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SHOWCASE 2018

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2018 SHOWCASE

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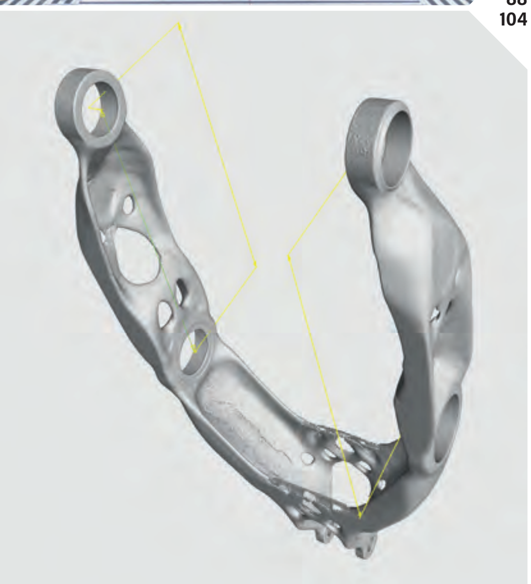

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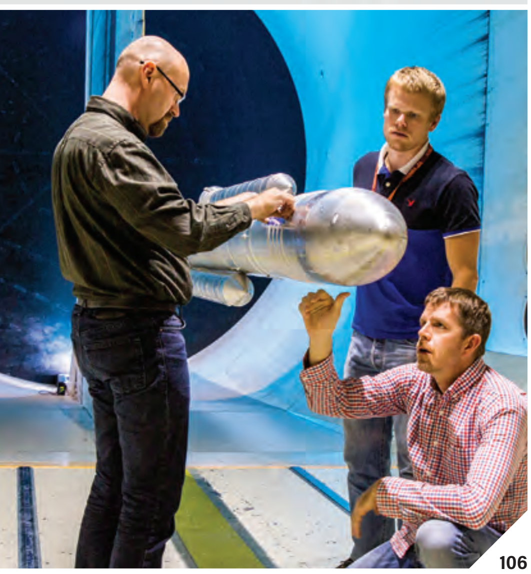

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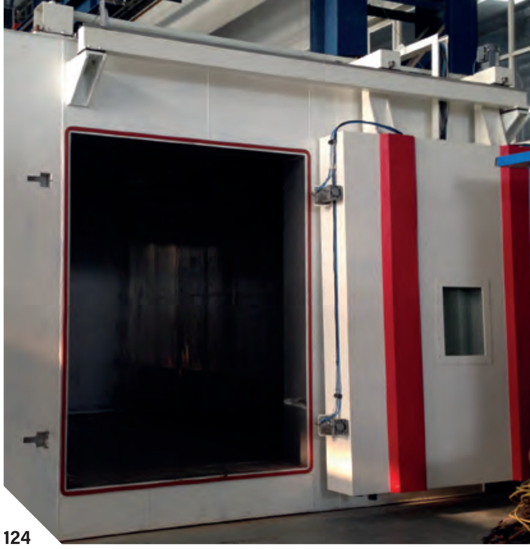

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SCALEXIO always fits your needs – what are you aiming for?

// BRAVE NEW WORLD

Could we be entering a new era for aerospace, and consequently, aerospace testing? Airbus Helicopters' recent completion of the first full-scale test for the propulsion system of its CityAirbus demonstrator – a multi-passenger, self-piloted electric vertical take-off and landing vehicle designed for urban air mobility – suggests we could be on the threshold of a new era of autonomous, personal aircraft.

CityAirbus is a battery-powered air vehicle able to vertically take off and land and designed to carry up to four passengers over congested 'megacities' to key destinations such as airports or train stations, traveling at up to 120km/h (75mph). Its innovative four-ducted propeller configuration is designed to improve safety and ensure a low acoustic footprint.

Meanwhile, another exciting new announcement was recently made by e-volo, following the first test flight of its Volocopter autonomous air taxi concept in Dubai. The German startup also recently secured €25m (US$30m) investment in a funding round led by Daimler, the parent company of Mercedes-Benz. Electric propulsion again ensures the Volcopter features low noise levels, with the current prototype offering a maximum flight time of approximately 30 minutes at a cruise speed of 50km/h (31mph), and a maximum airspeed of 100km/h (62mph).

"The future will see an increase in demand for transportation services," argued Florian Reuter, chief executive officer, e-volo, at the Future of Transportation Conference held in Cologne, Germany, in July 2017. The conference is organized by UKi Media & Events, the same company that publishes *Aerospace Testing International* magazine.

"Autonomous automobiles will not solve the problem as the road capacity enhancements will be overcompensated by an increase in driven miles," argued Reuter. "Congestion will continue to pose a serious challenge. On-demand air taxi services will be a fundamental piece of the puzzle to solve these challenges. Initially, we see an implementation of defined point-to-point connections, which will gradually be expanded into full air taxi networks – first piloted, later on-demand and fully autonomous. e-volo's Volocopter offers revolutionary simplicity in piloting, unprecedented safety and the absence of emission and noise – which makes it the perfect vehicle solution for urban transportation."

Such a scenario will require a huge amount of testing and development. However, it's encouraging to see how already within the pages of this very publication, the technologies and expertise required to turn what many currently see as science fiction into science fact already largely exists. A number of the papers in this showcase provide insight into the challenges of testing electric components and propulsion units, while other articles address the specific challenges of environmental testing to ascertain and verify noise emissions – an essential component in any 'air taxi' ever being allowed to fly over densely populated areas.

And if you're looking for more inspiration on what technologies will pave the way for such a future, don't forget to check out our forthcoming Electric & Hybrid Aerospace Technology Symposium. Now in its third year, the conference has firmly established itself as a must-attend event for high-level aerospace engineers, leading research academics, and heads of electrical system design and engineering, to get together to discuss, debate and analyze the development of hybrid electric aircraft – and even the possibility of pure electric-only commercial flight.

As ever, it's been a privilege to be involved in the production of this annual showcase, and as a keen sci-fi fan old enough to remember the original *Blade Runner* movie, I for one can't wait to ride in my first air taxi!

***Anthony James**, editor-in-chief*

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Aerospace Testing International Showcase

COVER IMAGE: Gripen fighter jet deploying flares

TESTING TIMES

There are more new commercial airliners (including variants) currently in flight testing than there have been for many years. *Aerospace Testing International* summarizes activities underway among seven manufacturers

// IAN GOOLD

Airliner manufacturers (including some companies looking to join the club) are busy preparing the next chapter in the story of the shape of wings to come. Many of the entrants come from famous stables, being offspring of well-performing runners, while others are newborns trying hard to find their feet. *Aerospace Testing International* asked seven – Airbus, Boeing, Bombardier, Comac, Embraer, Irtuk and Mitsubishi – for the latest flight-test news (and found some hangar doors more open than others).

AIRBUS

A320neo series: In August, Airbus Commercial flight tested the first current A320-series aircraft built at its US factory in Mobile, Alabama. The four-hour flight involved checks on engines, systems and structural performance.

Principal Airbus flight testing centers, however, on the A320 New Engine Option (neo) variants offered with Pratt & Whitney (P&W) PW1100G-JM geared-turbofan or CFM International (CFMI) Leap-1A engines replacing earlier CFMI CFM56s or International Aero Engines V2500s on models now called Current Engine Option (ceo) variants.

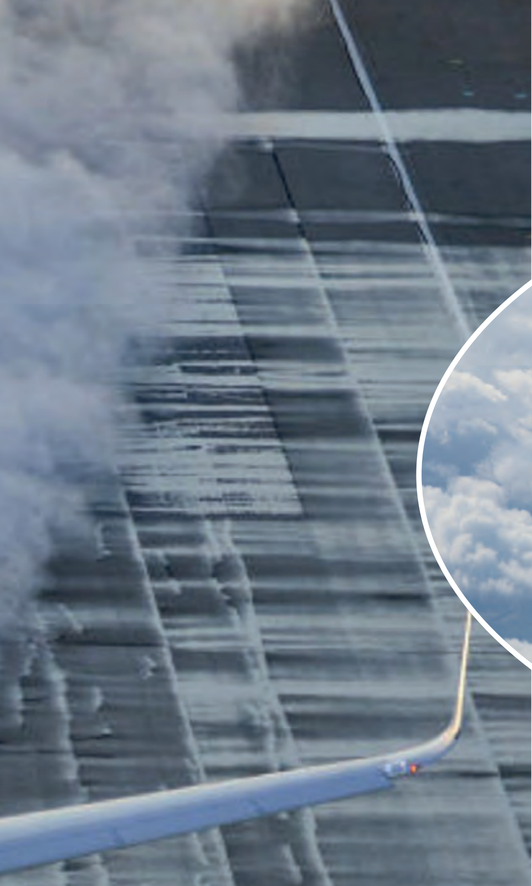
By mid-2017, testing had generated over 4,000 flight hours (FH) with a fleet comprising four A320neos, two A319neos, and a pair of A321neos, with PW1100G-JM and Leap-1A installations split evenly within each group. After completion of Leap-1A airworthiness approval (or certification) work next year, the first Leap-X1A24-powered A319neo (Manufacturer's Serial Number (MSN) 6464) will be converted to fly the second PW1124G-JM-engined A319neo-certification campaign.

2

The variants accommodate more-recent airworthiness requirements, while Airbus has also retuned fly-by-wire (FBW) flight-control computers. Accordingly, each Neo model has, for example, a new tail-strike protection control 'law' for take-off. All powerplant-related certification tests have been performed on the two re-engined A320neos, which has meant that the A321neo and A319neo are being tested primarily for engine-integration approval.

Airbus says that the original A320neo (MSN 6101) is dedicated to the PW1127G-JM engine-maturity campaign. A Hamburg-assembled A321neo (MSN 6673) – the second-built, but first PW1133G-powered example – is engaged in Cat III automatic-landing (autoland) development until mid-2018. A Leap-X1A32-powered A321LR (MSN 7877) is earmarked as an interior-configuration flight-test aircraft. The first A321neo (Leap-X1A32-powered (MSN 6839)) performed at June's Paris Air Show.

A330neo: Ahead of A330neo flight testing, Airbus flew some planned improvements on A330neo MSN 871. Installation of Rolls-Royce (RR) Trent 7000 engines on the first A330neo (MSN 1813) in August is being followed by a 'fully defined' flight test campaign. A second A330neo



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COMAC

Having flown the first C919 in May, China's Commercial Aircraft Corp (Comac) – which did not contribute directly to this summary – hopes to fly a second 150-passenger C919 single-aisle passenger aircraft before the end of the year as it continues a 4,200-FH test program involving six aircraft (MSNs 101-106). The next two aircraft are scheduled to be rolled out in 2018 and flight testing will be conducted at three Chinese locations, understood to be in Dongying, Shanghai and Xian.

MSN 101 is being used to test flying conditions, onboard equipment and landing gear; second aircraft MSN 102 will undertake auxiliary power unit, engine, extreme-weather and fuel systems tests. Other assigned duties include:
MSN 103 – aircraft platform and functionality, and landing gear;
MSN 104 – avionics and electrical system;
MSN 105 – avionics and environmental control system; and
MSN 106 – overall reliability and airline configuration.
Comac has requested assistance from German airworthiness officials in obtaining European Aviation Safety Agency clearance.

1 // A321neo undergoing water trough trials

2 // The A380plus will have an increased maximum take-off weight (MTOW) of 578 metric tons

3 // The first Boeing 787-10, which made its maiden flight on March 31, 2017, is powered by the Rolls-Royce Trent 1000-TEN engine, featuring a 75,000 lb-thrust rating

(thought to be MSN 1795) will fly 'shortly after' the first to support the certification flight-test campaign, according to Airbus.

A350: Flight-testing milestones with three A350-1000s (MSNs 059, 065, and 071) have included an 'Ice-shapes' campaign, handling-qualities certification flights, and high-temperature operations. The aircraft have been engaged in performance and handling-qualities certification, autopilot approval, braking- and landing-performance certification tests, crosswind and tailwind operations, and air-inlet distortion and transients.

A380plus: Should the 'A380plus' development study revealed in June go ahead, Airbus says that a 'relatively short' flight-test program would be required to assess and certificate handling qualities and performance improvements. "We need, for instance, to assess impact on aero/structure-coupling behavior and measure fuel saving to be accounted for in the flight-management system with the improved aerodynamics."

6
New A320-series variants Airbus is developing

7
MRJ90 flight-test aircraft Mitsubishi might have to build

BOEING

Boeing is very much more circumspect than its European competitor, telling *Aerospace Testing International*, "Limited information is [made] available publicly on our flight-test programs." The US manufacturer is assembling the first 777X twin-aisle twinjet, has completed half the smaller 787-10's planned test flying, and is busy with 737 Max 9 certification work.

737 Max: Four 737 Max 8s (dubbed 1A001 to 1A004) have completed testing, while two Max 9s (1D001 and '002) are engaged on model-specific trials. Max 9 1D001 is used for autoland, avionics, flutter, and stability and control, with 1D002 on environment-control system testing.

Before delivery to an operator, Max 8 1A001 was engaged on take-off performance-data verification, stability and control, and flutter testing. Performance and production-representative Leap-1B engine testing occupied 1A002, supported by 1A003's aircraft-systems testing, including autoland.

Max 9 flight testing, expected to finish this year, began with 1D001's first flight on April 13. The manufacturer estimates that 30% of Max 8 testing, particularly involving stability and control work, will be repeated on this initial 'stretch' model.

Developments also involve the high-density seating Max 200 variant aimed at low-cost carriers and the smaller Max 7 (both planned to enter service in 2019), and the further-stretched Max 10 (with redesigned main landing gear for necessary runway clearance during take off and landing and other changes requiring additional flight testing). In December, Boeing expects to join the Max 7 fuselage and wing and to have finalized Max 10 configuration.

787-10: Powered by RR Trent 1000-TEN engines and dubbed ZC001, the first 787-10 is used for autoland, avionics, flight-envelope expansion, flutter, propulsion, primary flight controls, and stability and control testing. The General Electric GEnx-1B-engined second example (ZC036) is employed on aircraft maintenance manual (AMM) validation, and flutter, performance, and stability and control testing. ZC002 has a passenger-cabin interior and is used for Trent 1000-TEN fuel-burn measurement, performance and systems testing, and the AMM.

777X: Flight testing for Boeing's planned 777X, comprising -8, -9, and -10 variants, will use six aircraft in a development schedule that is spread over the coming three years:

4 // The third E190-E2 prototype conducting flights in natural icing conditions, in the USA, in April 2017

5 // E190-E2 undergoing a critical load test that saw a 250-ton load applied for three seconds, causing the wing to bend upward

2018 – Final assembly and 777-9 roll-out;
2019 – Flight test begins; and
2020 – First delivery.

The first and sixth 777-9s are destined for ground-based airframe static- and fatigue-testing. Some 70% of detailed airframe-design work had been completed by mid-2017, with Boeing already conducting a large array of avionic, and power and other systems ground testing.

BOMBARDIER

C Series: By August, Bombardier's six CS100 flight-test vehicles (FTV), including first-production example FTV6, had logged almost 4,500FH and CS300 siblings FTV7 and FTV8 had passed the 1,000FH mark.

To obtain approval for steep 5.5° approaches – almost double the standard 3° glide slope – at London City (LCY) airport, Bombardier demonstrated a 7.5° approach. The Canadian manufacturer also has introduced an additional flap setting ('flap 5') and modified the flight-management control 'laws' to permit a larger spoiler deflection for increased drag during descents into LCY.

Bombardier is working on two further aspects of performance approval: Category III autoland and 180-minute extended twin-engine operations (ETOps), with certification expected for both before April 2018. ETOps system-level testing included cargo fire extinguishing performance to show that suppression-agent concentration reached required certification levels for CS100 and CS300 120- and 180-minute (plus 15 minutes for each configuration following initial discharge) approval.

Bombardier has improved aircraft specifications, based on in-service performance, and plans further upgrading (with lower fuel burn and increased range) before the end of the year. Four of the eight FTVs remain on test duty (or providing airline demonstrations), one has been withdrawn from use, and the others are available for sale to customers.

"THE MANUFACTURER HAS INCREASED THE ORIGINAL ESTIMATED MAXIMUM RANGE"

EMBRAER

E-Jet E2 – Embraer is midway through a seven-year detail-design, certification and manufacturing phase covering three re-engined and re-winged E2 variants of the established E-Jet. Testing is ahead of schedule, on budget, and the aircraft are out-performing targets, which has led the Brazilian manufacturer to raise performance figures.

The initial 97-passenger E190-E2 variant, which flew in May last year, is scheduled to receive certification in the first half of 2018. The larger, 120-seat E195-E2 that flew in March 2017 will follow about 12 months later.

Five E2s are flying – four E190-E2s and the first E195-E2 – while a sixth was scheduled to fly in September. By mid-2017, the new aircraft had accumulated 1,020FH, just over half of the planned total. With the three E2 variants (including the smaller E175-E2) each having an optimized wing, rather than a single common design, the manufacturer has increased the original estimated maximum range after discovering lower airframe drag than expected.

90
Seconds permitted for manufacturers to demonstrate complete cabin emergency evacuation

200
Additional nautical miles range that flight testing showed Embraer could offer E190-E2 customers

As a result, E190-E2 range from 'hot-and-high' airports, such as Denver in the USA, has been increased by about 200 nautical miles (370km) to 2,500 nautical miles (4,630km). Range from short-field runways like London City (UK) has grown by about 100 nautical miles (185km) to 1,650 nautical miles (3,056km).

The first E190-E2 (MSN 20.001) is being used for aero elasticity, crosswind handling, external noise, loads and systems tests, with the second example (MSN 20.002), which flew in July last year, supplementing systems work and general aircraft performance.

Having flown first in August 2016, MSN 20.003 – the third E190-E2 – has been involved primarily in evaluating flying

IRTUK

By mid-July, the 180-seat Irtuk MC-21-300, which first flew on May 28, had performed about 10 flights from a planned 40 to be completed by October. The first six flights involved:
- Characteristics of stability and controllability in various configurations, with landing-gear extended and retracted;
- Calibration of height and speed indication;
- Various modes of ground and inflight engine operation; and
- Systems checks, including emergency ram air turbine operation.

Irtuk, which did not contribute directly to this summary, plans to achieve Russian certification for PW1400G-JM-powered MC-21s in 2019, followed two years later by European Aviation Safety Agency approval. Subsequently, it is expected to seek approval for aircraft powered by Russian-made Aviadvigatel PD-14 engines that completed testing this year on an Ilyushin Il-76LL testbed.

