible micro-endoscopes and rigid endoscopes to HDTV video microscopes with TFTs. Xenon cold light sources, and IR cameras, as well as software for image processing, are among the available products. ∎

CONTACT

Lutz Bruderreck is the head of technology at TechnoLab in Berlin, Germany
TechnoLab GmbH
www.technolab.de
info@technolab.de



'Whiskers' (arrow) on solder joints after solderability test and exposure to dry heat

Unmanned air competition

"The prototype has been specifically tailored for the competition"

MADRAS INSTITUTE OF TECHNOLOGY'S UAV RESEARCH TEAM IN INDIA HAS BEEN WORKING ON A FULLY AUTONOMOUS DEVELOPMENT OF A FIXED-WING UNMANNED AIRCRAFT TO BE ENTERED INTO AN INTERNATIONAL COMPETITION

BY SHILADITYA BHOWMICK

SHILADITYA BHOWMICK

Madras Institute of Technology's focus on research and development in the area of unmanned vehicle systems began in 2006 in the avionics division at Anna University, India. The project is part of an ongoing effort at the Madras Institute of Technology to develop technologies for autonomous aircraft for future use in scientific research and defense applications.

The immediate aim is to enter an international aerial-robotics UAV competition with an unmanned radio-controlled aircraft. The specification is that it has to be launched manually or autonomously and navigated on a specified course by using onboard-payload sensors, and then it must locate and evaluate several objects before returning to base.

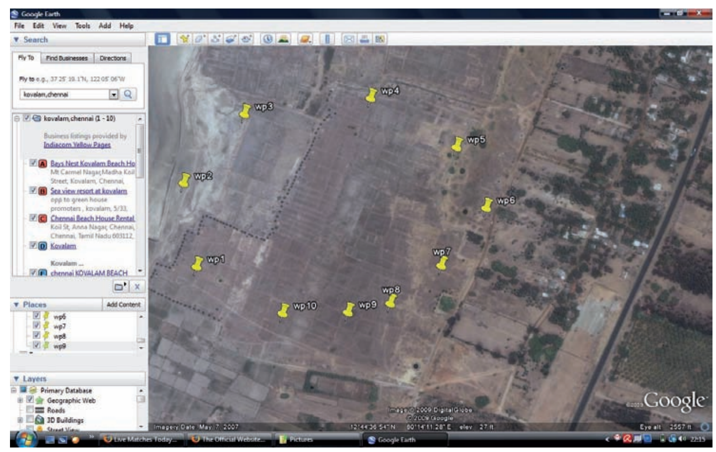
MIT's 2009 design is a fully functional prototype of a UAV intended for reconnaissance and surveillance operations. MicroPilot's MP2028/MP2128 autopilot system is now capable of operating fully autonomously from take-off to landing on pre-programmed missions. It enables the UAV to navigate a course by following selected waypoints (given through GPS-derived coordinates) as well as accommodating in-flight changes.

The prototype has been specifically tailored for the competition, which is hosted by various national and international specialist unmanned vehicle systems organizations. The airframe is fitted with a digital camera, which feeds down real-time footage of the flight and is programmed to locate potential targets through a panning motion of the video camera, which tags targets with a GPS coordinate and defines orientation according to the aircraft's heading.

Requirements and specifications

The MIT UAV is designed to perform high-risk missions and provide the ground station with intelligence, surveillance, and reconnaissance (ISR). Such tasks require a reliable aircraft with a high-performance flight computer and advanced payloads/sensors. A normal mission layout is to take off, climb to mission altitude, navigate to the target area, perform the assigned task, return home, and land safely.

The system comprises an airframe that is designed to carry a payload of sensors for target recognition, an autopilot system developed by MicroPilot for autonomous take-off, landing, and flight, a single normal monochrome surveillance video camera with varifocal lens and a 900MHz amateur-band FM transmitter for real-time video and downlink, and a pair of MaxStream 2.4GHz wireless data modems for a real-time datalink for flight communication. Joining together these systems is a ground station that monitors all real-time data through laptops in a linked network. To complete the



The MP2028g includes the Horizon mp ground-control software for mission creation parameter adjustment

reconnaissance mission, the network attempts to use computer-written code to analyze the real-time video feed and locate and evaluate several objects autonomously.

The camera incorporated in the system helps with online processing of the required target. Initially an optical flow method is implemented for object detection and tracking through the process sequence, giving high-density vectors along the direction of the motion of the object, which helps in better tracking. The algorithm detects the change in the velocity and monitors the motion. Using this concept, the moving targets are identified from the distribution of the brightness pattern (irradiance) in the captured videos.

Design process and airframe

There are three major tasks in the flight system implementation process: autopilot installation, system setup, and testing. The process is iterative and all modifications of the airframe, autopilot, and program codes are followed by a thorough analysis before the changes are implemented.

In considering the flight conditions, one of the major concerns of the airframe is whether it has the capability to carry a payload and withstand a sufficient amount of wing loading. In addition, the airframe must be practical and have real-life applications such as being small, undetectable, and quiet for covert military reconnaissance missions.

Three to four airframes have been considered. The Alpha Trainer has a wingspan of 1,811mm (71in), is 640mm (25.2in) in length, and has an empty weight (without fuel) of just 3.5kg. Using the wing loading and wing area, it can be calculated that the maximum allowable weight of the plane is approximately 3-4kg.

Avionics hardware and autopilot

The avionics system is based on the MP2028 core printed circuit board (PCB), the MP2028 servo system PCB, the GPS antenna, the ultrasonic rangefinder AGL PCB, the AGL transmitter/receiver antenna, batteries, servos, and the RC receiver. All sensors except the global positioning system (GPS) antenna and the AGL are mounted on the motherboard. The flight sensor equipment is built of standard components: two piezoelectric gyros, two piezoelectric accelerometers and two (one static and one dynamic pressure sensor) off-the-shelf pressure transducers.

> **"The MP2028g is the perfect choice to stabilize and guide a wide range of UAVs"**

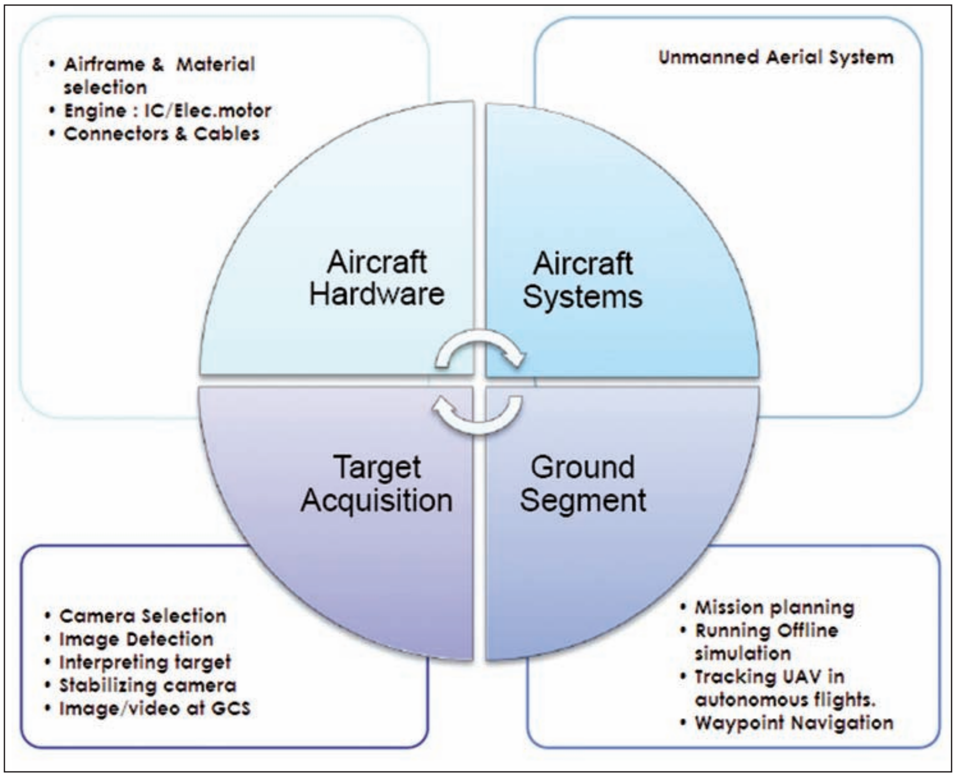
The MP2028g is the perfect choice to stabilize and guide a wide range of UAVs, from highly functional high-speed UAVs through backpack UAVs to handheld micro UAVs. The MP2028g is the only micro UAV autopilot designed for fully autonomous operation, from launch through recovery. Capabilities include airspeed hold, altitude hold, turn coordination, and GPS navigation as well as autonomous launch and recovery. Extensive data logging and manual overrides are also supported, as is a highly functional command buffer. All feedback loop gains and flight parameters are user programmable and feedback loops are adjustable in flight.

GCS software and guidance

The MP2028g includes the Horizon mp ground-control software for mission creation, parameter adjustment, flight monitoring, and mission simulation. The MP2028 ground-control station (GCS) is used to set control-loop gains, make servo adjustments, and for pre-flight simulations. It is an important tool for the programming of the autopilot as it reports all the fatal errors generated by the flight code and enables the user to simulate different weather conditions and flight problems, such as the loss of GPS signal and low battery.

The system is designed so that it can be controlled in both autonomous and radio controlled mode. Autonomous mode increases the versatility of the entire system and is also used, as required, for out-of-sight and long-distance missions. The program enables manual overriding of autonomous mode to manual mode and vice versa.

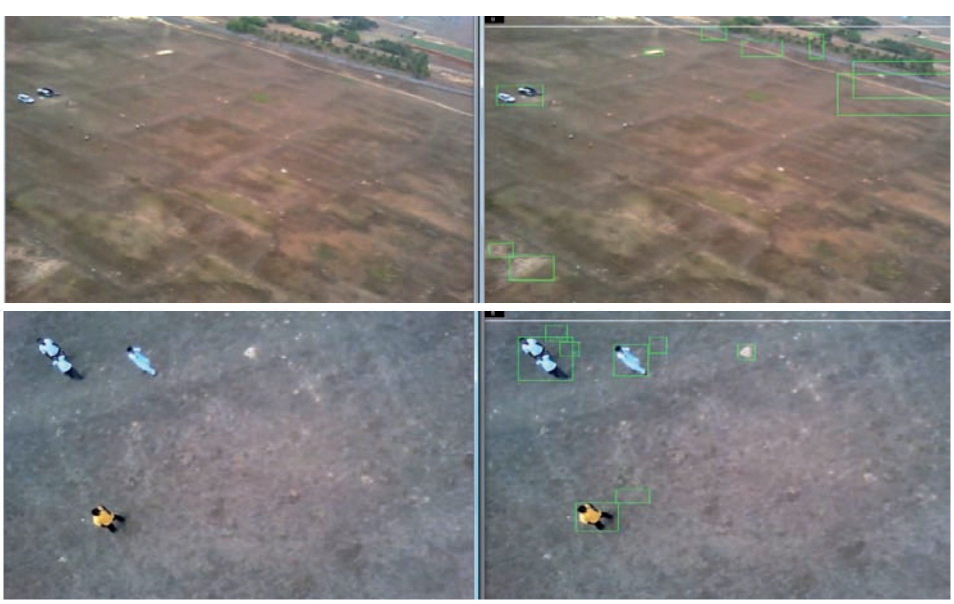
The autopilot works by getting GPS data from a window of minimum four satellites roughly 200km above the earth in mid-earth orbits. It is received in the UAV system by the GPS antenna mounted on top of the airframe,



gives the UAVs position with respect to the ground control station. In addition, the autopilot transmits the data from the accelerometer and gyros giving the attitude of the aircraft. The TTL modem transmits the current position and location of the aircraft in real time giving the ground-control station to decide to further manipulate the aircraft autopilot. The plot shows the latitude and longitude with respect to the altitude of the UAV system in cruise mode.

The MicroPilot autopilot is configured to use the elevator to control altitude and the throttle to control airspeed. It is reconfigured to use the elevator to control airspeed, then the pitch from the airspeed-feedback loop is enabled (instead of the pitch from the altitude) and the throttle is enabled by altitude rather than airspeed. The GCS consists of two laptops and a modem transceiver through which all information is received in GCS. Videos are transmitted in real time through one channel of 2.4GHz airborne modem and is received in a Horizon software-video window. Independent transmission of video is also possible through the camera transmitter board, where image processing is performed of the target on 'laptop two' and appropriately displayed on screen.

"The video signal from the UAV is obtained and its true color is converted into its respective intensity gradient"



Target identification

In a surveillance operation, the objective is to track the moving target. The optical-flow technique needs to be considered as it determines the optical flow vectors through the use of image-intensity gradients. From the movement of the brightness pattern in an image, the algorithm detects the change in the velocity and monitors the motion. Identification of the moving target from the distribution of the irradiance makes it possible to track the target in each video frame. The optical-flow technique used is based on Lucas/Kanade and Horn/Schunck techniques used for tracking the varying motion of objects. The overall block diagram of the proposed design is as shown:

The video signal from the UAV is obtained and its true color is converted into its respective intensity gradients. Optical-flow technique is implemented and then, by proper filtering, the output is displayed.

The model uses an optical-flow estimation technique to estimate the motion vectors in each frame of the video sequence. By thresholding and performing morphological closing on the motion vectors, the model produces binary feature images, locating the moving target in each binary feature of the image.

Optical flow technique

The optical flow method used is based on Horn/Schunck, which is a global method of estimating optical flow, which introduces global constraint of smoothness to solve the aperture problem. The algorithm used has the advantage that it yields a high density of flow vectors, such as the flow information missing in inner parts of homogeneous objects is filled in from the motion boundaries. The downside is that it is more sensitive to noise than local methods can be.

The optical flow constraint equation is obtained by:

$$I(x, y, t) = I(x + dx, y + dy,$$

Equation 1

...where I (x, y, t) is the image intensity function. First order Taylor series expansion of Equation 1 is:

$$I(x, y, t) = I(x, y, t) + \frac{\partial I}{\partial x}dx + \frac{\partial I}{\partial y}dy + \frac{\partial I}{\partial t}dt +$$

Equation 2

Cancelling I (x, y, t) on both sides of Equation 2 and eliminating higher order term:

$$\frac{\partial I}{\partial x}dx+\frac{\partial I}{\partial y}dy+\frac{\partial I}{\partial t}dt$$

Equation 3

Dividing Equation 3 by dt and denoting dx/dt=u and dy/dt=v, where u and v are velocity component in x and y directions respectively:

$$\nabla I \cdot v + I_t = 0$$

Equation 4

The smoothness constraint equation is given:

$$\left(\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2 \quad \text{and} \quad \left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial u}{\partial y}\right)^2$$

Equation 5

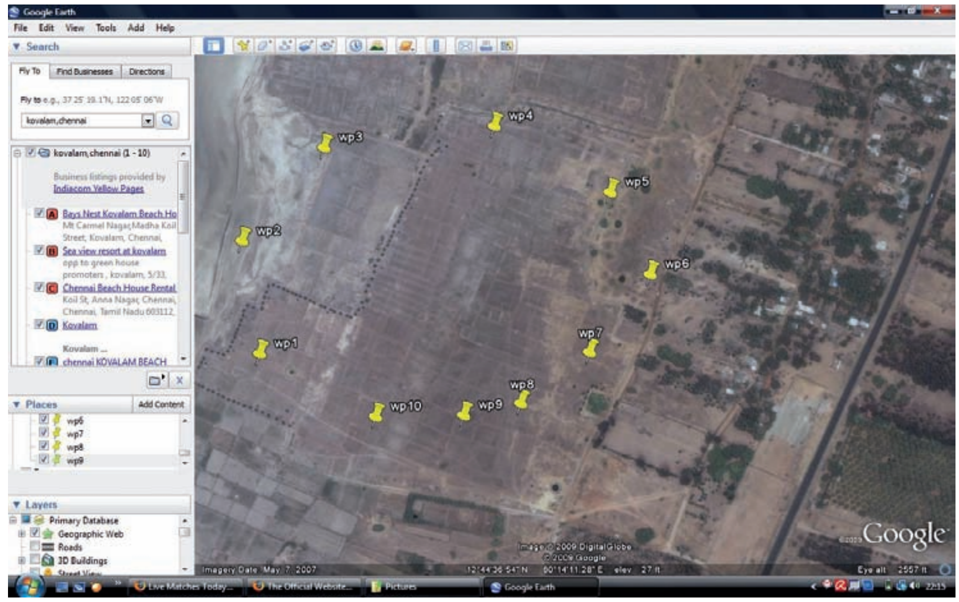
The Lucas-Kanade algorithm is an intensity-based differential technique used to align a set of images. This assumes that the optical flow field is constant within a neighborhood region of pixels. The optical flow is calculated through non-linear optimization applying a weighted least-squares fit of local constraints to a constant model for v for each spatial neighborhood N. Local methods use normal velocity information in local neighborhoods to perform a least-squares minimization to find the best fit for v.

Local methods offer robustness to noise, but cannot produce dense optical-flow fields:

$$C(v)=\sum_{z\in N} w^2(z)[\nabla I(z,t).v+I_t(z,t)]^2$$

Equation 6

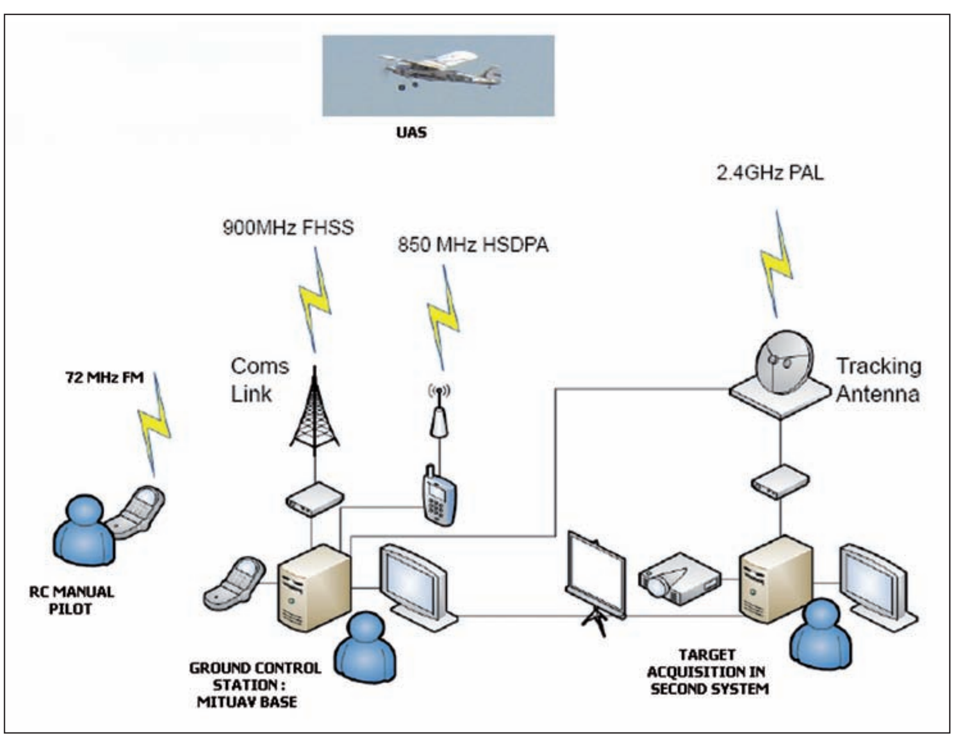
The velocity estimates, v, is given by:



$$\hat{v}=[A^TW^2A]^{-1}A^TW^2b$$

Equation 7

Here, the captured videos are analyzed using both techniques, and to avoid the drawbacks, both the local and the global functions are combined, thus obtaining a method that generates dense optical flow under noisy image conditions. The combined techniques are also implemented in the online tracking or surveillance system, and modified for detection and tracking. For initial testing, a low-resolution NTSC camera is currently used and it gives satisfactory image quality. The camera is tested within the campus and it is interfaced with a video overlay-board transmitter and a receiver at the GCS. The captured video is used for the purpose of identification of the target and in surveillance operations. The target is monitored on a real-time basis and the optical-flow technique is successfully implemented to detect and track the motion of the moving target. The background is later filtered out.



Airfield

All the test flights were carried out at the Cholavaram airfield, an old World War II base that is owned by the Indian Air Force and is now used by various aeromodeling enthusiasts. At 22m (72ft) above sea level, with 6,000ft x 150ft of flat concrete, and at a distance of just 60km (37 miles) from the MIT campus, it is a great site for testing.

Several successful manual and autonomous flights have been completed, including an automatic landing. Autonomous take-off and landing is difficult and there have been some unfortunate crash landings. As a result, work on building more airframes is underway for redundancy purposes. Waypoint navigation has been successfully carried out using autopilot in simulation and real time. The camera-control system is being tested in the UAV flight control research lab before being installed in the airframe.

The UAV system uses an off-the-shelf autopilot that facilitates an understanding of guidance, navigation, and control techniques and helps in current and future development of self-made autopilots. Parallel work is taking place on use of a microcontroller to perform a loop around the target, which can be a redundant system for the mission. The current system consists of all the components necessary for a successful and complete surveillance-system package capable of operation in autonomous and manual modes.

The proposed solution eliminates the need for a large computing platform and powerful microprocessors on board the UAV. The system's versatility has been shown as a complete surveillance package for line-of-sight and out-of-sight missions. The overall system design has prompted those involved to learn the complexities of aircraft design, mission planning and avionics systems, as well as overall project development. ∎.

Shiladitya Bhowmick has an M.E-Avionics, B.E-Aeronautical Engineering Division of Avionics, Department of Aerospace Engineering, Madras Institute of Technology (MIT), Anna University, Chennai, India

Global data collaboration

AS INTERNATIONAL COLLABORATION DEVELOPS, NEW TECHNOLOGY IS NEEDED TO ENSURE ALL RELEVANT TEST DATA CAN BE EASILY ACCESSED BY THE CORRECT QUALIFIED ENGINEERS

> **"All too commonly, the location and meaning of the data is only really known by the test engineer"**

JON ALDRED

BY JON ALDRED

The huge amount of data gathered in aerospace structural testing and operational load monitoring programs presents major challenges to modern test labs or ground stations because of the international nature of the business. Collaboration across departments and between companies in various parts of the world is increasingly important but can be challenging and costly.

Thousands of channels of measured flight or test data can be kept on departmental file stores, but with only limited access to the rest of the organization. This can result in test departments wasting time looking for the right data, and the increased use of computer simulations means that wider groups of engineers are requesting measurements to correlate their models. Engineering data retrieval can be very costly.

For example, one major aerospace manufacturer has a need to share engineering data from full-scale test articles for its next-generation warplane. This includes test data from more than 4,000 simultaneous measurement locations, along with associated documents and spreadsheets, which need to be searched for content. It is equally important that global partners involved in the project are able to access only the data they require, while conforming to ITAR regulations.

Timely storage, retrieval, and data usage is advantageous because it ensures the right information is delivered to the right person on time. Failure to meet this criterion can easily cause costly delays or lead to incorrect decisions.

Additionally, finding the data is often not enough. Further analysis is usually required to extract useful information from gigabytes of measurements. Because aerospace manufacturers and suppliers are constantly challenged to develop and deliver products along ever-decreasing timescales, the need to quickly access the right information and maximize the value of testing has never been greater.

This need is not usually met by existing IT systems or by using a directory structure on a shared department disk drive. This is because storage of this type typically has little, or no, associated data describing the meaning of the data, which limits the effectiveness of the search.

Engineers may not be sure that they have actually found the right data once they have

completed a search. Simple questions such as, 'Was this measured before or after the wing spar was reinforced?' and 'Has this data been cleaned up to remove the problem spikes?' may not be easily answered.

All too commonly, the location and meaning of the data is only really known by the test engineer who was actually responsible for the measurements. If that engineer is no longer available, a great deal of time can be wasted trying to answer these questions. This can lead to data measured from expensive prototypes and time-consuming physical tests rapidly becoming worthless, and complete tests may have to be repeated.

Other information

Alternatively, there may be an abundance of associated data, such as spreadsheets, photographs, videos, and other electronic documents, which provides invaluable information about the test. But if this data cannot be accessed or searched, it is of little or no benefit to the rest of the engineering team.

When collaboration is required between departments, companies, or across borders and around the globe, these problems are compounded. In the aerospace industry, many projects require teamwork between global companies, and the exchange of data from US companies often needs to comply with ITAR export regulations.

Consider Lockheed Martin and its work on the F-35 Lightning II Joint Strike Fighter program. In addition to testing at the Engineering Structural Test Facility in Fort Worth, other variants of the F-35 are being tested by BAE Systems Structural and Dynamic Test Facility at Brough in the UK and at the Vought Aircraft facility in Grand Prairie, Texas. It needs to manage and share engineering data from full-scale test articles across all these variants and test

All these differences make it difficult to learn from data across the corporation or over an extended period of time. Analyses performed on the engineer's desktop are often manually converted into reports and are not easily accessible to others in the organization. If these key individuals leave the organization, the understanding and intellectual property often goes with them.

These challenges are driving interest in web-based systems to store data for improved search and automated processing techniques. A well-designed solution will achieve two objectives: it will enable effective collaboration between the design, analysis, and test departments; and also the web-based technology can be used to automate data analysis more efficiently.

HBM has developed its nCode Automation software to provide a web-based collaborative interface for sharing test data and associated information throughout an organization and across the globe. It offers a complete environment for engineering data storage, analysis, and reporting. Engineers equipped with only a web browser can access, view, and analyze stored data. Data, together with documents, images, and spreadsheets can be searched and downloaded.

facilities, and the ability to share stored images, reports, and documents is of immense value.

It may also be necessary to restrict access so that even within a single project, some measurements are shared with one partner but not with another. It becomes imperative that all searches are quick, secure, and provide the correct data to the relevant partner on a project. When there is a problem with the data, it may be necessary to carry out an audit to determine who has already seen the data so they can be informed about the error. Managing this type of process manually is incredibly time-consuming and complex.

Often it is not the data itself that is required, but a deeper understanding based on the data. This might be, for example, to quantify the variation in a strain measurement over time to detect cracks in a long-term test, or to investigate how one aircraft usage compares with another. Data must be summarized, characterized, and compared. It is the result of the additional analysis that really makes the data useful. Before performing the analysis, it is also important to identify any problems with the data such as drift or flat-lines that would make the results meaningless.

Pictures courtesy of Lockheed Martin

"Data, together with documents, images, and spreadsheets can be searched and downloaded"

Manual challenges

To perform this analysis manually requires that huge amounts of data are found, transferred, and often converted from different formats to be processed in a desktop tool or spreadsheet. At best, a manual process is inefficient and highly error-prone. Rather than developing and retaining corporate knowledge, it often relies on the expertise of key individuals whose methods may vary across an organization. One department may use one method, but another division has its own methods, giving conflicting results.

A wide range of engineering data formats is supported, avoiding the need for separate translation steps and the data is securely managed so that users can access only the information they are allowed to see. Using nCode Automation has enabled the major aerospace manufacturer to share its engineering data from over 4,000 simultaneous measurement locations, and the software also stores all associated documents and spreadsheets, ensuring they can be searched for content.

Maximizing the value of test data continues to be a challenge for many engineering departments. When collaboration is required between companies or across the globe, these problems are compounded.

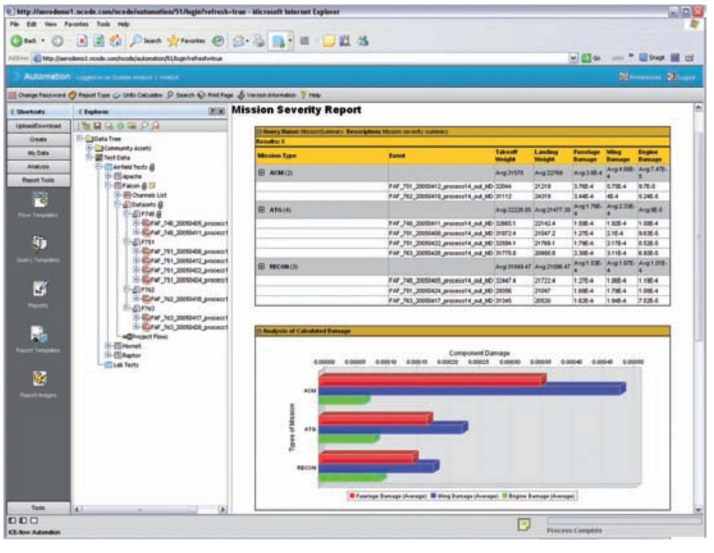
Using the system, engineers can define the server-side analysis processes to be performed over the web rather than through time-consuming data transfers and manual analysis tasks. This helps to standardize analysis processes, which improves the quality and repeatability of results. Automatically generated reports can be directly accessed by supervisors and managers via the web interface, shortening the time to communicate vital project information.

Latest flexibility

The 5.1 release of nCode Automation includes many new features that provide a higher level of flexibility for engineers needing to interrogate and learn from their test data. It features new extensible solutions to drive teamwork and inform decision-making.

A new 'characteristic values' capability enables users to tag data with additional information that can be used for searching, trending, and reporting. These characteristic values can be calculated using analysis routines that can be added by end users. Calculations are very flexible and even enable retrospective analyses to be performed on existing stored data. A new analysis routine can be applied to years of cataloged data, maximizing the value of the tests performed. This functionality ensures a future-proof system that can continue to learn from data and evolve as required.

Lockheed Martin has implemented nCode Automation on its F-35 program for managing and sharing engineering data from full-scale test articles (Pictures courtesy Lockheed Martin)



nCode Automation, a web-based collaborative interface for sharing test data and associated information

> **"Each test article is instrumented with several thousand strain gauges"**

For example, collecting data from each flight or mission for a fleet of 20 aircraft can be simplified. By calculating characteristic values on each data set, a trending analysis on strain gauges can be defined that indicates whether there has been a sudden but subtle change in strain response indicative of a potential crack. This ability to compare data over periods of time and understand the loading histories for different aircraft can provide extremely valuable input to condition-based maintenance initiatives.

This applies some of the same concepts used in business intelligence to engineering data, enabling data to be processed for trends and identifying relationships that can be used to make better decisions. Engineers can create complex queries without having to learn the structure of the underlying database or how to write SQL. Report layouts can combine analysis tasks with database queries to create a rich, graphical summary of information. Reports can even be scheduled to be performed at recurring intervals, for example weekly, and users can be notified with an email including a link to the latest report.

Customer implementation

Lockheed Martin has implemented nCode Automation on its F-35 Lightning II Joint Strike Fighter program for managing and sharing engineering data from full-scale test articles. nCode Automation provides a secure system that enables the multiple project partners (the Engineering Structural Test Facility, BAE Systems Structural and Dynamic Test Facility, and the Vought Aircraft facility) to upload new data and access the data they are allowed to see, while conforming to the required ITAR regulations.

Each test article is instrumented with several thousand strain gauges and it is vital that every user of the system can rapidly find the relevant subset of channels that are of interest among all this data.

Engineers do not need to download a thousand channels of strain data when they only want the 20 for which they are responsible. The ability to search for stored images, reports, and documents has also proved to be of immense value. For example, previously, photographs would have had to be manually located in a shared directory structure.

Bob Simmons, JSF structural test IPT leader at Lockheed Martin, says, "We are seeing great productivity benefits in the speed with which engineers can find the data they need. nCode Automation is saving us time and improving our ability to share data with our project partners." ∎

CONTACT
Jon Aldred is product manager at HBM-nCode
Email: jon.aldred@hbm.com

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Quantitative measurement techniques

EXPERTS AT THE UK'S CRANFIELD UNIVERSITY HAVE BEEN DEVELOPING A SUITE OF OPTICAL-BASED QUANTITATIVE TECHNIQUES TO MEASURE FLOW VELOCITY

> "For PIV measurements a laser light sheet is generated using a set of optical lenses"

PROF DIMITRIS DRIKAKIS

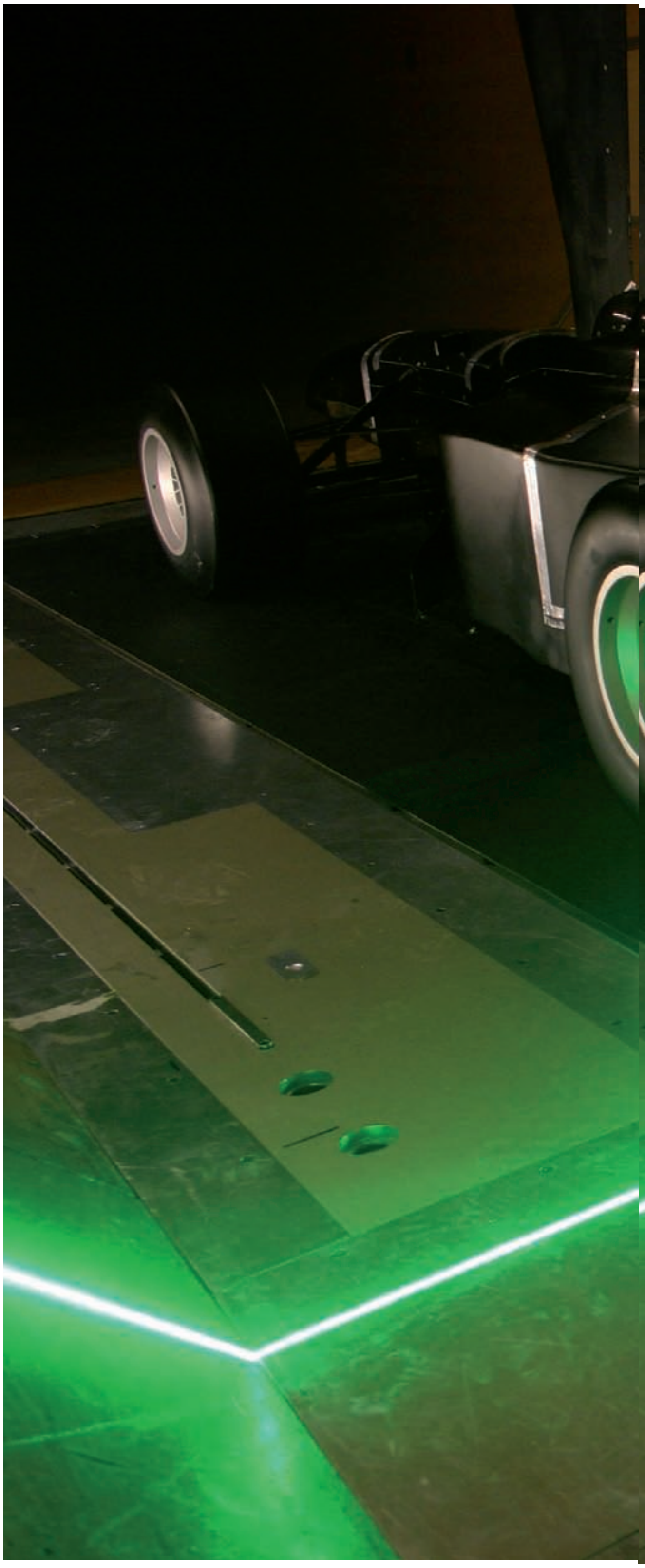
BY PROF DIMITRIS DRIKAKIS

In the past, methods of measuring flow velocity have been intrusive and therefore required the placement of a probe or device into the flow field. A clear disadvantage with this approach is that the measuring probe can adversely affect the flow field. Furthermore, it usually provides only single point measurement and therefore a common approach is to traverse the probe. However, this can be a very time-consuming process and does not provide synchronous data within the measurement space.

These limitations in conventional methods have led to the development of a suite of optical-based quantitative measurement techniques. These include methods such as laser Doppler anemometry (LDA) and particle image velocimetry (PIV). These techniques have some features in common, such as they both use a laser light source to illuminate the region of interest, and the velocity measurement is determined from the scattered or emitted light. The LDA technique can simultaneously measure the three components of velocity with a high spatial and temporal resolution. It is considered a highly accurate method; however, it is also restricted to taking pointwise measurements and consequently suffers from some of the same productivity difficulties as the conventional intrusive probe methods.

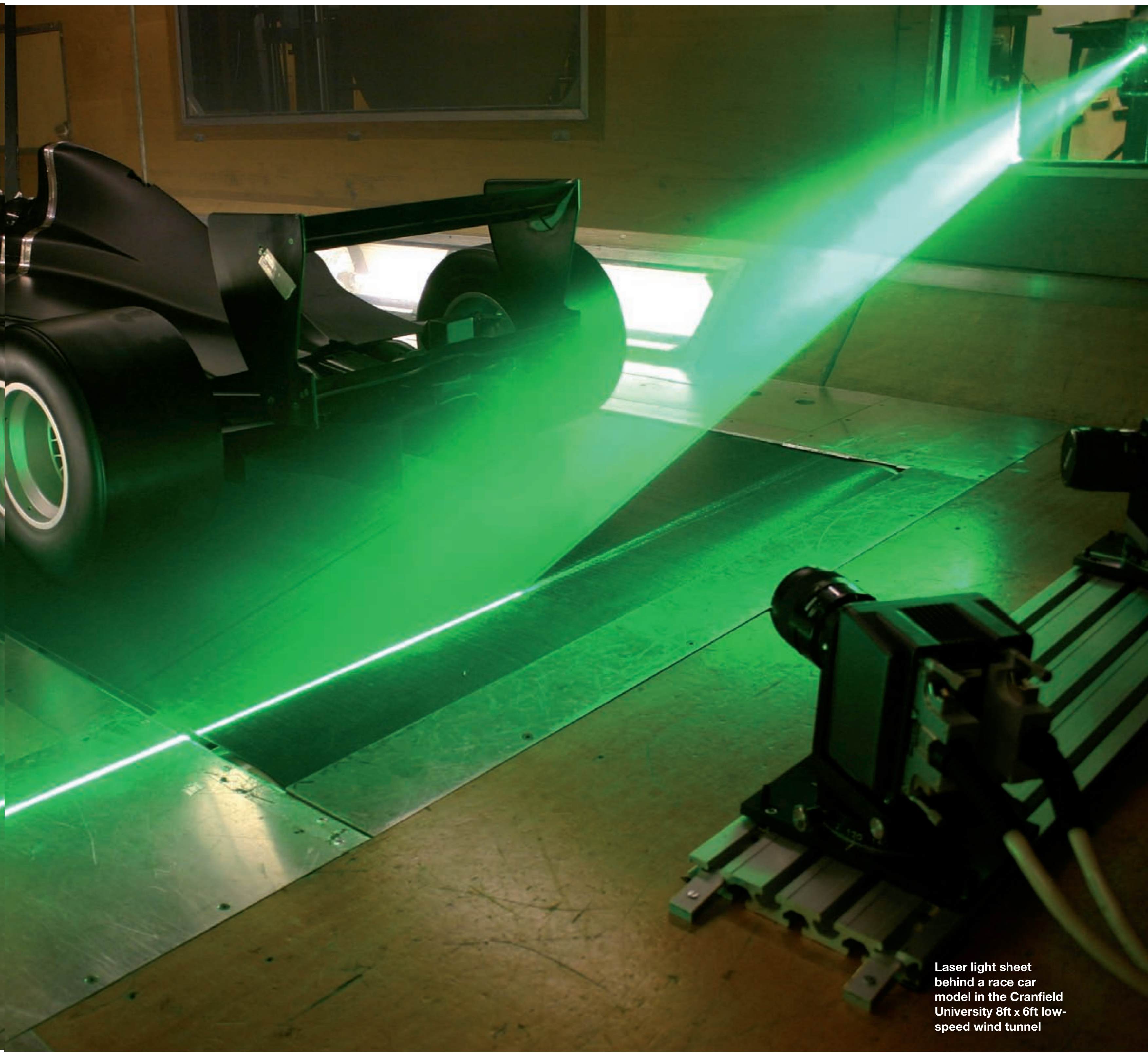
PIV measurements

For PIV measurements a laser light sheet is generated (using a set of optical lenses) and used to illuminate the area of interest. For wind-tunnel applications it is necessary to seed the flow with a light-scattering material. This seeding needs to faithfully follow the flow while



scattering sufficient light to obtain measurements. For PIV measurements in air it is common to use atomized oil with a mean particle diameter in the order of 1µm.

The laser is pulsed at a known time interval so that two digital images of the scattered light are obtained across the region of interest. These images are then discretized and processed using a cross-correlation technique, which ultimately provides the velocity distribution. This is the main advantage of the PIV technique, as

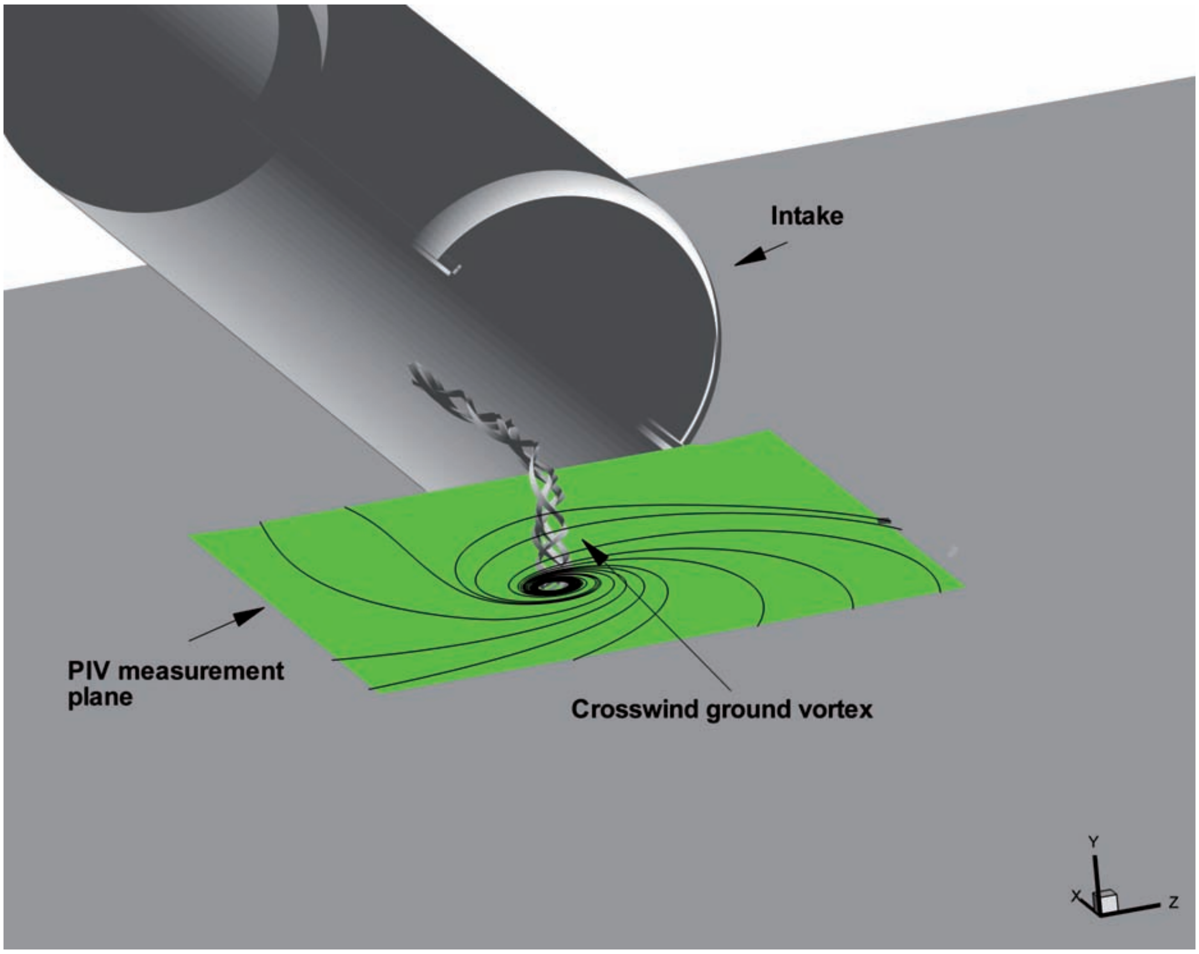


Laser light sheet behind a race car model in the Cranfield University 8ft x 6ft low-speed wind tunnel

it provides near-instantaneous velocity data in a 2D plane. By placing a pair of acquisition cameras in a stereoscopic arrangement, the three components of velocity can be determined. Consequently it is a technique that is ideally suited to complex, unsteady, and transient flows. For wind-tunnel applications the spatial resolution is typically less than that achieved with an LDA system; the system accuracy is similarly reduced. A stereoscopic PIV system was used in the 8 x 6 low-speed wind tunnel at Cranfield University to investigate the complex, unsteady flows associated with the ground vortex phenomenon.

When an engine intake is operating close to the ground, a vortex system is generated, which is ingested into the intake and can potentially adversely affect the engine. The three velocity components were measured using a TSI stereoscopic PIV system, which comprised two TSI 4MP Powerview CCD 12bit cameras orientated at ±45° to the measurement plane, with both operating in partial scatter with respect to the laser.

A New Wave Solo 120XT Nd:YAG laser with a wave length of 532nm was used, and a 1.5mm light sheet was generated using a combination of a spherical plano-concave and a cylindrical plano-convex lens. The flow was seeded using a Laskin-type seeder to atomize DEHS oil. The images were obtained over a region of approximately 100mm x 100mm, and were recorded at a total rate of 7.5Hz.



Schematic PIV measurement plane for the investigation of an intake ground vortex under crosswind conditions

The spatial resolution was in the order of 0.8mm. The PIV technique successfully captured the vortical flows under crosswind and headwind (see opposite) conditions. This enabled the in-plane vorticity and vortex strength to be calculated, as well as evaluation of the effect of different engine operating conditions. This was the first time that this flow field had been investigated in this way, and it provided unique, high-quality data that would not have been attainable with any other measurement system.

> "Particle image velocity has also been applied to the same Mach 2.4 SWBLI system"

High-speed imaging systems

A high-speed Schlieren system has been developed for the analysis of complex high-speed flow systems. The system has been developed in the Cranfield University 2.5in x 2.5in supersonic wind tunnel at Mach 2.4 conditions.

The system shown is based on a classic Z-arrangement of parabolic mirrors, a high-intensity LED, and a Photron APX Ultima high-speed digital camera. Using this arrangement a Mach 2.4 shockwave boundary layer interaction (SWBLI) has been imaged at frame rates of 10,000fps and with an image resolution of 512px (width) x 256px (height), corresponding to 12px/mm. These high frame rates were achieved using a continuous LED light source by direct projection of the Schlieren image onto the digital camera chip.

Further analysis of selected points from the instantaneous time series Schlieren images also allowed identification of the frequency characteristics of different parts of the shock structure. To obtain this temporal information, a simple spatial frequency image processing algorithm was developed to isolate the different areas of shock structures. Results from this analysis are shown at a frame rate of 10,000fps.

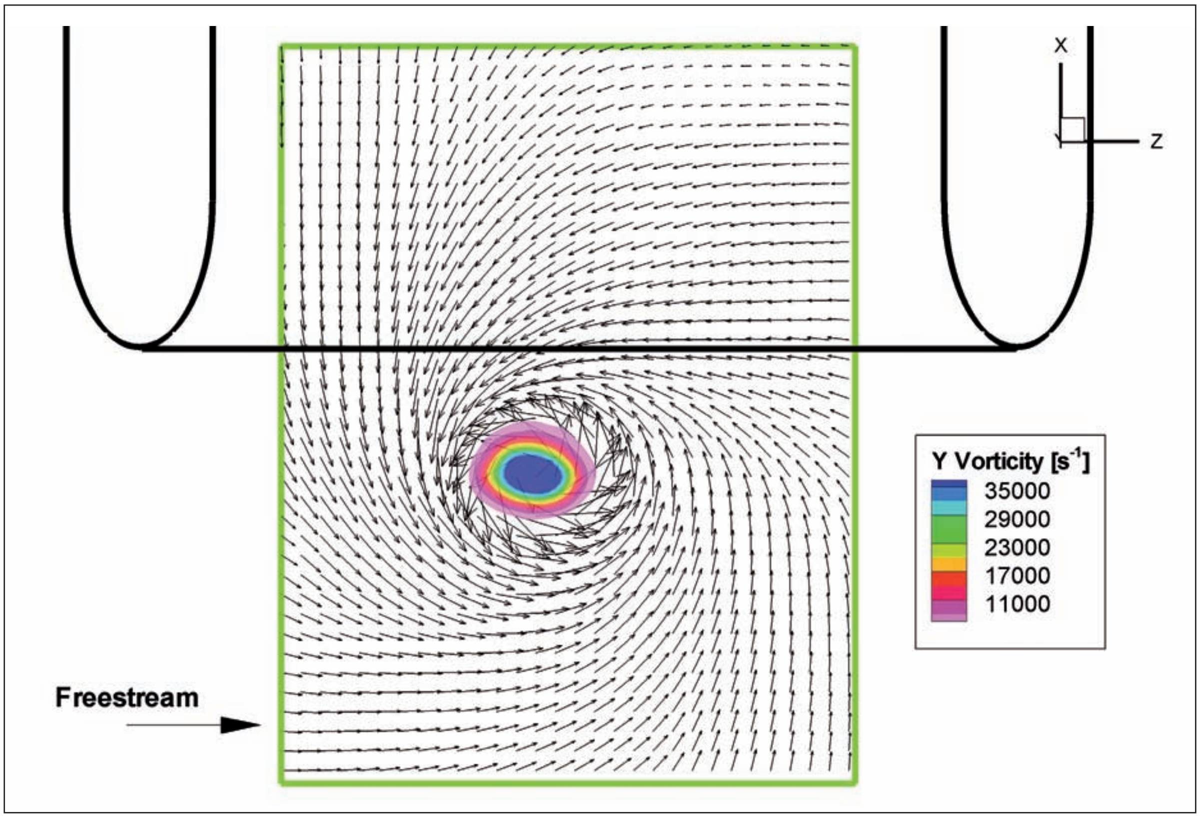
High-speed image velocimetry

Particle image velocity has also been applied to the same Mach 2.4 SWBLI system. A commercially available TSI system was used to record a set of instantaneous vector maps to generate a time-averaged vector map of the flow. The TSI system was based on a New Wave Solo III-15 50mJ per pulse Nd:YAG laser and a TSI 4MP Powerview CCD camera recording PIV image data at 15Hz over a field of view of 50mm x 26mm, yielding an image resolution of up to 26µm/pixel. The time-averaged vector map obtained from five correlation averaged images processed with a 64px x 64px interrogation window is shown opposite. The same major features observed in the Schlieren images are also now visible in the PIV vector map but now in a detailed quantitative format.

Wind-tunnel campaign of the DEMON UAV

The wind-tunnel test campaign was carried out to assess the longitudinal aerodynamics performance of the DEMON UAV, as part of the £6.5 million (US$10.6 million) FLAVIIR project. The aim of the project is to develop technologies for an unmanned air vehicle (UAV) with no conventional control surfaces.

The DEMON air vehicle selected for the project is derived from the Eclipse air vehicle, which is a pre-existing UAV design developed at Cranfield University jointly with BAE Systems. The Eclipse is a tailless configuration, with a cropped diamond wing plan-form. Wing section profile is an RAE 104 airfoil. The DEMON flying demonstrator is powered by a single AMT Olympus HP ES gas turbine engine, and has a wing span of 2.7m (8.9ft), an esti-



Time averaged velocity field for a single ground vortex for an intake under headwind conditions (left)

Time-averaged PIV flow field of a pair of contra-rotating vortices for an intake under headwind conditions. In-plane streak-lines and velocity vector field (below)

mated flying weight of ~80kg (176 lb), and speed range that varies from 30 to 60m/s.

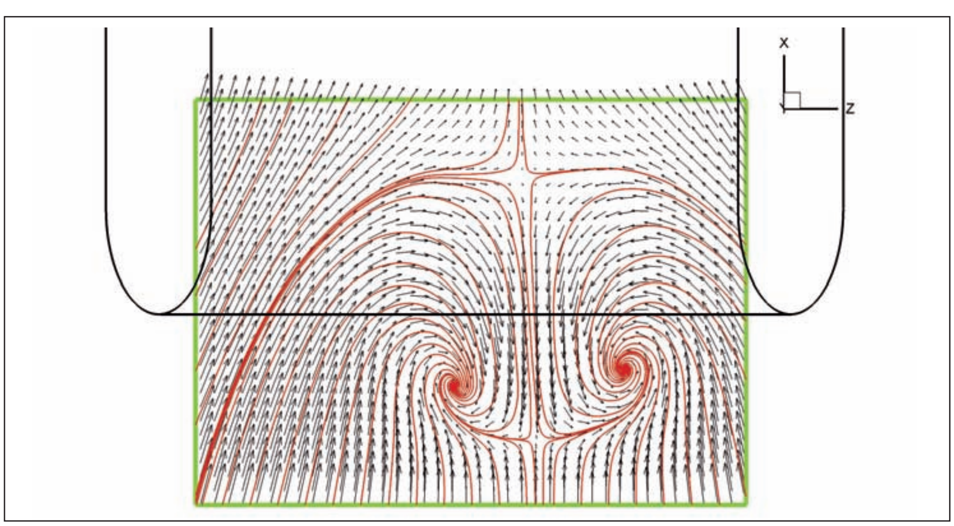
The wind-tunnel test campaign with the full-span 50%-scale DEMON model was carried out in the 8ft x 6ft facility at Cranfield University. The model was suspended from the wind-tunnel ceiling with a rigid faired strut, which was mounted to a six-component strain gauge balance placed inside the model. This positioned the model just off-center within the working section of the 8ft x 6ft closed-return wind tunnel at Cranfield University. The model also incorporated a tail-arm supported by a set of high-tension bracing wires that were used to set the angle of attack of the model.

Representative control surfaces and undercarriage were incorporated. The engine system and jet exit system were not simulated, and a simple fairing was added to the front of the intake. Results were corrected for flow blockage and induced angle of attack.

Due to the small aspect ratio and large leading-edge sweep the DEMON configuration performs not unlike a conventional delta wing. Lift increases linearly until wing stall occurs, after which a complex three-dimensional vortex structure is formed. This is evident by an increase in the lift curve slope and drag coefficient. Pitching moment taken about the center of gravity decreases gradually with increasing angle of attack. The longitudinal and lateral aerodynamic performance obtained from the 50% full-span model is satisfactory for -5°<a<15° and b<±12°; however, strong nonlinearities occur for a>15°.

The DEMON prototype is currently being built, with the first flight planned by the end of this year. The five-year Flapless Air Vehicle Integrated Industrial Research program (FLAVIIR), funded by BAE Systems and the UK's Engineering and Physical Sciences Research Council, is led by Cranfield and BAE Systems. The project involved the UK's Imperial College of Science, Technology and Medicine, Leicester, Liverpool, Manchester, Nottingham, Southampton, Warwick, and York universities, and the University of Wales at Swansea. ∎

"The DEMON prototype is currently being built, with the first flight planned by the end of this year"



Prof Dimitris Drikakis is head of the aerospace sciences department at Cranfield University. Contributors include Dr Al Savvaris, head of platform integration and head of wind tunnel facilities, and Prof Kevin Garry. Also, Dr David MacManus and Dr Nick Lawson (Experimental Aerodynamics & Instrumentation). For more information, go to www.cranfield.ac.uk

Alcohol-fueled experiment

THE TECHNOLOGICAL INNOVATION PROCESS INVOLVED IN THE DEVELOPMENT OF THE ETHANOL-FUELED BRAZILIAN IPANEMA WAS LONG – BUT VERY EFFECTIVE

“The decision to use 25% alcohol was so effective that it remains in place today”

PROF JOSÉ HENRIQUE DE SOUSA DAMIANI

BY PROF JOSÉ HENRIQUE DE SOUSA DAMIANI

Since the early 1970s, Brazil has been playing a leading role in the development of renewable fuels for various purposes, ranging from automobiles, trucks, buses, and electricity generation to airplanes. The development of an agricultural alcohol-powered airplane, the Ipanema, by the General Command of Aerospace Technology (CTA) and Embraer (Brazilian Aeronautical Enterprise) highlights the technical and managerial challenges.

A long process of technological development was initiated in the early 1950s to demonstrate that alcohol could be an effective substitute for gasoline. Pioneering efforts in academic institutions can be traced back to the Institute of Aeronautical Technology (ITA), from where aeronautical engineer Professor Ernesto Urbano Stumpf graduated. The first results were published in 1952 in institutions such as the ITA, the Institute of Sugar and Alcohol, and the Engineering Review of Rio Grande do Sul. The papers were presented in conferences organized by several engineering institutions, including the Institute of Engineering of São Paulo.

Professor Stumpf was a faculty member of the School of Engineering of São Carlos, where he undertook research about the use of alcohol as a fuel for internal combustion engines, comprising theoretical and experimental studies with the purpose of investigating the effects of several levels of hydration, compression ratios, and supply systems using carburetors and fuel injection systems.

The action plan

In 1974, Stumpf conceived an action plan to substitute alcohol for gasoline. This was to be implemented in three stages, involving joint interministerial actions and including the participation of private companies.

The first phase took into account the mixture of anhydrous alcohol and gasoline, and led to a saving of up to 25% in the volume of gasoline used to power automobiles, the reduction in the emission of pollutants, an increased octane level, and the elimination of environmentally harmful additives such as the tetraethyl lead. The decision to use 25% alcohol was so effective that it remains in place today.

The aim of the second phase was to convert existing gasoline engines to use ethylic hydrated alcohol, using technologies developed in Brazil, including the several by Stumpf. At the peak of this stage, in 1986, more than 90% of the automobiles manufactured in Brazil ran on alcohol. However, this situation was reversed later due to the increase in international sugar prices in the late 1980s, as well as the reduction of the oil prices.

The third phase, initiated in the early 1980s, encompassed the development of engines specially designed to run on alcohol. The research conducted at CTA indicated that the efficient use of alcohol required engines with different characteristics from those conceived for the use of gasoline. Important features are: higher compression ratios; different valve opening, closing, and crossing; new piston diameter to course ratios; and new admission and ignition systems.

CTA developed a multipurpose engine – the MCOE (ethanol Otto cycle engine) – to run exclusively on ethanol. A prototype was installed in an urban bus for testing purposes, and it ran inside CTA's campus for demonstration purposes for several years. The industrialization phase of the project was initiated but did not prosper. The MCOE project enabled the Propulsion Division of CTA's Institute of Aerospace Technology (IAE) to develop from it the first natural gas engine for urban transportation in Brazil.

"The prototype of the EMB 120 Ipanema agricultural airplane flew for the first time on July 30, 1970"

The third phase of the action plan conceived by Stumpf was not fully implemented. The first and second phases were driven by a very clear external threat – the first oil price shock – but the full development of the third phase or implementation of other initiatives, such as a new Proálcool, would require future perception and thorough understanding of the range of opportunities linked with the expansion of the alcohol-based industry. The team coordinated by Stumpf also pioneered the testing of fuels derived from vegetable oils. An aeronautical biokerosene, called prosene, was developed and tested in one of the turbines of a Brazilian Air Force Bandeirante aircraft in 1984. These spin-offs from the research program for the use of ethanol as a renewable fuel contributed to the development of the Ipanema by Embraer.

The alcohol-powered Ipanema

The prototype of the EMB 120 Ipanema agricultural airplane flew for the first time on July 30, 1970. It was developed by the Aircraft Division (PAR) of CTA's IPD (Institute of Research and Development). Delivery of the aircraft, by the then recently incorporated Embraer, occurred in February 11, 1971. At that time, the aircraft ran on aviation gasoline.

During the 1980s, CTA conducted several tests with the engine of the T-25 Universal aircraft running on ethanol, using the technologies developed by the center during the 1970s. The tests were part of a project initiated in 1980 that investigated using use ethanol as an aeronautical fuel. It was interrupted in 1987 and again in 1990 due to the lack of funds. It should be noted that the T-25's Lycoming engine (IO-540-K series) was the same used in the Ipanema airplane.

The Neiva Company, an Embraer subsidiary, became interested in that project and decided to consider an alcohol-powered Ipanema. The availability of technologies developed by CTA motivated Embraer and Neiva to analyze the feasibility of their application to the Ipanema aircraft. Several risks and technological uncertainties were considerably reduced by the research projects and tests conducted by CTA.

The Ipanema has a piston engine and its operational characteristics seemed suitable for it to run on ethanol. (According to Embraer's vice president, Satoshi Yokota, feasibility studies proved that it would be possible to develop an adaptation of that engine, and also showed the adequacy of its tanks and systems for the use of alcohol.) The development process led to CTA's certification of the Ipanema as a pioneering aeronautical product capable of using ethanol as its fuel.