Irtuk owner United Aircraft Corporation is evaluating potential further development, which could include both 150-seat MC-21-200 and 220-seat MC-21-400 variants.

6

6 // The MRJ flight test fleet was grounded after an engine 'flameout' on FTA-2 on August 21, 2017

7 // The FAA awarded Boeing a type certificate for the 737-8 in March 2017, following the conclusion of a 13-month flight test campaign

7

qualities and in confirming aircraft handling in icing conditions. Under such circumstances, test aircraft are flown to accrue specific volumes of ice on unprotected surfaces, with various maneuvers then being flown to check performance and handling to validate ice-detection and -protection systems and confirm that other systems (such as anemometrics, radar and radios) work satisfactorily, says Embraer.

The fourth E190-E2 (MSN 20.004) first flew in March, configured with a full airline cabin interior. It was used to measure internal sound levels and to demonstrate emergency evacuation. (Airworthiness regulations demand that the highest number of passengers ever likely to be carried can leave the aircraft using half of the doors in 90 seconds.)

The initial E195-E2 (MSN 20.005), which also flew first in March, is establishing aerodynamics and performance; second example MSN 20.006 is to validate maintenance tasks and the cabin interior. Like its smaller sibling, the E195-E2 enjoys enhanced performance compared with preflight expectations: after increasing the wingspan by 1.5m (4.9ft) last year, Embraer raised its maximum take-off weight by 1,500kg (3,307 lb) to 61,500kg (135,584 lb) and the 2,000 nautical miles range (3,704km) up to 2,450 nautical miles (4,537km) – which has since grown by a further 150 nautical miles (278km).

Finally, the manufacturer expects to fly the E175-E2 in two years' time, after the outcome of new US airline pilots' agreements that will define the weight (and related passenger capacity) of aircraft flown by regional operators feeding major carriers' hubs.

MITSUBISHI

Mitsubishi Regional Jet (MRJ) – On September 6, the MRJ90, Japan's first new airliner in half a century, resumed its US-based certification campaign. Four flight-test aircraft (FTA) were being prepared to fly again following a pause after a precautionary landing by FTA-2 on August 21.

FTA-2's left hand PW1200G-JM powerplant had suffered an uncommanded inflight shutdown, and P&W is investigating the malfunction following a borescope check that revealed unspecified minor damage.

With the MRJ program several years behind schedule, the manufacturer is working with US flight-test and type-certification partner Aerospace Testing Engineering & Certification (AeroTEC). After a design review, it is moving avionics bay components and re-routing electrical wiring harnesses.

Flights by FTA-3 between MitAC's center at Groom Lake (Washington state) and the Paris Air Show brought total fleet experience close to 1,000FH and allowed MitAC to check systems behavior – primarily autopilot and avionics: "We focused on testing functions, collecting data on GPS accuracy, weather radar, autopilot and flight management systems to ensure maturity."

A current design review, likely to be completed before FTA-5 flies (possibly later in 2017), is expected to stimulate additional flight-test time and require one (or two) more test aircraft. \\


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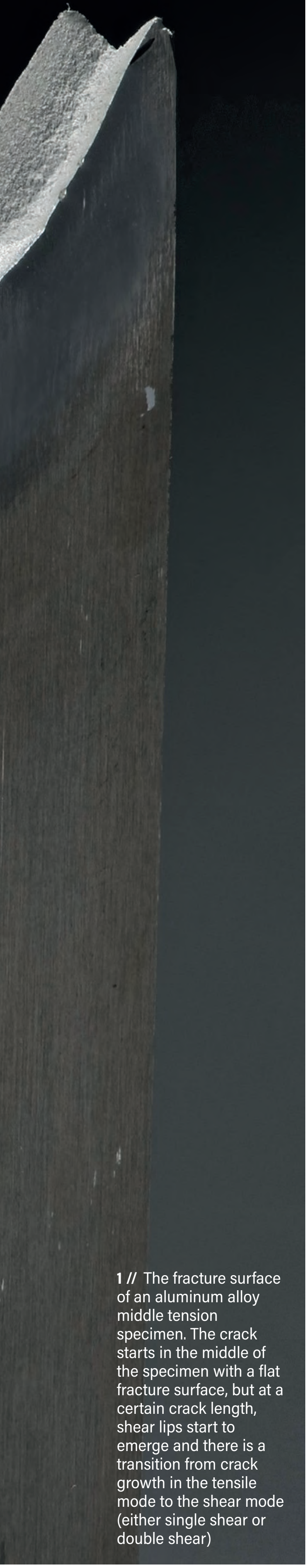
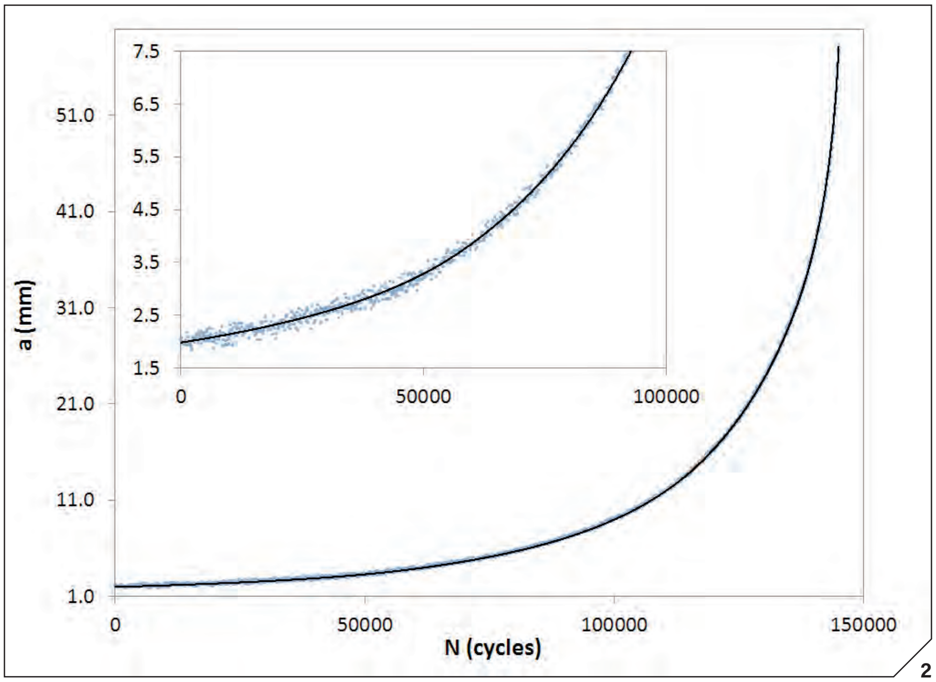
FATIGUE TESTS FOR ALLOYS

Research into fatigue crack growth rates, supported by an international research project, shows that introducing pivot points and modern computer technology can determine very accurate crack growth rates that may require less testing in the future

// **EMIEL AMSTERDAM AND MARCO NAWIJN**



1 // The fracture surface of an aluminum alloy middle tension specimen. The crack starts in the middle of the specimen with a flat fracture surface, but at a certain crack length, shear lips start to emerge and there is a transition from crack growth in the tensile mode to the shear mode (either single shear or double shear)



2 // Crack length versus cycles (*a-N*) curve for an arbitrary AA 7075-T7351 middle tension specimen. The crack lengths (blue dots) are measured with potential drop (PD) and the black line represents the best fit using the developed approach in Pivotal. The insert shows the same data, only for smaller crack lengths

At the International Committee on Aeronautical Fatigue and Structural Integrity (ICAF) on June 5-9, 2017 in Nagoya, Japan, Marcel Bos became the new General Secretary of ICAF, the third person from the Netherlands Aerospace Centre (NLR) to hold this position. Bos presented a summary of the research on fatigue and structural integrity performed in the Netherlands in the past two years, including the first results from an international fatigue research project called Prediction of Fatigue in Engineering Alloys (PROF). This four-year project started in July 2016 with Fokker, Embraer, Wärtsilä, Royal Netherlands Air Force and Delft University of Technology.

PROF GOALS

The objective of the project is to improve the prediction of fatigue in aluminum and other engineering alloys by the application of a more physics-based approach. Even though much research on fatigue crack growth has been performed since the 1950s, the most widely used equation to describe fatigue crack growth (the Paris equation) remains empirical and only dimensionally correct when the dimension of the constant in the equation changes with a change in the power law exponent.

New insights into the physics behind fatigue crack growth can improve predictions under constant and variable amplitude fatigue and contribute to the development of materials with improved fatigue resistance. In the future, this should lead to reduced numbers of coupon tests that are required for material characterization, lighter aircraft, optimized inspection intervals and less maintenance.

In the PROF project, fatigue crack growth rate testing is performed on middle tension specimens. The potential drop method is used to measure the crack length as a function of accumulated cycles and the potential drop is stored every 100 cycles. ASTM standard E647 recommends two data reduction techniques for computing the fatigue crack growth rates.

The first is the secant method and the second is the incremental polynomial method. The latter is the most widely used and involves fitting a second-order polynomial to sets of (2n + 1) successive datapoints, where n is usually 1, 2, 3 or 4. However, it would be beneficial to fit the entire crack length versus cycles (*a-N*) curve directly using an appropriate fatigue crack growth equation. In earlier work at NLR it was shown that it is only possible to model the fatigue crack growth in AA 7075-T7351 by using different power law exponents before and after a pivot point.

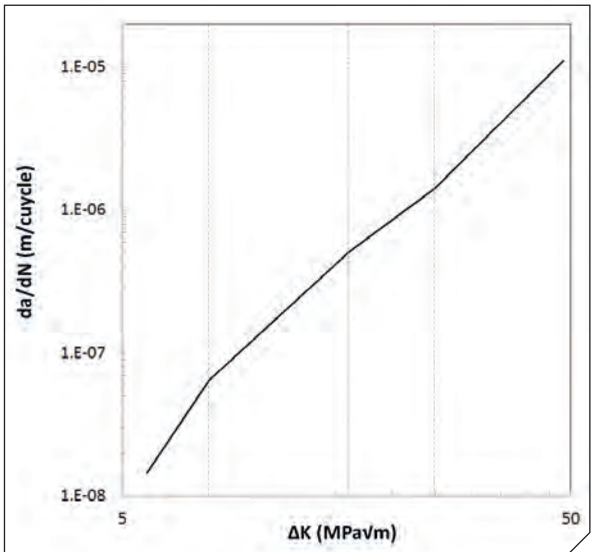
PIVOT POINT IMPORTANCE

A pivot point represents a point in the fatigue crack growth rate curve where the slope changes. This point also corresponds to a physical location on the fracture surface where shear lips start to emerge and crack growth changes from flat to slanted (Figure 1). An additional advantage of introducing a pivot point into the Paris equation is that the equation becomes dimensionally correct. The change in slope of the fatigue crack growth rate from the flat to slanted crack was noted for different engineering alloys in 1967 and has been the topic of several studies. However, a mathematical pivot point has never been employed in a crack growth equation to model the behavior.

In the current study it is assumed that fatigue crack growth is controlled by power law behavior at all crack lengths and stress intensity factor ranges (ΔK) and multiple pivot points are present at different effective ΔK values. This approach is used to fit the entire *a-N* curve to obtain the fatigue crack growth rates instead of using incremental polynomial fitting. A fitting algorithm corresponding to this approach is implemented in Pivotal, which is a coupon and component testing software framework developed by Colosso.

OPTIMIZING PIVOT POINTS

The core of the algorithm implementation in Pivotal consists of an optimizer. The optimizer selects pivot points and calculates the crack growth for each cycle to construct the *a-N* curve. The error between the constructed and measured *a-N* curves is minimized by the optimizer.



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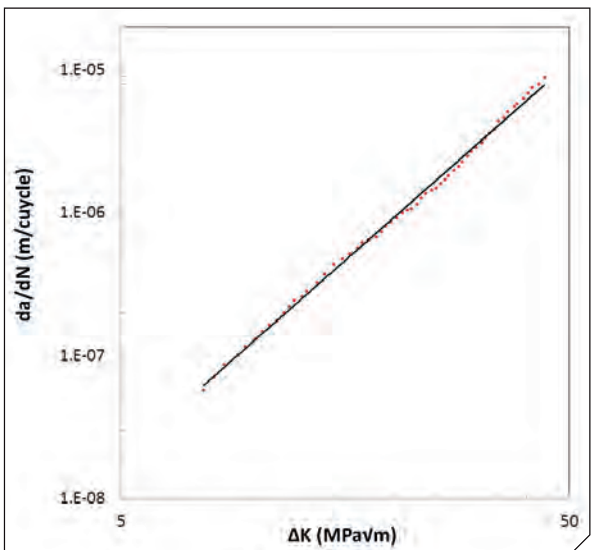

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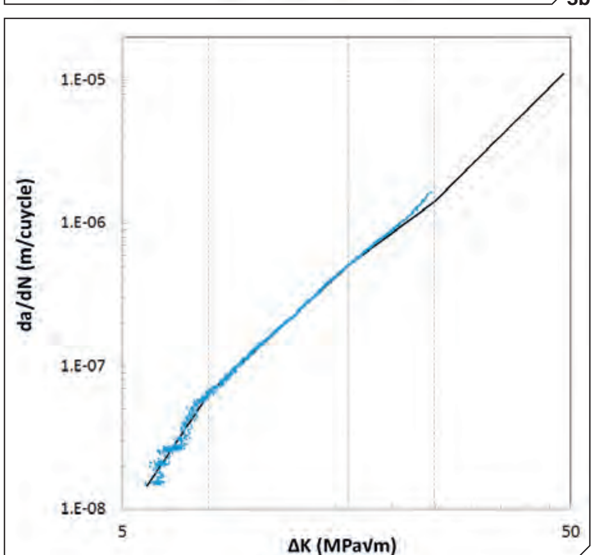

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PROF

The Prediction of Fatigue in Engineering Alloys (PROF) project is part of the Materials Transition Program that was initiated by the Dutch government to make the material knowledge that is present at NLR and TNO more accessible for industry. In the project, NLR will perform accurate measurements of crack growth in different engineering alloys that have to result in a better physical model of fatigue. The measurements will be performed at different length scales and scanning electron microscopy and quantitative fractography will be used to measure the crack growth rate for small cracks. Additionally, fatigue tests will be performed to measure the influence of test conditions and variable amplitude loads.

3a // (a) Crack growth rate obtained by fitting the entire *a-N* curve using the developed approach in Pivotal. The dashed lines indicate the pivot points

3b // Crack growth rates obtained by incremental second-order polynomial fitting of virtual visual crack lengths measurements using seven datapoints. The black line represents a power law fit with a single exponent

3c // Crack growth rates obtained by incremental polynomial fitting of the potential drop (PD) crack lengths using 401 datapoints

For each iteration, the *a-N* curve is constructed cycle by cycle because there is no analytical solution for *a-N* due to the specific function of the beta factor. This beta factor is the finite width correction that is necessary to calculate the value of ΔK for a plate with a finite width. Therefore, the *a-N* curve has to be determined numerically.

For an entire fitting of the *a-N* curve of one specimen, several thousands of full *a-N* iterations are used to find optimal values for the pivot points. The fitting process for a single specimen typically takes an hour on a standard modern computer, because of the large number of cycles and the cycle by cycle *a-N* curve construction.

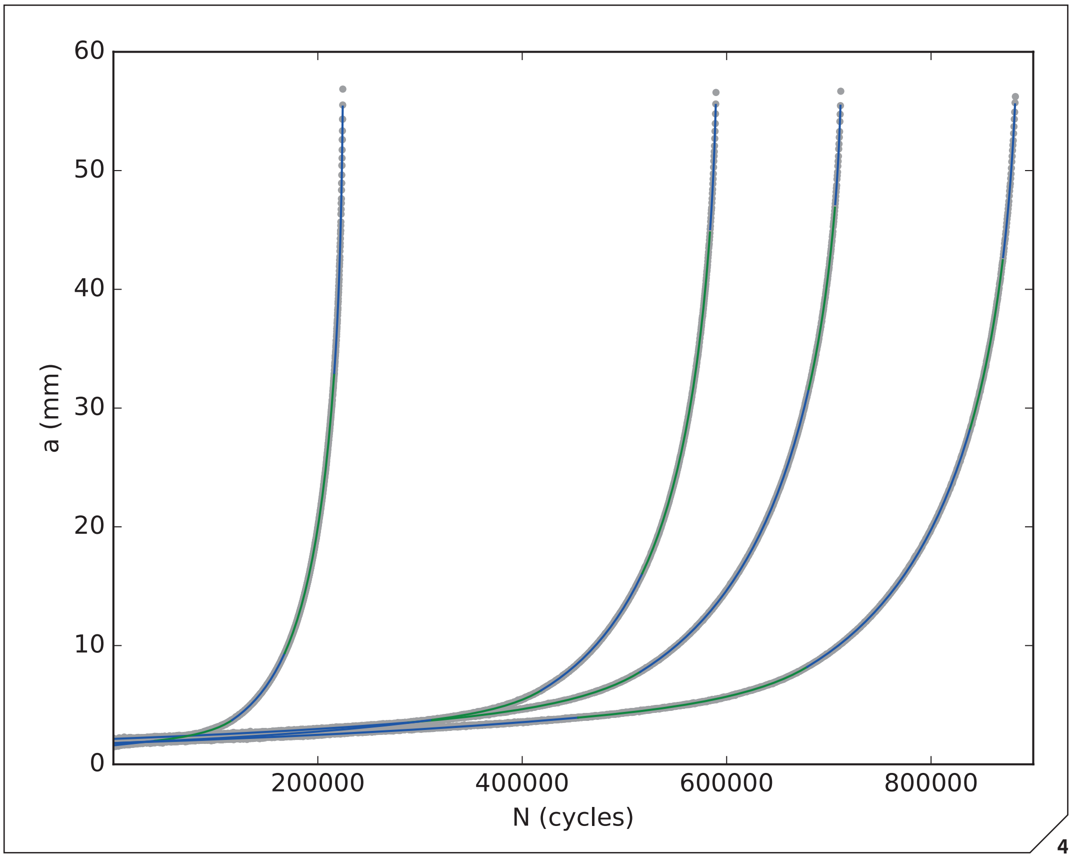
In the 1970 and 1980s, when experimental techniques, storage capacity and computational power were less advanced, fitting the *a-N* with this number of datapoints would have taken several months. Historically the secant or incremental polynomial fitting method was performed on a limited number of visually obtained datapoints. However, in the modern age computational power is no longer a limit and fitting raw data directly to the model is widely done in scientific investigation.