Yokota lists the technical activities involved in the development of the alcohol-powered Ipanema as: substitution of the fuel injector for the new limits of calibration; redesign of the mechanical fuel pump of the engine, dimensioning it to the greater levels of flow and pressures; substitution of fuel injection ports; substitution of the electrical fuel pump, in order to provide an increased ethanol resistance; adding the starting system for low temperatures; adding anti-corrosion protection to the fuel tank; substitution of the fuel filter; selection valve and liquid meter built with corrosion-resistant material; O-rings and diaphragm with new compounds; and substitution of hoses, drains, and transmission lines. "Several of these modifications were similar not only to those incorporated in automobile engines developed by CTA and later included in regular production cars, but also to gasoline cars that were converted to alcohol by their owners," he says.

Ipanema's engine, propeller and structure were analyzed and tested by Embraer in order to enable operations at a higher power level as a result of the use of the new fuel. Neiva launched the alcohol-powered aircraft on October 10, 2002.

The certification of the propulsion system was issued by CTA in October 2004 in line with the Brazilian Requirements for Aeronautical Homologation RBHA 33, along with the Certificate of Supplementary Type Certification CHST 2004S10-01. After meeting RBHA 23, cell certification occurred in February 2005, with the issuing of the amendment to the original type project of the Ipanema EA 7104.

It is important to note that ethanol is a cleaner burning fuel and costs approximately three times less than aviation gasoline, therefore leading to a 17% reduction in operational costs. Additionally, there is an increase in the performance of the aircraft, resulting in a global productivity increase in excess of 11%. The Ipanema proved to be a viable option for the agricultural aviation market, using a more environmental friendly fuel than aviation gasoline.

"Ethanol is a cleaner burning fuel and costs approximately three times less than aviation gasoline"

Yokota says that, as of July 2007, 26 Ipanemas, modified to run on ethanol, have been delivered by Embraer, and 140 conversion kits were installed in units originally manufactured to run on Avgas. The following operational indicators were registered by the company regarding the harvests of 2005 to 2007: 128,000 flight hours; 12 million liters of alcohol consumed; and 8.5 million liters of Avgas saved, which equates to a saving of US$7 million. Embraer currently holds 85% share of the Brazilian market for agricultural airplanes.

CTA's Division of Aeronautical Propulsion, which played a fundamental role in the development of the alcohol-powered Ipanema, is currently developing projects such as the adaptation of the T-25 trainer aircraft to run solely on alcohol. According to its manager, engineer Paulo Sérgio Ewald, the project was scheduled to be finished at the end of 2007. The T-25 trainer will be the first alcohol-powered military airplane. The engineer considers that the use of ethanol will be an important solution to the use of piston engine aircraft in Brazil. The division is also developing flexfuel technologies that can play an important role for general aviation and also regional air transportation in Brazil and overseas.

Challenges and recommendations

Martin's 1994 quotation of Ernest Braun and Stuart MacDonald in *Revolution in Miniature* summarizes the essential dimensions addressed by this article. In their words, a technological innovation is like a river – its growth and development depend on its tributaries and on the conditions it encounters on the way. The tributaries to an innovation are invention, technolo-

The Ipanema engine had 20% lower maintenance and operational costs than its nearest equivalent

gies, and scientific discoveries; the conditions are the vagaries of the marketplace.

The Brazilian efforts in the development of alcohol as a viable fuel and the alcohol-powered Ipanema showed the relevance of the behavior of environmental factors in the development of new technologies, and highlighted the importance of developers and facilitators in promoting and sustaining technological changes. Bright's and Narayanan's scientific models of the general technological innovation process provided suitable frameworks for understanding the stages and facets of the technological changes involved. The role of CTA, its institutes and researchers, and the support of governmental organizations showed the fundamental behavior of institutions and individual researchers, as was the case of Professor Stumpf, whose contributions for the development of alcohol as an alternative to fossil fuels were of the utmost importance.

The contributions of the innovation cluster environment to the technological developments required for the use of ethanol as a feasible alternative to fossil fuels were also noticeable. The innovation networks in the region of São José dos Campos facilitated the transference of the new technologies developed by CTA to Embraer, not only in the case of Ipanema, but also in the broader context of the Proálcool to the Brazilian automotive industry.

Not only did the results provide substantial economical savings for the country, but more importantly, they set the stage for the further development of flexfuel technology, which is currently used in large scale by automobile manufactures installed in Brazil. As mentioned, research projects underway at CTA make it possible to anticipate the use of this technology in airplanes, which would be able to run on any combination of alcohol and gasoline.

The results achieved in the development of alcohol as a fuel, for which the Ipanema aircraft is an important and emblematic result, indicate new challenges to the country. In the same way that the impressive results of the semiconductor industry is based on the synthesis of know-how and expertise in chemistry, physics, materials science, electronic engineering, computer science, and mathematics, the development of the alcohol industry will also benefit from a similar combination of knowledge from different specialties. Bright's description of the proliferation phase for the innovation of wireless telephony technology showed its use in the radio industry, radar, TV industry, and many others.

An analogous evolution can be anticipated for the alcohol industry, with huge potential benefits to Brazil. Programs such as the one developed by Professor Stumpf at CTA and the Proálcool are certainly in order for consideration and implementation, due to the results already achieved. They are the foundations on which the development of a Brazilian alcohol industry is based. Fundamental components of such foundations are already available in the country, in the government sector as well as in the private sector . A national program, similar to those developed in the past, will complement them and provide the additional components and complementary assets required to support the country's ambitions to competitively participate in the new world markets derived from the production and use of renewable energy sources. ∎

José Henrique de Sousa Damiani is a professor and researcher at the Institute of Aeronautical Technology (ITA) in Brazil

Embraer and the environment

Environmental issues are increasingly taking center stage. As a consequence of the damage being done to the planet, which is proving more obvious, there is a resulting drop in the quality of life and the emergence of problems such as the greenhouse effect, polar ice-cap melting, water shortages and droughts.

However, technological advancement cannot be interrupted; neither can attention be deviated from environmental issues. In other words, in technological advancement resides the solution for the maintenance of sustainable growth in order to ensure suitable conditions for future generations. This is the reason for the growing concern of Embraer with the environment.

In 2002, the Faria Lima Unit obtained its Environmental Management System certification, by attaining the ISO 14001 Standard, and in 2004 this unit managed to maintain the certification through Maintenance Auditing, carried out by the ABS certifier (American Bureau of Shipping).

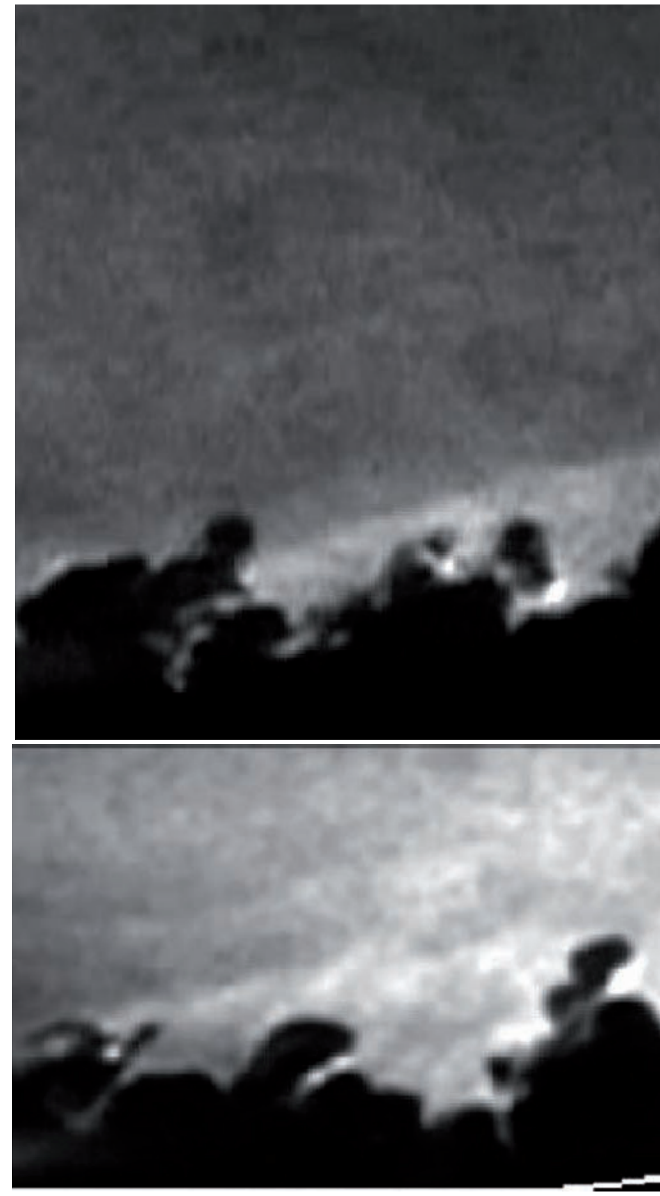
To control all these certificates, Embraer created the Environmental, Occupational Health, Safety and Quality Integrated Management System (SIG-MASSQ), which aims to facilitate the analysis of all actions in a global fashion, integrating the company, employees, third parties, partners, the environment, health, safety and quality, while always focusing on the results of the company.

The behavior of turbulence

RECENT DEVELOPMENTS IN INTERROGATION TECHNIQUES FOR HIGH-SPEED FLOWS NOW ENABLE DETAILED QUANTITATIVE ASSESSMENT TO TAKE PLACE

> **"New techniques have emerged that enable detailed quantitative assessment of high-speed flows"**

ALEXANDER J. SMITS



BY ALEXANDER J. SMITS & RICHARD B. MILES

With the test and development of high-speed vehicles and propulsion devices, accurate measurements of the flow-field behavior are often difficult to obtain. The engineer and scientist need to know many different quantities, and have a 'blue sky' wish list that includes the instantaneous temperature, pressure, and velocity at all points in the flow, as well as the corresponding species distributions and spatial and temporal correlation functions.

Until recently, the 'possible' list would include flow visualization (using techniques such as Schlieren, shadowgraphy, and interferometry), hot-wire and laser-Doppler anemometry (at least at supersonic Mach numbers in non-reacting flows), and wall-pressure sensors. At hypersonic Mach numbers, quantitative information is extremely difficult to obtain, and much of the data available for code validation and transition and turbulence modeling has been restricted to qualitative flow visualization results.

The situation has dramatically changed in the last decade. New techniques have emerged that enable detailed quantitative assessment of high-speed flows, even inside model engines, and although the wish list is not yet filled, the scope of the new data-acquisition systems is formidable. What's more, they are almost all non-intrusive, so they do not disturb the flow field.

One of the first techniques to make a serious impact on our understanding of turbulence at high speed and the behavior of shockwave boundary layer interactions was Rayleigh scattering.[1] Here, laser light is scattered from the molecules making up the fluid, and the scattered light is proportional to the number of scatterers, that is, the density. By using a thin laser sheet, the flow in a plane could be interrogated. This represented a major advance over techniques that integrate the signal across the flow field such as Schlieren and shadowgraphy. Because the molecules are in bulk motion, the light is Doppler-shifted, and so the signal also includes information on the local velocity. This is an aspect used in Filtered Rayleigh scattering (FRS), an approach developed at Princeton in which a very sharp molecular absorption filter, created by a transparent cell containing a gas such as iodine, is placed in front of the camera, and the simultaneous density and velocity fields can then be mapped as part of the data analysis.

Alternatively, FRS can be tuned to filter out the signal from stationary objects, and so only the moving fluid is visible, without any extraneous reflections from the test article surfaces. FRS has also proved to be a very useful tool for imaging temperature fields, as the fraction of light scattered from molecules passing through the filter is proportional to the thermal motion of the molecules and thus to the temperature.

By combining FRS with a pulse-burst laser and a very fast camera (MHz framing rates), it became possible to make movies of the flow behavior, showing cross-sectional views through interesting parts of the flow (Figure 1). The black bulges mark the turbulent boundary layer, and the bright lines indicate shockwaves. In this way, the fascinating interaction of turbulence with shockwaves could be examined in real time as the turbulent patches passed

Instantaneous FRS images of two shockwave boundary layer interactions at Mach 8

"In the last 10 years or so, however, the capability of PIV systems has grown by leaps and bounds"

through the shockwave. The distortion of the shock as it swallows the turbulence became visible for the first time, showing how the shock ripples and even splits to form short-lived shock cells. The strong deformation of the shock is graphically illustrated in the figure above, showing instantaneous FRS images of two shockwave boundary layer interactions at Mach 8. The wall location coincides with the bottom of each image, and the flow is from left to right. Here the shock is seen to warp around the passing turbulent bulges, in a highly unsteady interaction. This information has since been used to develop flow control techniques, to minimize the wall pressure and heat transfer loading generated by the violent shock motion.

Particle image velocimetry

The other technique that is fast becoming indispensable for fluid flow interrogation is particle image velocimetry (PIV). Here, small particles are seeded into the flow stream, illuminated by a sheet of laser light, and two images with a short time delay are taken of the particles. By finding the displacement of the particles over the short time interval, the local velocity vectors can be found. The first PIV systems became available about 20 years ago, but they were slow and limited to low subsonic speeds.

In the last 10 years or so, however, the capability of PIV systems has grown by leaps and bounds. Stereoscopic systems are common now, with the ability to give three-component velocity vectors in a plane. Time-resolved systems can provide continuous data streams, and holographic systems are capable of volumetric imaging of the instantaneous velocity field. In high-speed flows, we have seen very successful applications at supersonic speeds, and they have given spectacular views of the three-dimensional character of large-scale turbulence in supersonic shockwave boundary layer interaction. At Princeton we have applied the technique successfully at hypersonic speeds.[4]

Experiments are especially useful when coupled with numerical simulations. In particular, at Princeton we have run parallel efforts on the measurement and computation of turbulent boundary layers and shockwave boundary layer interactions in supersonic and hypersonic Mach numbers.[5] The simulations are Direct Numerical Simulations (DNS) in which all scales of the flow are computed, so that no turbulence model is necessary. The most important aspect of this program is that the simulations and experiments are performed under identical flow conditions (Mach and Reynolds number) so that a direct and valid comparison can be made.

The experiments are used to validate critical aspects of the DNS, and then the DNS can be used to help answer fundamental questions on the flow physics, such as what is the cause and what is the effect of the shockwave motion and the resulting growth and decay of the separation bubble? Early comparisons at Mach 3 were based on wall-pressure signals, which give important information on shock movement and the size of the separation bubble, and were used to improve the DNS methodologies. Currently we are using PIV to measure the turbulence statistics in Mach 7 boundary layers with and without roughness, with and without gas injection.

The comparison with previous data (of which there is very little) is very promising, as is the comparison with DNS. The tight coordination of experiment and DNS is fast-tracking our progress, and we are entering a new era in which the wish list of information demanded by the fluid dynamicists is rapidly becoming reality.

The demand for even more capable diagnostics that can go beyond the limitations of PIV and operate in unseeded flows with very high temporal and spatial resolution has led to the recent development of Laser Ionization Tagged Radar Anemometry (LITRA).[6] In this case, a short pulsed laser is focused to the location of interest such that there is a very small (tens of microns) region of ionization created that moves with the flow. The motion of this ionization

> "It is important to be able to respond rapidly to transient engine phenomena, particularly phenomena that might lead to engine unstart"

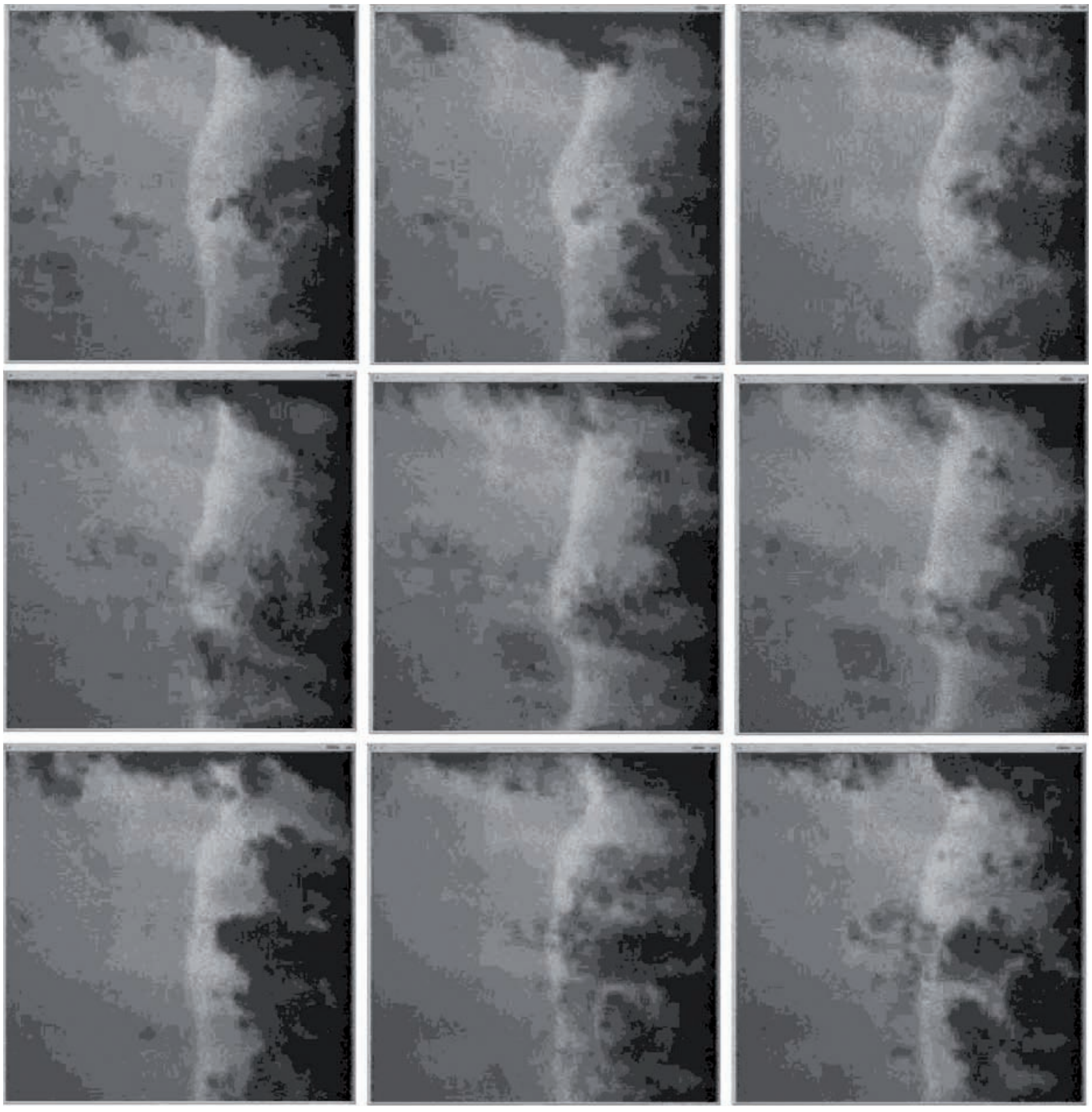
region is followed in real time by microwave scattering using quadrature heterodyne detection. In the figure on the far right (LITRA) we see the increasing phase shift of the signal due to the acceleration of the tagged region as it approaches the Mach disk of an under-expanded supersonic jet, and its subsequent deceleration as it passes through the Mach disk. The red trace is the time dependence in ambient air in the absence of flow. Due to the high sensitivity of microwave systems, the motion can be followed with submicrosecond time accuracy. Using multiple microwave detectors, the vector velocity can be measured. The advantage of this approach is that seeding is not required and measurements can be taken with precise timing and spatial selectivity. It is expected that this will be most useful for measurements in high-speed flows and shock facilities where precise timing is required and seeding is problematic.

Control of shockwaves

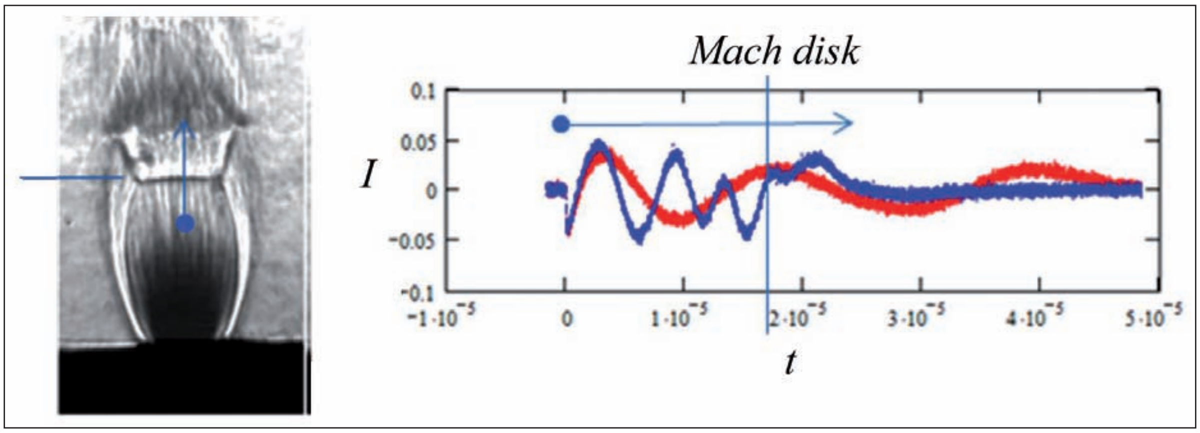
An important potential advance for the design of high-speed vehicles is the control of shockwaves and shockwave boundary layer interactions. New approaches for accomplishing this involve the use of surface plasmas and shape morphing structures. Surface plasmas can be created from flush-mounted electrodes and only turned on when they are needed, such as in maneuvers or when instabilities occur. Morphing surfaces have the capability of changing shape during flight, therefore providing a method for accommodating changes in the inlet and engine in response to changing Mach number.

Recent work at Princeton has succeeded in suppressing shock-induced boundary layer separation by using an MHD-driven constricted-surface discharge to force the flow downstream through the shock impingement region. The electrodes that are used to accomplish this are buried in the wall of the wind-tunnel facility and diverge slightly from each other in the downstream direction.

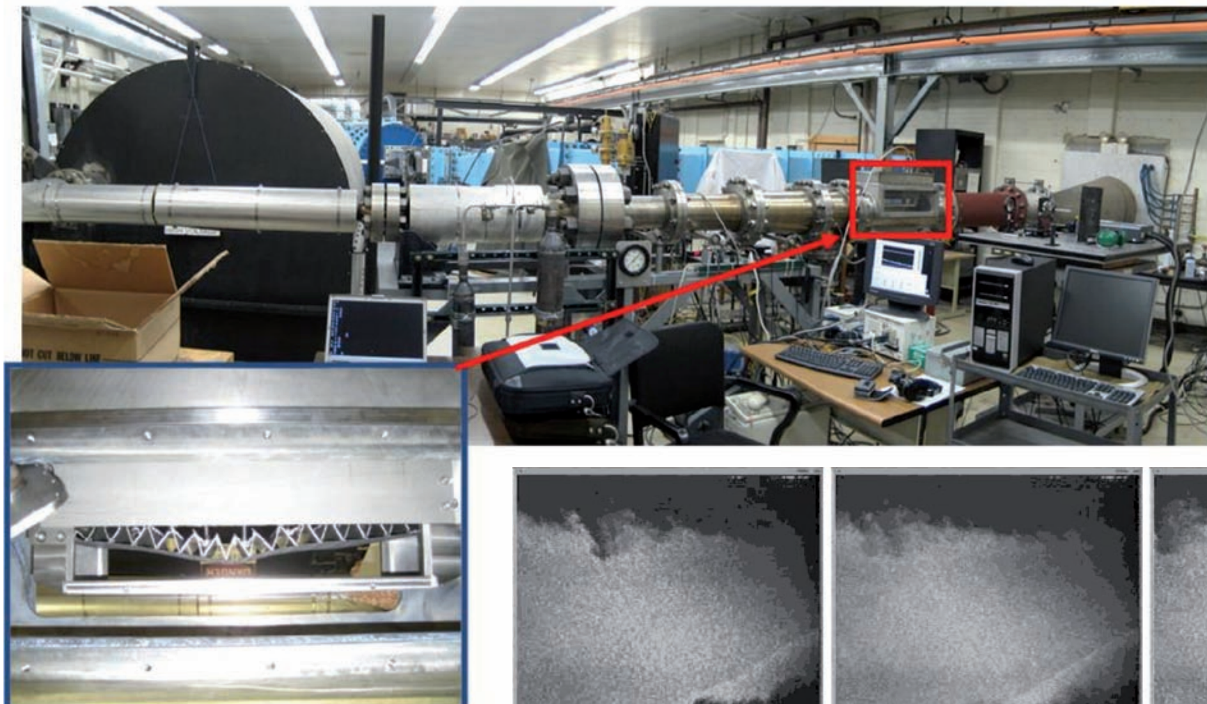
When a DC voltage is placed across them, a breakdown generates a transverse arc that is forced downstream by a magnetic field that is perpendicular to the surface. When the arc reaches the end of the electrodes, it blows out and another is formed upstream and subsequently forced downstream. In this manner, each flow element is forced many times by



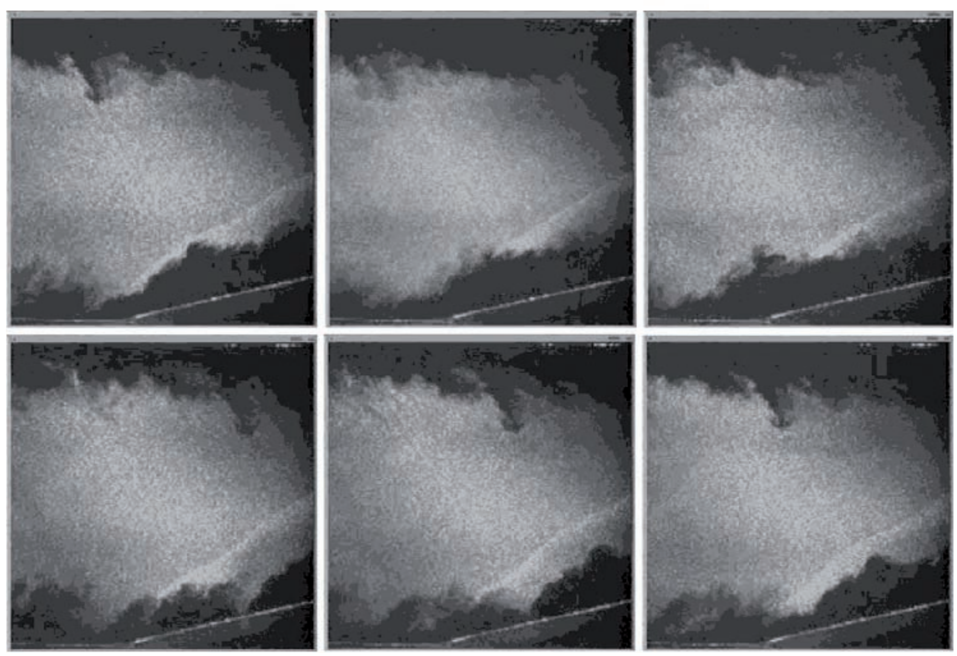
Successive frames from a movie using filtered Rayleigh scattering to visualize a 12o Mach 2.5 compression corner interaction



LITRA signal (blue) with the motion of the tagged region as it approaches the Mach disk of an underexpanded supersonic jet. The red trace is the time dependence in ambient air in the absence of flow (left)



Princeton Mach 8 wind tunnel facility (below)



repeated arc passings, so even though the interaction between the arc and the flow is small, the overall impact is considerable.

Due to the change in Mach number, the shape of the hypersonic inlet and the internal configuration of the high-speed engine and isolator must be altered for optimum performance over the flight envelope. In addition, it is important to be able to respond rapidly to transient engine phenomena, particularly phenomena that might lead to engine unstart or to severe reduction in engine performance. Shape-morphing materials can accomplish this, but they must be able to perform at the very high temperatures characteristic of internal engine and inlet surfaces.

Through collaboration with Teledyne, Princeton is examining the ability to shape high-temperature woven ceramic surfaces for inlet and engine applications. Tests are underway with a morphing inlet configuration in the Princeton Mach 8 facility, where the pressure profile through the inlet is dynamically controlled by the varying shape and area ratio of the inlet (see the figure above of the Princeton Mach 8 facility with maximum displacement seen through the observation window). ∎

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CONTACT

Alexander J. Smits and Richard B. Miles are from the Department of Mechanical and Aerospace Engineering Princeton University, NJ, USA

High-temperature accelerometer

INTEGRAL ELECTRONICS IN HIGH-TEMPERATURE 100MV/G TRIAXIAL ACCELEROMETERS IMPROVE PERFORMANCE

Triaxial IEPE accelerometer (175°C)

> "Typically, IEPE accelerometers incorporate a PE transducer along with a charge or voltage amplifier"

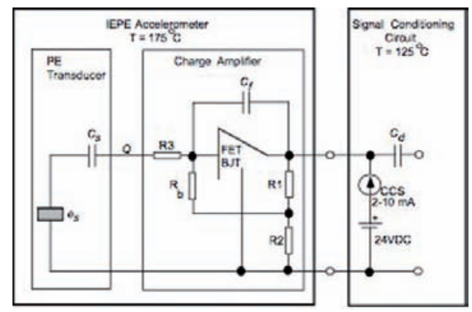
JOSEPH QUE

BY JOSEPH QUE

The need for reliable, high-performing, and low-cost electronics capable of operating at temperatures higher than 125°C is ever increasing. Many applications require high-temperature electronics, including the zones of high heat found in automobiles, aircraft, satellites, and spacecraft, as well as deep wells for oil/mineral exploration and other geothermal applications. Silicon-based electronics have become favored for the above applications because of their better performance, smaller size, and lower cost. Although there is scientific literature describing the possibility of using silicon-based semiconductors in circuits operating at temperatures of 250°C, most silicon-based electronics today are rated no higher than 125°C. Designing high-temperature (greater than 125°C) silicon-based electronics continues to be a great challenge.

The Endevco model 67 high-temperature (175°C) piezoelectric accelerometers with integral electronics (IEPE) is described here. Typically, IEPE accelerometers incorporate a PE transducer along with a charge or voltage amplifier combined into one package. The PE transducer usually operates at frequencies below its natural resonance frequency. At this frequency range, the PE transducer is essentially a capacitive signal source. As such, a charge amplifier is more suitable, and it is frequently used in the IEPE accelerometers. A charge amplifier has the advantages of providing more gain, physical compactness, and independence of the PE transducer's capacitance.