Figure 2 shows the measured *a-N* datapoints of an arbitrary specimen and the black line represents the fit. The insert shows the same data for smaller crack lengths only. The fit follows the shape of the curve well and is also good for small crack lengths.

Figure 3a shows the resulting fatigue crack growth rate (*da/dN*) as a function of ΔK. Four straight lines with different slopes on a log-log scale can clearly be distinguished. The straight lines indicate power law behavior and the different slopes indicate different power law exponents. The good correlation between the fit and the raw *a-N* data indicates that the entire crack growth of a single specimen can be described by power law behavior using multiple exponents. There is no noise in the resulting crack growth rate and it is not necessary to fit the crack growth rate with a model, because an exact description of the crack growth rate is known from the fit of the *a-N* curve.

POWER LAW BEHAVIOR

The question arises as to why the power law behavior with multiple exponents was not noticed in the early days of fatigue research when similar tests were performed. To answer that question, the way the tests were performed at that time should be replicated. For that reason, the fit of Figure 2 is regarded as the actual crack length, and virtual visual crack lengths measurements are taken at every 0.5mm of crack increment. Noise of 0.1mm and 0.2mm for crack lengths below and above 15mm, respectively, is added to the actual crack length to simulate errors in the virtual visual measurements. Figure 3b shows the results when incremental second order polynomial fitting with seven datapoints is used to obtain *da/dN*. The changes in slope cannot easily be distinguished from this data and it is understandable that in the past the entire range of *da/dN* was fitted with a single



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4 // Crack length versus cycles (*a-N)* curve for four AA 7075-T7351 middle tension specimens with different maximum stress and different stress ratios. The colored lines represent the best fits using the developed approach in Pivotal and the alternating colors represent areas with different power law exponents

straight line to analytically describe the crack growth rate as a function of Δ*K*.

Employing the incremental second order polynomial fitting to the raw *a-N* data obtained with potential drop will result in crack growth rate data with a lot of noise when, for example, 51 datapoints are used. When 401 datapoints are used, the data becomes smoother for intermediate crack growth rates, but noise is still present for lower crack growth rates, while the method overestimates the crack growth rate at higher values (see Figure 3c).

Figure 4 shows the measured crack length as a function of the number of cycles for multiple specimens with different maximum stress and different stress ratios. The colored lines represent the fits and the alternating colors represent areas with different power law exponents. Each fit matches the raw *a-N* data well for all crack lengths. Each specimen has multiple pivot points and the results show that the changes in slope occur at the same crack growth rates for all specimens. The crack growth rates at the pivot points match the crack growth rates of the transition points that are described in literature for aluminum alloys (AA).

The transition points are attributed to changes in the micromechanism of crack growth. For example, the transition from flat to slanted crack growth (Figure 1) is one of these physical transition points. The plastic zone around the crack tip becomes larger after the transition to slanted crack growth. The increase in plasticity around the crack results in a decrease in the power law exponent and vice versa. The crack growth resistance is mostly determined by plasticity, so it is expected that a change in the plastic zone size will result in changes in crack growth rate. Similar correlations between the plasticity in materials and the power law exponent are observed for materials in general. Decreasing the plasticity by decreasing the test temperature also results in an increase in the power law exponent.

From the data it is clear that fatigue crack growth in AA 7075-T7351 shows a power law relationship with Δ*K* at all tested length scales/Δ*K* values. The power law behavior at all crack lengths, the introduction of the pivot points and modern computer technology allow fitting of the *a-N* curve to obtain crack growth rates without any noise. This replaces the method of incremental polynomial fitting, which introduces noise and errors in the crack growth rate results.

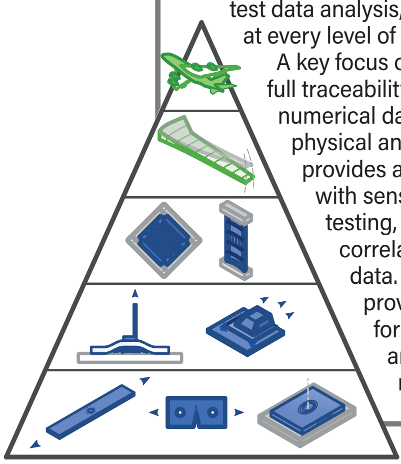
The ability to obtain very accurate crack growth rates will require less testing in the future and opens up a whole range of opportunities for understanding crack growth in constant and variable amplitude fatigue. It can also be used, for example, to exactly determine the influence of small factors such as temperature, humidity and frequency. Future work will include testing of different materials to determine if similar conclusions can be made for steel, titanium or nickel alloys. \\

Dr Emiel Amsterdam is senior scientist at the Netherlands Aerospace Centre (NLR), and Marco Nawijn is the owner of Colosso Applied Research & Engineering and a specialist in physical and virtual testing

PIVOTAL SOFTWARE SUITE

The Pivotal software suite developed by Colosso is designed to efficiently support test data analysis, correlation and storage at every level of the test pyramid.

A key focus of Pivotal is to provide full traceability of meta- and numerical data associated with physical and virtual testing. Pivotal provides a rich set of tools to work with sensor, non-destructive testing, digital image correlation and simulation data. In addition, Pivotal provides an web interface for querying, annotating and visualizing test results.



HAVE YOU MET...?

Meet Robert S Rutledge, fatigue testing expert at the National Research Council of Canada

// ANTHONY JAMES

HOW DID YOU FIRST BECOME A TEST ENGINEER?

My route to becoming a test engineer started after graduating with a Bachelor of Science degree in Mechanical Engineering from the Nova Scotia Technical College, now part of Dalhousie University. I was hired by Canada's leading aircraft manufacturer, Canadair, now Bombardier, directly after graduation from university in 1979, joining the experimental department of the company.

WHAT WAS YOUR FIRST TESTING JOB?

One of the first memorable jobs I was assigned was to design an *in situ* load cell calibration jig to accommodate all the load cells for a full-scale fatigue test of the CL-600 Challenger. At that time [1980] there was no computer-aided drawing capability in my department; all drawings were created manually on a drafting board.

The critical instrumentation from today's tests continues to be the load data

recorded from the feedback of the load cells – the actual applied loads. Current tests have the added benefit of high channel count strain data measurements taken on the test articles complementing the load data. For this data, the test team configures an expandable multichannel data acquisition system and integrates it with the load control system. The data from the data acquisition system and the load control system are collected through a combined data stream into a single data file and data is recorded at every peak and trough.

WHAT WERE THE MOST VALUABLE EARLY LESSONS FROM THE BEGINNING OF YOUR CAREER?

The most valuable lesson in carrying out a full-scale test that still applies is test configuration management. Test article configuration must be representative, recorded and revised. The test rig designs must be documented and standard revision control practices must be carried out to ensure that all components and assembly drawing configurations remain traceable. Damage reporting and dispositioning of engineering orders must be carried out within strict timelines and approval processes. Test plans, progress reports and test final reports must document the entire body of work and get through the approval process efficiently. Information that is not written down is of little value and will be easily forgotten.

1

WHAT IS YOUR CURRENT POSITION?

My current position is the project lead for structural full-scale testing at the Structures, Materials and Manufacturing Laboratory within Aerospace Engineering at the National Research Council of Canada. I lead projects that involve multidisciplinary teams within the laboratory that respond to requests for proposal, determine tasks and level of effort and estimate costs. Tasks in these projects typically include: test rig and test article interface design, manufacture, instrumentation, assembly of the test rig, calibration, inspection, carrying out the test (durability, damage tolerance, and residual strength), teardown, documentation and the day-to-day management of full-scale aircraft and component testing. I have been working at NRC for 29 years, with the first four as a contractor, seconded to NRC from IMP Aerospace, the repair and overhaul company I was working for at that time, to help NRC carry out the full-scale test on the CT114 Tutor, an aircraft originally designed as a training aircraft, but currently used exclusively in the Canadian Snowbird aerobatic role.

"TEST ARTICLE CONFIGURATION MUST BE REPRESENTATIVE, RECORDED AND REVISED"

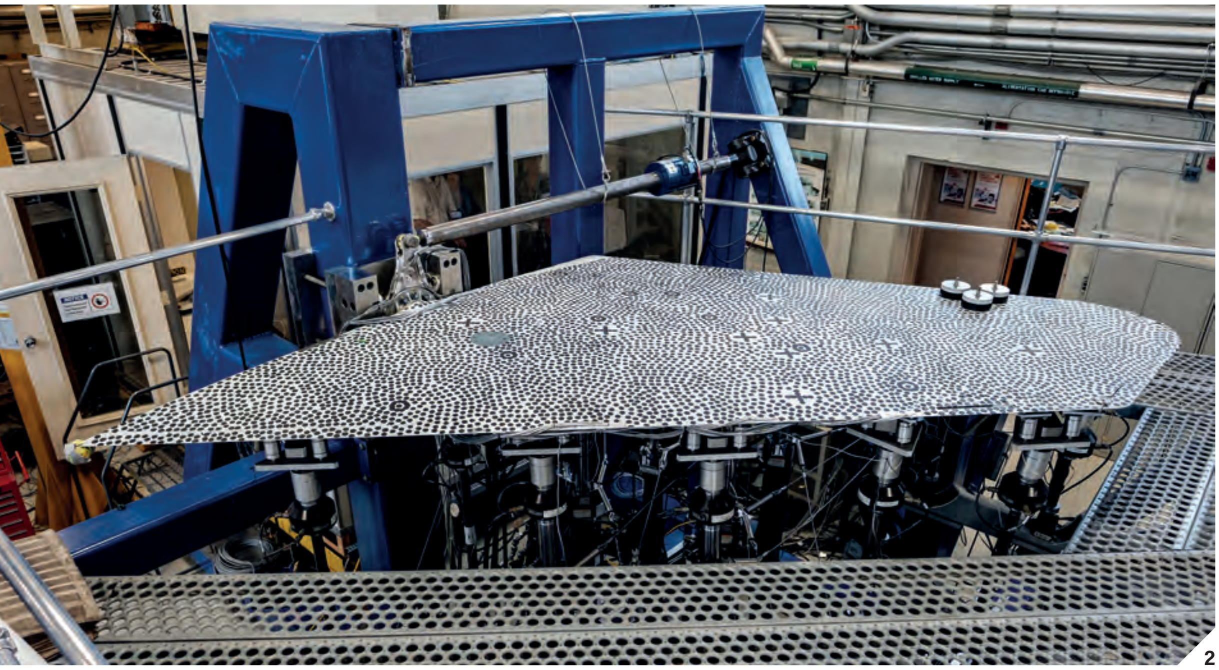
1 // Robert S Rutledge, aircraft structural test project manager, Aerospace Structures and Materials Manufacturing Laboratory, National Research Council Canada

2 // Canadian Forces CF188 horizontal stabilator full-scale fatigue and damage tolerance life evaluation and extension test article

PLEASE DESCRIBE A TYPICAL DAY.

Currently my typical day starts with checking the progress of two active life extension component tests, as these tests are running 24 hours per day, seven days a week. This may include preparing progress reports to the clients and collaborators. With this accomplished, I would typically review my email and revise priorities within my list of action items. For issues relating to a specific test I would discuss/assign engineering resources, review upcoming inspection requirements, and discuss these directly with the inspector. If damage is found during testing, a damage report would be written, approved and sent to the client and collaborators within 24 hours, and a follow-up meeting would be scheduled. Then I would meet with the facility manager to assess impediments to project progress on both testing and assembly of new tests that have not yet achieved test readiness status.

Following this, I would check with my engineering student to see if he had any issues with current assignments. I would review the project management requirements for project changes and revisions to contracts. After lunch, I would check my email and assign priorities for the incoming requests and check on load frame testing of the redesigned tension-compression whiffle tree. I would review the trend data from the full-scale tests for structural strain changes and then work on the documentation of current or upcoming tests, or a proposal to potential clients based on priorities. If time permits, I would prepare or correct reports, presentations and papers for conference proceedings.



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WHAT MAJOR PROGRAM(S) ARE YOU CURRENTLY WORKING ON?

My current position includes direct support to the Aeronautical Product Development Technologies (APDT) Program and the Air Defence Systems (ADS) program within Aerospace

Engineering. We are testing commercial aircraft components and prototype structures in conjunction with aircraft manufacturers, developing new ways to cost-effectively speed up certification testing and developing new methods for environmentally controlled testing of components for certification. We are currently carrying out life extension tests supporting the Royal Canadian Air Force (RCAF) to safely extend the life of aircraft structures and components based upon in-service load spectra and usage.

3 // Fatigue test rig hydraulics and purpose-built test frame

4 // Fatigue, damage tolerance and static residual strength testing underway at the NRC

WHAT ARE SOME OF THE SPECIFIC FULL-SCALE FATIGUE TESTING CHALLENGES INVOLVED?

Such challenges typically relate to schedule and cost. The clients keep pushing for the fatigue tests to be completed as soon as possible. In the civil world, it is needed for certification, which determines the go-ahead for the sale of new aircraft or the development of the latest prototype at the lowest development cost.

For RCAF aircraft, fatigue tests are carried out to either extend the life of the component or to make decisions to procure replacement parts. In all cases, they need the results to make judicious decisions on long lead-time repairs or replacements.

Over my career, attachments to the test article have evolved significantly.

The latest developments at NRC utilize thin aluminum disks bonded directly to the surface with either acrylic or epoxy adhesives, depending upon the substrate. These are lower in mass than typical steel-backed neoprene rubber pads and these aluminum disks effectively reduce fixturing weight without introducing significant stiffness in the test articles. This allows for increased testing speeds without the risk of introducing dynamic strain errors.

Recent enhancements to this have included one-sided tension-compression whiffle trees. The development of this new whiffle tree concept both speeds up time during pre-test assembly and reduces test time during fatigue test running. The one-sided whiffle trees have reduced mass further, but more importantly they have made it easier to assemble the test rig because all the actuators are mounted on one side of the test article. This reduces time to assemble the test because there are no portal frames or hydraulics directly above the test article.

WHAT UNIQUE FACILITIES FOR STRUCTURAL TESTING ARE AT THE NRC?

NRC has standard structural test facilities with a hard floor and a small test bay suitable for testing fighter aircraft, helicopters and small coastal patrol aircraft. The structures laboratory dates back to the 1940s. In instances when a larger facility is required, test hangars can be accessed. In the past 29 years, NRC has chosen to investigate and develop systems that allow for high-fidelity testing of aircraft that use state-of-the-art data acquisition systems.

We continue to investigate improvements to computer control systems – both software and hardware. Hardware improvements generally occur at about every 10 years with improvements to computer systems, but investigations into software methods can be applied and investigated independently.

If a new methodology control improvement can be made, NRC has a track record of working with equipment suppliers to get the new improvements implemented in future versions of software updates. The truly unique facilities that NRC has recently added to our structural testing are in environmental testing and on the data acquisition side. For controlled environmental testing, a project was carried out to address issues of high-temperature engine exhaust on composites that must be certified to both static and fatigue testing requirements.

WHAT WORK ARE YOU DOING IN SUPPORT OF THE RCAF'S F/A-18s? WHEN IS THIS DUE TO END, GIVEN THE F-35'S IMMINENT ARRIVAL?

NRC is currently working on extending the life of the flight control components of the RCAF's F/A-18s. We are currently testing a horizontal stabilizer, an aileron, and will soon be testing the inboard leading edge flap. A test of the hinges of the trailing edge flap may also soon be under test. Testing of these components should be completed in two to three years depending on the requirements. Currently we have extended the life of the horizontal stabilizer by a factor of 1.66 times the original design life. With a replacement cost of over US$1.2m per aircraft, the testing of this one component test has proven to be a very cost-effective measure. As for the when the imminent arrival of the F-35s will occur, I can't comment on this. Canada has not yet decided on final selection of its next-generation fighter aircraft fleet.

HOW LONG IS A TYPICAL FULL-SCALE FATIGUE TEST AND WHAT DOES IT INVOLVE?

There is no typical length to a fatigue test and all are different but involve design, instrumentation, manufacturing, assembly, calibration and commissioning before the test can start. After test start, appropriate spectrum loads are applied to a representative test article. For the RCAF tests, the spectrum is usually typical of an average spectrum in a severe squadron. The intent is to determine when the fleet-average aircraft or component needs to be removed from service. In civilian certification tests, the spectrum is usually defined by the client based upon the intended use, and the supporting documentation is approved by Transport Canada and/or the FAA.

The critical instrumentation parameters measured in a full-scale test are the feedback loads. The data is recorded at every end level, applied using a data acquisition system and stored in the computer. The data is retrieved and provided to the client and collaborators periodically along with the strain and displacement data that has been recorded. The data is analyzed in-house and trends are checked for changes in the structural response. Test articles are instrumented with conventional foil strain gauges, fiber-optic strain gauges, displacement transducers and digital image correlation cameras. All the conventional foil strain gauges and displacement data are provided to the client. NRC processes all the foil strain gauge and displacement data and plots data to files. These processed files are provided to the client periodically during the testing.

WHAT IS THE MOST COMPLEX TEST YOU HAVE EVER CARRIED OUT?

In 2001, as part of an International Follow-On Structural Test Program (IFOSTP) to better define the service life of the US Navy's F/A-18 aircraft under typically more severe RCAF and Royal Australian Air Force usage, the NRC's Aerospace Research Centre commenced active testing of FT-245, a full-scale fatigue test of the aircraft's wing. The objective of this test was to determine the economic life of the inner- and outer-wing box under representative loading.

As the most complex test undertaken by the NRC's Aerospace Research Centre to date, FT-245 posed a series of formidable challenges. To meet these challenges, the structures laboratory engineering team pursued an array of innovative approaches to full-scale fatigue testing including: development of a service-based spectrum for an actively controlled aircraft, including buffet; aggressive spectrum editing techniques to reduce the number of load lines to a workable quantity; and a new method for calculating actuator loads more suitable for large numbers of actuators.

The team also worked closely with its test equipment supplier, MTS Systems Corporation, to effectively extend the limits of the test equipment and software available at the time. Improvements included: incorporating optimally sized hydraulic components and developing low-mass fixturing to maximize test speed; developing a sophisticated trend monitoring system to automatically detect structural changes during testing; and developing an automated load checking system to document any missed end levels directly, rather than having to store data at nominal end points for subsequent verification.