The maximum operating temperature of today's high-temperature IEPE accelerometers is restricted by the maximum temperature rating of the integral electronics. Extreme high-temperature acceleration measurements (>250°C) are achieved by piezoelectric accelerometer without the electronic amplifier. These accelerometers are capable of operating up to 455°C. The PE accelerometer is situated at the hot zone and wired to a remote signal conditioning module located away from the hot area. Connection between the PE accelerometer and the input of the signal conditioning module is provided by a high-temperature coaxial cable and connectors. A separation of PE accelerometers from a signal conditioner creates an additional connection interface, reduces reliability, increases noise (very high impedance line), decreases dynamic range, and is relatively costly.



Configuration of the high-temperature charge amplifier and its connections with the PE transducer and the SCC

Another approach is the use of silicon-on-insulator (SOI) or silicon carbide technology for the design of the IEPE accelerometer's electronics, enabling temperatures to reach more than 300°C. However, such accelerometers are larger in size and are more expensive than silicon-based electronics sensors, and exhibit inferior performance. In some automotive, aircraft, and deep well applications, where the operating temperature is not higher than 175°C, the silicon-based electronics accelerometers are attractive by virtue of their performance, compact size, parts availability, faster turnaround, and lower cost.

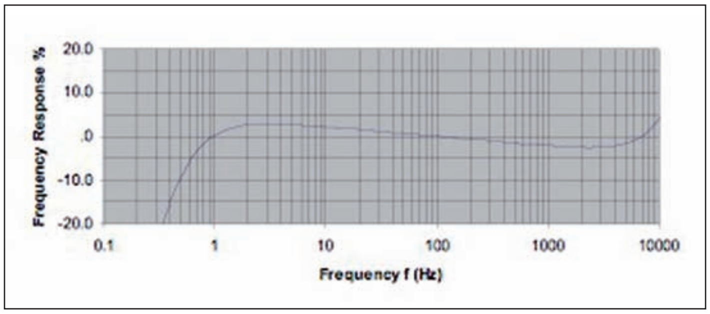
Few silicon-based high-temperature IEPE accelerometers have been designed in recent years. Most do not operate beyond 150°C and the sensitivity is no higher than 10mV/g. It is important to discuss the successful development of a 100mV/g miniature triaxial accelerometer capable of continuous operation at 175°C temperature.

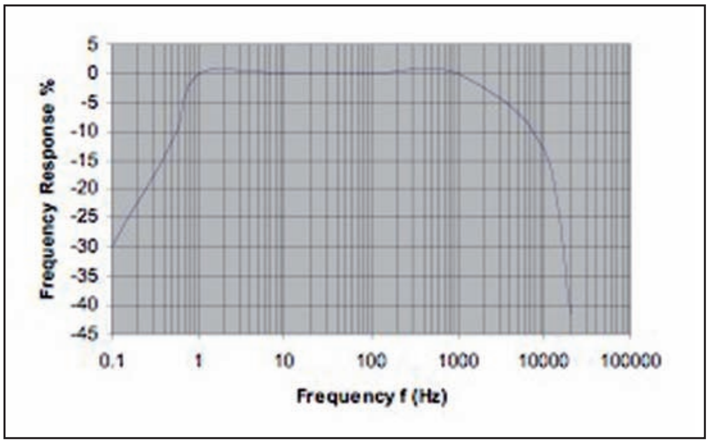
High-temperature charge amplifier

The figure above shows the basic configuration of the high-temperature charge amplifier and its connections with the PE transducer and signal conditioning circuit (SCC). It converts the charge generated by the piezoelectric transducer into a low impedance voltage output. The charge gain G_q of the charge amplifier is gained by the equation:

$$G_q = \frac{1}{C_f}$$

C_f is the feedback capacitance. The SCC provides the constant current source to the charge amplifier and further processes the signal as desired. The high-temperature charge

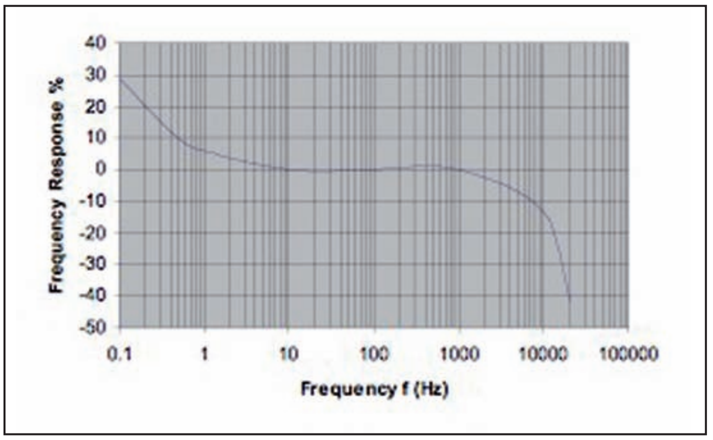




Frequency response of the IEPE accelerometer at room temperature (above)

Frequency response of the charge amplifier at room temperature (top right)

Frequency response of the charge amplifier at temperatures of 175°C (right)



amplifier is composed of two direct-coupled stages. The field-effect transistor (FET) input stage provides a high-impedance match to the PE transducer and the bipolar transistor (BJT) output stage provides a low impedance output circuit. The FET plays an essential role in high-temperature operation. It is selected based on its critical parameters, enabling it to operate at high temperatures. This is known as the 'zero temperature coefficient' (ZTC) FET operating point. Careful circuit design and proper selection of components enable operation at or near the ZTC, optimizing the high-temperature circuit performance. A theoretical value of drain current ID = I_{DZ} (ZTC drain current) for n-channel FET corresponding to the ZTC bias point is:

$$I_{DZ} \approx I_{Dss} \frac{.63}{V_{GS\,(off)}}$$

I_{Dss} is the saturation drain current, and $V_{GS\,(off)}$ is the gate-source cut-off voltage. The ZTC operating point was achieved by the adjustment of resistors R_1 and R_2. One undesirable temperature effect in FETs is its temperature dependence on the gate reverse current (leakage current) IGSS. IGSS will increase with temperature, causing the ZTC operating point to shift. FETs used in the design of a charge amplifier have a typical IGSS value of ≤1pA at room temperature. Resistors (R_b, R_1, and R_2) and capacitor C_f forms a single pole high-pass filter, which determines the lower corner f_1 of the frequency range. The -3dB low-frequency corner f_1 equals:

$$f_1 = \frac{1}{2\pi R_{in} C_f}$$

$$R_{in} = R_b \frac{R_1 + R_2}{R_2}$$

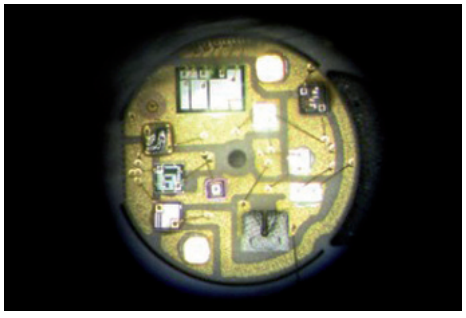


Figure 3: Microphotograph of the hybrid substrate

According to this equation, to obtain low f_1 response, R_b should be high. However, the upper value is restricted due to the leakage current IGSS of FET at high temperature. R_b must therefore be optimized to obtain acceptable low-frequency response while maintaining near ZTC operating point. The upper -3dB corner f_2 of the frequency range is dictated by resistor R_3 and crystal capacitance C_s by:

$$f_2 = \frac{1}{2\pi R_3 C_s}$$

According to this equation the upper -3dB corner of the frequency range can be adjusted only by the value of R_3 as the crystal capacitance C_s is fixed. In some cases where the maximum frequency response is desired, R_3 is reduced to zero. In other cases, R_3 can be optimized to extend the frequency range at the upper frequency as the response approaches the resonance rise.

A circuit based on the above was assembled on a miniature 8mm ceramic disk substrate. It is very important that any point-to-point interconnections must be executed by compatible metals to avoid inter-metallic diffusion and inter-metallic formation, which weakens the bond.

High-temperature PE design

The high-temperature aspect of the PE transducer design has been less of a problem since PE materials have proved to operate reliably well beyond temperatures of 175°C. The main challenge is to maximize the charge output of the PE sensing element in the small space available. The charge output Q is given by the equation:

$$Q = KM$$

K is the piezoelectric crystal charge output coefficient and M is the seismic mass of the sensing element. The crystal voltage output e_s is related to the charge output Q by:

$$e_s = \frac{Q}{C_s} \quad (6)$$

In order to achieve high charge output, PZT (lead zirconate titanate) crystal was used in the design due to its high charge output coefficient, and tungsten alloy metal was used for the seismic mass due to its high weight density.

Silicon-based high-temperature IEPE has been designed, built, and tested. The high temperature charge amplifier uses standard and readily available components assembled on a miniature 8mm ceramics disk substrate. This electronics hybrid circuit was integrated with a high charge output PE transducer that led to the successful development of a low-cost, reliable, miniature (14mm³), lightweight (12.5g), and low noise 100mV/g Triaxial Accelerometer capable of operating from -55°C to +175°C. ▮

CONTACT
Joseph Que
www.endevco.com
www.meggitt.com
Tel: +1 949 493 8181

The evolution of inspection

THE LATEST DEVELOPMENTS AND TECHNIQUES FOR INSPECTION TECHNOLOGY FOR CIVILIAN AND MILITARY AIRCRAFT 'IN-MANUFACTURE' EVALUATION

> **"Digital radiography has now expanded to encompass techniques such as computed radiography"**

BY THIERRY LAFFONT

The need for systemized inspection in the aircraft sector did not arise until World War II, when inspection techniques were introduced during the manufacture and operation of military aircraft. Then, coupled with the dramatic increase in aircraft travel that took place in the late 1940s, it was realized that more rigorous regimes were necessary to ensure the safety of the pilots, aircrew, and passengers, who endured the hardships and strains of long flights over potentially hostile areas.

In addition, aircraft stresses were increasing as propulsion changed from propeller to turbo jet, and materials such as advanced metal alloys and composites began to be increasingly applied. Consequently, inspection procedures were introduced, although at first these were often little more than intense visual examinations. Advanced NDT (non-destructive testing) techniques now play a critical role in locating, identifying, and sizing defects during manufacture to ensure compliance with stringent quality control procedures, and throughout equipment service life to meet the demands of airworthiness certifying agencies.

A wide range of inspection technologies is used during aircraft manufacture, and NDT is an essential component of stringent quality-control procedures. Radiography is still the most widely used volumetric inspection technique, but traditional film radiography is fast converting to digital techniques.

THIERRY LAFFONT

Digital radiography

Digital radiography covers a range of techniques. In its most basic form, digital radiography uses an x-ray source, an image intensifier to convert x-rays into a standard video image, and integrated image-enhancement software. Such equipment combines best-practice mechanical concepts and software solutions with innovative designs to create a system that can be integrated within a production line to provide fast and accurate quality control. In addition, the use of a fast and reliable x-ray tube manipulator allows exact positioning of the source without the need to tilt the object under inspection.

All movements can be visually controlled through a lead-glass window. Door loading times are typically less than three seconds; to accelerate mounting times of testing parts, special three-jaw chucks and dedicated part fixtures can be introduced. User-friendly software can allow easy programming and intuitive operation of the system, and a variable speed mode can further shorten inspection cycles in line with inspection tasks and operator experience.

In operation, a real-time image of the item being inspected is displayed on a control desk VGA monitor while, simultaneously, an image that can be enhanced and evaluated is also shown. Enhancement can be carried out using functions such as contrast adjustment, calibration, and zoom, to allow calculation of defect areas and reference comparison, greatly facilitating evaluation and sentencing.

Digital radiography has now expanded to encompass techniques such as computed radiography and direct digital radiography. A computed radiography system consists of a

radiation source (x-ray or isotope), an imaging plate, a scanner, a high-resolution monitor, a PC workstation, and the associated software.

The imaging plate of a CR system contains phosphors that retain a latent image produced by means of a conventional source. When the plate is scanned with a laser beam in a digitizer or scanner, the latent image is released as visible light. This light is then captured and converted into a digital stream to create the digital image, which can then be viewed on a proprietary monitor. Once used, the imaging plates can be wiped clean and reused, typically up to 1,000 times. Today's computed radiography systems combine flexibility, versatility, and reliability with extremely wide latitude and excellent image quality.

With digital x-ray, a flat panel is covered with a cesium iodide scintillator, which converts the x-rays into light. This light is then converted into electronic charges in a low-noise, photodiode/transistor array, where each photodiode represents a pixel or picture element. The charged electrons then pass to read-out electronics for digitizing and immediate display on a suitable monitor.

This is instant radiography, where images are viewed in real time. As with computed radiography, images can be viewed on a local monitor, a remote monitor, or shared among a number of monitors. They can then be filed and archived for future reference and traceability; being digital, they can be enhanced to focus on particular areas of interest.

3D radiography or computed tomography (CT) is also being increasingly used in the aerospace sector. CT can be used for carrying out critical measurements of components such as turbine blades, which because of their complex shapes are extremely difficult to measure using conventional NDT or CMM techniques. In addition, CT is applied by aerospace subcontractors to examine castings for porosity and inclusions.

Today's turbine blades are lighter, stronger and more creep resistant than ever at higher and higher temperatures. These demands have seen the development of single crystalline turbine blades, which need to have a certain crystallographic orientation relative to the macroscopic shape. The investigation of this orientation is a major step in quality control and performance of the blade. Inspection equipment to carry out this sophisticated task relies on the Laue method, in which white radiation is used to determine the single crystal orientation. Current single crystal readers can handle samples/blades/parts of lengths up to 20in and weights up to 20 lb.

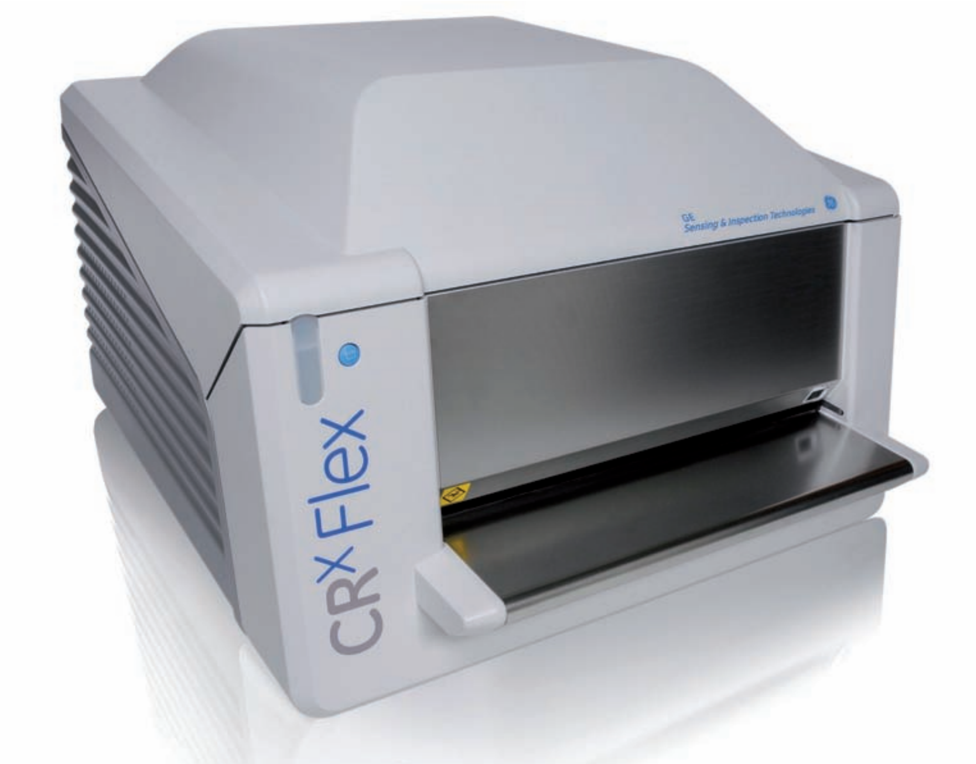
Ultrasonic inspection techniques

Ultrasonic inspection, in terms of fixed systems and portable instruments, is used throughout aerospace manufacturing. Utxx from GE is a versatile ultrasound electronic platform for industrial applications, testing machines, and online systems. Configurations are available for conventional pulse-echo, through transmission, multiple channels in parallel or multiplexed, as well as phased array. Immersion tanks can have squirter coupling, bubbler coupling, and contact transmit/receive coupling; tanks are designed to handle a diverse range of aerospace components of various sizes, material compounds, and geometries.

In-line immersion systems have been used successfully in aerospace manufacturing for many years. However they do sometimes cause inspection problems when dealing with complex geometry components and composite structures. A recent development that solves these problems is the ultrasonic robotic system. Instead of the conventional gantry arrangement, this uses industrial robots and a turntable arrangement to manipulate the item being inspected. It features an integrated probe head and water couplant system, and offers positional accuracy to 0.2mm, allowing excellent through-transmission and contour-following.

Although large ultrasonic systems perform the majority of in-line inspection tasks, there is still an important place for portable inspection equipment on the production line. Typically, portable ultrasonic flaw detectors such as the USM Go from GE are used to check or provide more precise identification of indications identified by x-ray or ultrasonic testing machines to obviate the need for re-passing components through large machines, saving cost and time. With its special flip facility, the USM Go can be operated by left-handed and right-handed personnel using the navigation joystick and the familiar function keys. The instrument's 800 x 480 pixel display affords extremely high resolution, and the optimized aspect ratio ensures better echo separation. The display screen can be easily viewed in handheld or desk-mounted position, and has been sized for optimal ergonomic use.

Portable phased-array instruments are being successfully used to drastically reduce inspection times and improve probability of detection.



A computed radiography scanner. The CrxFlex

"The NDT data produced from the major modalities of radiography, ultrasonics, and RVI is created in the form of images"

Using ultrasonic phased array technology

Offering the capability for rapid, large surface area inspection, phased array also affords better, clearer visual imaging. Instruments such as the Phasor XS can provide inspection images in four modes: A-scan only, A-scan and sector image, sector image only, and the latest Topview software. The full-color sector image is easy to understand and interpret, and is derived from medical technology, specifically obstetrics. The A-scan image is that normally used as a defect sizing tool by NDT inspectors. Snapshots of sector images and associated A-scans can be stored on an onboard SD card for subsequent analysis and archiving, and all images are displayed in real time on a high-resolution TFT display panel.

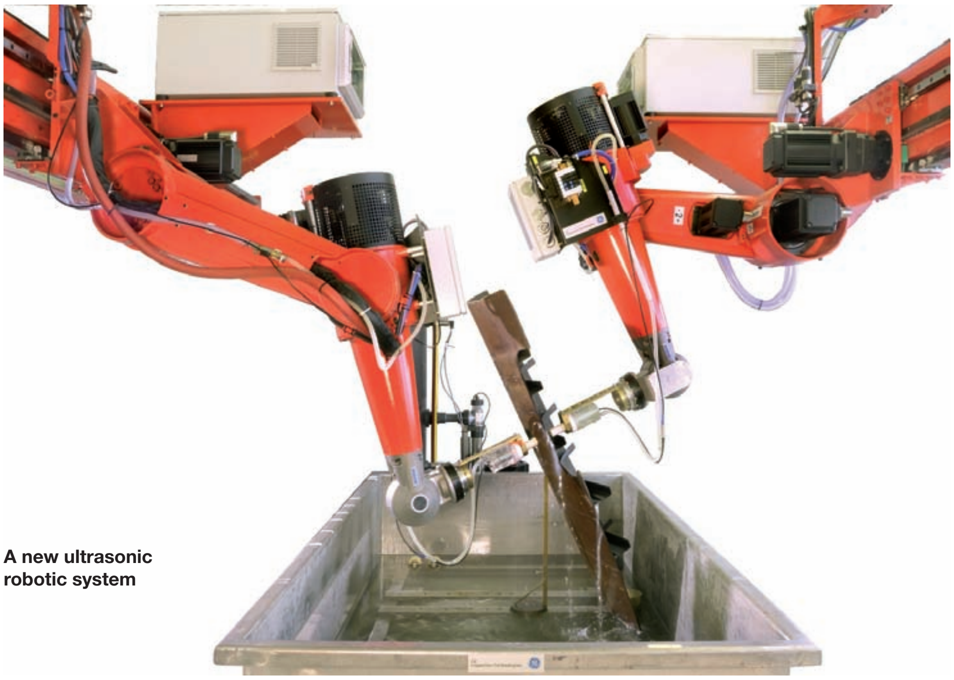
Remote visual inspection

Although much of today's inspection is still visual, a great deal of this relates mainly to in-service inspection. However, remote visual inspection using borescopes and videoprobes is used extensively in manufacture and in service.

There have been many advances in remote visual inspection (RVI) since the early days of rigid borescopy. Overall imaging quality has greatly improved as a result of fully digital data streams and improved optical and illumination technology. The integration of PC operating systems and their associated processing power within borescopes has expanded their versatility and greatly facilitated data sharing though connectivity. Application-specific software such as MDI is helping to improve probability of detection, while reducing the occurrence of false calls. And now, advances in technologies such as miniaturized processing power and LCD light generation have allowed RVI instruments to become even lighter and more compact than many portable flaw detectors in other modalities, improving their production line versatility.

Turning data into intelligence

The NDT data produced from the major modalities of radiography, ultrasonics, and RVI is created in the form of images. This data can be stored in image form but there is now a protocol that can save all this data in one format: the DICONDE (Digital Imaging and Communication in NDE) format. This is a non-proprietary format, developed from DICOM used through-



A new ultrasonic robotic system

out the medical sector in radiography, but incorporating many features that are purely NDE-focused. As it is non-proprietary, it ensures that users will avoid legacy data issues and will not have to maintain old systems or convert old data in the future. It is also the adopted protocol and eliminates the need for data conversion and simplifies integration with other NDT information systems. DICONDE is the basis of the software platform developed by GE to acquire, review, and archive visual inspection data.

This software platform, Rhythm, uses off-the-shelf hardware and DICONDE to ensure that inspection data can now be acquired, reported, analyzed, stored, and shared on a stable platform of scalable architecture, which will allow users to assimilate future NDT software capabilities with no danger of the information becoming obsolete.

It is a system that allows images to be saved with context, in that all the technique information, and information on location, date and time, and inspector is saved with the image. Such information can then be included in any report generated, although its inclusion with the image into databases means that database searches can be carried out on a variety of criteria.

Moreover, the system is compatible with image data from radiography, RVI, and ultrasonic inspections; this capability will soon be extended to include eddy current. As a result, it is possible to compare inspections of the same item using different modalities to greatly improve probability of detection and accurate identification of flaws, ensuring even better quality control during manufacture, and safety in operation. ∎

CONTACT

Thierry Laffont is global account manager, aerospace, GE Sensing & Inspection Technologies. www.geinspectiontechnologies.com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C-Band telemetry allocation

A COMPLETE C-BAND TELEMETRY PACKAGE HAS BEEN DEVELOPED IN RESPONSE TO THE ALLOCATION OF C-BAND TO THE AVIATION SECTOR

"One study shows that, by 2022, a high data rate telemetry system will transmit up to 500Mbps"


DR IBRAHIM KHALIL

BY DR IBRAHIM KHALIL

Future fighter aircraft and UAVs will include computer-controlled subsystems comprising a vast number of sensors, actuators, and embedded subsystems. Hundreds (or even thousands) of analog and digital input signals, as well as video streams and digital buses, will be able to be captured by versatile multichannel airborne instrumentation data acquisition systems (ADAS) and will be transmitted online to the ground station.

To have a successful mission or test campaign, ground operators need to gather as much housekeeping information as possible about the vehicle itself and of the various onboard subsystems, as well as payload data and video streams, all in real time. For detailed flight analyses, mission controllers, test engineers, and scientists typically prefer to receive unprocessed raw data on the ground rather than heavily processed and compressed data. Important details could be lost through the use of processing and compression algorithms. As a result, it is evident that the available RF spectrum is a critical resource for modern telemetry systems, as the requirement for data bandwidth continues to increase.

Demand on the spectrum has been increasing exponentially over the past 30 years. One study shows that, by 2022, a high data rate telemetry system will transmit up to 500Mbps data, which will need at least 400MHz occupied bandwidth even assuming advanced modulation techniques. In conventional L-Band and S-Band, where less than 100MHz of allocated spectrum is available for aeronautical telemetry, such a high data rate would not be possible.

In the World Radiocommunication Conference 2007 (WRC07) a major step was made by allocating additional spectrum in C-Band in consideration of the spectrum requirements for aeronautical telecommand and high bit-rate telemetry. In total, 1.4GHz of spectrum was allocated around the world in several sub-bands. The band 5,091-5,150MHz is allocated worldwide, which now makes possible to use the same telemetry radios and systems across the international boundaries. However, this frequency migration involves new challenges and the demand for efficient, rugged, and reliable airborne telemetry equipment.

Design challenges and devices

Future telemetry applications not only require high data rate but also high transmission power due for long-distance communication applications. Fighter aircraft require high transmitted power in order to maintain uninterrupted communication with the ground station during abrupt motion changes and with non-directive onboard antennas. Demand for higher transmission power, at higher frequency, severely challenges transmitter designers, since the other constraints such as efficiency and size remain unchanged, due to space and power scarcity on board.

On the other hand, the new transmitter should be mechanically and electrically compatible with existing L- and/or S-band transmitter units to keep any modification efforts to a bare minimum. The best would be a 100% 'Form-Fit-Function' replacement with no need to change mounting provisions or cable harnesses. Therefore, from the device point of view, it is necessary to have highly efficient and rugged devices with high power density at the newly allocated frequency band, which is considerably higher.

Fortunately, in the last decade semiconductor research groups successfully developed GaN-based high-performance devices for RF applications. GaN-based devices have been proved as prominent in high frequency and high power application. GaN devices take the benefit of inherent material properties such as high band-gap, which enables high voltage operation and makes the devices very rugged. High carrier concentration and high electron velocity enables high current concentration and therefore high power at high frequency operation.

Due to its excellent material properties, GaN devices offer a unique combination of performance in power, efficiency, noise, linearity, high breakdown voltage, and high temperature operation. Single devices have been reported to be capable of delivering a few hundred watts. A GaN layer grown on good thermal conductive substrate such as SiC or Si can operate at very high junction temperature due to its high melting temperature.

Successful operation of GaN devices cooled down after heating up to 1,000°C is reported in the literature, indicating extreme ruggedness. It seems to be the perfect technology for the next-generation telemetry transmitters. GaN devices also show good results on the radiation tests carried out so far, and therefore seem to be well suited to demanding space applications as well.

The C-Band transmitter

In view of the fact that the telemetry industry will have to gradually migrate to the newly allocated frequency band over the coming years, STT-SystemTechnik took the initiative to design a multipurpose C-Band transmitter. As C-Band transmitters can no longer use LDMOS transistors, GaAs transistors would usually be the obvious choice.

However, in recent years GaN transistors have entered the market with great potential and it has been decided to use this promising GaN technology for the new C-Band design. Having high power density and ruggedness, GaN technology has clear advantages over GaAs technology. Due to this new GaN technology, the challenging requirements in output power and power efficiency can be met while the module size can be kept reasonably small.

A single packaged GaN HEMT device with its high power density and high gain delivers enough transmission power at the final stage to avoid bulky and space-consuming multistage power amplifiers. These GaN devices are highly efficient and rugged and therefore most suited to the demanding needs of military and aerospace applications. They have high input and output impedance levels, resulting in quite efficient matching. The new STT C-Band transmitters provide 10W RF output power and offer remotely programmable carrier frequency and deviation facilities.

A wide range of different input configurations facilitates adaptation to different onboard acquisition systems and computers. The modular design enables the addition of common or customer-specific functionalities when required. The user can choose between different modulation schemes, such as analog (FM) and digital (SOQPSK – shaped offset quadrature phase-shift keying). A suitable C-Band airborne antenna is required to operate this new transmitter as the existing S-Band antennas will not operate in the new frequency band.

The Barracuda, equipped with versatile multichannel airborne instrumentation data acquisition system

"A direct radio link is possible over a distance but requires direct line-of-sight"

Typical applications

Autonomously flying UAVs require a bi-directional communication link. On the one hand they do need a telecommand (control) uplink at moderate data rate to upload most recent target or mission information. They also require a high-rate telemetry downlink to send payload data (video, radar, scanners) and housekeeping data back to the ground. The mission controller needs to receive sensor data and payload data in real time, and has to fully remote control the UAV or upload new mission plans.

A direct radio link is possible over a distance but requires direct line-of-sight. As this is not always possible, modern communication links use a geo-stationary satellite or another flying platform (balloon, fighter, or helicopter) as a relay to extend their operational range. In this configuration it is possible, even for objects flying at quite low altitude, to update target data at any time, as well as to get payload/status data and video streams back until the very end of the mission.

Flight testing of military and civilian aircraft is another area where high rate telemetry links are demanded. Flight controllers and test engineers on the ground need to have a precise and full picture of the whole aircraft as well as of all

The standard S-Band antenna. This is now the new C-band transmitter (right)

> **"S-Band is still available, but will probably not be continued in the near future"**

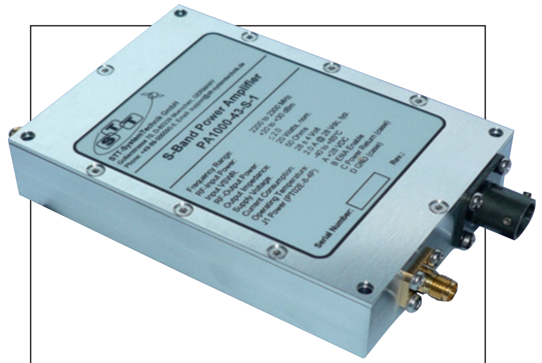
subsystems at any time during the flight. Based on this data, they decide whether everything is operating normally or if any immediate action is required.

There is a great number of electronic systems on board a modern aircraft and structural, thermal, and all other engineers want to monitor every part of the aircraft in great detail. Although some data pre-processing is already done on board, there is still a strong demand for a very high rate telemetry link, because of the enormous amount of data to be transmitted to ground.

The need to migrate to a different frequency band with public mobile services increasingly occupying the current band was ignored by the community for quite some time. The outcome of WRC07 has made it very clear that the future of aeronautical (and other) telemetry will be in the 4,400-6,700MHz range, with the European area being allocated in the 5,091-5,250MHz band. These bands are now reserved for telemetry use and do not suffer from disturbance/noise from other services, as was the case of L- and S-Band. Unfortunately, this means that all existing ground and airborne telemetry systems need to be replaced with new equipment capable of operating in these frequency bands.

To assist smooth migration from S-Band telemetry to C-Band, STT-SystemTechnik will offer a complete C-Band telemetry package, including an airborne stub antenna for this new frequency band. To avoid mechanical modification on the fighter or missile, mounting provisions of the C-band antenna will be kept equivalent to the existing S-band antenna standard. Test of the new C-Band transmitter along with the corresponding antenna on board a modern fighter aircraft in a real testing/mission scenario is planned for 2010.

S-Band is still available, but will probably not be continued in the near future. Users should start building up test systems in order to experience the differences when operating at 5GHz instead of 2GHz. The C-Band transmitter, based upon the most modern GaN technology, is one of the first transmitters to operate at the newly allocated band (C-band), enabling interested users to start investigating the new frequency band and its specific behaviors. The GaN technology will certainly make a great contribution to next-generation telemetry equipment. ∎

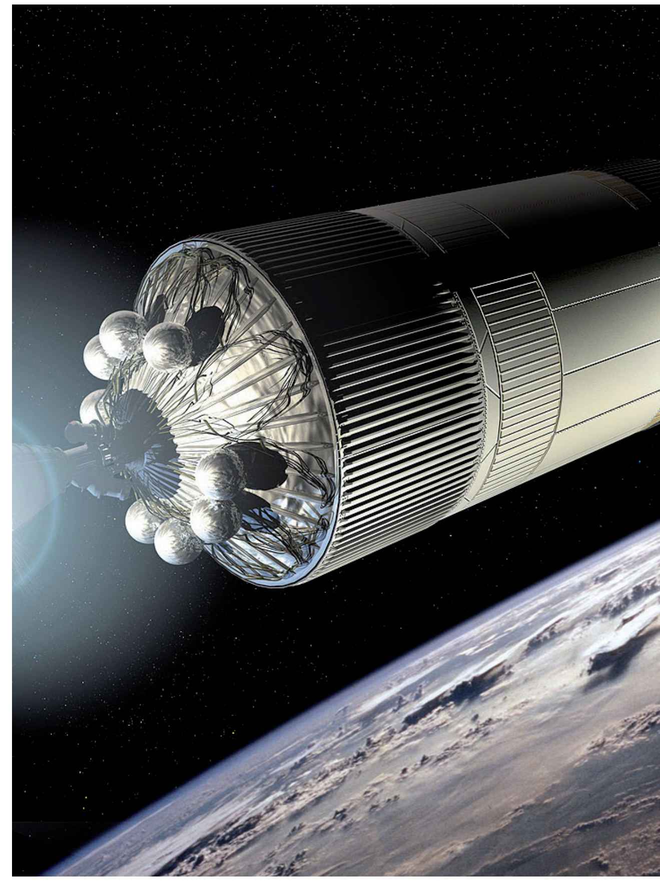


Aa 20W high efficiency S-Band Power Amplifier Module

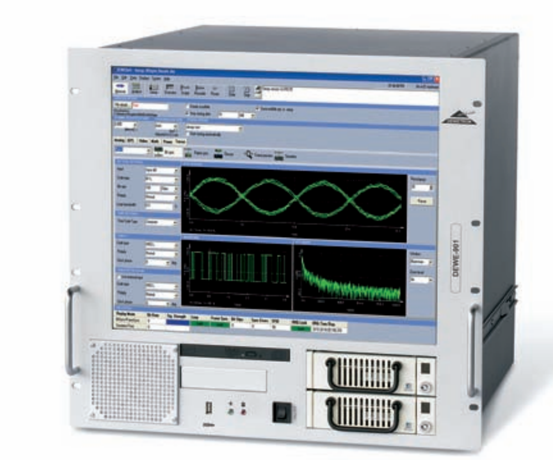
CONTACT
Dr Ibrahim Khalil is a specialist at STT-SystemTechnik GmbH in Germany
Email: mail@stt-systemtechnik.de
Web: www.stt-systemtechnik.de

Launch control systems

GOING FROM FROM ANALOG TO DIGITAL: THE REMAKING OF NASA'S GROUND STATION LAUNCH RECORDERS



> **"All the data coming from the Orbiter was in the digital domain, and had to be converted back to analog for input"**



GRANT SMITH

BY GRANT SMITH

Until 2006, most of the graphical recorders in NASA's Launch Control Center at the Kennedy Space Center were paper recorders with analog inputs. Clearly, it was time for an upgrade, so NASA and its main contractor for the US Space Shuttle program, United Space Alliance, set about finding the ideal instrument: one that combined the best of the analog and digital worlds. In the tense seconds surrounding lift-off and landing, they wanted to retain the highly graphical presentation of mission data afforded by traditional analog recorders, because the information can be assimilated instantly without decoding numbers or interpreting tolerances. On the other hand, paper recorders have a very limited bandwidth, and could only accept analog inputs.

All the data coming from the Orbiter was in the digital domain, and had to be converted back to analog for input to the recorders. This was done at great expense via PDACs (programmable digital to analog converters). They could provide only a handful of channels each, with very limited resolution. A better solution was required, one that would enable the raw pulse code modulated (PCM) digital data to be input directly into the recorders.

Data is sent down to Earth from the Orbiter and other spacecraft via radio signals that contain PCM streams of data, including hundreds and even thousands of parameters. This data is packed very tightly on the spacecraft prior to transmission, and therefore must be decoded on the ground and separated into individual parameters again. This is the job of the bit synchronizer, frame sync, and decommutator. Luckily, these complex electronics can be hosted on a single PCI card today. Knowing this, NASA set about finding the best graphical recorder that would display the analog data, and incorporate such an interface card.

After a rigorous selection process, NASA and the United Space Alliance selected Dewetron's computer-based recorders to replace all the paper-based recorders, and contracted with the company to develop a comprehensive interface to a digital bit-sync/frame-sync interface card. Dewetron software engineers spent months working with NASA on the user interface, and after six months of effort, NASA accepted the new interface. It was then installed on the dozens of Dewetron systems that had been purchased.

The hardware can handle PCM data in numerous popular formats, and at rates up to 20Mbps. This hardware and software combination, installed within DEWE-901 instruments, is heavily used by NASA's Kennedy Space Center on the US Space Shuttle program, and will also be used on Constellation.

System architecture

At the center of most systems is a Dewetron Orion A/D card. Not only does this card provide high-resolution digitizing of the analog signals, but it serves the vital role of providing a high-speed master clock for synchronizing the incoming data from PCM, ARINC, 1553, video cameras, CANbus data, and more. If the system has only PCM inputs, the Dewetron Orion card is not needed, as time code can be inputted directly into the PCM interface card. If other input types are needed, however, the Orion A/D card and a Dewetron IRIG or GPS clock are needed, to synchronize all the data.

Hardware interface

The PCM interface card is a completely integrated bit synchronizer, frame synchronizer, IRIG Class II PCM decommutator, PCM simulator, and IRIG timecode reader. Due to advanced DSP (digital signal processor) and FPGA (field-programmable gate array) electronics, all these functions are hosted on a single full-size PCI card, which is installed into all but the smallest instruments.

Intelligent algorithms run on the onboard DSP, including FIR (finite impulse response) filters, multistage recursive decimation filters, MNCOs (modulated, numerically controlled oscillators), and PLLs (phase-locked loops), and the bit synchronizer section eliminates the need for calibration and tuning. Of particular importance is the use of FPGAs, which can be updated via software in the field.

Mission to Mars

At the end of 2008, Dewetron won an important contract from NASA to build a 600-channel system for recording physical parameters from the new MLP (mobile launch platform) that will carry the Ares I and Ares V rockets to the launch pad. This contract was the largest order in Dewetron USA's history, and like the previous one, came only after an exhaustive competition which Dewetron won on technical merit. The tough selection procedure at NASA scrutinized the potential project partners in great detail. NASA sent engineers to all the companies to assess their abilities, as well as their technical and functional organization. NASA had already visited Dewetron operations in the USA, and therefore visited the headquarters in Graz, Austria, before making its final decision. In so doing, NASA was able to gauge Dewetron's engineering and corporate resources, as well as the company's scientific expertise in the fields of dynamic signal analysis, networking, and A/D conversion. In the final analysis, the choice was between Dewetron and one US competitor. After the company visits, NASA decided in favor of Dewetron.

The approach of the Constellation Space Program is similar to the Apollo program of the 1960s and 1970s, but with much more advanced technology. In Constellation, two rockets will be employed: the unmanned Ares V heavy lifter, which is able to carry more tons of cargo into orbit than any rocket ever made; and the thinner Ares I, which will host the Orion space capsule on top, carrying four or more astronauts into orbit, or to the moon. The stated mission map is to put men back on the moon to build a small science station, and to stage enough hardware in orbit that a manned mission to Mars can be undertaken within the next 15 years.

NASA has already ordered another 100-channel add-on to the original 600-channel system, so Dewetron is currently integrating a distributed instrument with approximately 700 channels for the MLP.

Versatile input configuration

The bit synchronizer accepts all of the IRIG 106-05 code types and has eb/n0 rejection of better than 1dB to the theoretical BER published curve. The input AGC accepts inputs from 75mVpp-10Vpp. Each channel can be easily set up with Dewetron's easy-to-use GUI interface, which includes indicators for loop lock, frame lock, subframe lock, and AGC strength, as well as scope outputs for the AGC data, eye pattern lock representation, and a full frame dump display.

The output of the frame synchronizer can be dumped to the host computer hard drive for archival and data reduction applications. The decommutator section of the PCM card is designed to support all the IRIG Class II features, including variable word lengths per channel and non-standard PCM frame formats. The input serial bit stream to the decommutator is either TTL or RS-422 differential levels with input data rate capability from 1bps to 33Mbps. There is also a full PCM simulator on board that has all the same frame and word features as the decommutator. Finally, an IRIG Time Code reader AM demodulator section enables the user to embed externally or internally generated time into the output data of the decommutator. ∎

CONTACT

Grant Smith – is general manager of DEWETRON Inc based in the USA
www.Dewetron.com

Electro-hydrostatic actuator innovation

THE NEED FOR ELECTRICAL TESTING CONTINUES TO GROW AS THE NUMBER OF ELECTRONIC ASSEMBLIES WITHIN AN AIRCRAFT INCREASES. QUADTECH PROVIDES INNOVATIVE APPLICATIONS TO THIS SECTOR OF THE INDUSTRY

"Deterioration of the insulation has been known to occur due to heating or electrolysis"

SHARI RICHARDSON

ROBERT M. BROWN

BY SHARI RICHARDSON & ROBERT M. BROWN

Traditional aircraft hydraulic systems are migrating toward electro-hydrostatic actuators (EHAs). This emerging technology is intended to replace hydraulic systems with self-contained electrically powered actuators, commonly referred to as 'power by wire'. Power is received from an electric source and an input command signal is transformed into motion.

Actuation systems

All elements of this system require electrical testing. Mil Standard 202: Test Method Standard for Electronic and Electrical Component Parts: Method 301 and 302 is a common reference for most electronic parts within the aerospace industry. Test Method 301 calls for Dielectric Withstand and Test Method 302 for insulation resistance.

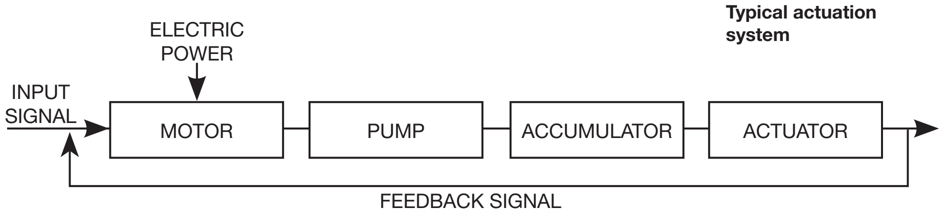
Dielectric Withstand, also referred to as Hipot, applies a voltage higher than the rated voltage of a part or between mutually insulated portions of a part or between insulated portions and ground. The voltage is held for a specific duration, typically 60 seconds. The intention of the test is to ensure that the part can operate safely at its rated voltage, as well as it can withstand higher voltages. This test is sometimes called a dielectric breakdown test. However, the intention of this is not to breakdown the insulation, but instead to determine whether or not the insulation is adequate. Applying high voltage to an inferior insulation will produce flashover, also known as arc, or breakdown.

An insulation resistance test applies direct voltage to the insulating portions of a part to produce a leakage of current through or on the surface of these portions. Low insulation values permit the flow of leakage currents, which can disturb the operation of circuits intended to be isolated. Deterioration of the insulation has been known to occur due to heating or electrolysis as a result of excessive leakage.

Insulation resistance (IR) and Hipot are common tests for assessing the quality of insulation to ground of electric motors. In the case of a motor, a DC voltage is applied to the motor windings. The resistance (in megohms) is measured between the motor windings and the motor frame. The dielectric strength of the insulation is also measured. The aim of this test is to ensure the insulation will not fault to ground if subjected to high transient voltage surges. The pump, accumulator, and actuator, as well as the complete system, are subject to both these tests.

Typically an electrical safety analyzer that contains Hipot as well as IR is used to perform this test. Most analyzers enable full programmability of voltage and high and low limits. Unique functions to look for within the analyzer are ramp, dwell or hold, discharge, and arc detection.

> **“Anyone familiar with aerospace electronics is aware that the dominant frequency for aircraft is 400Hz”**



Typical actuation system

Test cycles

The figure above shows a test cycle for DC Hipot or insulation resistance test. AC Hipot has a similar cycle. However, dwell is not necessary for AC Hipot. Ramp time is defined as the amount of time to increase the voltage to its full potential. Dwell time is a settling time prior to leakage measurements being made. This function is particularly important for parts that contain capacitors. The current used to charge the capacitor can easily exceed the high limit, producing a false failure. Ramp and dwell are a necessity when testing capacitors. Test time is the duration the voltage is held at full potential while the leakage is being monitored. Most testers will automatically discharge the part under test. At times it is desirable to discharge in a controlled manner. Fall time will do so.

AC testing has some advantages over DC as it stresses the insulation equally in both polarities, whereas DC is only single polarity. There is no charge time associated with AC and it is not necessary to discharge the product after testing. AC Hipot also enables voltage to be applied at various frequencies.

Anyone familiar with aerospace electronics is aware that the dominant frequency for aircraft is 400Hz. Aircraft design is a series of compromises due to space and weight constraints. An electrical system at 400Hz makes the power supplies smaller and lighter. There is no specific standard that calls out dielectric withstand testing at 400Hz; however, many manufacturers test their product under conditions in which the product will be used. Many providers of aerospace components have selected the QuadTech Guardian 6000 Plus Electrical Safety Tester or a similar unit to perform AC Hipot at 400Hz. This unit can program frequency from 50Hz to 600Hz in 1Hz steps. Testing at 400Hz provides an understanding of the product behavior at 400Hz, and tests the product insulation in a more realistic environment.

Supplying variable frequencies

DO-160F is the requirement for equipment to operate under variable frequencies depending on the category of equipment. One new term that has come about is ‘wild frequencies’, which refers to the ability of equipment to operate from a variable frequency supply that covers the frequency range from 400Hz to 800Hz.

DO-160F outlines testing of equipment intended for use on aircraft electrical systems. Where the primary power is from a constant or variable frequency AC system, DO-160F specifies three categories for equipment: A(CF), A(NF) or A(WF).

A(CF) designates AC equipment intended for use on aircraft electrical systems where the primary power is from a constant-frequency (400 Hz) AC system.

A(NF) designates AC equipment intended for use on aircraft electrical systems where the primary power is from a narrow variable-frequency (360 to 650 Hz) AC system.

A(WF) designates AC equipment intended for use on aircraft electrical systems where the primary power is from a wide variable-frequency (360 to 800 Hz) AC system.

Single-phase and three-phase testing to DO-160F Section 16.5.1.1 requires the equipment be tested for 30 minutes under a wide variety of voltages and frequencies.

AC programmable power sources such as QuadTech’s 31000 Series AC Sources enable fully programmable voltages from 0V to 300VAC and power output from 500VA to 18,000VA, to meet single and three-phase applications. Whereas most AC sources only go to 500Hz, one of the innovative features of the 31000 series is a standard frequency range from 15Hz to 1,000Hz to meet the testing requirements outlined in DO-160F. Data collection is also made easier with SoftPanel software that configures the source and enables easy data collection to a PC running Windows.

Beyond the frequency

There are hundreds of miles of wire harness throughout an aircraft. Electrical wiring harnesses are a critical component of any aircraft. It is essential to ensure the continuity, isolation, dielectric withstands and insulation of every harness installed. It is also essential to ensure the components within the harness are in place and functioning properly. It is common within aerospace to find thermocouples within wire harnesses among other components such as diodes, resistors, and capacitors.

The turbine engine wire harness of a major manufacturer contains 14 thermocouples in parallel. During the manufacture of the harness, which contains 80 points, the system is tested for continuity and Hipot using a cable tester. An important note: the harness must be tested during manufacturing and again during routine service.

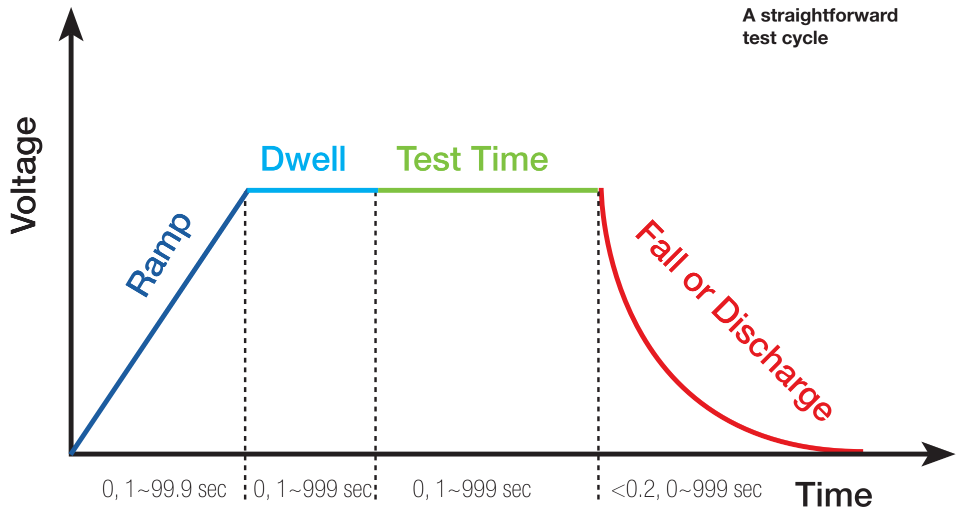
Not just for component testing

Traditionally, an LCR meter is used to measure the characteristics of components such as capacitors, resistors, and inductors. Today however, LCR meters are used in a variety of specialized applications

Capacitive fuel probes or gauges are used in a variety of applications from aerospace to marine. A capacitive fuel probe, determines the amount of fuel present in the fuel tank by measuring the capacitance between an electrically conductive inner tube that is surrounded by an outer tube or cylinder. The sensor is placed vertically in the tank so that as the fuel level goes up and down, more or less of the probe is immersed in fuel. This changes the amount of capacitance between the two tubes, which is measured and displayed as amount of fuel in the tank.

The principle of operation is very similar to measuring the dielectric constant of materials. Measurement of the dielectric constant of materials and liquid uses a dielectric cell or liquid cell that acts as a capacitor. An LCR meter is then used to measure the capacitance in air and with the material or liquid in the cell. The ratio of the two capacitance measurements gives dielectric constant. In the formula eo, A, and d1 are constants. The value er is the relative permittivity of the material between the center tube and other cylinder, which does change, based on the ratio of tube in air versus fuel.

LCR meters such as the 1920 Precision LCR Meter have been used by numerous manufacturers of capacitive fuel probes and sensors during production for calibration and quality control. The 1920 is ideally suited to integration into automatic test systems.



A straightforward test cycle

Dielectric measurements

The dielectric constant measurement, also known as relative permittivity, is one of the most popular methods of evaluating insulators such as rubber, plastics, powders, and other materials. It is used to determine the ability of an insulator to store electrical energy. Dielectric constant measurements can be performed more quickly than chemical or physical analysis techniques, making them an excellent analysis tool. The dielectric constant is defined as the ratio of the capacitance of the material to the capacitance of air.

A complete system for dielectric constant measurements includes an LCR meter for capacitance and dissipation factor measurements, the dielectric cell, and the connecting cables and adapters. This system enables rapid, precise measurements over a wide frequency range.

A measurement of capacitance Cp is performed at the desired test frequency both with and without the test material in the dielectric cell. Dielectric constant is then calculated using the formula k'=Cx/Co where k' = dielectric constant, Cx = capacitance with a dielectric material and Co = capacitance without a material.

Dielectric cells are manufactured by a number of companies. The dielectric cells are manufactured by Dielectric Products Company, USA. QuadTech LCR Meters have been tested with these dielectric cells.

The trends in aerospace of migrating power extraction from hydraulic toward electric will surely increase the amount of electrical testing within an aircraft. Many of the applications are straightforward and governed by standards. However, as new trends develop standards may not be in place for those new and specialized applications.

Seemingly basic electrical testing equipment can be used in many other ways. LCR meters can be used for more than measuring resistance, capacitance, and inductance. Cable testers can be used to detect and test parts within a harness. A full understanding of the properties of the parts to ensure long-term safety and functionality is key. ∎

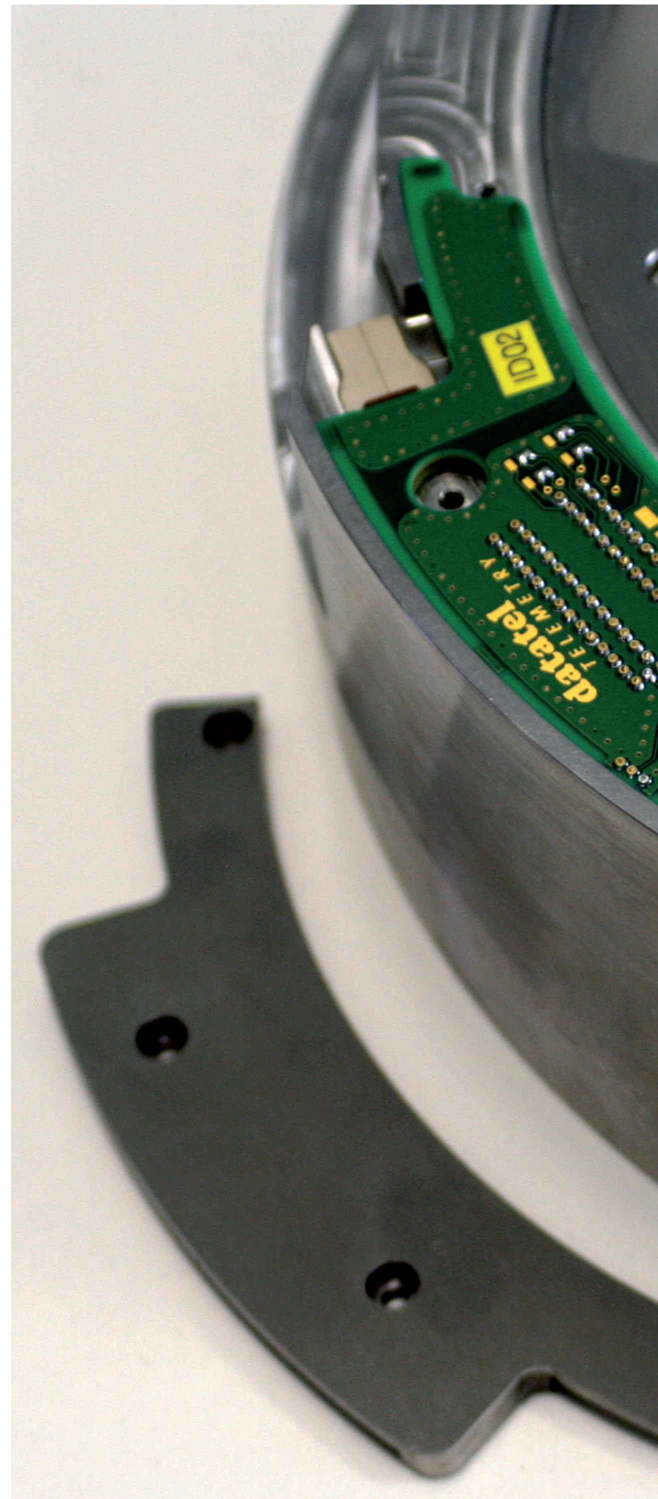
QuadTech's 31000 Series AC Sources enable fully programmable voltages from 0V to 300VAC

CONTACT

Shari Richardson is director of engineering and Robert M. Brown is vice president of technical operations at QuadTech Inc. www.quadtech.com

Next-generation telemetry

AEROSPACE TESTING INTERNATIONAL LOOKS AT THE NEXT-GENERATION DIGITAL TELEMETRY SYSTEMS FOR MODERN AEROSPACE PROPULSION TESTING, PARTICULARLY ROTOR CRAFT



"Current major projects using digital telemetry include open-rotor, counter-rotating wind-tunnel propulsion"


MICHAEL DIEFENTHAELER

BY MICHAEL DIEFENTHAELER

Telemetry in basic forms has long been used to transmit instrumentation measurement data from rotating machinery. Earlier systems were limited in capacity and performance although perhaps an improvement on slip rings with their susceptibility to wear and signal noise. However, recent advances in technology have dramatically increased the capability of such systems.

The use of compact, high-speed, digital electronics has in particular enabled two big steps forward. The first is the provision of individual applications with very high channel counts and all data transmitted simultaneously. Second, the ability to readily provide a mixture of sensor types in the same small transmitter, which greatly enhances the flexibility of transmitter choice to match sensor requirements. The figure on the far right shows a couple of multichannel, multisensor transmitter modules from Datatel, which can be built up into systems with 600+ channels of simultaneous data transmission from a mixture of dynamic and static strain gauges, thermocouples, RTDs, and pressure transducers.

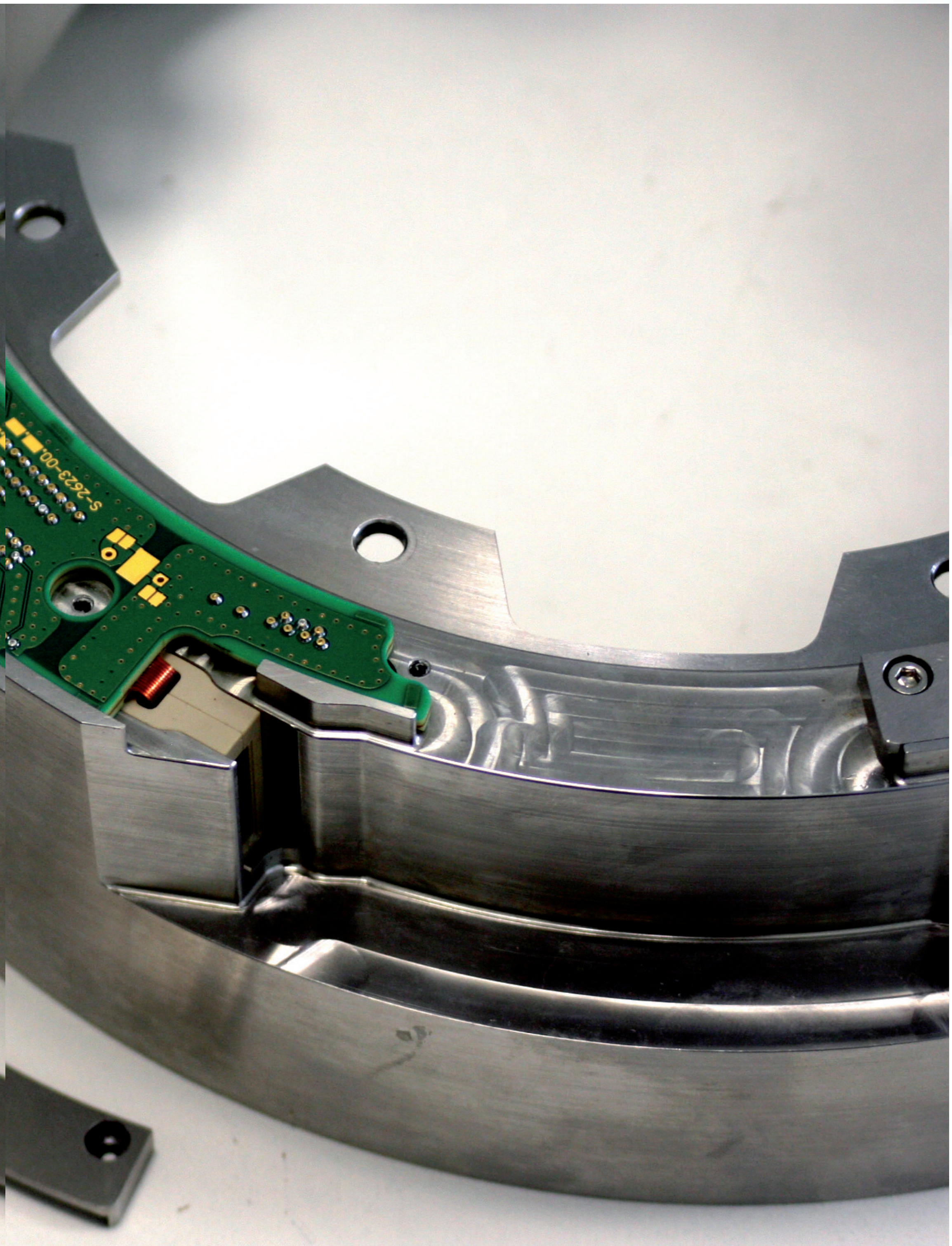
Blade vibration and temperature

The most often mentioned aerospace application for such telemetry is on the rotors of aircraft engines where large-scale surveys of blade vibration and material temperatures are required. However the technology is equally suited to propellers, helicopter main and tail rotors, turbochargers and turbopumps, aero component test rigs, and a wide variety of transmissions.

Current major aerospace projects using digital telemetry include open-rotor, counter-rotating wind-tunnel propulsion models with demanding acoustic measurement specifications and tight space constraints; next-generation compressor and fan test facilities with high-capacity telemetry as a permanently installed feature; in-flight testing of the fans of large turbofan engines involving extremes of environmental conditions. Datatel is heavily involved in all these areas.

For dynamic signals (such as blade vibration, dynamic pressure) modern digital telemetry transmitters can provide bandwidths up to 96kHz per channel with all channels operating simultaneously, although 20-50kHz is adequate for most measurements. Note that this refers to true signal bandwidth, or frequency response, not 'sampling rate'. For static measurements (such as steady strain, torque, static pressure, temperature) a bandwidth of DC to 2-3kHz may be adequate.