This test had a block spectrum sequence length of approximately 150K load conditions that represented about one year's usage within an operational squadron. At that time, there was a limit of 50K load conditions that could be used within the control system, so similar conditions were binned. The total number of test loads applied during the wing fatigue and damage tolerance test was 8.68 million and these load cases were applied with 63 actuators and six reactions.

WHAT IS THE MAXIMUM SIZE AIRCRAFT THAT YOU COULD TEST?

The test size, control system, data acquisition system, number of actuators and dedicated hardware used in a test depends on the request for test by the client. NRC has bid on full-scale tests of large new commercial aircraft within consortiums that require 150-200 actuators and would have required a dedicated hangar to carry out the testing.

HOW HAS FATIGUE TESTING CHANGED OVER THE YEARS?

Fatigue testing has changed significantly over the years in many aspects, from the use of draftsmen producing drawings, to the use of CATIA with three-dimensional layouts of the test and loading systems. The advances in computer control systems and data storage has allowed us to carry out tests with much more complexity and higher fidelity in shorter periods of time. This has been predominately due to NRC's ongoing efforts to decrease project time. From lower mass fixturing to control system cross-coupling compensation, NRC has been striving to provide its clients with accurate test results efficiently in the shortest possible time.

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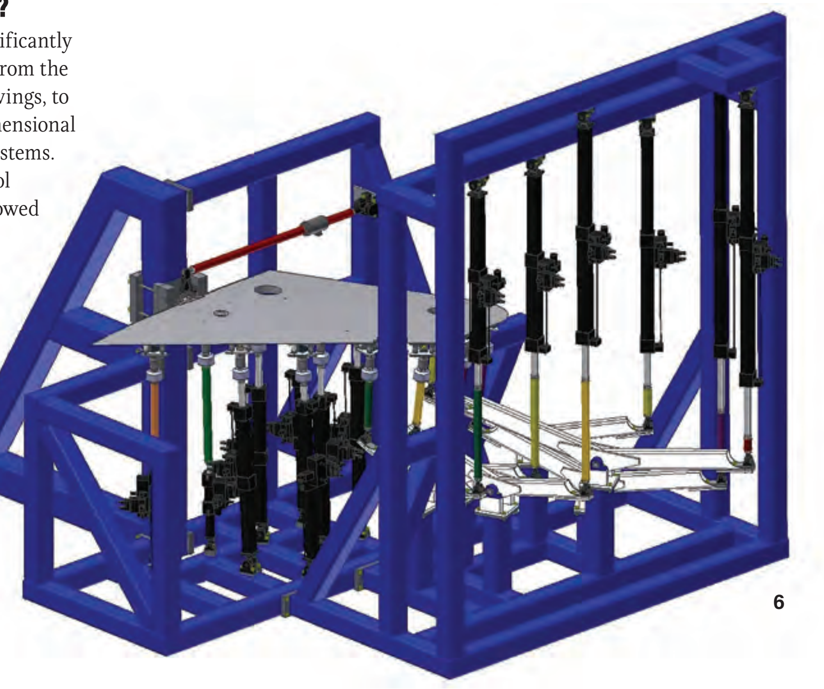

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5 // Upper surface digital image correlation paint scheme for strain comparison with strain gauges and fiber-optic strain sensor

6 // Tension-compression single-sided loading system with bond pads on the lower surface

DO YOU TEST TO THE POINT OF CATASTROPHIC FAILURE?

In some test protocols, NRC has tested to the point of catastrophic failure. However, in these static cases, typically the client defines the requirement for the failure loads, and although the structures are designed to sustain ultimate loads (typically 1.5 times once in a lifetime loads), they do not necessarily fail catastrophically at these loads. The more likely outcome that we have encountered when trying to test to failure after a fatigue test is that the test configuration is insufficient to apply additional loads on an actuator and the test is automatically stopped without failure. Dangers to personnel and operators within full-scale fatigue and static testing is minimized by limiting access within the test bay, adding Plexiglas fixturing to test rigs surrounding the test article, and wearing personal protective equipment. In some cases when we planned a failure case on a composite part that was to be loaded to above ultimate loads, we have bagged the test article to contain the carbon-fiber dust that would likely be generated upon failure.

WHAT DOES IT COST TO CONDUCT A FULL-SCALE FATIGUE TEST AND WHAT IS CURRENT AVAILABILITY?

The full-scale fatigue test cost is commensurate with the test requirements, complexity, equipment and data requirements. However, for follow-on structural test that we are carrying out for the RCAF components, the return on investment can be higher than 50 to 1 based only on the replacement cost of the parts relative to the cost of the test. To illustrate this point, I will use the example of the horizontal stabilator of the RCAF CF188 currently under test at NRC. The CF188 horizontal stabilator had a replacement cost of US$600,000 in 2011 and there are two on each aircraft. If the current test was not carried out, then the RCAF would have had to procure a sufficient number of replacement components to keep the active squadrons aircraft flying until the aircraft was replaced. For the current fleet, for this one component this would have resulted in a cost over US$100m to the RCAF Department of National Defence. Other components under test may not be as expensive, such as the ailerons, but they too can be cost-effectively in-service tested to extend the life, saving the RCAF procurement of replacement parts. Civil certification and structural demonstration tests for new aircraft are part of developmental costs to aircraft manufacturers, and these costs must be built into the sale value of the product for cost recovery after certification is achieved.

ANY PARTICULAR TEST OR EXPERIENCE STICK IN MIND?

The costs and schedule of full-scale tests are always under scrutiny and both collaborators and clients have priorities that don't always align. After completing the full-scale test of the RCAF CF188 wing, I found myself reflecting on the cost of the testing project and questioning the design decisions I was responsible for and wondering how we could have improved on the full-scale test we carried out. We had decreased mass of the loading system and increased the speed at which we could apply the loads, but one of the client's remarks, a liaison officer from the Royal Australian Air Force who was seconded to observe and help with testing, always sticks in my mind. When, after test start, NRC had accelerated the testing speed by a factor of two by tuning the lower mass whiffle tree system to run faster, one of my colleagues, an IAR technologist, stated in a meeting that we had saved two months on the test schedule. Whereupon the RAAF officer responded that we were not two months ahead on the schedule, we were actually two years behind! This was actually the case because the pace of the loads development had delayed the definition of the spectrum loads and test start. So in subsequent tests, I found myself challenging the test designers to make things lighter and simpler, which eventually led to the development of a novel set of tension compression bonded whiffles, which has reduced assembly time and which factors in reducing test running speed, but really does not address the time to develop loads for in-service tests. For this, NRC has currently been investigating the use of fiber-optic strain gauge measurements on a full-scale ground test. Recent investigations in a full-scale fatigue test have found that the response of the fiber-optic strain measurement system can provide calibrated relationships with the applied loads, which can be used to provide bending moment, shear and torsion curves – just like foil strain gauges that are used to measure loads during flight tests. In the future, fiber-optic strains may be used to derive the operational usage from flight test aircraft, but currently we are still working at the ground test level to address issues with current state-of-the-art fiber-optic equipment.

"I FOUND MYSELF CHALLENGING THE TEST DESIGNERS TO MAKE THINGS LIGHTER AND SIMPLER"

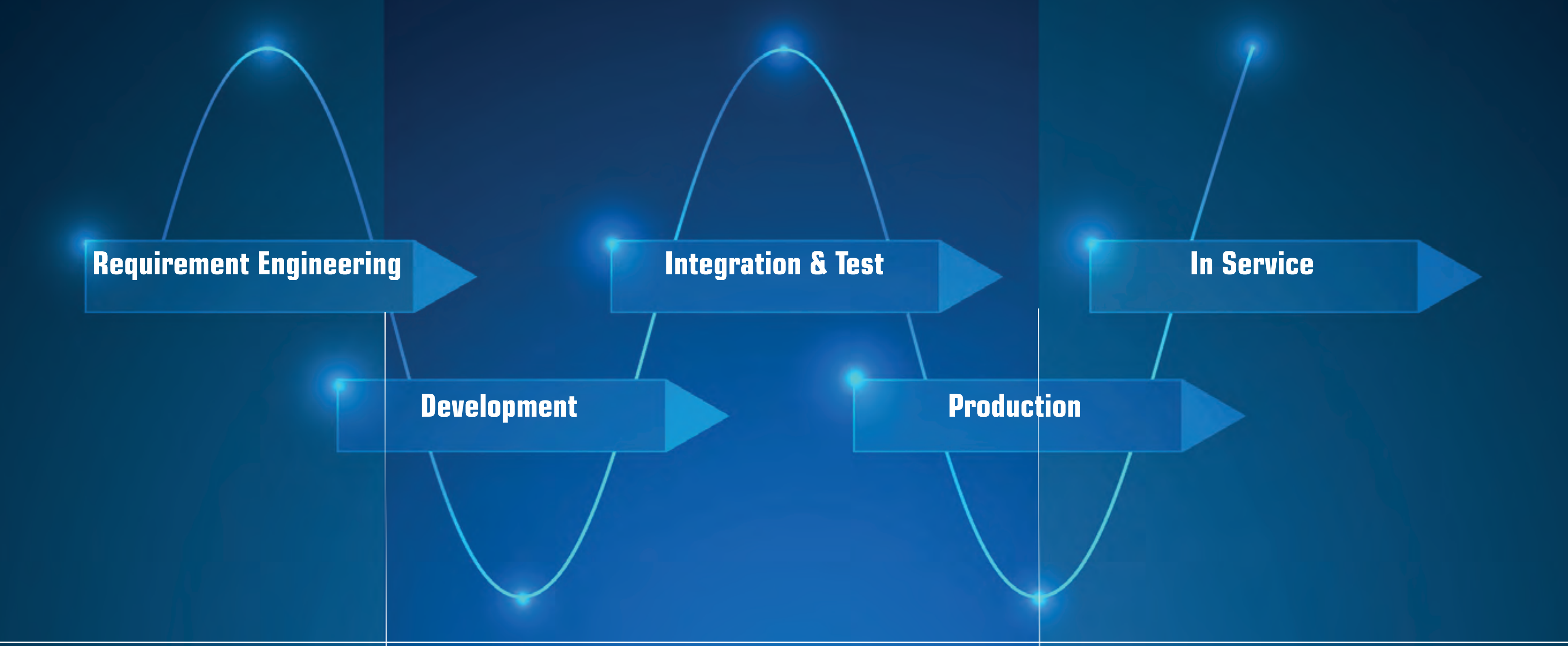
7 // Canadian Forces CF188 wing full-scale fatigue and damage tolerance life evaluation test

WHAT FUNDAMENTAL LESSON WOULD YOU LIKE TO SHARE?

When considering how long a test takes to complete, particularly in life extension tests, I always give the example of testing on the RCAF CF188 wing. From the outset of the test, the plan was to test the wing to three lifetimes of usage, followed by residual strength testing to loads that exceed limit. At the time I suggested, to the DND technical authority, that we carry out an additional damage tolerance life for the possibility that the RCAF may need to extend the life of the wing beyond what was assumed to be the current requirement. At that time in 2005, the test was running consistently with few problems and investing an additional two to three months of run time with limited inspection could provide valuable life extension data at minimal cost. My suggestion fell on deaf ears and the test proceeded into the residual strength testing phase. Twelve years later, and with the next-generation fighter aircraft replacement not yet selected, let alone purchased, this additional certification test data would have provided greater confidence in extending the useful life of the wings for the RCAF. Of course it wasn't as simple as that, as both international collaborators, the RCAF and the RAAF, wanted the testing to be completed as soon as possible to obtain certification to the original objective for their fleets at that time. So I tell visitors, particularly those from the RCAF, to test more and inspect less in a damage tolerance life prior to the required residual strength testing. The more you test, the more money taxpayers save.

HOW DO YOU SEE FATIGUE TESTING CHANGING IN THE FUTURE?

Fatigue testing of aircraft, components and elements should not, and will not, change in the foreseeable future, other than that there may be more required with the introduction of 3D-printed parts. There is no way that the computer models that we have today will be sufficiently accurate to account for assembly stresses, embedded flaws in manufacturing or 3D printing, or accounting for special process damage effects in product manufacture, such as ion vapor deposition acid etching prior to coating a part with pure aluminum for corrosion protection. Besides, all structural finite element models require boundary conditions, and although they are useful to bound a problem by running analysis with and without various constraints, they are no match for a real test in finding the weakest link. If emphasis continues to be put on safety and protection of the public, then aircraft full-scale fatigue tests need to be undertaken to prove the required performance and life, identify faults, and provide a testbed to verify repairs, dispositions and define inspection intervals, as well as maintenance actions for operators. \\



MDVS Model-based Development & Verification System
VSIB Virtual System Integration Bench

SDIB Single Device Integration Bench
SIB System Integration Bench
FIB Functional Integration Bench

FAL Final Assembly Line Tester
PAT Production Acceptance Tester
IST In-Service Test Bench

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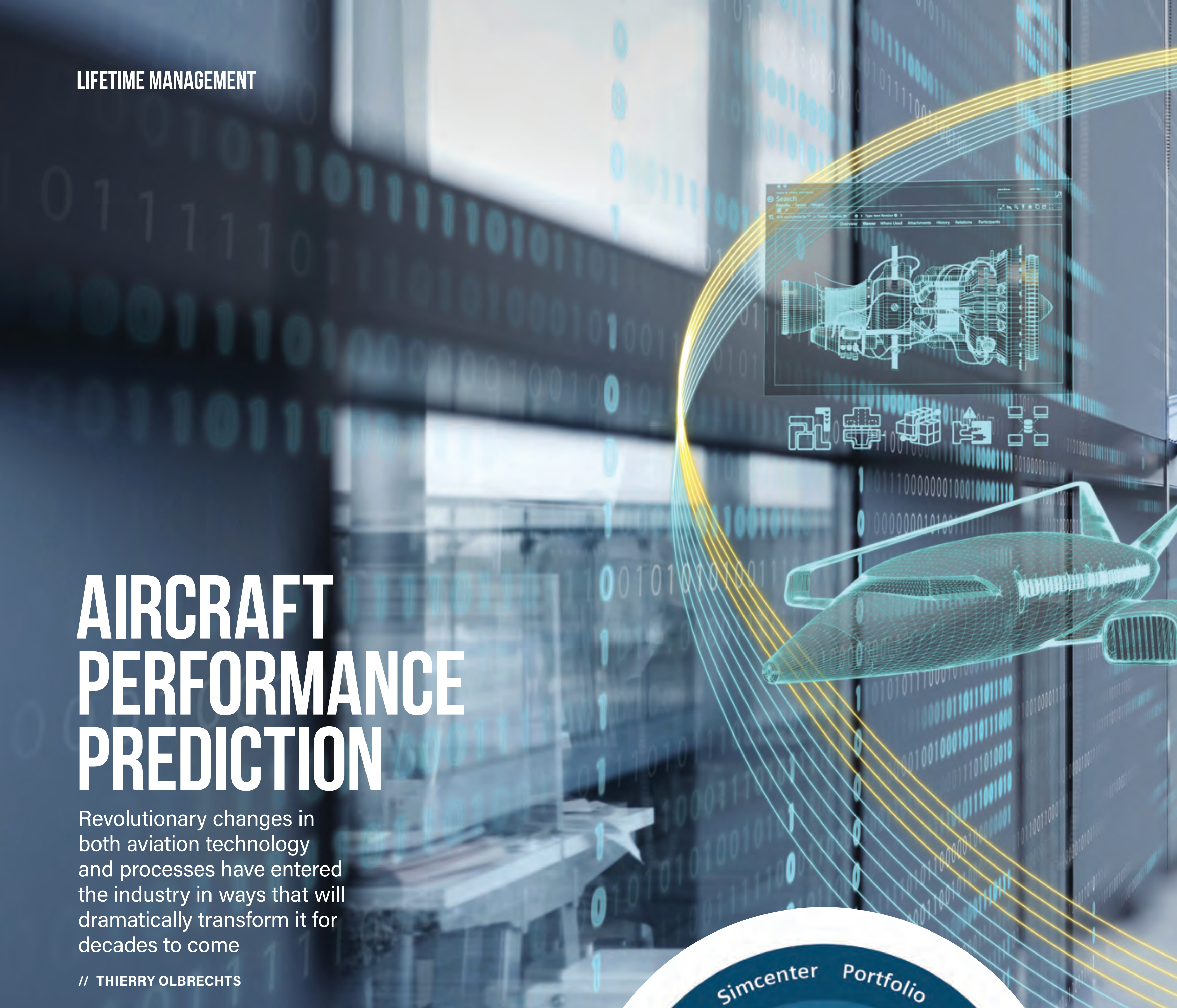

AIRCRAFT PERFORMANCE PREDICTION

Revolutionary changes in both aviation technology and processes have entered the industry in ways that will dramatically transform it for decades to come

// THIERRY OLBRECHTS

Today's environmental and business challenges and how they are met will dramatically transform aviation product and equipment engineering for decades to come. One big challenge in aviation products and equipment is the continuous demand for increased performance and improved fuel economy. Together with safety and reliability, these are without doubt the most function-critical design aspects for aviation products and structures. This is not only because of regulations, but also because these design aspects directly result in measurable economic added value for customers, and can even determine whether missions are possible at all.

Aviation companies are at the forefront of research into new materials to reduce weight. The aerospace industry has naturally been the number-one laboratory for new lightweight materials, such as composites. Famous examples are the Boeing 787 Dreamliner and Airbus A350, the first commercial aircraft with major structural elements made of composites.

At the same time, strong improvements to fuel economy and performance will come from increased use of intelligent systems and aircraft using electronic controls and software to reduce energy use.

Additive manufacturing is changing the way products are made. Revolutionary machines and processes are rapidly pushing this part creation method from a prototype environment onto the production floor.

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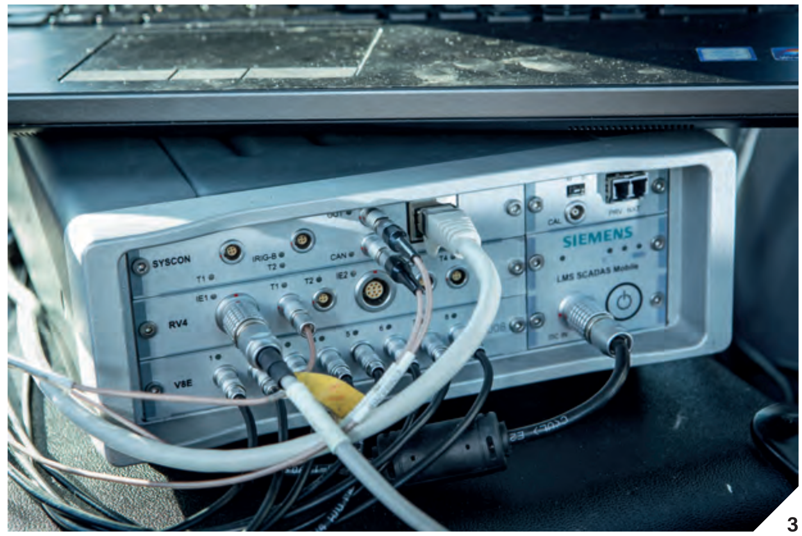

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1 // The Simcenter portfolio enables prediction of product performance across all critical attributes and throughout products' entire working life

2 // The Simcenter portfolio encompasses simulations of a variety of stages in development, including the ability to perform multiphysics explorations for design optimization

3 // Simcenter testing solutions enable intelligent data analytics and reporting to address aircraft verification and certification processes

This will have a huge impact on aviation engineering – on design and development, manufacturing, maintenance, and the relationship between all these phases in a product's life. It will also change entire industries as many of these innovations will find their way into other commercial applications.

CREATING LIFETIME VALUE

Another major challenge is related to the economic reality of the aviation business. Equipment orders are usually large investments that leave little margin after price negotiation, and late delivery can lead to expensive penalties. It is critical for business success to have effective processes to turn demand into delivered products. On top of that, OEMs try to establish solid relationships with their customers by offering packages that also include maintenance.

To be successful, they need robust processes that can track whether the functioning of all their products meets requirements from cradle to grave. They need to collect, manage and analyze huge amounts of data to continuously improve products and define the most effective, individualized plans that embrace development, production and maintenance.

THE DIGITAL TWIN

An important way to create value is through good product life management to deal with complex materials, manufacturing methods and intelligent systems. This includes building a set of highly accurate models that help predict product behavior during all phases. These models, as a collection, are called the digital twin (DT), and exist in multiple scales and instances for various applications, integrate multiple physical aspects, contain the best available physical descriptions and mirror the life of the real product and its production process.

There is no clear-cut and finite definition of the DT. Rather, it refers to the linking of all activities related to advanced simulation and prediction and their integration over the product's life. If well conceived, the DT should bring clear advantages to product development, manufacturing and after delivery.

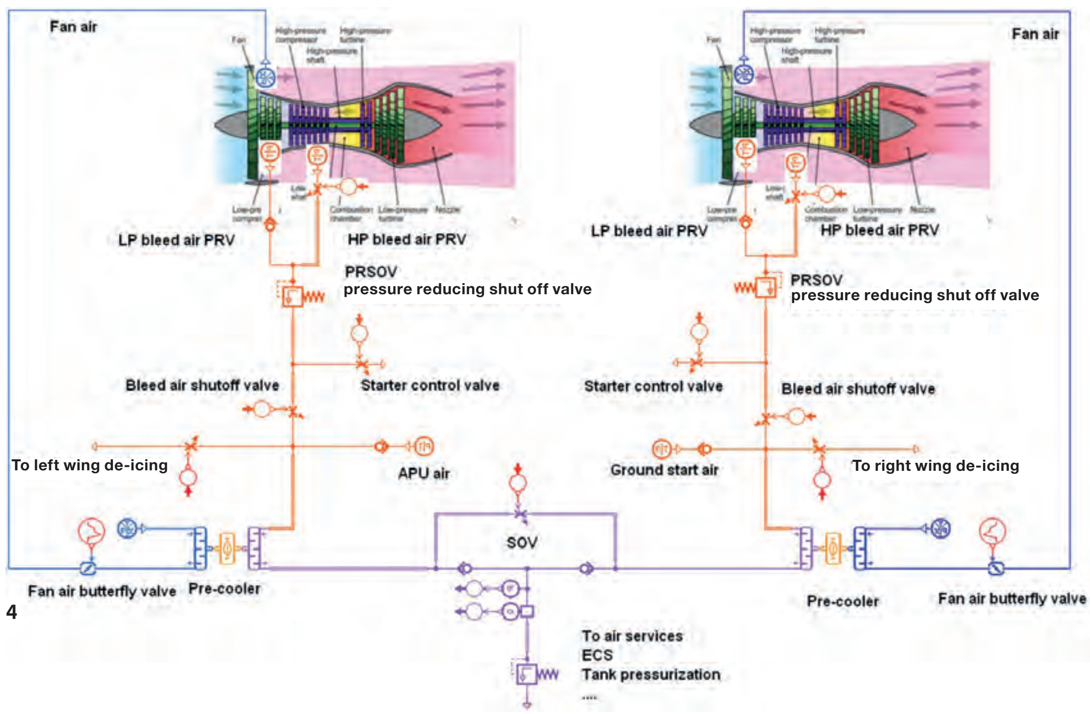
The extent to which the concept is deployed still depends on what a company can or wants to do, and on what the technologies used are capable of. Especially in the aviation industry, a lot of work still needs to be done in the coming decades. Even though various applications already exist, the industry looks forward to new methods and developments, for example in the fields of modeling realism, calculation speed, data management and the integration between various activities, that will enlarge the current scope of the DT.

SIMCENTER FOR PREDICTIVE ENGINEERING ANALYTICS

Siemens PLM Software offers manufacturers the most comprehensive possible solutions to build and maintain the DT. This is seen in Siemens' acquisitions of companies that cover missing pieces and in development plans for more realistic simulation, accurate testing and powerful data management applications, as well as their integration.

With this comprehensive offering, traditional verification and validation processes that currently deliver discrete product generations and incremental improvements will evolve to a new, predictive approach for systems-driven product development, called predictive engineering analytics (PEA). At its core, PEA combines the application of multidisciplinary simulation and test with intelligent reporting and data analytics in an integrated workflow to build a DT.

PEA achieves higher modeling realism and simulation performance by removing the boundaries between development stakeholders. It integrates technologies such as 1D simulation and 3D computer-aided engineering (CAE), including computational solid mechanics (CSM), finite element analysis (FEA), computational



HAND-IN-HAND WITH CUSTOMERS

In parallel with the software applications, engineering services are a strategic part of Siemens PLM Software's business because, through this activity, the company has the opportunity to work with customers on real engineering problems. That understanding has always been critical in terms of driving innovation in what is done in simulation and testing. Through Siemens' engineering services and technology exchange with the industry, the maturity levels of some of the more advanced areas of simulation could dramatically be improved.

4 // Thermal-pneumatic system mock-up designed with LMS Imagine.Lab Amesim, the 1D simulation software of Simcenter

fluid dynamics (CFD) and multibody dynamics, controls, physical testing, visualization, multidisciplinary design exploration and data analytics in a managed context.

Siemens has bundled all the underpinning solutions for this vision into the Simcenter solutions portfolio to address aircraft structural, mechanical, aerodynamics and systems performance engineering as well as integration testing, verification and certification.

This solution combines decades of experience by putting well-known products such as LMS Test.Lab, LMS Imagine.Lab, NX Nastran, Femap, Star CCM+, Heeds and more under one umbrella. It also features Simcenter 3D as the combined successor of NX CAE, LMS Virtual.Lab and LMS Samtech. As well as these tools, PEA is also about a good alignment of processes.

CLOSED-LOOP, SYSTEMS-DRIVEN PRODUCT DEVELOPMENT

PEA supports closed-loop, systems-driven product development, the fastest path to turn a set of requirements into a product. In this multidisciplinary simulation-based approach, the global design is considered as a collection of mutually interacting subsystems from the very beginning. From the very early stages, selected architectures are virtually tested simultaneously for all critical functional performance aspects.

These simulations use scalable modeling techniques, so components can be refined once the product configuration is defined and as data becomes available. This comes down to creating a DT starting from the concept stage and gradually adding details.

In this context, closing the loop refers to concurrent development of mechanics with controls. A closed-loop-systems-driven product development process relies on strong tools for 1D simulation and 3D CAE, combined with 1D-3D co-simulation capabilities for model-in-the-loop (MiL), software-in-the-loop (SiL) and hardware-in-the-loop (HiL) validation processes. A good alignment of these tools with physical testing is required to increase modeling realism and for final verification.

MULTIDISCIPLINARY EXPLORATION

Simcenter includes an efficient and easy-to-use multidisciplinary exploration framework, called HEEDS MDO, that easily integrates with current design and simulation tools, thus protecting a company's existing investment in high-performance computing infrastructure and generating a higher return.

Keeping models and results in sync is achieved through the Teamcenter data management environment. Capturing and managing data and processes permits organizations to build long-term knowledge and value.

Improving a single component or a complex system becomes easier as Simcenter can automatically explore the design space within the constraints of specified goals, such as reducing costs while maintaining stresses below certain levels. HEEDS MDO software can help manage conflicting targets such as mass, cost, manufacturability and performance.

THE FUTURE

To fully exploit the capabilities of the DT once the product is in the field, and involve it in future applications such as activating self-healing mechanisms, proactive damage control and history-based updating of intelligent systems, all parameters that define the complete behavior should be traceable and kept in sync.

Data analytics, reporting and exploration are becoming increasingly important because lots of data must be gathered over the entire product life. Siemens continues to invest in advancing the software's ability to process simulation, testing and usage data, to gain insights that can improve the next design.

By connecting Simcenter to Teamcenter, together with reporting and exploration capabilities and its cloud-based IoT operating system, MindSphere, Siemens will try to remove the boundaries between design and a product's life after delivery. This will transform product development from a process that delivers discrete generations into a continuous process that keeps track of individual products and constantly updates them until end of life. That will allow applications that exploit the DT to its full extent. \\

Thierry Olbrechts is director of the Aerospace Competence Center at Siemens PLM Software, Simulation and Test Solutions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ACOUSTIC EXCITATION OF TURBOMACHINERY BLISKS

Specialized software can be used in the design of turbine blisks by replicating and capturing the crucial excitation patterns set up during testing of the rotor blades

// **SEBASTIAN SCHWARZENDAHL**

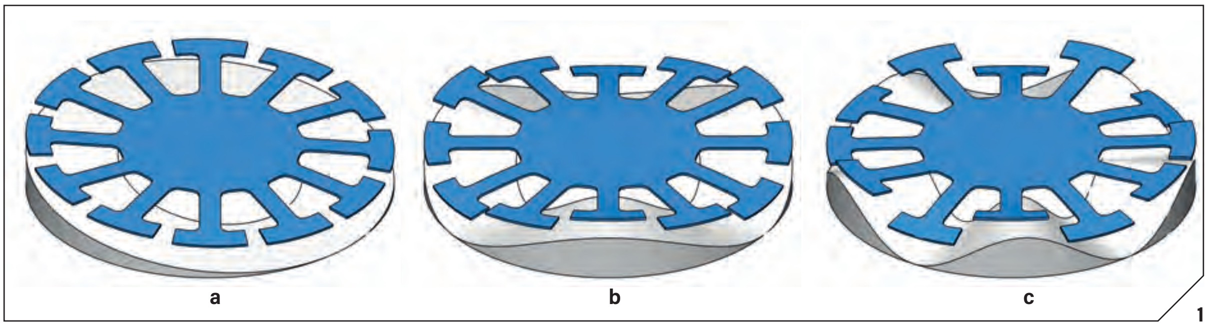
During operation, rotor blades of aircraft turbines are subject to high dynamic forces introduced by the working fluid. To assess the structural health of the blades, dynamic analyses are carried out in laboratory tests. Highly specialized test rigs are designed for analyses of blades in rotating and stationary operating conditions. Especially for stationary tests, it is crucial to artificially replicate the typical excitations acting on the rotor blades during operation, known as engine order excitation. A software package designed by m+p international enables engineers to generate an engine order excitation and analyze the dynamic responses of the turbomachinery blisks in the safety of the laboratory.

BACKGROUND

During operation, the working fluid acts on the rotating turbine blades, creating a pulsating pressure field. Circumferentially expanding this pressure field yields a harmonic series whose coefficients are called engine orders (EO). Basically, an EO describes the number of sine waves traveling along the circumference of the rotor (Figure 1). The corresponding excitation frequency is the product of the rotational speed and the specific EO.

$$f_e = \mathrm{EO} f_{rot}, \quad \mathrm{EO} = 0, 1, 2, \ldots$$

Only a few EOs will be encountered during operation. Thus, it is often possible to reduce the whole pressure field to a single EO. m+p international's excitation generation and analysis software replicates



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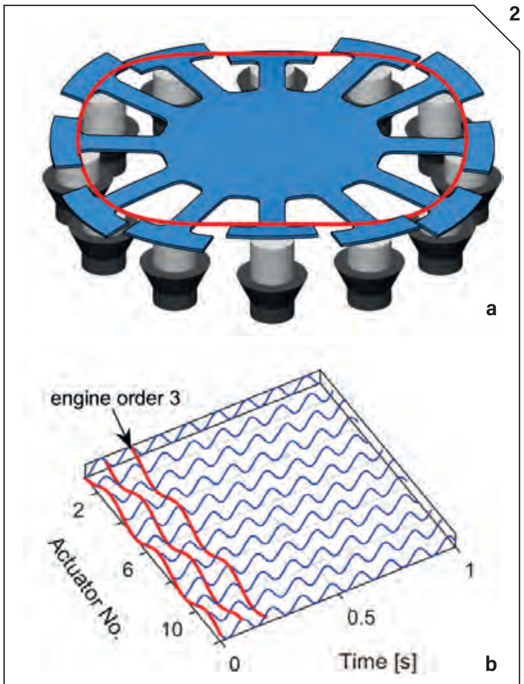

1 // Simplified bladed disks (blue) with pressure fields (gray) representing three engine order excitations: a) engine order 1; b) engine order 3; c) engine order 5

2a // The stationary blisk in blue is equipped with 12 speakers (black). Sound pressure (gray) of each speaker adjusted to fit an engine order excitation

2b // Harmonic excitation signal (blue) for each speaker with relative phase lags adjusted to create an engine order 3 excitation (red)

3 // m+p VibRunner system used for sensor input and excitation signal output

4 // Experimental setup consisting of 10 rigidly clamped loudspeakers and a simplified blisk

this engine order excitation by controlling the given actuators accordingly. Magnetic, acoustic, or electrodynamic actuators are just some examples of the excitation sources that can be chosen according to the applications needs based on the required excitation forces, excitation frequency range, etc.

A common experimental setup is shown in Figure 2a in which one actuator is placed beneath each blade. Thus, the continuous circumferential pressure field (engine order) is replicated at discrete points (the actuators). For example, in a setup with 10 actuators, an engine order EO=3 is generated by replaying a sine wave of a given frequency on each loudspeaker and introducing a constant phase lag between neighboring loudspeakers of:

$$\triangle\varphi = 360° \cdot \mathrm{EO}/N_{\mathrm{blades}} = 360° \cdot 3/10 = 108°$$

Figure 2b demonstrates how this excitation replicates a steady-state operation of the machine at constant rotational speed. Run-up or run-down can be simulated by sweeping the excitation signal while keeping the required constant phase lag between the loudspeakers.

This article describes acoustic excitation using loudspeakers, which is well suited for excitation frequencies above 1,000Hz. The experimental setup was developed together with the Institute of Dynamics


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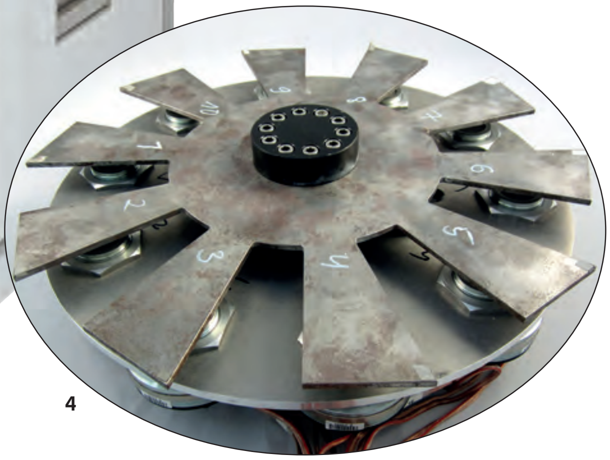
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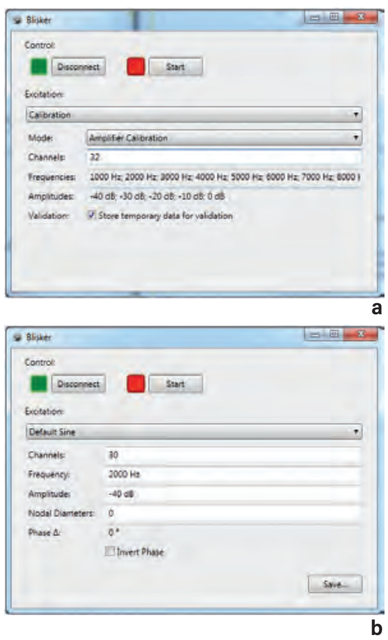
"IT IS CRUCIAL TO ARTIFICIALLY REPLICATE THE TYPICAL EXCITATIONS ACTING ON THE ROTOR BLADES DURING OPERATION"



5 // GUI for amplifier calibration (a). GUI for sine excitation (b)

and Vibration Research (IDS) at Leibniz Universität Hannover, Germany, and is used in several scientific research projects.

EXPERIMENTAL SETUP

The experimental setup designed at IDS consists of a simplified bladed disk with 10 blades. In the center, the blisk is clamped on a vibration isolation table. Loudspeakers (type BMS 4540) are mounted on a rigid plate and placed beneath each blade. Acoustic amplifiers (type IMG Stageline STA 1508) are used to drive the loudspeakers. The input signals (excitation) are generated using m+p VibRunner hardware. Multiple m+p VibRunner chassis may be combined into a single multichannel system, providing high output and input channel counts. Simultaneous sampling of all output channels ensures minimal phase error and high excitation signal quality, which is crucial in this type of application. The vibration response of the blisk is measured with accelerometers or a laser vibrometer.

Although the geometry of the IDS experimental blisk is very simple, it exhibits the main features of real-world blisks, such as traveling waveforms with different nodal diameters and mis-tuning effects. The m+p software provides a way to excite these traveling waveforms and measure the operational deflection shapes.

TYPICAL TEST PROCEDURE

Setting up the excitation system is a two-step process. The first step is to calibrate the system and the second step is to parameterize and configure the excitation. To calibrate the excitation system, the software offers a calibration routine (Figure 5a). All amplifiers and loudspeakers can be calibrated at distinct frequencies and amplitude levels. The results are saved to a database for future use and validation purposes. The system configuration (Figure 5b) is quick and straightforward.