Temperature measurements with rotating telemetry are overwhelmingly metal temperatures with inherently very low response rates, and effective bandwidth with thermocouples is down in the DC to 10Hz range. However, Datatel recently launched a static transmitter with several innovative features. In addition to having 10 simultaneous channels per module,

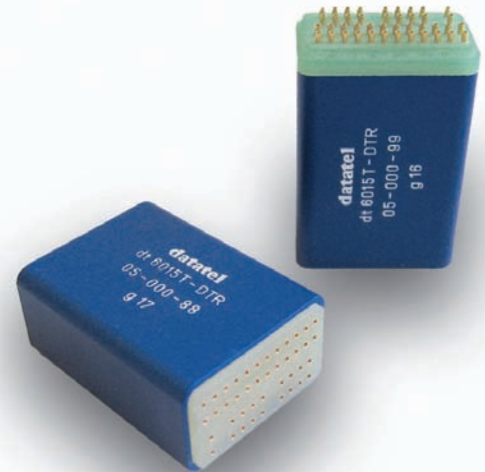


which are fully interchangeable for use with static strain gauges, pressure transducers, thermocouples, or RTDs in any combination with a bandwidth of DC to 19kHz, constant current is used for strain gauge excitation. In contrast to the more usual constant voltage excitation, this automatically eliminates the effects of lead wire resistance variation due to temperature with a consequent improvement in accuracy and linearity.

It should also be noted that all these complex electronic transmitter modules are subjected to severe mechanical constraints and must be able to operate continuously at temperatures up to +125°C and CF loads up to 100,000g. The temperature limit is set by the capability of commercially available solid-state components but operation in higher-temperature environment is possible by using a cooling system.

Diagnostic functions

A major feature of the new systems is the provision of diagnostic functions to permit continuous monitoring of parameters throughout the measurement chain to check data integrity. These include sensor excitation current on/off, selection of excitation current level, dynamic



Multichannel digital telemetry transmitter modules

S/G shunt calibration, detection of open or shorted sensors, resetting of sensor measuring range, monitoring of transmitter onboard temperature and power supply, etc. These functions are controlled remotely at the system receivers via Ethernet connection.

Digital telemetry systems can offer either traditional analog data outputs or a digital interface for direct readout to external data acquisition, display, and analysis through, for example, a high-speed Ethernet link. In addition to providing data in the formats required for modern digital recording systems, the digital interface offers improved accuracy and a more compact, and hence lower-cost, receiver. This is seen, where the analog and digital receiver for a system of 80 strain gauges and 80 thermocouples is shown.

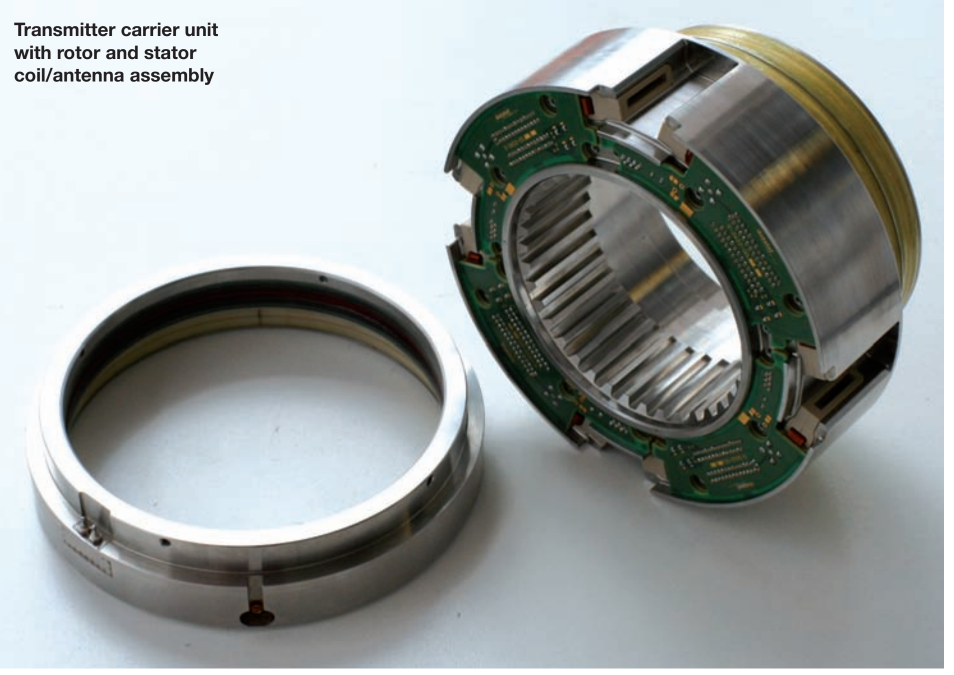
The Ethernet link to the receivers can be used to connect with a graphical user interface (GUI) as is provided with Datatel systems. In this way a PC can be used to configure the complete telemetry installation, inputting component and sensor IDs, calibrations, frequencies, measurement ranges, excitation levels, gains, etc. This configuration, which is unique to that test installation, can then be stored on the PC for reuse or modification as required. If the test is taking place at a remote site, a central laboratory can monitor the system performance continuously via the Ethernet link checking diagnostic parameters for system integrity. However, even more importantly, if problems are observed or data is questioned the laboratory can take control of the telemetry remotely, check any individual channels, make adjustments to settings as required, reconfigure the system and return control to the test operator. This is a powerful support capability.

Circuits as connectors

With compact multichannel transmitters and their arrays of closely spaced connections, sensor lead wire hook-up becomes increasingly difficult, particularly since access is restricted in most applications. For systems with perhaps several hundred channels this becomes a major issue. A technique for dealing with this has now been developed. With this approach printed circuit boards are used as connectors, with pins or tabs on one side to which wires from sensors, RF antenna terminals and power supply terminals can be attached. This is usually done by soldering, but crimp connection is also possible. On the other side of the boards are pins that plug directly into sockets in the transmitters and their associated power supply modules.

In some cases, for example with centerline-mounted systems, the board can make direct connection with a mating half of a proprietary multipin connector that brings the sensor leads to the interface. The board tracks provide all the required interconnections. Standard PCB industry gold-plated pins and sockets are used to ensure safe and reliable contacts. In this way not only is hook-up easier and quicker but possible damage to the transmitters by direct soldering is avoided. Moreover, this technique gives greater flexibility in the direction of sensor wiring to the interface, since connector boards can be arranged to suit preferred routing and clipping. Boards of this type are comparatively cheap to design and manufacture, and can be produced as custom assemblies for each new application. The boards must be carefully located and supported at their periphery and securely retained with screws, but extensive experience has proved them to be entirely satisfactory at the CF g levels involved. This technique has become an integral part of Datatel's application engineering, and has been used on many telemetry installations from the very small to the very large.

All telemetry transmitters require a low-voltage DC supply; this can be supplied directly from batteries, but in the aerospace context inductive power supply is used in almost all cases. This requires stationary and rotating coils, usually arranged as concentric windings, acting as a rotary transformer; AC power is supplied to the rotating element typically in the frequency range of 80-120kHz. Some telemetry systems incorporate the rectification and voltage reduction functions in the transmitters, others use separate AC/DC power modules to provide the conversion. Since inductive transfer by its nature requires small gaps between rotor and stator, of the order of 2-5mm, it is usual to arrange the transmitting and receiving RF antennae with the power coils to give the best coupling. Coil/antenna assemblies are often integrated with the transmitter carrier, but they can be quite separate if the installation requires it. For example, telemetry on the fans of large aero engines with 'overhung' rotors may have the transmitters mounted forward, close to the sensor lead-outs, but the coil/antennae set is located at the rotor bearing and support structure. Examples of coil/antenna sets are shown in the figure above.

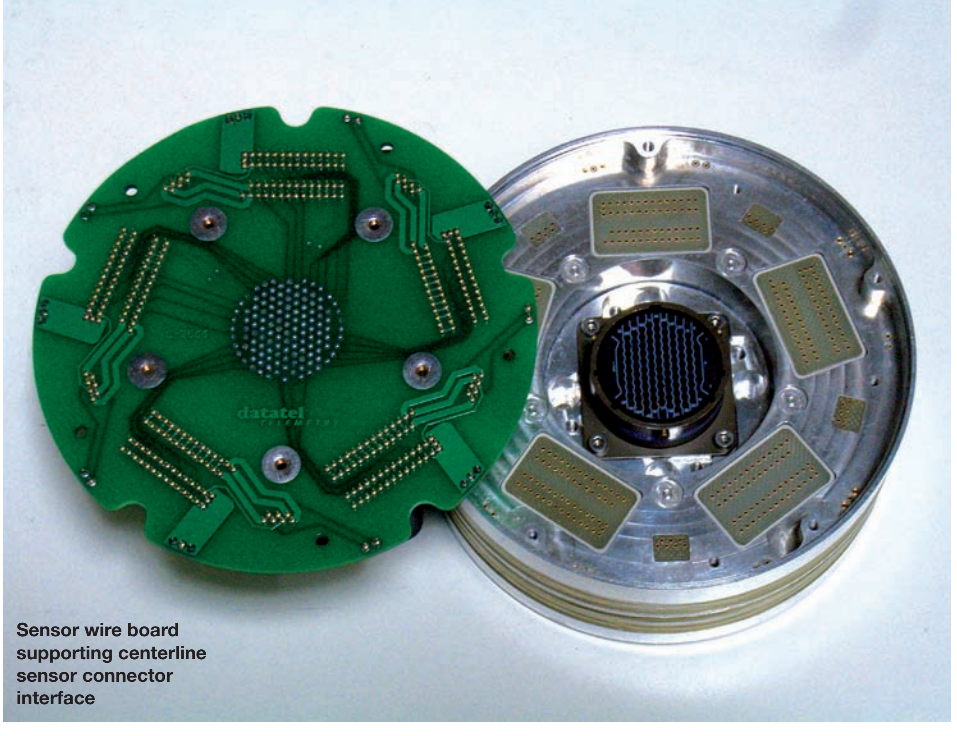

Transmitter carrier unit with rotor and stator coil/antenna assembly

Rotating telemetry system

It will be clear from the above that in the development testing arena the creation of a rotating telemetry system for a particular application is not a simple matter of selecting a set of off-the-shelf components and wiring these together. Although the electronic units are fully modular and can be assembled into an architecture to meet the broad measurement requirement, each physical installation is a distinct application engineering task. Having chosen numbers and types of transmitters to provide the required channel counts of various sensors, a carrier must be designed to support them at the speed involved. If the sensor hook-up technique described above is used, the circuit board connectors and their mounting arrangements must be designed.

A coil/antenna arrangement must be designed to match. It is essential that variations in the relative positions of rotating and stationary parts during operation are determined as the design of the power coils and antennae must allow for these movements while maintaining correct coupling. Space constraints always make integration into the engine or machine difficult, and parts will need modification to accommodate the telemetry. If ambient temperature is too high, cooling by air or oil or both will be needed and must be built into the design.

So the design process becomes an exercise in close cooperation between the telemetry supplier and the customer, each supplying relevant skills and knowledge to ensure that the installation is fully integrated into the machine and gives satisfactory performance with prolonged and reliable operation. Datatel has developed particular expertise in this type of application engineering, and has all the experience, skills and resources needed to provide complete turnkey telemetry installations. ∎



Sensor wire board supporting centerline sensor connector interface

CONTACT

Michael Diefenthaeler is international sales manager at Datatel. Paul W. Cooper is the US agent of Datatel Telemetry.

Sound proving techniques

IMPROVEMENTS IN ULTRASONIC INSPECTION OF PARTS CAN HELP TOWARD REDUCING THE COST OF THE DEVELOPMENT PROCESS

"The couplant used in automated testing is usually water; a gel can be used for manual inspections"

BY CHRIS GARTSIDE

The increasing use of composite materials in aerospace structures brings with it the need for more cost-effective non-destructive testing (NDT) equipment and procedures. The application of advanced manufacturing processes using exotic materials is another factor that places demands on NDT equipment suppliers. Aerospace manufacturers constantly strive to reduce the cost of testing, and the inspection time is a crucial factor. Test equipment suppliers have to continuously refine their equipment to help manufacturers reach this goal.

One of the principal NDT methods is ultrasonic testing using frequencies of 0.5-25MHz. Pulses of ultrasound are transmitted into the material under test, and the reflected or transmitted signals are analyzed to provide information on the material structure. Although manual testing is still widely used, an increasing number of inspections are carried out using automated systems that generate acoustic images, known as C-scans and B-scans. These display plan-view and cross-sectional images respectively.

There is a wide range of features in aerospace materials and structures that can be imaged in this way. For wrought metals such as plates and forgings this includes porosity, inclusion, and lamination defects when they exceed a specified size. In welded assemblies the problem features are likely to be lack of fusion, porosity, and cracks. As far as composite structures are concerned, producers need to detect bonding defects, delaminations, and porosity as well as the presence of foreign materials in the lay-up. Because of their multiple layer structure, metallic parts fabricated by SPFDB processes (superplastic forming and diffusion bonding) are inspected for similar defects.

As ultrasound at the required frequencies cannot be transmitted efficiently through air, a liquid 'couplant' is used between the probe that generates the ultrasound and the part under test. The couplant used in automated testing is usually water; a gel can be used for manual inspections.

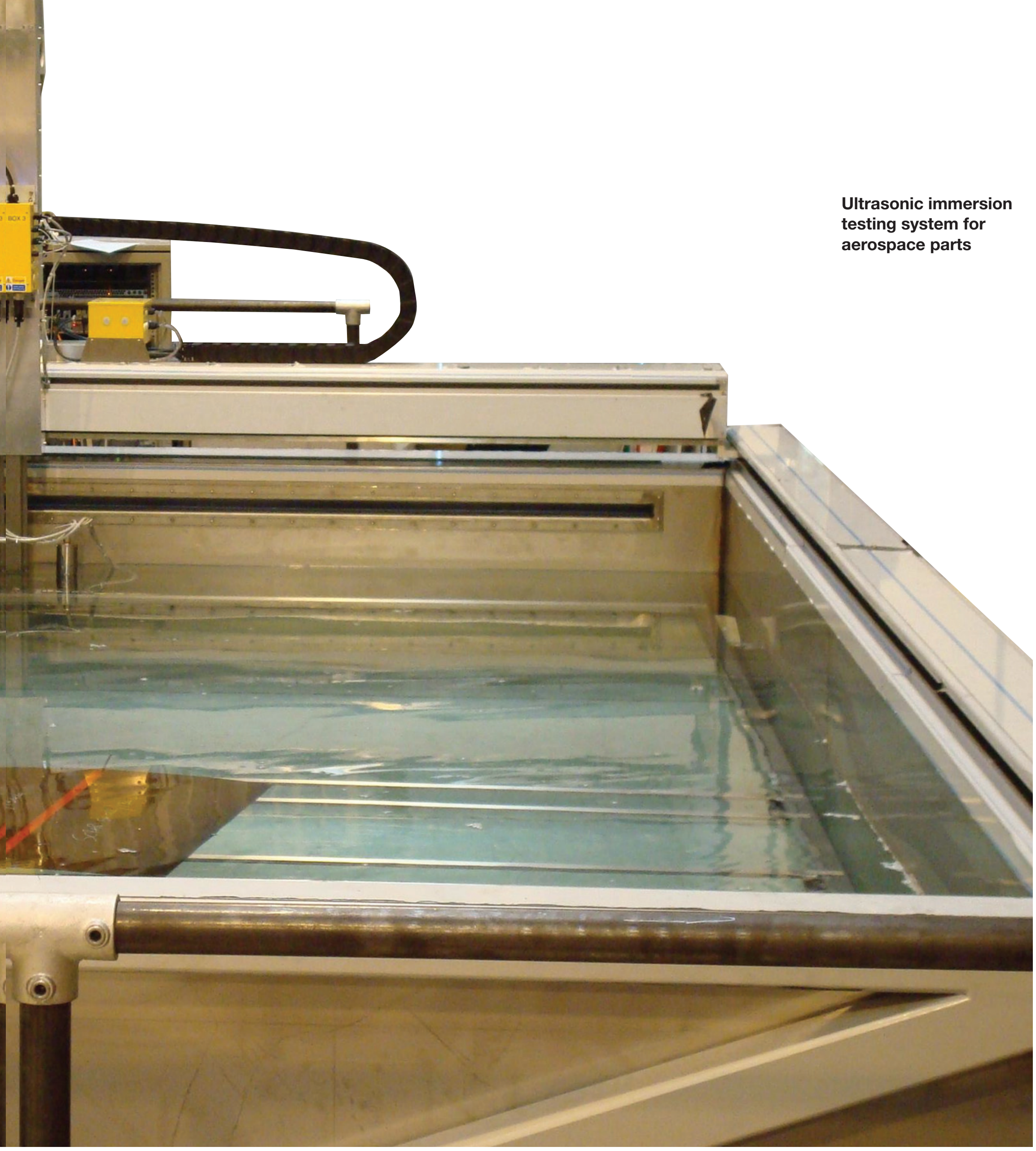
CHRIS GARTSIDE

Inspection techniques

Machines designed for automated testing use one or more of the three main techniques for coupling the sound into the test material. These are contact, immersion, and water jet (squirter) inspection. With contact testing, as the name implies, the inspection probe is in contact with the product being tested. This has the advantage that mechanical followers can be used to test shaped products, but the inspection speed is usually limited and there are other technical issues that prevent wider application.

In most cases immersion or squirter techniques are used, where the tested parts are completely immersed in water or where the sound is transmitted through water jets. Immersion methods usually involve inspection from one side only, using the pulse-echo technique, in which the same probe is used as transmitter and receiver. In recent immersion systems installed by Ultrasonic Sciences Ltd (USL), the productivity of the system is improved by the ability to operate in two different modes, dependent on the requirements of the inspection and the shape of the part. In the first mode, complex-shaped parts are scanned using a single probe. This is relatively slow, with typical linear speeds of 500mm/sec, scanning in a raster fashion at 1mm pitch – this is roughly equivalent to a coverage of $2m^2$ per hour. For much higher throughput the system can operate in the second mode. This uses an array probe typically 100mm wide, with a combination of electronic scanning across the array and mechanical motion. This is capable of achieving a throughput of more than $1m^2$ per minute on flat and single-curved products, which is a dramatic increase in productivity compared with a single probe.

With this system a probe array containing



Ultrasonic immersion testing system for aerospace parts

up to 128 individual elements is used. Groups of these elements are fired sequentially, with the selected group being indexed across the array in small increments. This occurs at very high speeds, typically up to 20,000 times per second, which means the complete array can be electronically scanned several hundred times per second as the array moves mechanically to cover the entire area of the part. Each individual sound beam, or 'focal law', can be controlled so that it interrogates a small area of the test material, producing a very detailed image.

With squirter methods the sound is transmitted by a probe through a water jet on one side and received by a second probe on the opposite side. During scanning, the angle of both water jets must be accurately controlled and they must also remain coaxial, otherwise the ultrasound signals are lost. This places severe demands on the control of the mechanical systems, especially when scanning complex parts with dual curvature. Productivity improvements here are more difficult, but in USL systems scanning speeds have been increased even on complex shapes without compromising the quality of the inspection.

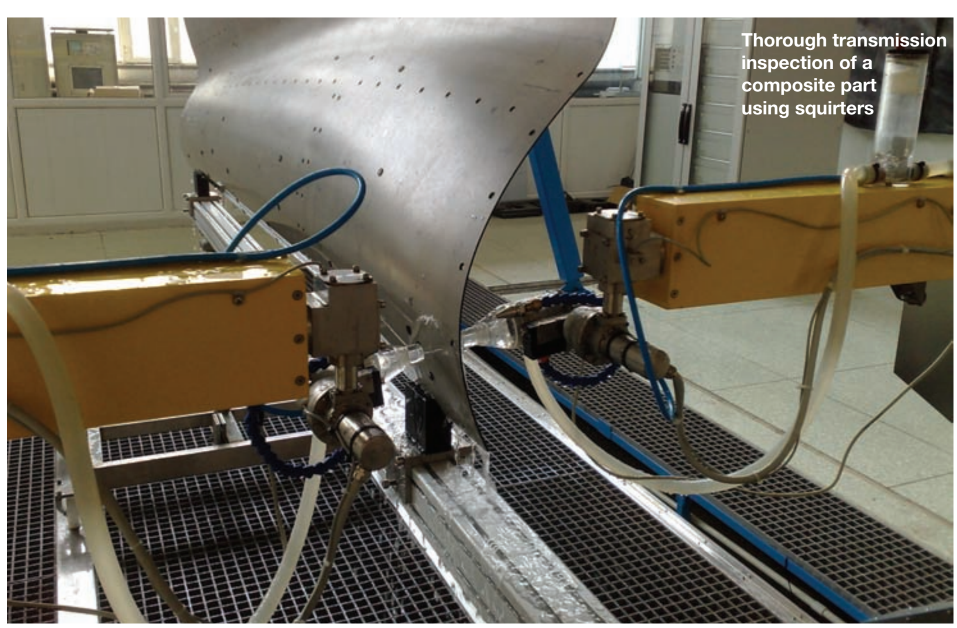
The shape of manufactured composite parts can be very complex in military and commercial aircraft structures. Ultrasonic testing systems need to incorporate multiple mechanical axes in order to scan these complex shapes. Typically systems will have 10 to 12 axes, with all of these simultaneously controlled in order to follow the profile. The illustrations show USL machines with two different configurations: one with horizontal opposed manipulators and the other with vertical manipulators in a gantry or portal style. The choice is governed by the range of shapes to be inspected and also by the test methods specified by the user. Sometimes the squirter and immersion methods are both required; in these cases the vertical system is the preferred option.

CATIA models

For immersion and squirter systems a major potential bottleneck in programming the shape of the parts has been by-passed by generating the complex scan profiles directly from CATIA (computer-aided three-dimensional interactive application) data.

Unfortunately the CATIA model, especially in a composite component, does not always represent the actual shape of the part at the inspection stage. This is partly a result of 'springback' after removal from the molding tool, and also because these parts are not usually self supporting and can easily droop or twist when held at two or three location points. In addition to this, there may be small differences in the location of the part in the testing machine.

Although the sum of the differences may be small, it is enough to affect the validity of an ultrasonic test on a complex-shaped part. USL has developed procedures that automatically measure the true position and shape of the part before the inspection begins. This adjusts the scanning profile in three dimensions, recalculating the instantaneous positions of up to 12 axes so that the probes follow the actual shape rather than the theoretical shape. This procedure avoids the need for rescanning, which in normal circumstances may only become apparent toward the end of



Thorough transmission inspection of a composite part using squirters

Squirter system with 12 axes – vertical gantry type

Large-scale immersion system for plate inspection

> **"In any ultrasonic test it is crucial to control the angle of the sound beam with respect to the surface"**

a lengthy scan.

In testing semi-finished aerospace products it is usually necessary to generate detailed ultrasonic images, so that any problem areas can be visualized. A degree of automated analysis can be applied to these images, but this is limited because of the complexity of structures. It is much easier and quicker for an operator to analyze the images. Homogeneous materials, however, can lend themselves to automated analysis, so that defects are highlighted and the operator merely has to confirm that an indication is a defect and not an artifact. A typical example is in inspection of aerospace aluminum alloy plate, where defects as small as 0.4mm diameter may have to be detected with 100% reliability in material up to 200mm thick.

Ultrasonic squirter system with 10 scanning axes – horizontal type

It is essential to use highly specified ultrasonic instrumentation, with a high signal-to-noise ratio and exceptional immunity to external noise sources. However, this alone is not enough to ensure 100% detection of small defects. This has prompted USL to incorporate special features in systems of this type, which are now in widespread use throughout the world.

Sound control

In any ultrasonic test it is crucial to control the angle of the sound beam with respect to the surface. This is simple if the tested product is perfectly flat, level, and parallel, but this is seldom the case in practice. In fact the variation in surface profile may be random and unpredictable.

In order to achieve a high material throughput in plate inspection, multiple probe assemblies are employed with multiplexing instrumentation. Typically seven to 15 rectangular probes will be used in a staggered formation, covering a band of material between 80 and 150mm wide. As the material is scanned in an immersion tank, the surface position of the plate is measured by all the probes, at the same time as they are being used for defect detection. The measured distance between the probe face and the plate surface, known as the water path, indicates the angle of the surface relative to the probes. This is used to adjust the probe manipulator in real time, so that the inspection angle is maintained at the correct value – usually 90°. This helps ensure that defects are reliably detected over the entire plate surface.

At the end of the scan, possible defect indications are highlighted on the C-scan image. The scanner automatically moves to each one in turn and the operator confirms that the indication is a defect or an artifact, such as a surface mark or air bubble. Because the rectangular probes are designed for defect detection, but not accurate defect sizing, the system uses a circular focused probe for this part of the sequence. In some cases electronically scanned arrays, as described earlier, are used for these plate-testing applications, but the throughput using multiple probe assemblies is generally higher.

NDT is frequently one of the last things to be considered when parts are designed, and this can create difficult problems. Advanced assembly methods such as diffusion bonding, friction welding, and friction stir welding are now being routinely used to produce very complex metal parts that require some form of NDT. This places new demands on test equipment manufacturers and NDT practitioners alike because the complexity can make access very difficult. Similar problems arise in aerospace composite materials as a result of the wider use of processes such as resin transfer molding. These need to be solved without causing manufacturing bottlenecks and productivity issues, so innovative solutions in instrumentation, mechanisms, and software will continue to be required. ∎

CONTACT

Chris Gartside, sales director
Tel: + 44 (0)1252 350550
Email: chris.gartside@ultrasonic-sciences.co.uk
www.ultrasonic-sciences.co.uk

Digital model airborne cameras

IN AIRBORNE APPLICATIONS, HIGH-SPEED FILM CAMERAS ARE BEING REPLACED BY LATEST-GENERATION DIGITAL MODELS, WHICH HAVE A VARIETY OF ADVANTAGES OVER THEIR PREDECESSORS

BY RETO HUBER


RETO HUBER

Among a wide range of possible applications for high-speed airborne cameras, release and store separation tests are the most popular. Until recently, 16mm film cameras were the standard high-speed imaging devices and offered excellent results; technology-specific disadvantages such as film processing time and the need to digitalize the film for software-based motion analysis were accepted.

Since most manufacturers of 16mm film for high-speed cameras ceased production or announced the possible phase-out of specific materials, all parties affected have had to think about replacing their existing high-speed film cameras. The change from film to digital will be eased by the advantages of this new technology, such as immediate access to digital image data without the long processing time, plus a range of new, advanced functions such as multiple digital inputs and outputs to integrate external signals with the image data.

On the other hand, an airplane is not like an industrial assembly line where modifications to reposition a camera are usually simple to accomplish. What about installing extra data and control cables to an airplane? Or connecting a camera to the airplane's power system? There is also the test routine itself: does it need to be modified to accommodate new digital cameras? How easily are they adopted by the pilots and camera operators?

Take one example: a film-based camera has a specific ramp-up time because its film transport motor needs to get up to speed. Digital cameras have no transport motor and hence no such ramp-up time, and they also offer a flexible and sophisticated trigger setting unknown by film cameras.

Digital high-speed cameras by AOS offer a built-in PowerPC, which enables customer-specific configuration of its input and output signals as well as its functionality. This keeps necessary modification on the airplane as well as on the test routine to a minimum.

Case studies

Two examples of various real-life applications will illustrate this. In the first example, the film-based camera started to record as soon as voltage was applied, and the transport motor was up to speed for as long as there was film in the camera.

The replacement digital high-speed camera was configured in exactly the same way, the same voltage (28VDC) was switched on and supplied the camera with power, and after a software-simulated ramp-up time of three seconds, the camera started recording until its built-in image memory was full. The test procedure could remain the same; no modifications to the procedure were necessary.

The second example is substantially more sophisticated. A number of external input and output signals – many of these in hand-shake routines – were used to operate the camera, including IRIG-B time-stamping. Similar to the first example, the digital high-speed camera was configured to accept the very same input signals, to simulate in a correct way the output signals, including the hand-shaking routines, as well as to mark each digital frame with the correct time stamp as received from the IRIG-B source.

In addition to simulation of the film camera, the customer requested the highest guarantee against the unlikely loss of digital image data due to power failures or electromagnetic noise. This request could be easily and successfully answered by two camera features. First, a built-in rechargeable battery that can bridge power failures of the airplane's power system for up to three hours. To eliminate the risk that the image data could not be retrieved and securely downloaded via a data network to a mass-storage device like a hard disk within these three hours, the camera transfers the image data from its RAM memory to a built-in non-volatile memory

The AOS manufactured X-EMA MIL-certified high-speed camera

('flash disk'). But what if the airplane's engine – and therefore the camera – is started, but then the airplane has to be shut down unexpectedly for security reasons? The battery of the camera would drain if there is no more external power from the engine. This would result in an empty battery for the airborne test. A digital high-speed camera with a built-in PowerPC can be configured so it shuts down automatically if there are no images in the memory and external power is removed.

These are just a few examples of the variety of smart features the AOS X-EMA high-speed camera offers.

In addition to these customized configurations, other basic features of airborne high-speed digital cameras are compact size so they fit into the existing space, which is in most cases limited; ultra-solid design and structure to withstand the harsh environmental conditions of flight; and immunity to shock, vibration, changes of temperature, and moisture. Cameras designed for airborne applications, such as the AOS X-EMA, are tested and certified to rigid standards including MIL-STD 461 and MIL-STD 810.

Hostile environments

In demanding environments such as the airborne test and measurement world it is sometimes unavoidable to adapt the digital camera to meet the specific needs of the test setup. Another reason for adapting cameras to test environments is the emerging range of applications for which digital high-speed cameras are used. As an example, in a UAV (Unmanned Aerial Vehicle) the high-speed camera is used to record a specific event. However, the ground station likes to have a live video out from the camera on the ground. Integrating such a feature into a camera sounds easy but is a major task to accomplish.

The main purpose is to record the high-speed event. The live image transfer to the ground must be realized in parallel. This live image data transfer is done by converting the images into a common digital format (such as JPEG or MPEG stream). Furthermore, it is important to implement bandwidth control in order to limit the data stream sent to the onboard telemetry system, otherwise the large amount of image data would jam the telemetry system and critical flight data would not reach ground control. Finally, ground control wants an efficient, reliable, easy-to-use software interface to see what the high-speed camera sees.

For such projects AOS Technologies takes on responsibility starting with the concept. Working closely with customers, the company develops special mechanics and, where necessary, add-on electronics to the specific camera; it also provides the necessary software, sometimes accommodating DO standards. Some customers request that after such changes the camera goes through retests of MIL 810 or equivalent procedures. AOS works closely with a renowned test lab to obtain independent judgement of its products and work. In the final project phase AOS Technologies works closely with customers when installing the camera and getting ready for the mission.

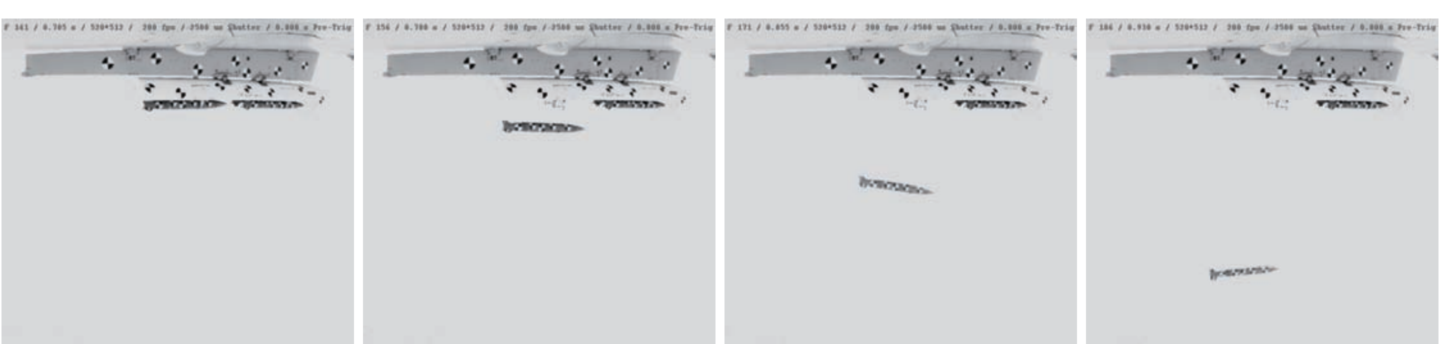
AOS Technologies has successfully completed projects with major aircraft manufacturers, and has a proven record of successfully installed cameras.

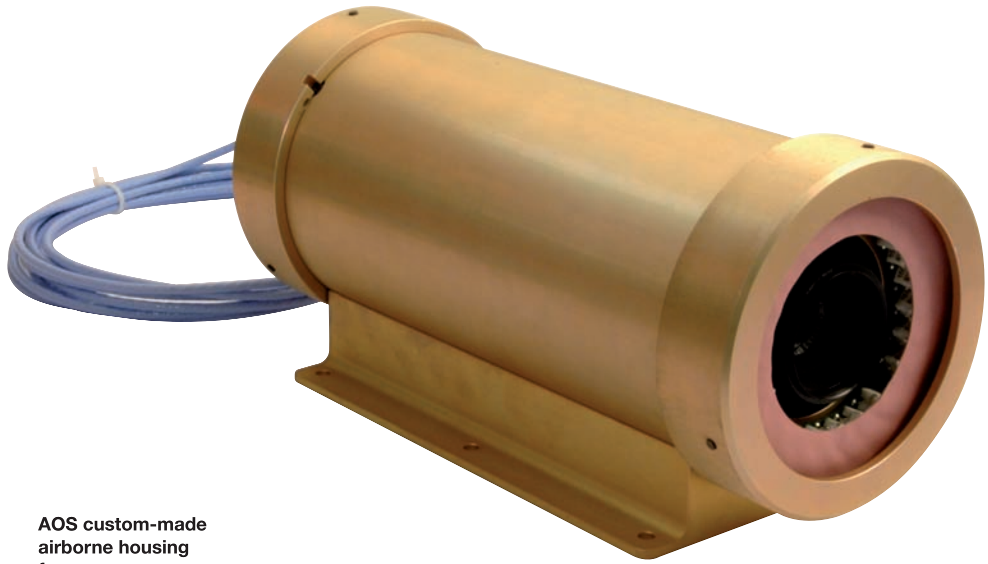
Using a chase plane

In a wider interpretation of airborne applications, AOS Technologies produced a product named X-CHASE. X-CHASE is used to record phenomena on an airplane chased by a second airplane in which a cameraman is seated in the cockpit. The AOS X-EMA camera equipped with a handgrip, a trigger button and either an optical viewfinder or a video screen attached to the video output acts as a handheld high-speed camera. Some changes in the firmware enable the filling of the camera memory with multiple buffers, each buffer containing one test. These

"X-CHASE is used to record phenomena on an airplane chased by a second airplane in which a cameraman is seated in the cockpit"

High speed camera military drop sequence





AOS custom-made airborne housing for camera

buffers are then automatically downloaded to the internal compact flash card. As soon as download is completed the cameraman replaces the CF card and is instantly ready for another set of tests.

With the camera's internal battery, viewfinder, and trigger button on the grip this setup does not require any cabling to the airplane or the cameraman. But what is a camera without carefully made and selected accessories? Lenses used for airborne applications are often of the highest quality and therefore expensive. AOS X-EMA cameras are designed to accept 16mm film lenses, which cover a sensor area of 800 x 600 pixels which, at that format, recording up to 1,000 frames per second (800 x 600 pixels at 12µm pixel size) producing images equivalent to 16mm film format.

If the cameras are not installed inside the airplane or in a specially designed bin, a robust and well-built airborne camera housing is an essential part of a camera system, providing reliable camera performance not only on the ground but during challenging flight test conditions as well. Due to the compact size of the camera, the camera housing is equally compact and enables mounting to the airplane in almost any position.

Finally, experience in airborne applications is essential to guarantee not only the best fit of the camera and accessories to meet the customer's needs and requirements, but also to fit their budget. In many cases certain specific requests can be answered by a special firmware configuration for the camera, eliminating the need for additional hardware.

Since airborne cameras have to perform reliably and over a long period of time, after-sale service as well as long-term availability of spare parts must not be overlooked during the evaluation process. Specially trained partners and subsidiaries around the world and on all continents offer ongoing technical service and support not only during installation and integration, but also in case of a need for assistance – be that user support, repair, system extensions or upgrades. ∎

CONTACT

Reto Huber is from AOS Technologies AG, based in Baden-Daettwil, Switzerland
info@aostechnologies.com
www.aostechnologies.com
Tel: + 41 56 483 3488

Structural dynamic models

GROUND VIBRATION TESTING OF LARGE AIRCRAFT CAN BE OPTIMIZED BY THE USE OF FINITE MODELS

"The main GVT objective is to experimentally determine the low-frequency modes of the whole aircraft structure"

BART PEETERS

BY BART PEETERS & HÉCTOR CLIMENT

Ground vibration testing (GVT) of aircraft is performed late in the development process. Its purpose is to obtain experimental vibration data of the whole aircraft structure for validating and improving its structural dynamic models. These models are used to predict flutter behavior and to plan the safety-critical inflight tests.

Recent technology advancements have realized a testing and analysis time reduction without compromising the accuracy of results. Highly efficient testing is achieved by integrating complementary excitation techniques in a single software environment. Built-in modal analysis capabilities ensure that test data is validated almost in real time during the test.

GVT can also be planned using a virtual prototype. The integrated use of test and FE (finite element) models provides optimal GVT planning and generates an updated FE model shortly after the test.

A new 700-channel GVT system was successfully deployed during a demonstration test on the A310 Boom Demonstrator Aircraft and a certification test on the A330 MRTT.

EADS CASA

Spain-based EADS CASA Military Transport Aircraft Division (EADS CASA MTAD) is a division of the European Aeronautical Defense and Space Organization that develops aircraft and space systems. EADS CASA MTAD has experience in designing and manufacturing advanced aero structures and can build and certify complete aircraft.

Currently EADS CASA MTAD develops aero structures for various aeronautical programs: horizontal stabilizers (A400M, Falcon 7X), flight control surfaces (B-777, B-737, Falcon 7X, A400M, Eurofighter), engine nacelles, fiber placement technology fan cowls (A340-500/600, A380, A318), metallic structures (A380 belly fairing, A318 fan cowls, A320 Section 18, A330/340 central box) and leading edges (Airbus). MTAD offers customized solutions based on two Airbus platforms: the A310-300 and A330-200.

For the A330 MRTT (Multi Role Transport Tanker) and A400M certification processes, MTAD partnered with Álava Ingenieros and LMS International to renew their GVT measurement system.

The EADS CASA flight test program aims to prove the performance of the new boom installed on an Airbus platform and includes opening the tanker work envelope or performing dry/wet contacts with an F-16. Preliminary test results have shown that the aircraft platform and boom structure are free of any flutter vibration. The influence of the boom installation on the aircraft handling has proved to be minimal, and no influence on the APU air intake has been detected.

The A330 MRTT is an aircraft with a maximum fuel capacity of 140,000 liters, which retains its full passenger capacity and the aircraft's dual-use capability.

Inflight fuel transfer can be performed by hose-and-drogue systems or by boom system. The new ARBS (Air Refueling Boom System) has an advanced air refueling boom structure, fly-by-wire control with a larger refueling envelope and controllability, including an automatic load-alleviation system.

Trends with GVT

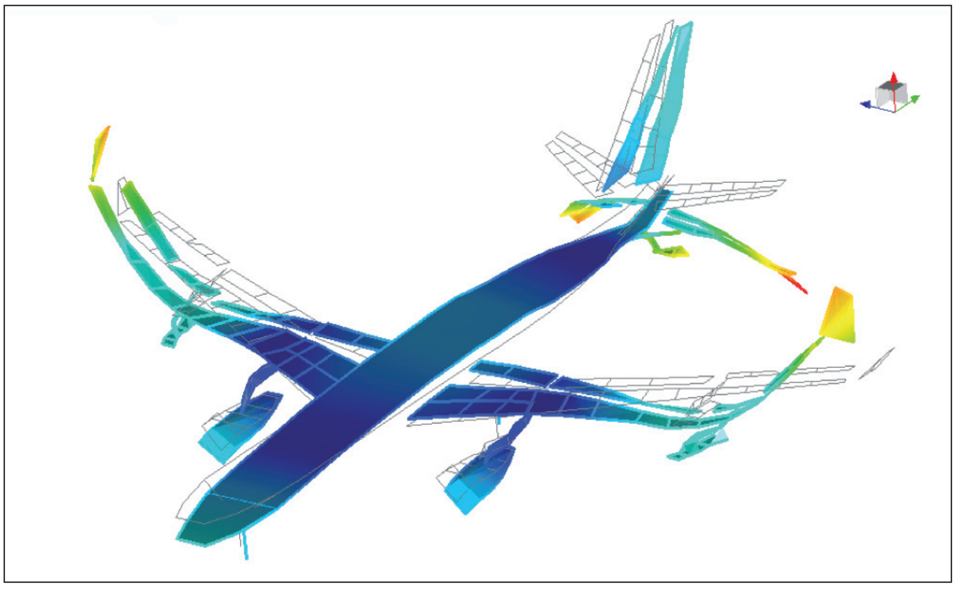
The main GVT objective is to experimentally determine the low-frequency modes of the whole aircraft structure for validating and improving its structural dynamic model as part of the flutter clearance process. More complex aircraft designs have raised additional testing requirements related to the increased use of composite materials, active systems, and non-linear behavior quantification.

Reconciling test complexity and result accuracy with cost and time reduction requirements for a GVT has motivated much research. The integration of test and CAE is the path to follow for further research.

For more than three decades, the phase resonance method or normal mode testing has been required for GVT on large aircraft because it is well suited for the separation of closely

A330 Multi Role Transport Tanker (left). Pictures courtesy EADS CASA

A330 MRTT mode shapes (below)



spaced modes. In normal modes testing, single sine excitation at natural frequencies of the modes is used. By carefully selecting the shaker locations and phase relation between the sine excitation signals, the aircraft is forced to act as a single degree of freedom system, and the vibration response only contains a contribution from the mode of interest.

The main disadvantage is that it is a very time-consuming test procedure. Therefore, the phase resonance method is complemented by phase separation techniques that find the modes by evaluating FRFs (frequency response function). Most modes are extracted from a fast phase separation technique, but 'critical' modes are identified via normal mode testing. Modes are considered critical if they differ considerably from the predictions, show non-linear behavior, or if they are important for flutter calculations.

Since the 1980s, EADS CASA has been promoting 'random excitation' for small and medium-sized aircraft. This approach was successfully applied to the CASA trainer aircraft C-101 GVT. The same approach was applied to the Eurofighter aircraft DA6 prototype GVT in the 1990s.

Many shaker excitation signals can be used to experimentally determine the aircraft broadband FRFs. These excitation signals include harmonic signals such as discrete stepped sines, periodic signals such as multisines or a periodic chirp, and transient signals such as an impulse, a (burst) random, or a swept-sine signal. They differ in their spectral energy contents and test duration. Swept-sine excitation represents a compromise between magnitude of excitation level needed and testing time.

Virtual prototype

For this GVT campaign at EADS CASA, teams from EADS CASA, Álava Ingenieros, and LMS Engineering Services cooperated.

The shakers were controlled and the transducer signals recorded by a 700-channel LMS data-acquisition system consisting of four Scadas III front-end frames connected in master/slave mode with eight sources and 700 measurement channels. The LMS Scadas III is a completely digital front-end with one sigma-delta ADC per channel, 24-bit data transfer and ultra-low-noise floor. The V12 modules provide voltage, ICP, and TEDS signal conditioning. The sensor connectivity was facilitated by embedding the front-ends in two racks with patch panels.

In addition to a data-acquisition PC that processed and stored data, two analysis stations performed on-site modal analysis, ensuring optimal use of testing time and engineering resources. The PCs were equipped with LMS Test.Lab data-acquisition and analysis software. This software combines all GVT test modes in one user environment: MIMO random, swept sine, stepped sine, and normal modes (phase resonance), working with the same database for fast transition from one test mode to another.

Seamless integration between test and analysis was realized by offering analysis capabilities as add-on functions for almost real-time modal parameter estimation, which was considered as an advanced check of measurement quality and data validity.

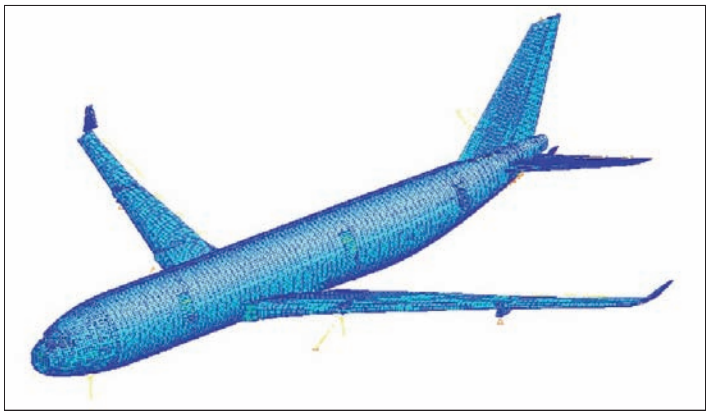
Test conditions

During the test, the aircraft must be in a 'ready for flight' condition and as close as possible to the flight test configuration. The flight control systems are serviceable and kept in a 0° position. The flap and slat systems are serviceable retracted and locked. The control systems of the trimmable horizontal tail are serviceable and the horizontal tail is kept in 0° position. The hydraulic systems are switched on. The refueling boom system is empty and stowed. The landing gear is extended and the tires flattened to reproduce free-free boundary conditions.

The first test was a random excitation test involving six shakers at the wings and the horizontal tailplane. The random test gave an initial indication of the presence of resonances. This test suffered from low energy input at low frequency. This was observed in low force levels at the lowest frequencies, incorrect driving point behavior, and poor reciprocity. A solution was to add masses to the shakers so that the force level became the limiting excitation factor rather than the stroke.

The LMS PolyMAX modal parameter estimation method was applied to the random excitation frequency response functions. The PolyMAX method analyzes a large frequency band containing a high number of modes in a single analysis run. A measurement quality indicator is the coherence function that combines leakage, noise, and non-linearity effects on the FRFs measured at a certain degree of freedom. Because of high channel counts, browsing through all coherence functions is cumbersome. Averaging the coherences over certain frequency ranges and plotting average values at each sensor location in a geometry display could help. The coherences of close and structurally related locations should not differ too much. The FRF quality at the wings was relatively good, whereas the fuselage and horizontal tail plane locations had lower coherences.

"The FE model, available prior to the GVT, can be used to predict the aircraft dynamic behavior"



A330 MRTT FE model (left)

Driving point FRF from random excitation test. LMS PolyMAX stabilization diagram from sine sweep excitation test (below)

After the random test, MIMO sine sweep excitation was applied using two shakers attached at different locations. The FRFs obtained by sine sweep testing are higher quality than when exciting by random noise. The PolyMAX method was used to estimate the modal parameters.

It is interesting to look at the 'system FRFs'. These are transfer functions [N/V] between source signal voltages [V] and actual forces [N] measured by force cells between the shaker stingers and the aircraft. These system FRFs are not flat in the lower frequencies. It is also clear that a voltage sent to a certain shaker has a considerable influence on the force measured at the other shaker due to the large shaker-structure interaction that exists in the lower-frequency band.

Phase resonance

With the selection of two-shaker excitation combinations used for MIMO sine sweep testing, the phase resonance (or normal modes) testing capabilities of the new GVT solution were verified. The following modes were subjected to phase resonance testing: all engine modes, horizontal tail plane (HTP) roll mode, HTP yaw mode, as well as elevator rotation and twist modes. The automatic tuning algorithm immediately detects the modes under investigation.

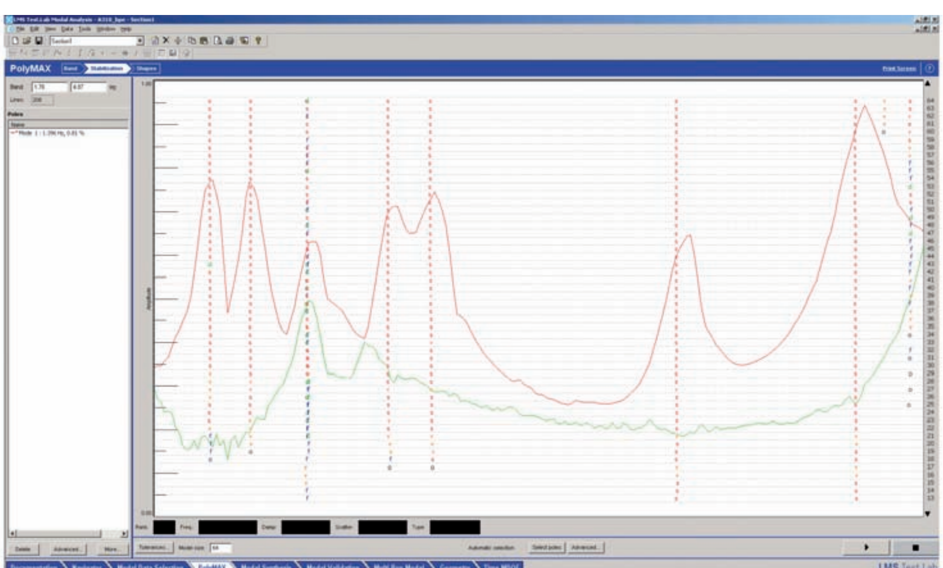
When the mode is perfectly tuned, the real part should be zero. A non-linearity check was also performed. The tuning procedure was repeated at five different shaker force levels and a relationship between the eigenfrequency of the normal modes and the force level was established.

Integrated use of FE models

The FE model, available prior to the GVT, can be used to predict the aircraft dynamic behavior and optimize the test arrangement and duration.

The normal modes obtained from the FE model before the test represent an estimation of the aircraft eigenfrequencies and mode shapes. This information is used to determine excitation conditions, shaker and accelerometer locations. At the start of the GVT the aircraft is weighted and the rigid body eigenfrequencies measured.

With these results recorded, a second loop of normal modes calculations is then performed. Once the model has the correct test-measured masses and boundary conditions, the right comparison between all flexible modes indicates whether the FE model needs to be updated or not. If the frequencies are greater than 5%, the model needs to be corrected accordingly to account for local effects or absent components. ∎



CONTACT

Bart Peeters, LMS International, Interleuvenlaan 68, B-3001 Leuven, Belgium
www.lmsintl.com
Héctor Climent, EADS CASA

Equipment protection systems

PROTECTION SOLUTIONS AND ADVANCED LIGHTING SYSTEMS ARE OF COURSE INVALUABLE FOR THE CIVIL AND MILITARY AEROSPACE PROFESSIONAL

> **"Tool theft prevention comes in the form of tamper-resistant, stainless steel padlock protectors"**

BY MARISA SILVA

Following the acquisition of Hardigg Industries on December 23, 2008, Peli Products SL (the EMEA headquarters of Pelican Products Inc, a leader in the design and manufacture of advanced lighting systems and virtually indestructible cases), now offers the world's most diverse group of protective case and lighting solutions for the aerospace test engineering community.

Built with engineering-grade polymers, Peli cases are the toughest on the market and come in more than 40 models that can protect sensitive equipment of all sizes. Peli cases are watertight and feature a fully stackable, trademarked 'dual band' design. They also feature an automatic pressure equalization valve that keeps moisture out and prevents vacuum lock so the case is easier to open at any altitude.

The 0450 Mobile Tool Chest combines the flexibility of seven removable tool drawers (six shallow and one deep drawer) designed for a multitude of configurations with the mobility and benefits of a Peli case. Additionally, the top compartment features a removable utility tray and a lid that opens 180° to create a mobile workspace that is capable of holding 23kg. Tool theft prevention comes in the form of extra-large, tamper-resistant, stainless steel padlock protectors.

Storm cases

Engineered for extreme, military, and industrial applications, Peli storm cases are built from Pelican's patented HPX high-performance resin, which makes them lightweight and virtually indestructible. With 23 models to choose from, all Peli storm cases feature the company's durable 'press & pull' latches, which open smoothly yet hold fast when the case is taking a beating. Durable, wide, soft-grip handles with rigid cores make the cases comfortable to carry.

Peli case and Peli Storm case interiors can be easily customized to protect anything from a laptop to weapons.

Hardigg rack-mounted cases are lightweight and compact, offering light- to medium-duty protection for hard drives and servers. Removable lids on both ends enable rapid access to rear connections and front controls.

Specialty products

Well-engineered portable workspace solutions include portable desks that set up in minutes, and storage chests with metal drawers and dividers to keep all supplies safe and organized. For protecting personal gear, Peli's footlockers and trunk lockers are lightweight and lockable.

Big equipment can be transported and protected in Large, X-Large, or XX-Large ruggedized shipping cases. They are lightweight, shockproof, watertight, dustproof, and heat and chemical-resistant, which make them extremely tough. They offer ultimate protection that will move your equipment from point A to point B without a scratch.

Advanced lighting systems

Peli's advanced lighting solutions are preferred by professionals who work in extreme conditions. From NVG-compatible and IR lights to rugged Xenon and LED submersible work lights, Peli's extensive array of advanced lighting tools (almost 60 models) has a lighting solution for just about any application.

The company currently offers a selection of 15 torches that are certified to ATEX Zone 0 & 1 (Cat. 1 & 2), and there are some more awaiting approval. Designed for use in hazardous areas, professionals working in chemical, electrical, gas, oil, power, pharmaceutical, fire rescue, hazmat, and other high-risk industries can be confident that their light will not cause an explosion when used in these areas.

Recently, Peli launched the 2690Z0 HeadsUp Lite, a tough, weather-resistant headlamp with a twist-actuated switch, designed for easy gloved-hand operation and certified to ATEX Zone 0 (Category 1) areas.

Peli Products has applied required design changes and improvements on most of the current Peli catalog to match new specifica-

tions of the ATEX Directive. The Advanced Area Lighting Group (AALG) presents its range of Remote Area Lighting Systems (RALS). The new line brings fully portable, powerful, energy-efficient, and environmentally responsible lighting technology to places where trucks and gas-powered generators cannot. RALS portable lighting ranges from one to four head units in four models. These battery-powered portable area lighting systems are harnessing the power, reliability, and energy efficiency of LED technology. They provide multiple hours of continuous light: the 9470 RALS provides a blistering 8,000 lumens of brightness for seven hours (high-power setting) and 4,000 lumens for 14 hours (low-power setting), and the 9460 RALS offers a beam of light of 4,000 lumens in high power mode for seven hours and 2,000 in low power mode for 14 hours.

The 9430 RALS produces 2,000 lumens of brilliant light for eight hours at maximum output and 1,000 lumens in low power during 15 hours. The 9450B RALS offers a beam of light of 1,280 lumens in high-power mode and it has a peak output of nine hours. ■

CONTACT

Marisa Silva
marisa.silva@peli.com

Aerodynamic and acoustic validation

A ONE-STOP SHOP FOR ENGINEERING AND TESTING SERVICES FOR THE AEROSPACE ENGINE AND GAS TURBINE INDUSTRY CAN STREAMLINE THE PROCESS

> "A single interface to the customer is responsible for the complete service"

BY MARC BECKER

At component level, aerodynamic and acoustic validation is a key factor in the success of new products in the aero engine and gas turbine industries. These validation tests focus on improving efficiency while reducing emissions and noise, and enable the optimization of existing designs to fully understand the complete aerodynamic, including its limits in the product.

AneCom AeroTest offers the complete range of services to support its customers in this area, covering: mechanical and instrumentation design, including analysis of the test vehicle; supply chain management for all necessary hardware; assembly, instrumentation, and integration into the testbed; test execution, data acquisition and pre-analysis; and strip inspection and rebuilds.

This service is offered for aerodynamic testing of fans, compressors, combustors, and turbines, acoustic testing of fans, and calibration services for all kinds of aerodynamic probes, including flow checks.

To reduce customers' administration, AneCom AeroTest has developed a one-stop shop concept comprising project management of the complete engineering and testing package. A single interface to the customer is responsible for the complete service, minimizing the effort on the customers' side.

AneCom AeroTest now has facilities that enable the most effective testing and the latest technology in measurement and data acquisition. More than 60 successful tests in the last six years is testament to its professionalism. ∎

Combustion chamber tests

For combustion chamber testing, Anecom uses the German Aerospace Center (DLR) chamber in Cologne, Germany.

DLR is a long-time partner of Anecom, and the company also maintains a close partnership with the Institute for Aviation Propulsion at the University of Stuttgart (ILA), giving it a suitable testbed for testing turbine components at altitude. Employees have an intimate understanding of the altitude testbed and can use it to obtain clear results.

AneCom AeroTest can also evaluate the technical aptness and costs of other testbed options as needed, to ensure clients have the optimal environment to carry out testing.

High-performance data collection systems facilitate simultaneous online monitoring in every testbed and can record and analyze up to 2,500 stationary and 256 dynamic signals at once.

Static and dynamic signals are averaged over a predefined period. Signals, or the elapsed time of signals, can be recorded at a sampling rate of up to 200Hz. The dynamic measurement system is capable of simultaneously recording up to 256 measurement channels with a signal spectrum of 80kHz (sampling rate: 200kHz, with an oversampling factor of 2.5). The system also supports simultaneous monitoring of all signals with up to 30 alarm values each in the frequency range, a feature that is used to monitor the security of oscillating components. In addition, the company provides various tools online (FFT, Campbell diagrams) to enable detailed signal analysis during testing.

All testbeds are controlled and monitored from a central control room. The computer-aided control system can be configured flexibly for the test at hand and regulating devices can be controlled manually, fully automatically, or based on control curves. Although all the systems operate independently, they are connected in order to exchange data. Plus, every system relevant to security is protected against power outage by means of pressure reservoirs and/or battery backups.

The system also features other extensive security functions for worst-case scenarios. These functions include everything from limit-monitoring of critical parameters up to a fully automated shutdown. Additionally, preprogrammed actions make critical testing operating conditions safer. For example, a compressor can be driven back to normal operating levels (anti-surge) at the push of a button during surge line investigations. Other functions automatically bring the compressor to its working line or idle state.

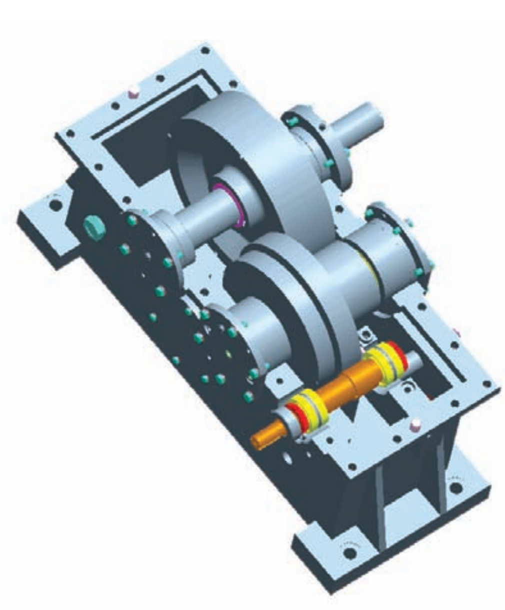
CONTACT

Marc Becker, vice president of business development
AneCom AeroTest GmbH, Freiheitstraße 122, 15745 Wildau, Germany
Tel: +49 3375 92 26 42
www.anecom.de

High-speed transmission

ADAPTING TEST EQUIPMENT TO DIFFERENT REQUIREMENTS CAN OFTEN BE VERY CHALLENGING BUT ONE TRANSMISSION COMPANY HAS IT SORTED

"The SN2105 is a candidate for the most cost-effective, true high-speed transmission on the market"



BY LARRY MOWELL

A test scenario: you are tasked to conduct a 5,000-hour, high-speed endurance test of a new generator. The generator needs to produce 500kW at 24,000rpm. You equip your test cell with a new electric motor and 10:1 speed-increasing gearbox, controls, and instruments to monitor the equipment. Several months from now, you may be required to run a test for 500kW at 35,000rpm.

A solution? When the time comes, tear down and store the old gearbox, perhaps forever. Source and install a new gearbox that meets the new performance specs.

But there is an alternative solution: when the new speed requirement comes, remove the 24,000rpm output cartridge from the Cotta SN2057 and install a 35,000rpm cartridge. Move nothing, store nothing, except the dormant 24,000rpm cartridge. Save the cost of a new gearbox, save the lead time, installation labor, plumbing, alignment, run-in, and other costs.

The latter is the path one prominent manufacturer of aircraft power-generation equipment chose, and it saved six figures in capital cost while avoiding the aggravation and time delays in refitting a test cell.