The user inputs the channel count, test frequency, engine order (nodal diameter) and amplitude level. Everything else is automatically generated by the software. The excitation types are available in four different modes:

Sine is the most basic excitation. Users select a frequency, amplitude and nodal diameter; the software calculates the correct phase lag and generates the engine order excitation.

Custom sine is a mode where the user can introduce arbitrary phase lags between output channels at given frequency and amplitude levels. This can be useful if the number of loudspeakers is not equal to the number of blades.

Periodic chirp adds a periodic chirp using the engine order excitation. This replicates the run up/down of a rotating machine.

Custom periodic chirp, like custom sine, the user introduces arbitrary phase lags.

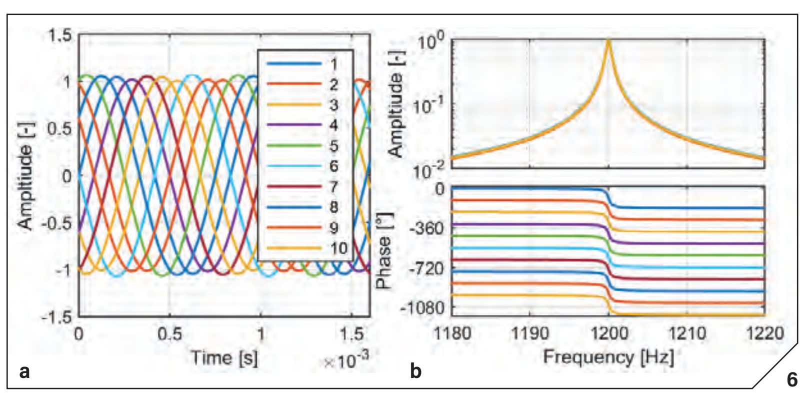
Standing wave excitation is also supported for all excitation types.

TEST RESULTS

Typical test results are depicted in Figure 6. A laser vibrometer was used to measure the tip amplitude of each blade in the frequency range from 1,180Hz to 1,220Hz. All data was acquired using m+p Analyzer, a multipurpose measurement software capable of acquiring and post-processing huge amounts of data. m+p's excitation generation and analysis software was configured to harmonically excite the engine order three (EO=3). The loudspeakers produced a rotating pressure-field with three circumferential waves. As can be seen in Figure 6a, the response of the individual blades is harmonic but phase-shifted. Just like the phase lag of the excitation between two adjacent loudspeakers was 108° (EO=3), the phase lag between the responses of two adjacent blades was also 108° (Figure 6b). Note that the maximum amplitude of all blades is nearly identical because of the rotating nature of the mode shape. Small differences in amplitudes of the individual blades are expected due to mis-tuning effects resulting from material and manufacturing imperfections.

m+p international's software package enables engineers to perform dynamic testing of aircraft turbine blisks. Replicating the engine order excitation on a stationary test stand rather than in a rotating regime saves test costs and time during turbine development. \\

Dr Sebastian Schwarzendahl is product manager with m+p international

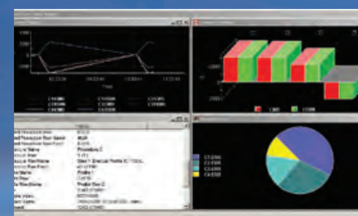


6 // Measured time history (a) at each blade tip under excitation with engine order 3 at 1,200Hz. Phase-referenced spectra (b) of the blade responses in the frequency range from 1,180-1,220Hz (phase ref. at 1,180Hz blade 1)

MTS


Photo courtesy Airbus Military


Photo courtesy Cessna Aircraft Company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ADVANCING SAFETY WITH VIDEOSCOPES

Videoscope inspections facilitate safety by making it easier and faster to access critical components in hard-to-reach areas. Recent technological advances are ensuring aerospace safety

// LIAM HANNA

The aerospace industry has come a long way since the days when aircraft were made from wood and cloth. In the present day those materials have been exchanged for complex alloys and composites, and internal combustion engines are replaced by highly efficient gas turbines. But one area that remains as important as ever, and has evolved organically alongside the evolution of modern aircraft, is the aspect of safety and the importance of maintenance and testing in ensuring the continued safety of flight.

During this evolution, the requirement for testing critical structural components of both commercial and military aircraft has increased greatly. Regular inspections of hundreds of critical areas on each aircraft, as well as careful attention to quality assurance in the manufacturing process, are essential to maintaining the aerospace industry's recognized outstanding safety record.

Aircraft manufacturers and operators use a variety of non-destructive testing methods and other inspection technologies in these examinations – with different methods being recommended according to the manufacturer's test procedures and service bulletins. Aircraft that were once maintained retrospectively are now being designed with inspection in mind, with access ports introduced into the design at the manufacturing stage. This means that hard-to-reach areas can be inspected simply, with the use of specialist equipment and little or no need for disassembly. These improvements help to remove the element of human error, increase the ability to maintain a high level of safety, and lead to reduced downtime and maximum operational capabilities for both airlines and military organizations.

REMOTE VISUAL INSPECTION

In the past decade, the requirement for advanced remote visual inspection (RVI) in the aerospace industry has evolved rapidly.

1 // The IPLEX NX features intelligent illumination control, which helps to speed up inspections with variable light requirements

"GAS TURBINES PRESENT A CHALLENGING ENVIRONMENT IN WHICH TO WORK WITH A VIDEOSCOPE"

2

2 // Remote visual inspection makes viewing hard-to-reach areas easier

RVI extends the reach of the human eye into small, enclosed spaces that otherwise cannot be seen. Modern RVI devices use a combination of CCD, LED and video-capturing technologies. A slim and highly flexible viewing device is inserted through a small opening and guided by the operator with a joystick, providing a bright, clear image. Software commonly provides the magnification and carries out dimensional measurements of the observed surface.

By far the most common application of RVI in the aerospace industry is in the inspection of gas turbine jet engines – predominantly for turbine blades, compressor blades, combustion chamber liners, fuel nozzles and other components. It can detect potential problems including combustion deposits, erosion, surface cracking and foreign-object impact damage. RVI also helps in the inspection of inaccessible areas of the airframe for visible corrosion and cracking.

A gas turbine is subjected to extremely high temperatures; at take-off, the Rolls-Royce RB211-524, used to power a Boeing 747-300, reaches temperatures in excess of 1,400°C at 430psi. At these temperatures there is the potential for parts of the engine to melt instantly, were it not for the clever design of the components that make up this section of the turbine. For example, each component is covered in a special plasma-based thermal barrier coating to prevent heat damage. Also, hundreds of small holes are designed into the components – specifically the nozzle guide vanes and the turbine blades – which form a cushion of comparatively cooler air that passes over the components and protects them from this possibility.

"AN INSPECTOR CAN NOW SEE AND MEASURE FOUR TIMES MORE THAN WOULD BE POSSIBLE USING A CONVENTIONAL SCOPE"

3

3 // Portable RVI equipment further facilitates inspection of inaccessible areas

There is the potential for these cooling holes to become blocked, which can lead to portions of the turbine blades becoming damaged. The aerospace industry has a number of guidelines specifying how large a defect can be before it becomes adverse to safety. During routine inspection, any defects are closely monitored and measured using RVI techniques to determine whether the aircraft can be deemed airworthy.

Gas turbines present a challenging environment in which to work with a videoscope or video borescope. Some areas, such as turbine blades and burner assemblies, are highly reflective, while other are extremely dark, such as the combustion chamber, the nozzle guide vanes and certain areas of the turbine. Capturing a bright, sharp and clear image in these areas is equally difficult – and certain advances in RVI technology have helped to improve workflow, providing inspectors and operators with an easier platform with which to obtain the best possible images.

RVI TECHNOLOGY ADVANCES

In the latest generation of videoscopes, several improvements have been made that are particularly beneficial for inspections in the aerospace industry. With the launch of Olympus's IPLEX NX, the issue of different requirements for both bright and dark areas (such as found in turbojets) was solved overnight. It meant that inspectors could move from dark matt sections to highly reflective components with no requirement to adjust the illumination manually. A new processing technology, PulsarPic, works with the CCD sensor, the processor and the new high-powered laser illumination system to automatically adjust physical light output, CCD exposure time and electronic gain.

When this technology is used in darker areas, more light is released, along with more gain and a longer exposure time. In more reflective areas, on the other hand, less light is used, with lower exposure and less gain. This intelligent adaptation enables much more efficient inspection, delivering high-quality, high-resolution results every time.

Another new feature of the IPLEX NX is 3D stereo measurement technology, which allows an inspector to quickly and simply calculate the depth, length, area, perimeter and perpendicular distance – all with one touch of a joystick.

The inclusion of a proprietary technology with five-point spot-ranging, provides the inspector with a simple traffic light display, gives a clear indication of surface condition and structure, as well as the measuring the distance from the tip to the target.

When the scope is positioned to obtain an accurate measurement, single screen viewing removes the requirement to use a binocular view, as with older stereo measurements. This update has been well received and has changed the way in which inspection can be done at this high level. Inspectors can now see and measure four times more than would be possible using a conventional scope, enabling measurement of larger defects from further away.

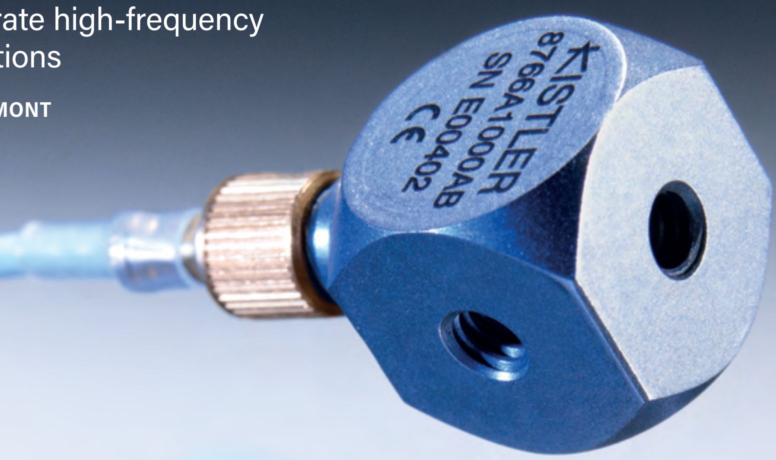
A final area where a lot of progress has been made in recent years is in the weight of the equipment. Historically, large equipment was required, weighing more than 20kg in certain circumstances. Newer lightweight videoscopes, such as the IPLEX NX, provide full functionality, combining the industry's highest resolution images in a portable package with a controller weight of only 150g. \\

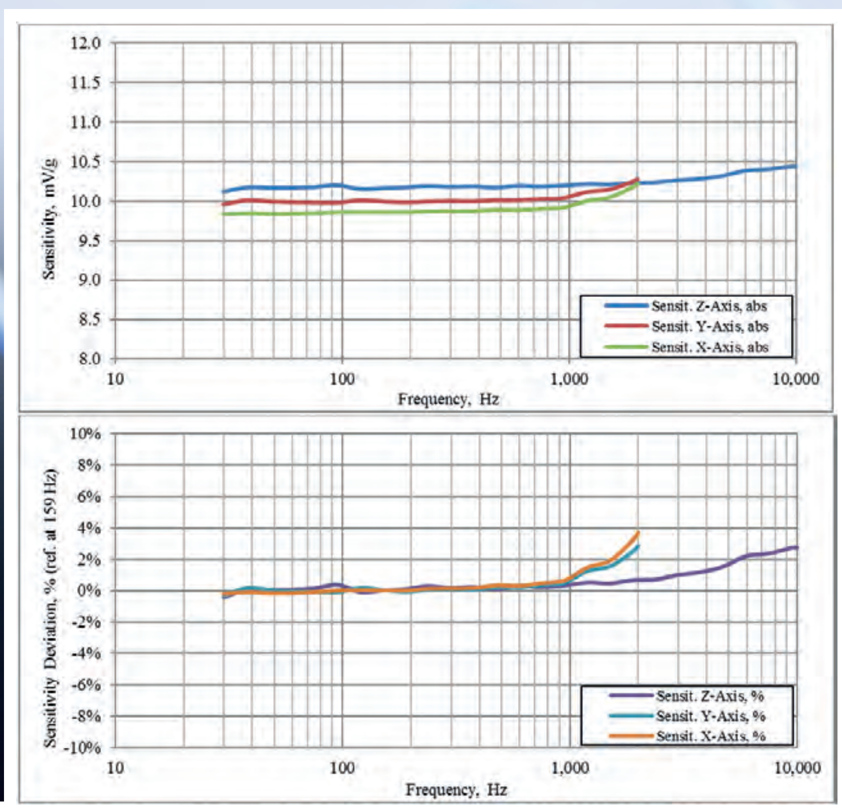
Liam Hanna is a vertical market specialist with Olympus Europa

OPTIMAL SENSOR DESIGNS FOR HIGH-FREQUENCY RESPONSE

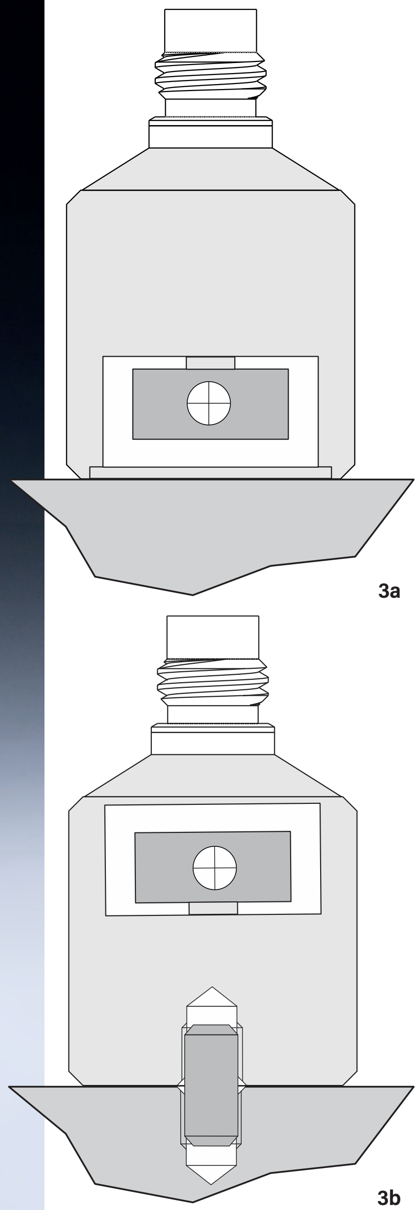
Accelerometers have been designed with stud mounting for each axis, solving the problem of accurate high-frequency response in the three orthogonal directions

// THOMAS PETZSCHE, ANDY COOK AND MARINE DUMONT





1 // Frequency response of a typical triaxial accelerometer calibrated in x and y from 30Hz to 2kHz using mounting fixtures and in the z-axes from 30Hz to 10kHz with direct stud mounting



3 // Triaxial sensor design requiring adhesive mounting on cover of x-axis (3a) versus a triaxial design allowing for stud mounting of the x-axis (3b)

2 // Kistler sensor family profile with novel three threaded holes for high-frequency calibration in three orthogonal axes

Many applications such as environmental and structural testing require increasingly more triaxial Integrated Electronics Piezo Electric (IEPE) accelerometers with higher frequency operation in the three orthogonal directions. Accurate measurement at high frequencies can be ensured only by very careful consideration to mounting and very specific calibration methods in these three directions. A new, novel mounting for triaxial cube accelerometer families offers a practical solution. The seismic elements of these IEPE triaxial accelerometer families have inherent benefits, resulting in high-resonance frequency where the sensor design provides stud mounting for each orthogonal axis with threaded holes on three sensor faces, supporting calibration frequencies up to 20kHz without additional mechanical fixtures.

MOUNTING CONSIDERATIONS

To obtain useful measurement information, an accelerometer must be coupled so that complete event information is transferred. Mounting methods may vary, with some transferring event information more effectively than others. A high-performance accelerometer will behave like a low-performance accelerometer if the mounting method is inadequate. The transfer function behavior between the mechanical input properties and electrical output properties can be characterized by a single degree of freedom (SDOF) system with a mounted resonance frequency that will decrease if the mounting method becomes less stiff.

If we simplify the sensor and its mounting method as being an oscillating system with a period T_n in seconds and a natural frequency $f_n = 1/T_n$ in Hz, where the natural frequency of the system will be dependent on the mass *m* of the system and the stiffness of the system through the spring constant *k*, given in the equation:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

As a rule, the most rigid and lightest available mounting method should be used at all times. The easiest mountings, such as wax mounting, affect the high-frequency event information reaching the accelerometer. The reason for this is that it reduces the spring constant of the system. The application and the type of data desired should ultimately drive the mounting approach.

To achieve the most accurate frequency response with the highest stiffness of *k*, the stud mounting method should be used. Unfortunately, this often leads to a more demanding preparation, such as drilling and tapping a mounting hole, creating a high-quality surface and requiring a torque wrench. More importantly, this requires a threaded hole or a stud on the sensor housing side of the measuring direction. Adhesive mounting using glue or wax is easier to handle but will restrict the measurement temperature range and may also require solvent or heat to remove the sensor.

CALIBRATION CONSIDERATIONS

According to ISO EN DIN 16063 standard series, the calibration of the frequency response of an accelerometer is performed by primary laser or secondary comparison calibration methods. The characterization of the frequency response above 2-3kHz becomes more complicated for triaxial accelerometers because of required mechanical adaptations to the reference side of a back-to-back (B-to-B) standard.

Direct mounting is not possible in the x and y directions. Even if beryllium is used as the material in making the adapters, they are still too flexible. And going further, if the highest ratio between elastic stiffness and density of any materials is used, the relative motion between the coupling area of the unit under test (UUT) and the reference accelerometer is still an issue as both amplitudes cannot be identical.

The frequency response of a sensor along the x- and y-axes at higher frequencies will then be limited by the calibration mounting fixture. Therefore, due to the limits of the fixture, specifications for high frequency must be noted more conservatively. An estimation of the frequency response in the upper end can often be performed with resonance excitation of the seismic element.

For example, Figure 1 shows an overview of the obtained frequency responses up to 2kHz (x- and y-axes) and to 10kHz (z-axis).

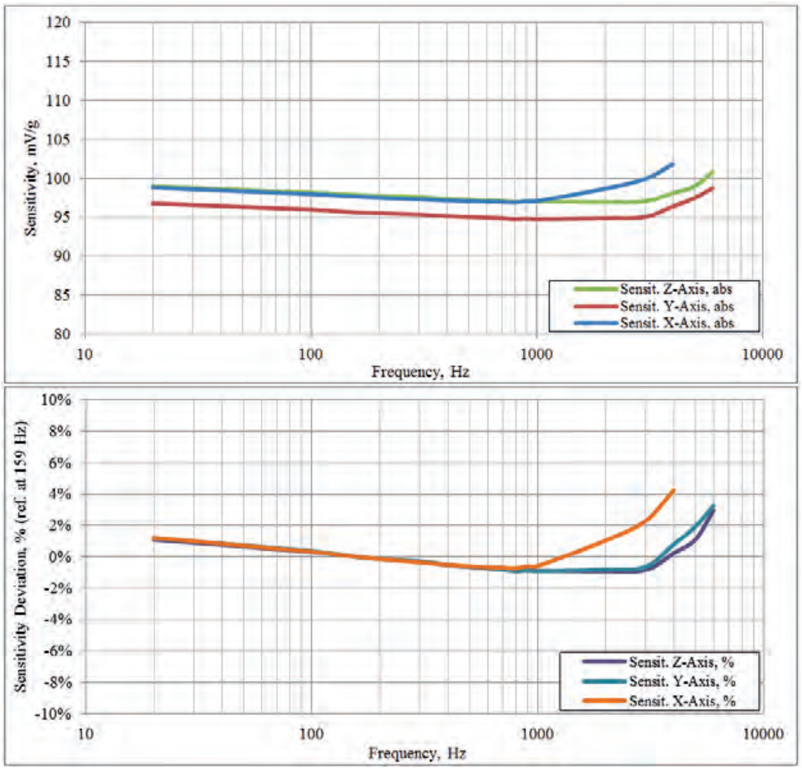
It is obvious that the results of the frequency response in the x-axis and y-axis are mostly influenced by the relative motion between the UUT and B-to-B reference side. In these two axes, the frequency response can be measured only up to 2kHz. Some improvements can only be achieved by the use of beryllium mounting adaptors of optimized design.

A TIP FROM THE EXPERTS

The Hsu-Nielsen source test is a simple method for analyzing the resonance frequency. For a given accelerometer, the working frequency range with a sensitivity deviation of ±5% is typically around 20% of the mounted resonance frequency.

A higher input frequency spectrum excites the mechanical resonance of the accelerometer and creates 'amplified' output signals. Linearity between the mechanical input and the electrical output signal in this frequency range is to be expected.

To get a rough estimate of the frequency response of the sensor using a given mounting method, the Hsu-Nielsen source test method per EN ASTM Std. E976-1984 can be used. This test is an easy method using the breaking of a mechanical pencil lead to produce a wide frequency range excitation signal. Originally used for testing acoustic emission sensors, the test is also excellent for testing the mounted resonance frequency of an accelerometer. The method is shown in Figure 5 where an accelerometer is connected to an appropriate amplifier and the signal captured on a transient recorder or fast sampling rate scope with trigger mode. Once the pencil lead breaks, it generates a wide frequency content pulse that makes the accelerometer start 'ringing'. This is the resonance frequency in the mounted state for the accelerometer.



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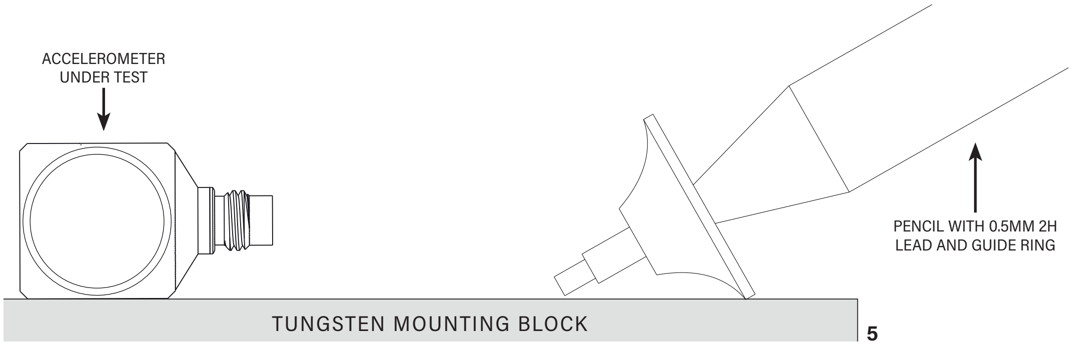

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This will be costly for a very slight improvement at higher frequencies. In addition, these adaptors would not just be expensive and time consuming to manufacture, but would also be problematic from the toxicological point of view.

Another common design found in triaxial accelerometers is a cube-shaped housing with only a z-axis mounting hole. Calibration of this design of sensor consists of stud mounting the z-axis and adhesively mounting the x-axis and y-axis. The y-axis is mounted, like the z-axis, through the base and into the mounting point of the element post. The x-axis, on the other hand, is adhesively mounted on the cover of the sensor. Figure 3 shows the problematic nature of mounting on the x-axis cover. This type of calibration yields a similar frequency response in the y- and z-axes, but an x-axis response that is considerably lower, similar to using a calibration mounting adapter. Figure 4 shows the frequency responses of the three axes of a piezoceramic triaxial accelerometer using this type of calibration mounting. Again, a conservative frequency response specification needs to be used for the x-axis due to the available calibration method.

NOVEL HOUSING DESIGN

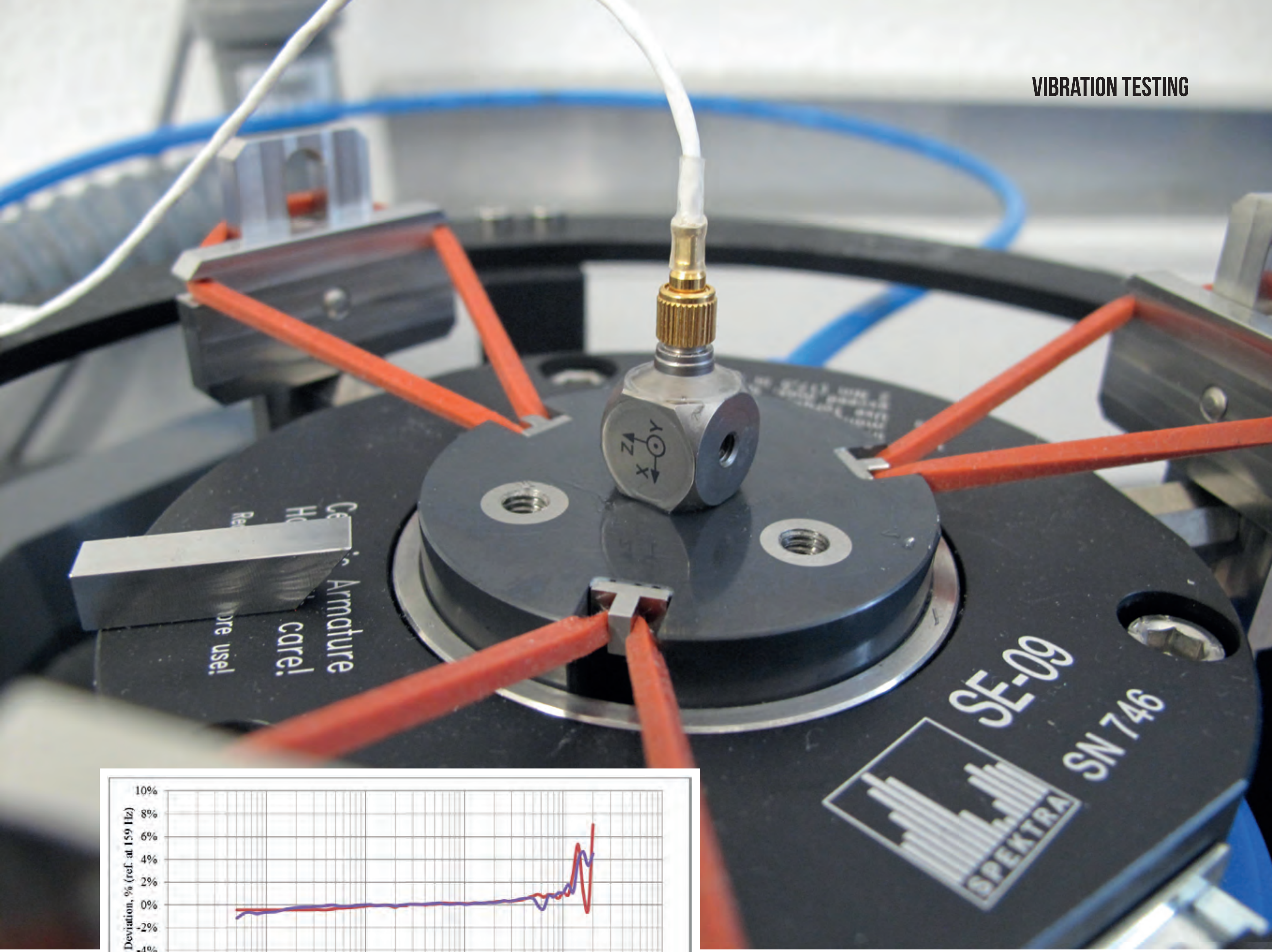
To solve this problem, triaxial accelerometers have been designed by Kistler that incorporate stud mounting for each orthogonal axis. This is achieved by supplying threaded holes on three sensor faces. This concept has been used for the past few years and is available in three Kistler sensor families.

In the case of the triaxial Piezostar sensor family, along with the advantage of three mounting holes, the very rigid and unique crystal element allows measurements up to 10-12kHz (+5%) with mounted resonance frequencies up to 70kHz. As the measurement uncertainty for the sensitivity is much higher beyond 10kHz, the datasheet specifies an upper frequency response value of 10kHz with ±5% sensitivity deviations referenced to a specified frequency. This design principle allows a frequency response of 0.5Hz to 10kHz and offers a generic use of these sensors in a very wide frequency range where quite often two sensors would have been used in the past.

A triaxial Piezostar sensor with three threaded hole housing was tested for frequency response from 5Hz to 50kHz. The amplitude and phase responses are shown for the x- and z-axes in Figure 7; the sensitivity deviation was referenced to its sensitivity taken at a frequency of 160Hz.

4 // Frequency response of a piezoceramic, adhesive mounted accelerometer calibrated in x-, y-axes from 20Hz to 4Khz and z-axis from 20Hz to 6kHz

5 // Sample setup of the Hsu-Nielson test to find the resonance frequency of an accelerometer (ASTM E976-10)



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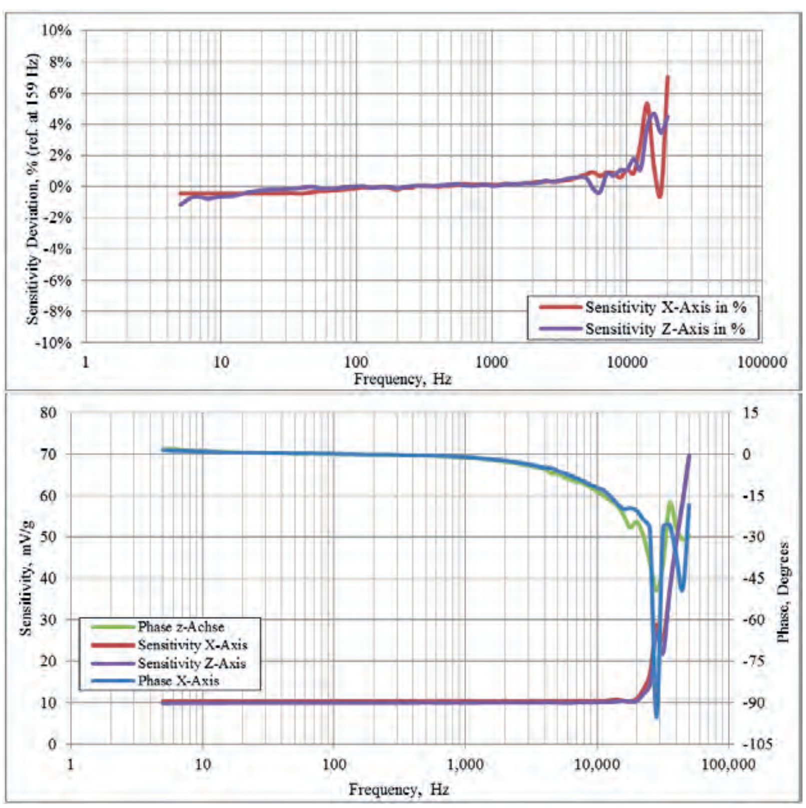

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The results for the y-axis are qualitatively identical to the z-axis. We can observe some minor resonances above 10kHz with less than 7% sensitivity deviation. The rest of the spectrum is linear. Over the entire range, the frequency responses and phases between axes match very closely.

A sensor mounted on a calibration shaker with a single stud is shown in Figure 6. In this setup, the reference sensor is integrated into the shaker armature. Both reference faces of the UUT as well as the reference sensor are assembled directly together and relative motion is almost impossible. The calibration equipment being used was traceable to a National Measurement Institute (NMI) up to 20kHz.

In our case the reference standard frequency response has been modeled with a 70kHz resonance at 20dB amplitude.

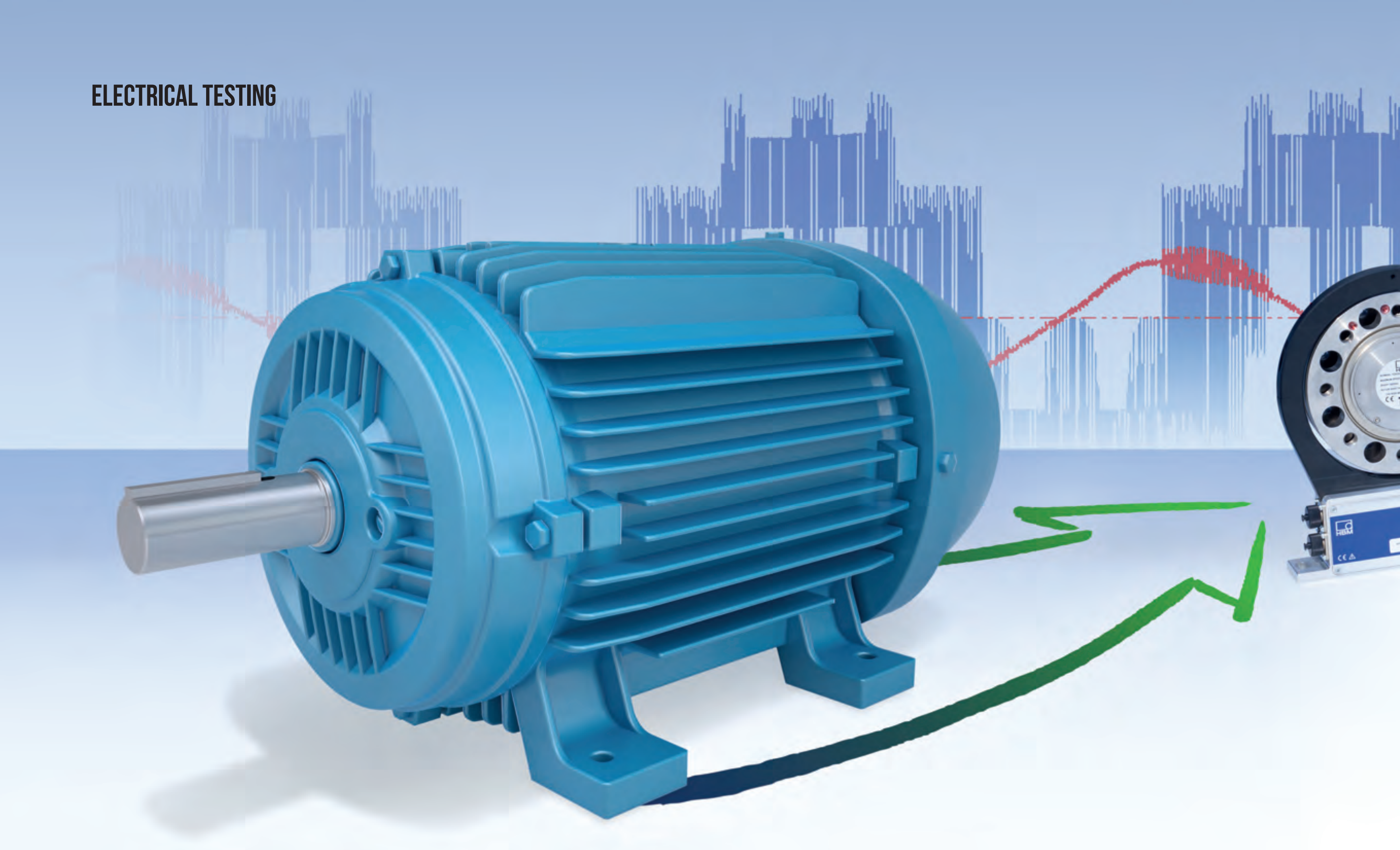
The overall measurement uncertainty for the UUT is 1% up to 1.25kHz, 2% from 1.25kHz to 5kHz and 3% from 5kHz to 10kHz, using k=2 (95% coverage factor). The result above 20kHz is then purely qualitative due to the fact that an uncertainty cannot be specified.

The occurrence of additional smaller resonances below the main resonance and the deviations from the ideal frequency response may have a different cause than the UUT, for example the rocking motions of the shaker armature in relation to cross-axis sensitivity of the UUT as one possibility. Potential error sources have not had detailed investigations. \\

Thomas Petzsche is a vibration application specialist, Andy Cook is development engineer and Marine Dumont is business driver, Test and Measurement with Kistler Instruments

6 // UUT triaxial Piezostar sensor with a three threaded hole housing mounted in the x direction on the armature of an air bearing shaker

7 // Frequency response of a triaxial Piezostar sensor with a three threaded hole housing along the x- and z-axes directly stud mounted to a reference



1

ADVANCED TESTING OF ELECTRIC SYSTEMS

Efficiency testing of electrical machines and electrical inverters is critical to development of advanced aircraft and future technologies

// MITCHELL MARKS

The electrification of aircraft is driven by the vision of making them more efficient, cheaper to operate, and more environmentally friendly in terms of exhaust gas and noise emissions. To transform today's conventional aircraft into electric ones, hydraulic and pneumatic actuators and systems will gradually be replaced by electric actuators and systems.

The main challenges are to reduce the weight and increase the efficiency, power density and reliability of the components of an electric system, i.e. the generators, batteries, power controllers and motors. Testing the energy conversion efficiency of these components requires data acquisition systems that are able to measure aggregate input and output power with high accuracy and reliability and deliver the underlying raw data necessary to understand and improve energy efficiency in the R&D process.