The Cotta SN2057 was developed in 1988. In 2002 the changeable-ratio version was introduced for use by manufacturers, military, and others. All SN2057s remain in service today.

Available as speed increasers and decreasers, Cotta high-speed transmissions and gearboxes are also used in non-aviation applications, ranging from magnetic levitation trains to centrifugal driers.

Cotta is now offering a special-purpose transmission for integration into aircraft high-speed component test stands. Although very compact, the SN2105 features a nominal capacity of 200hp and overspeed ratios up to 5.5:1. The SN2105 is a candidate for the most cost-effective, true high-speed transmission on the market.

Cotta high-speed transmissions fall into several basic designs. The independent-mount transmission comes with either single or dual outputs. Each type is available with either one-stage gear trains with ratios to about 1:7, or dual-stage gear trains with ratios up to 1:22. Higher ratios are available in planetary designs or via multiple gear trains. Although each model is highly specialized, the wide range of existing high-speed designs is likely to provide a suitable transmission for most applications, or a candidate that can be easily modified.

A hybrid of these transmissions is the coaxial unit. The co-ax has test heads at both ends of the output shaft, which is hollow. This transmission is designed to test a constant speed drive and generator simultaneously, by mounting one at each end of the hollow output shaft and connecting the two by means of a quill shaft through the hollow shaft.

Cotta flex drives are add-on transmissions. Flex drives come in ratios to just over 1:3 and are installed on the output of existing transmissions to multiply the output speed. The output of the Flex drive replicates the output of the base transmission.

In addition to high-speed test-stand drives, Cotta manufactures (standard, modified-standard, custom) industrial and specialty gearboxes, including speed increasers/reducers, transfer cases, split-shaft power takeoffs, and pump, reversing, creep, and right-angle drives. ∎

CONTACT

Larry Mowell is the manager of sales and marketing for Cotta Transmission Company in the USA
www.cotta.com/highspeed.shtml
Tel: +1 608 368 5600

Hydraulic flight components

THE TESTING OF HYDRAULIC FLIGHT COMPONENTS HAS CERTAINLY MOVED ON. TESTEK HAS APPLIED SERVO-CONTROLLED PRESSURE, COMPUTER CONTROL, AND ADVANCED TEST SOFTWARE TO ADVANCE THE TECHNOLOGY

"The FAA mandates that all critical flight components be tested in accordance with the CMM"

SUNIK PATEL

BY SUNIK PATEL

When man first started to fly more than 100 years ago, the Wright Brothers invented an aircraft that was controlled through the use of cables, bell cranks, and pulleys. This system of flight control was simple and adequate for the application. As air transportation progressed to the modern era, flight control technology had to change and improve. Aircraft became faster and bigger, so flight controls had to progress with aircraft technology.

By the early 1950s it became necessary for flight control components to be tested prior to being installed on the aircraft. Flight control technology had advanced to hydraulic systems with pumps, hydraulic lines, and actuators. It was determined that installing hydraulic components in the aircraft and then finding out their performance was not a satisfactory method of testing the components. Early aviation pioneers such as Joe Abdo, Bob Spraque, and Ed Greer determined that a test environment could be designed to duplicate the flight conditions, which would verify component performance. As a result of their wisdom the hydraulic test stand was invented.

In the beginning, the hydraulic test stand was comprised of a pump, pressure control circuits, valves, flow meters, and pressure gauges. The operator was responsible for controlling all test functionality and satisfactory component performance. As aircraft became increasingly sophisticated, fast, and complicated, the hydraulic test stand had to follow.

Hydraulic test stands

As flight control technology went from simple hydraulic systems to fly-by-wire, and aircraft performance increased to two or three times the speed of sound with 9g turns, flight control systems became very complex. Servo-controlled actuators, power transfer units, pressure-compensated pumps, and hydraulic motors required that hydraulic test stands become computer controlled. No longer could the operator perform the test functions and determine satisfactory performance.

As the early pioneers focussed on hydraulic testing technology, Testek has advanced hydraulic

Electrohydraulic servo valve test stand Boeing Stand 2 - VHATS V-22 Osprey tilt rotor aircraft hydraulic test system

test-stand technology with the application of servo-controlled pressure, computer control, and advanced test software. The technology is most apparent on the hydraulic test system HTS740 designed for the Turkish Aircraft maintenance facility in Istanbul. Advanced servo-control pressure circuits, digital flow and pressure metering, and the most advanced computer control console (ETC750) perform all tests required by the Component Maintenance Manual (CMM) and ARP490 requirements automatically.

Test software programs are written in accordance with the CMM requirements and verified with aircraft UUTs. All 28 ARP490 functional tests (pressure gain, internal leakage, spring bias, proof pressure and internal leakage, symmetry, polarity, null pressure shift, threshold, hysteresis, linearity, null bias and null pressure, second stage spool lap, frequency response, limit cycle, velocity, cracking pressure, stroke

length, seal friction, free play, transducer output and phasing, LVDT, null coincidence, linearity, phasing and gain, actuator output force, autopilot override force, dynamic pressure null, and control port to return pressure drop) are performed by the Testek ETC750 automatic control system.

The Federal Aviation Administration (FAA) mandates that all critical flight components be tested in accordance with the CMM and verification be provided to the FAA prior to installation on a commercial aircraft. Testek's modern and efficient automatic hydraulic test systems perform the required FAA verification tests with required documentation.

With the use of the ETC750 computer console, semi-automatic and fully automatic test software steps are automatically performed. The possibility of operator error or potential UUT damage are reduced or totally eliminated. The need for operator expertise in servo-actuator technology in order to perform CMM tests is reduced considerably. The interface requires that the operator merely follows computer-prompted instructions. All test data is collected and formatted to verify UUT performance, and documented to meet FAA/local airworthiness authority directives.

The growing Chinese market is seeing a need for advanced hydraulic testing systems. As a large number of Boeing and Airbus aircraft are entering a non-warranty phase of their operation, hydraulic component testing is increasing. These technology-influenced MRO operations are turning to open, computerized testing systems. The test systems are the modern front-end data acquisition and control for Testek hydraulic test stands. The systems are compatible with indigenous aircraft programs such as the COMAC C919 large aircraft program and current ARJ-21 regional jet program.

Boeing and Airbus both needed to find a way to reduce aircraft weight while maintaining overall performance. The 787 and A380 have increased hydraulic system pressures that reduce hydraulic system component size and weight. Considering the 787 flight performance and the A380 size, increased fight component performance was required. Testek has accommodated these increased system pressures in its hydraulic test systems design for 787 and A380 support. The hydraulic test systems designed for the Turkish Aircraft maintenance facility in Istanbul are capable of providing hydraulic working pressures to 6,000psi continuously.

Military applications

Modern military aircraft require the same type of testing as commercial aircraft. The technology

> "Multiple levels of system authority by password protection prevent accidental operator changes"

Undergoing flaperon actuator test on the V-22 test stand (bottom) and Universal mounting interface under EHSV test stand (left)

remains the same; however in most cases, overall performance is increased. Testek has accommodated this increase in performance in the VHATS V-22 Osprey tilt rotor aircraft hydraulic test system. Innovative and sophisticated advanced technical solutions were required to achieve the test parameters needed for the V-22. The ETC750 automatic control system achieved the required performance; it replicates the pilot control functions with installed current drivers and data acquisition functions.

The ETC750 UUT test database is stored and organized in such a way that operator prompts provide the ability to recall all test software and testing data. The stored data controls the test being run in accordance with the governing test document parameters. Creation of specific test criteria is the result of years of application experience with OEMs and maintenance facilities throughout the world. Changes can be made to modify test programs or to create completely new test programs. Multiple levels of system authority by password protection prevent accidental operator changes.

Testek has made other advances in the hydraulic test stand technology, which directly affect hydraulic system performance. Hydraulic test systems of the past were comprised of hydraulic lines – many different hydraulic valves and components all interconnected with rigid tubing or hoses. As a result the systems and cabinets were very large in order to accommodate the component size and the very long lines required. Each valve or component had its own body or housing, and normally required mounting to a frame or bracket. Testek has developed a new, modern and more efficient method of manufacturing and assembling hydraulic systems through the use of hydraulic manifolds, which have a number of positive effects on hydraulic system performance.

A manifold is comprised of a given portion of the test circuit. Each manifold contains the various components required for circuit function, such as the servo-control pressure circuit. The servo-control pressure manifold has a servo pressure-control valve, check valve, and approximately four directional valves. All these components are threaded into the manifold. Each circuit of the total hydraulic system is designed in the same manner. All the system manifolds are then interconnected with an inlet pressure line, return line, and sense lines. Testek's application of system manifolds has reduced the overall test stand size and increased system performance.

Other advantages include simplified system maintenance and service. Hydraulic line-mounted components have always presented a problem of system leaks, but Testek's manifold technology has eliminated the need for removing components from hydraulic lines. All components mounted in a system manifold are simple to remove from the manifold and replace with a new component without jeopardizing system connections. All components are sealed with O-rings and mounted in SAE ports. Advantages such as direct port-to-port connections, reduced pressure drop, increased pressure control, reduced system contamination, simplified calibration, and ease of troubleshooting are achieved.

Testek's HPM730 hydraulic pump module, HTS740 hydraulic test station, and PMT760K pump/motor test module are designed and manufactured with the advanced technologies as described. These systems are capable of supporting all hydraulic components on any commercial aircraft currently in service in the world. A similar hydraulic system designed to operate with military-type red oil, MIL-H-5060, MIL-H-6083, or MIL-H-83282, will support all military aircraft. The systems can be operated in a manual, semi-automatic, or fully automatic operator mode to accommodate a given maintenance environment.

Versatile systems

Testek systems are designed to test commercial and military components such as valve assemblies, pressure control valves, power control units (PCU), power transfer units (PTU), hydraulic fuses, integrated servo actuator assemblies (ISA), hydraulic transfer cylinder assemblies, autopilot actuator assemblies (PCA), main engine-driven pumps (EDP), hydraulic motors, and servo valves. The systems are configured to universally support multiple components from different manufacturers and different airframes.

As aviation technology continues to swiftly advance, Testek is dedicated to providing the aircraft maintenance industry with the most user-friendly advanced hydraulic test platforms. The company invites potential customers to make contact for further details and an opportunity to visit one of the test sites. ∎

CONTACT

Sunik Patel is vice president of sales at Testek Inc based in the USA.
Tel: +1 248 573 4980
aerospace@testek.com
www.testek.com

Photogrammetry and 3D assembly

PHOTOGRAMMETRY USES 3D TECHNIQUES AND TECHNOLOGY TO ASSEMBLE AEROSPACE PARTS MORE EFFICIENTLY

"Photogrammetry works in much the same way as human stereo vision"

GARY JOHANNING

BY GARY JOHANNING

The term 3D assembly refers to the use of high-accuracy, in-place, 3D coordinate measurement devices for the digital assembly of parts. This process is often referred to as computer-aided manufacturing (CAM) or gaugeless manufacturing, and is replacing classical techniques centered on the use of tools, gauges, and other mechanical processes of part assembly. In a nutshell, 3D assembly can produce more accurate assemblies more rapidly, and at lower cost.

In the aerospace industry, where parts are large and accuracy is absolutely critical, 3D assembly is being adopted across the board.

Photogrammetry, although not as widely used as 3D assembly technologies such as laser trackers and articulating arms, has been found by manufacturers to be a versatile and reliable 3D assembly tool. It offers a unique set of capabilities, especially in situations and environments where alternative approaches fall short, either from the standpoints of accuracy and reliability, or practicability.

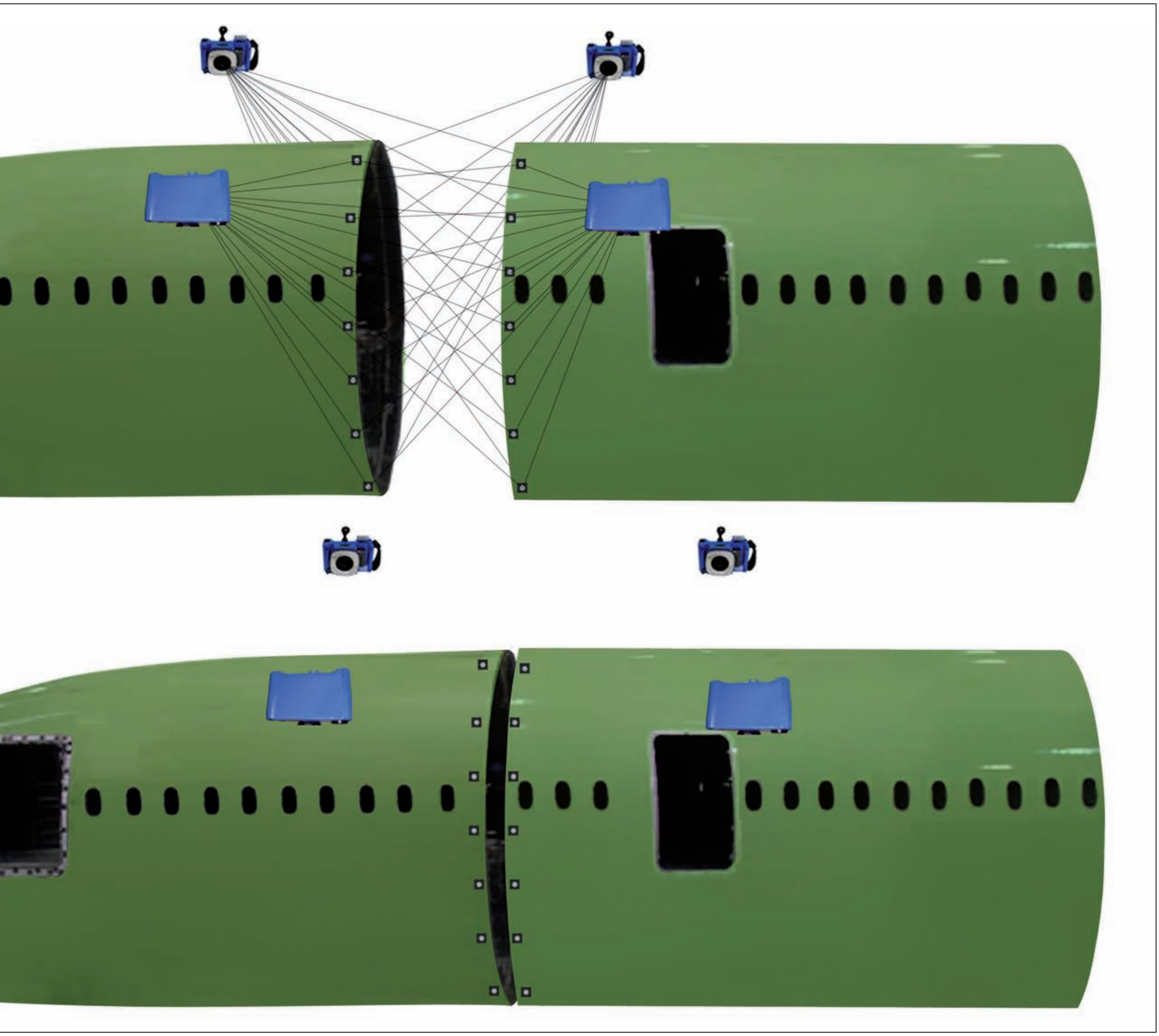
Meaning 'photographic metrology', photogrammetry works in much the same way as human stereo vision, where your eyes perceive depth partially as a function of the angle subtended by the two intersecting light rays running from the point of interest to your two eyes. The difference with photogrammetry, however, is that there is no limit to the number of images used in the determination of 3D position. Each 2D image that 'sees' a point of interest contributes a light ray in space, and the intersection of all corresponding rays yields the required 'XYZ' coordinates for the point through a mathematical reconstruction of 3D shape from the multiple 2D images.

One of the principal advantages that photogrammetry displays over alternative 3D coordinate measuring devices, such as laser trackers and articulating arms, is that rather than recording data sequentially, point-by-point, the images from which the 3D coordinates of points are determined capture the entire point field in an instant. This means that the shape and changes of shape of the object being measured can be determined in near real time. In fact, the position and orientation of several parts can be simultaneously determined at a high data rate to very high accuracy. Moreover, photogrammetric measurement configurations comprising two or more synchronized cameras can perform high-accuracy 3D part-measurement in situations where the part is moving or the camera supports are subject to movement or vibration; only the shape of a subset of reference points needs to remain stable. Therefore, photogrammetry with synchronized image

Dynamic alignment of fuselage sections via real-time photogrammetry

recording offers the unique capability of operating from moving platforms or in unstable environments, for example when the camera technician needs to record images from high above an unstable factory floor, or above a moving automobile assembly line.

A further feature illustrating the versatility of photogrammetry is that, because object shape is being determined in the first instance, there is considerable flexibility in assigning reference coordinate systems. The assignment of both a desired XYZ coordinate system and true scale to the determined 3D array of measurement points is generally achieved via a small number of reference points, along with known point-to-point distances on scale bars. This is distinct from laser



trackers and articulating arms where the initial XYZ coordinate system moves as the instrument moves between measurement stations. From a practical point of view, this means that photogrammetry is generally an ideal 3D assembly tool in situations where it is required to: dimensionally monitor in near real time an object that is shape invariant but moving within an unstable environment, and continuously measure an unstable object within a stable external reference frame.

The following example applications of near-real-time dimensional monitoring illustrate the applicability of photogrammetry. The cases range from design concepts through to implemented photogrammetric measurement solutions, and all focus on high-accuracy 3D measurement.

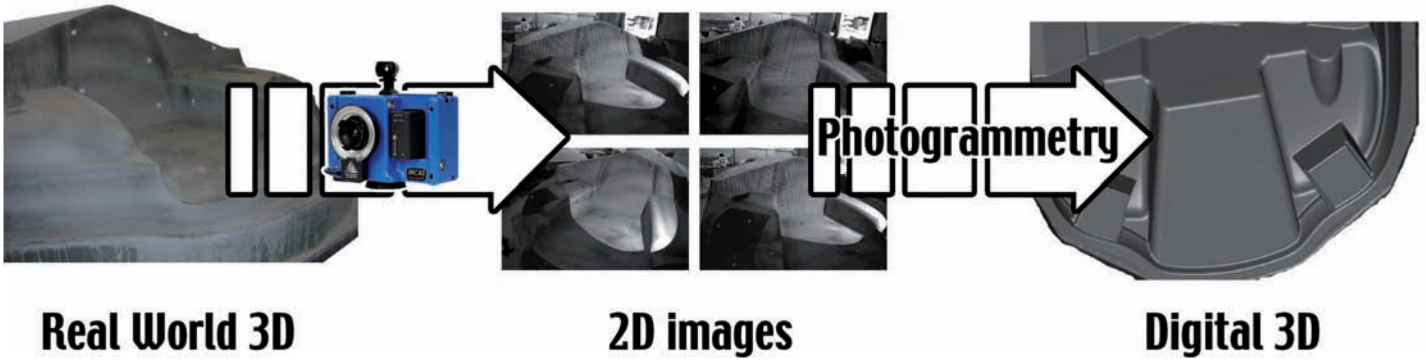
Tool tracking

Continual improvement in monitoring the proper usage of manually operated tools is a goal of all manufacturers of large-scale assemblies. One avenue for improvement is through use of an online 3D measurement system that could continuously track the spatial position and orientation of a tool during its application.

By the standards of large-scale vision metrology, the accuracy tolerances in such applications are relatively modest, though there are challenges of a more practical nature to be overcome. For example, the monitoring points on the tool would always have to be 'seen' from two or more camera stations, so the camera configuration would need careful design to ensure maintenance of lines of sight to the tool being tracked. The use of relatively inexpensive online industrial cameras enable multisensor arrangements whereby the tools of interest would be continually visible. The camera positions need not be stable, as their instantaneous position and orientation, along with that of the tool, could be determined by the use of visible reference control points. However, maintenance of platform stability would ensure that no additional control point information would be required.

Total component inspection

Auto makers have long needed access to more comprehensive 3D measurement data on the components of the vehicles they assemble. How-



The photogrammetric process. An object is photographed in multiple 2D images that are then used to digitally reconstruct the 3D object (above)

> **"An ideal alternative 3D measurement approach would be to measure all components on the assembly line"**

ever, in the past, the problem has been that dimensional inspection should not impede the rate of production, and so the majority of measurements to support 3D assembly are conducted off-line using only samples of component parts. Much of this off-line inspection requires a good deal of human interaction – the use of laboratory-based coordinate measuring machines (CMMs), for example. An ideal alternative 3D measurement approach would be to measure all components on the assembly line.

Such a dimensional measurement goal is yet to be realized, partly as a consequence of the varying nature of features requiring inspection. These include tooling points, holes, slots, surface profiles, and gaps and edges (sharp and rounded). Nevertheless, potential technology solutions exist for the online 3D measurement of some of these feature classes, with photogrammetry again showing promise as a viable, near-real-time automated measurement tool that can deliver partial solutions for this general problem even with today's technology.

Measurement systems available to auto makers include CMMs that can measure some of the features on some of the parts. The ideal online inspection system would measure required features on all the parts being assembled. A photogrammetry system comprising several digital cameras, an illumination system, a projection system, and specialized object feature extraction software could potentially be installed on the assembly line. Such a system would measure some, maybe even most, of the desired features types on every part. The projection system would project dots and lines onto the component surfaces, and the special illumination system would assist in the detection and measurement of surface points, edges, holes, etc., in the synchronized multiple images covering the measurement volume on the assembly line. As can be inferred, the development of a complete solution to this measurement task has yet to be achieved, but photogrammetric systems offering partial solutions are possible with today's technology.

Robot guidance

Nowadays, the cutting, shaping, and finishing of large and complex structures is commonly performed with very large, multi-axis computer numerical controlled (CNC) machines, many of which have integrated lasers to control end-effecter positioning. Over time, positioning sensors can suffer from drift that, even when small in magnitude, can be detrimental in high-accuracy machining tasks. Rectification of departures from design positioning is invariably left to the machine operator, who needs to take corrective action before an out-of-tolerance condition occurs.

Real-time positioning of the part and the machine head is one way of avoiding such problems. One option for online positional monitoring is photogrammetry. Two or more cameras can be configured to track the position of the end effecter of the CNC machine within its own coordinate system, and more importantly, within the 3D coordinate system of the part being machined. Targets need to be positioned on the end effecter to track within all its axes. However, if recently developed photogrammetric processing tools are adopted, all six degrees of freedom (three translations and three rotations) can be determined in real time within a target array where subsets of points are seen from only one camera position. This can be visualized in the figure above right, if one imagines that subsets of the targets on the drills, which have known relative positions, would be recorded in only a single image, although several cameras may be involved.

As with the case of the tool tracking, stable reference points on, say, the floor or machine tool supports are required if the camera stations are unstable, which they are permitted to be, whereas no control points are needed if the camera plat-

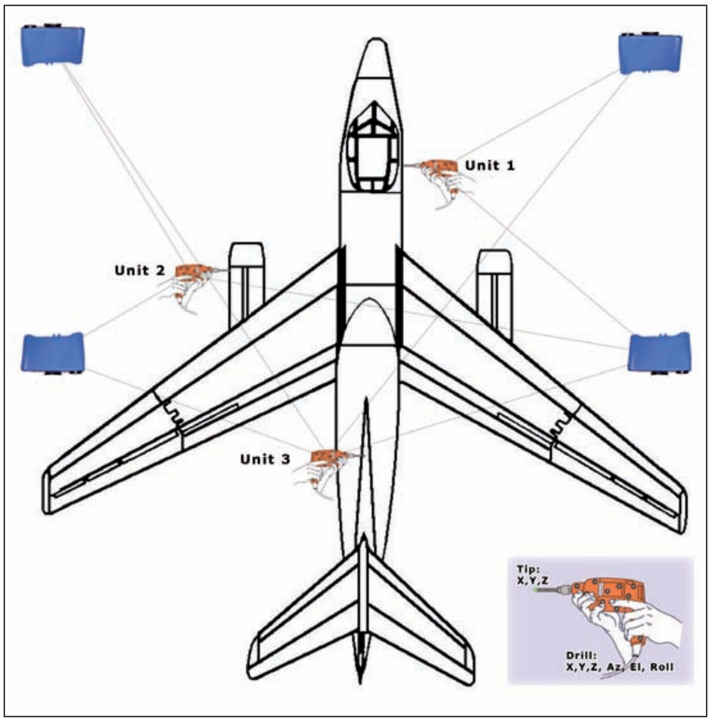


Illustration of real-time positional monitoring of tool operation via photogrammetry

forms are stable. In some complex machining cases, the actual part that is being machined needs to move during the process so that the CNC machine can access all areas of the part, as exemplified by the rotation of large cylindrical objects. In this case, the vision-based monitoring system has quite a complicated task to perform. Not only must camera positions be determined relative to the real world (the reference system of the whole machining assembly), but the part coordinates must be transformed into the same reference system in real time, as the part moves. In these instances, the 3D coordinates of two objects need to be tracked, the part being worked and the end effecter of the CNC machine. Moreover, the tracking needs to be accomplished from the photogrammetric measurement system, which is also potentially subject to movement, or to vibration at the very least. The use of highly synchronized cameras and control targets can compensate for such platform instability and thus achieve high-accuracy, real-time dimensional monitoring of the machining operation. If the relative position of the CNC machine to the part falls out of tolerance, a feedback loop enables online corrective action in the CNC positioning.

Guidance of large assembly joins

Recent developments in aircraft manufacturing have brought about a requirement to be able to dynamically control, with a great deal of accuracy, the joining process for very large assemblies such as fuselage sections.

The coordinates of targeted arrays of points on both abutting sections can be determined at desired time intervals to control, in near real time, the incremental positional movements undertaken in the joining process. Once again, stability of the cameras forming the photogrammetric network is not required, as long as stable reference points are imaged. These may well be built into the factory floor, for example. This photogrammetry solution can also be employed for related dynamic 3D assembly tasks.

An optimal 3D assembly solution

Photogrammetry displays a number of notable attributes that make it ideal for online 3D measurement tasks in large-scale manufacturing, where high-accuracy coordinate determination is required in near real time so that the measured data can be used for dynamic process control.

As well as being a very flexible measurement technology that can accommodate near instantaneous measurement of either dense target arrays or features, or even just a modest number of critical points, photogrammetry can operate in unstable environments that are the norm within large-scale manufacturing and assembly. This feature renders photogrammetry suitable for complex, often dynamic, 3D assembly tasks across a broad range of industries in situations where alternative 3D measurement tasks are invariably unsuitable. ∎

CONTACT

Gary Johanning, general manager

Geodetic Systems Inc, Melbourne, Florida

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Launch pad 2010

> "There is some high-level support for a UK space agency"

BY DR CHRIS WELCH

Dr Chris Welch is the winner of the 2009 Sir Arthur Clarke Award for Space Education, the space equivalent of an Oscar. He was a special advisor to the government enquiry into UK space policy in 2000 and 2003 and is work team member for the new government and industry initiative, the Space Innovation and Growth Team. In this account of a remarkable year for UK space endeavor, Chris suggests that despite the UK's recent lack of engagement, the country may now be undergoing a space renaissance.

In 2009, while many eyes have been focused on the USA and the 40th anniversary of the Apollo 11 moon landing, the UK has been quietly preparing itself for what could be a bright new future in space. In May, the European Space Agency (ESA) selected a British pilot, Major Tim Peake, as one of the first group of trainee astronauts to be recruited to the European Astronaut Corps since 1992. Their mission is to prepare for future travel to the International Space Station and, potentially, beyond.

Since the 1980s it has been UK policy not to support human spaceflight and it does not contribute to this part of ESA's activities at the moment. Nevertheless, some observers view the selection of Major Peake as an indication of a great shift in the UK's engagement with space.

In July, the ESA launched a facility at the Harwell Science and Innovation Campus in Oxfordshire. It is the ESA's first UK facility and will play a key role in a long-term strategy to stimulate the UK space industry. The center focuses on three areas. One will use space data and imagery to produce new applications for terrestrial users and to enhance existing ones. A second will examine climate change modeling. The third area will develop new technologies (for example, new power sources and robotic techniques) to assist the exploration of the moon and Mars.

The UK space industry is already one of the fastest growing sectors of the economy, contributing £6.5 billion (US$10.5 billion) a year and supporting 68,000 jobs. By 2020 this is expected to rise to £14.2 billion (US$22.8 billion) per year and 115,000 jobs. To provide additional impetus, the government has decided to create an International Space Innovation Centre (ISIC) at Harwell. It will be dedicated to innovation in space science, research, and technology. It will bring together academia and industry, and will feature cutting-edge scientific laboratories together with industrial research and development facilities.

On the same day that the ESA facility was opened, the UK government launched a three-month consultation into whether the country should have its own space agency. The outcome of this could be pivotal to the UK's future success in space. At present, UK space matters are overseen by the British National Space Centre (BNSC), a partnership of government departments and research councils that spends around £250 million (US$402 million) of public money annually, almost all through the ESA. A UK space agency would be a 'one-stop-shop' that could run a new national space program in addition to UK activities with the ESA and would also enable the UK to develop the scientific and technical skills and expertise to play a much larger role in Europe and beyond.

There is some high-level support for a UK space agency. Lord Drayson, Minister for Science and Innovation, is in favor, and two years ago the House of Commons Select Committee on Science and Technology also supported the idea, but with the caveat that it should go ahead only if the annual UK spend on space is increased.

At the same time, government and industry have jointly initiated the Space Innovation and Growth Team (Space IGT) to engage and involve the entire UK space community in identifying challenges and opportunities for the future. The team's brief is to develop a 20-year strategy for the growth of UK space, encouraging a 'space aware' culture in the UK, and leading to the UK becoming a world leader in the space sector and generating considerable economic benefits. The Space IGT will report its findings in early 2010.

It has been an unprecedented year for UK's space activities. If the result is the birth of a UK Space Agency, the economy – and Kingston University in particular – are likely to benefit considerably. The University has an excellent reputation in space engineering, particularly through the national and international successes of students on its degree in aerospace engineering, astronautics, and space technology. When they graduate, the current students will have an even larger range of jobs open to them. They will still be able to work in industry or carry out research in universities. However, soon they may also be able to work for either the UK or European Space Agency. In addition, UK involvement in human spaceflight could only strengthen the new research facilities being developed in the country, such as the microgravity drop tower at the Roehampton Vale campus, London – the first such facility in the UK. ∎

Dr Chris Welch is principal lecturer in astronautics at Kingston University, southwest London, UK