As a consequence of electrification, it will become more challenging to ensure stable operation of the aircraft's electric system. Individual components as well as the entire aircraft electric grid will need to be tested more extensively for power quality compliance. Data acquisition (DAQ) systems for such tests need to be able to continuously record the entire flight profile and switch to higher sample rates to capture singular disturbances. They should be able to perform harmonic analysis and power measurements with the same instrument.

What is needed to design an electric drive system for any application? Basically, there are three elements: power source, power converter and motor.

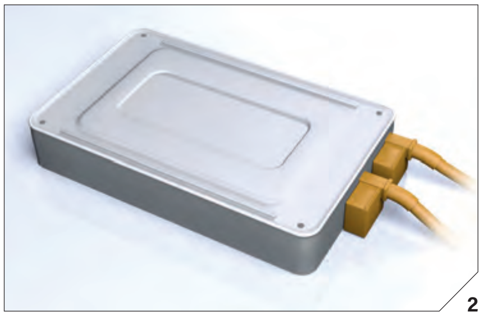
Often these elements come in the form of a battery acting as a DC bus – an inverter that changes DC power to AC – and a motor that uses the AC power to convert electrical energy into mechanical power. This is sometimes referred to as electromechanical power conversion.

1 // An eDrive testing setup

When designing these systems, engineers typically try to maximize efficiency across a drive cycle. They do this by maximizing the torque per amp for as many torque and speed combinations as possible. The number of combinations is more or less the resolution of the efficiency map on which they are the basing controller decisions.

WHAT ABOUT POWER SUPPLIES?

The power supply for these applications is almost always a battery, but sometimes there could be a rectifier system from a power line to create a DC bus. This DC bus can be raised or lowered using a DC-DC converter fed to an inverter. The DC-DC converter may also be included in battery systems to adjust the DC bus to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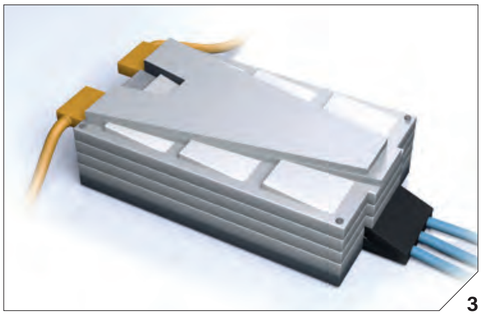
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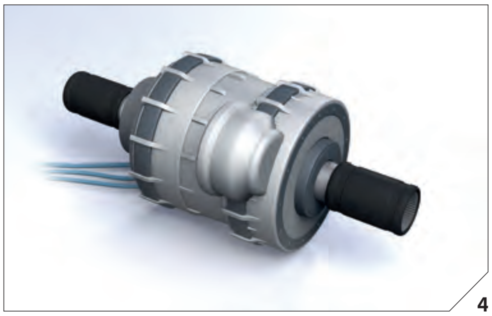
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2 // A rendering of an eDrive battery

3 // Illustration of an eDrive inverter for motor control

4 // A motor designed for inverter control

a level that the inverter likes. These batteries are typically of lithium-ion construction and in the range of 200-400V for automotive applications, but could be as high as 600-800V. Few designers choose to go higher than that because life gets more difficult with that much DC potential.

> “THE MATH FOR CONTROLLING AND UNDERSTANDING THE INDUCTION MACHINE TOOK ABOUT 50 YEARS TO SOLVE”

TAKING OVER CONTROL?

Control is something that everyone keeps pretty tight-lipped about. It’s done via software, so it is easy to keep under wraps. The controller will look at what the torque and speed are, and determine the switching frequency, pulse width modulation (PWM) method, and how to optimize efficiency. These aspects can change quickly throughout a cycle. Most types of control, regardless of the motor type, are a version of field-oriented control (FOC). A growing trend is deadbeat current control; however, all controls will be closed-loop current control.

The control is where the direct-quadrature-zero (dq0) reference frame transformation takes place. This is a mathematical translation to visualize and control the three-phase PWM, based on what the system needs. It is a sine and cosine manipulation with a position reference to make three phases look like two – and is by no means simple.

The math for controlling and understanding the induction machine took about 50 years to solve. It is amazing that people were using these machines for so long before they could understand the math controlling them. Everyone uses computer models before they do anything. Models are cheap and can be run very quickly in an optimized manner. Building motors and controllers is not a fast process. Motor and control optimization take place in models and FEA. Models are very good at predicting motor and inverter behavior and are an unbelievably useful tool.

5

5 // Testing of aircraft electrical systems

MODELS NEED TO BE VALIDATED

Most places have a whole group of engineers working on models. Researchers love model validation because it gives them more confidence in their models, which they can then use to predict motor and control behavior. This validation is an area where our products could come into play.

Ultimately most applications have size and cost restrictions, which determine many of the variables before motor design even begins. Hence we have the choice of topology and small details, based on the control scheme that groups want to use. There are also choices that can be made with cooling and in how the motors are wound.

The main types of motor are induction, permanent magnet, wound field and switched reluctance. Induction motors are the easiest to control; they are the best understood and are an industry workhorse. Their downside is that the field needs to be excited, which results in losses.

Permanent magnet (PM) motors are often used in applications where efficiency is important and size is a restriction, as they have a higher power density because the magnet supplies the rotor field rather than having the losses in the rotor. These PM motors require an inverter and a lot of cooling and care when operating in various modes. With a PM machine, more considerations need to be made because the magnets can become demagnetized during field weakening and back EMF may need to be monitored.

Synchronous reluctance (SR) motors have a very simple rotor that is simply a lamination with a specific pattern. These motors use the property of reluctance torque to create rotational motion. They are very useful in a variety of applications because of their simple construction, but have the downside of creating a large amount of noise and vibration. For this reason they have only been used in specific scenarios.

"PEOPLE WILL TEST THE LIMITS OF THE MACHINE AND BASICALLY BLOW IT UP, OR ATTEMPT TO"

The cooler the motor, the lower the losses; the lower the losses, the higher the efficiency. Hence keeping the windings and switches cool is very important. Switches will have higher losses and can also explode if they get too hot. Researchers spend a large amount of design time on exploring cooling strategies to make their machines more efficient. Cooling systems often have water, oil or glycol pumped and sprayed over the areas that need to be kept cool. The stress on cooling machines has made motor temperature monitoring an important part of operation and testing.

INCREASING THE EFFICIENCY

The best way to cover many of the topics mentioned above is efficiency mapping and dynamometer testing. Everybody wants to increase the efficiency of their systems. Having the raw data is important for this, because if something goes wrong you can reference previous tests and also perform in-depth analysis in a post-processing program such as MATLAB. Furthermore this is of the utmost importance for dynamic testing, because when carrying out dynamic loading or testing drive cycles, without the raw data you can get some weird and inaccurate results which have values of greater than one (or an incorrect value) because of bad data collection.

When the designers start testing they will have a set DC bus voltage, followed by a set speed. They will then load the machine with a certain torque and do this for all the desired torques and speeds available in the range of the machine. This will give the efficiencies for all desired set points, and generate an efficiency map. These points will be taken at a specific temperature range.

Sometimes the tester has to wait for the machine to cool down before taking a measurement at a set point. This is where HBM's eDrive testing system can save a lot of time, because taking test points in a number of cycles rather than a number of seconds will have the machine spending less time heating up.

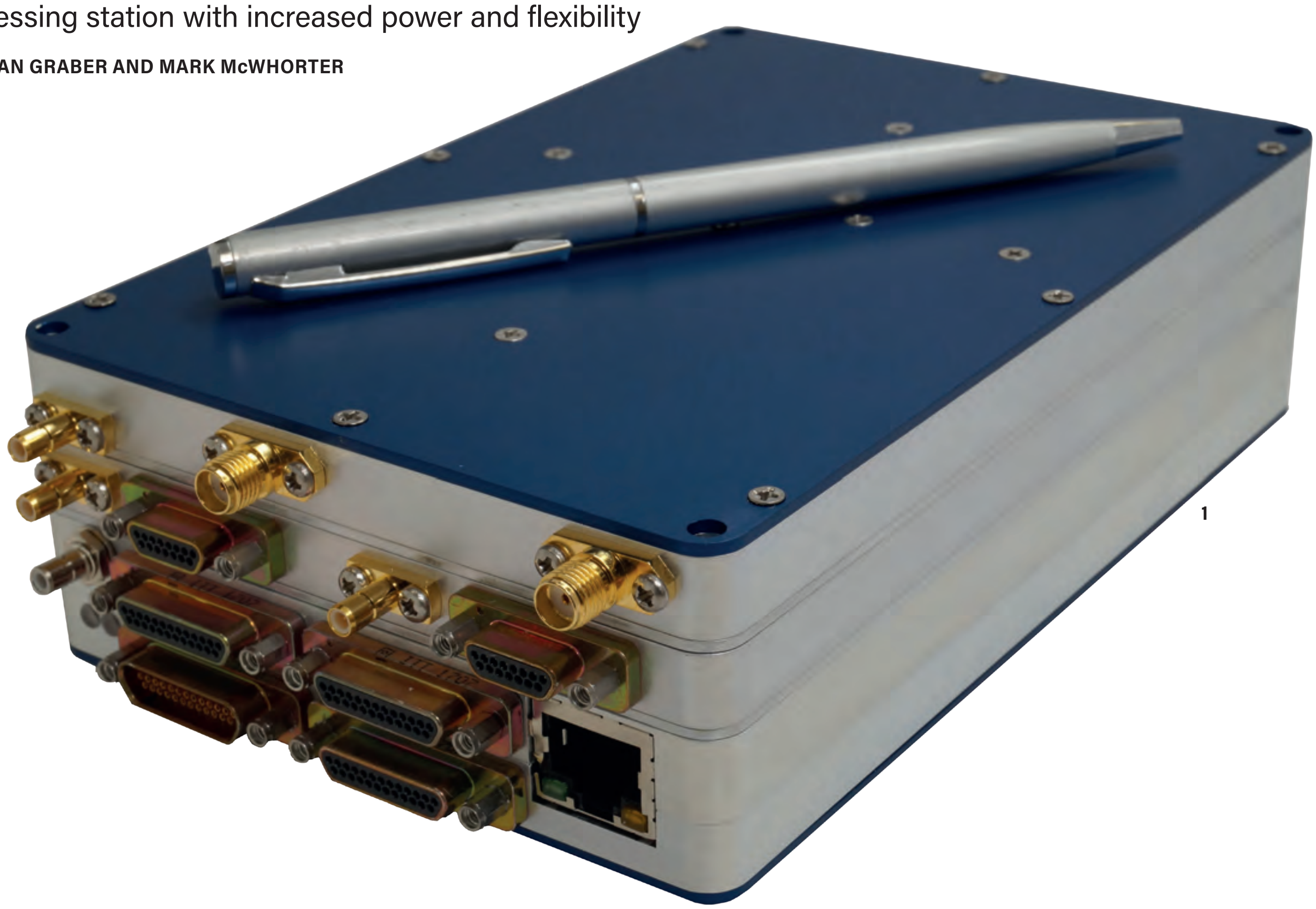
Often people will test the limits of the machine and basically blow it up, or attempt to. They will push to achieve the maximum speed to know the mechanical limits of the machine. The ability to trigger and have a buffer of data will allow researchers to understand not only where the machine failed, but how. \\

Mitchell Marks is an HBM sales engineer for eDrive Testing Solutions

MODULAR TELEMETRY RF, DATA RECEIVING AND PROCESSING ENGINE

Design and technology advancements have led to a greatly reduced footprint and weight for a fourth-generation telemetry processing station with increased power and flexibility

// BRYAN GRABER AND MARK McWHORTER



1 // The Lumistar LS-28-DRSM telemetry processing engine

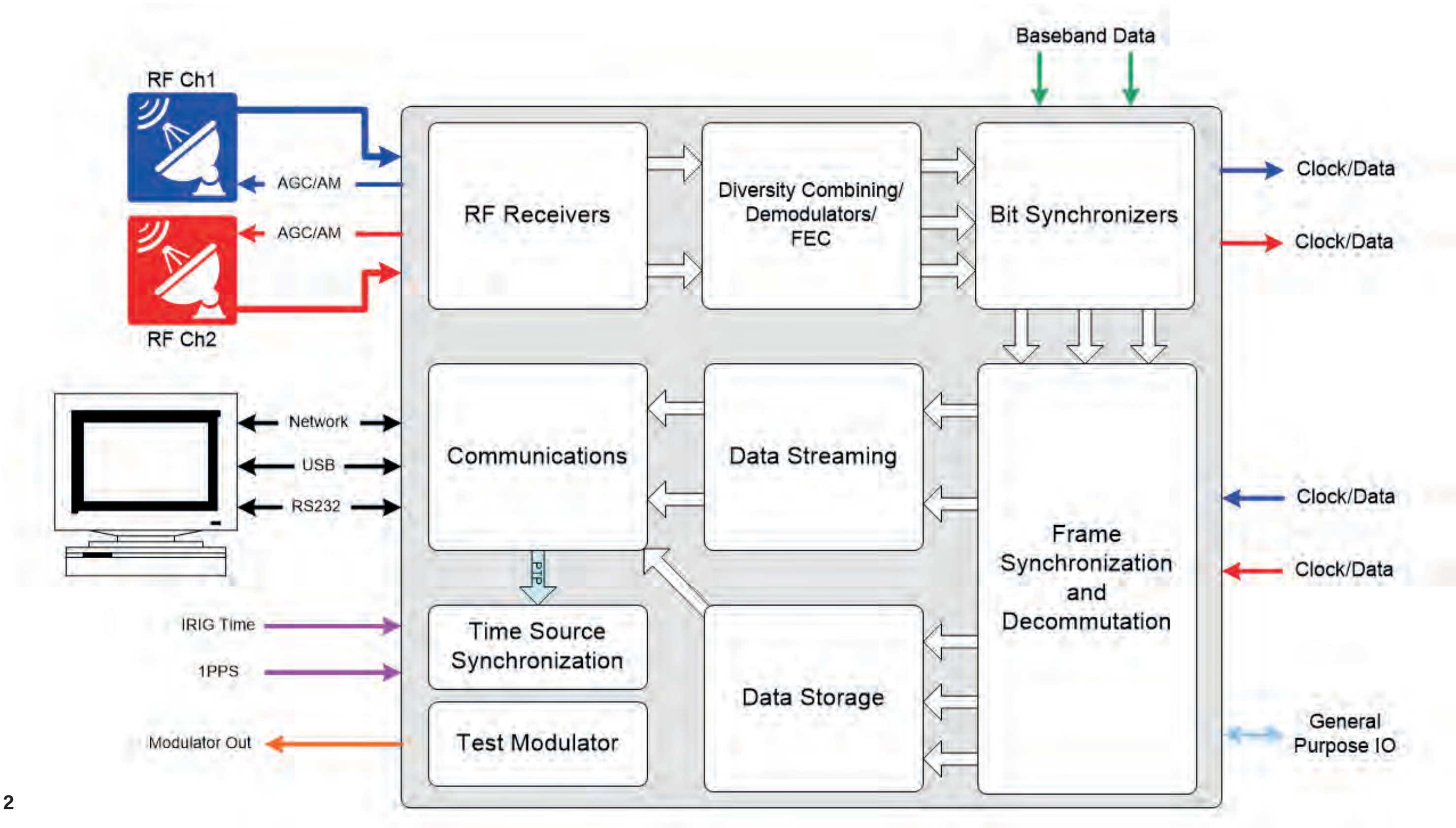
Lumistar has completed engineering development and begun production of a modular fourth-generation digital product that has been primarily designed for applications in testing for fixed ground, mobile and airborne flight test applications.

The LS-28-DRSM series includes all the traditional functions of a full rack mount telemetry processing station in the approximate footprint of a handheld 3.5in PC hard drive. Standard capabilities include two independent digital multiband RF receiver channels, each supporting multiple digital demodulation formats, bit synchronization, forward error correction, data recording, decommutation, graphical displays, baseband data acquisition and Ethernet data distribution.

The flexibility of the design architecture enables adaptability to many other applications, including, for example, remote site spectrum monitoring, command verification receivers, and traditional data acquisition applications, all with minor modifications to the standard device's factory-installed firmware personality.

Some of the primary design objectives of the LS-28-DRSM product line were to reduce the platform size, to provide an 'OS-less' environment by eliminating the use of commercial software operating systems for functional processing, to provide easy and flexible field upgrade/enhancements capabilities, and to provide a network appliance for device control and data transport.

A comparison with the previous generation Lumistar product line of similar capabilities illustrates the scope of the size, weight and power reduction achieved by



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the design team. Previous generations of equipment required 300W of power, weighed approximately 62 lb (28kg), and were housed in a 4U industrial computer chassis occupying approximately 3,100in³ (50,800cm³). By contrast, Lumistar's latest fourth-generation product typically consumes 45W, weighs 2 lb (0.9kg), and occupies a volume of 40in³ (655cm³). This is an 85% reduction in power, a 96.8% reduction in weight, and a 98.7% reduction in volume versus its predecessor. The unit is primarily controlled and monitored using a 1,000/100/10Mbps Ethernet interface with alternate controls being provided by USB and RS-232. Using available documentation from several sources, the customer can develop their own graphic user interface (GUI) or use the provided Lumistar network application.

Beyond excellent RF performance, at the heart of the modular design is a flexible and extensible multicore DSP Engine that can assume one of 12 'personalities'. The device construction is via four hardware 'slices': RF, IF, signal processing, and a control processing engine. The slices can be configured as a whole set or as a subset to perform targeted functionality.

"AT THE HEART OF THE MODULAR DESIGN IS A FLEXIBLE AND EXTENSIBLE MULTICORE DSP ENGINE THAT CAN ASSUME ONE OF 12 'PERSONALITIES'"

Operational firmware loads, or 'personalities', are retained internally in the device for quick switching between operational requirements. New firmware personalities and/or control processing revisions are easily updated in the field. There is no need to return the unit for most modifications.

When configured as a traditional range telemetry receiver/combiner, the LS-28-DRSM can handle up to six frequency bands per channel from 70MHz to 7GHz. All standard RF receiver functions are provided, including antenna tracking using AM demodulation and AGC feedback, down conversion, diversity combining, multimode demodulation, bit synchronization, IQ video output, Eb/No monitoring, and spectral and constellation displays with other data-quality indicators.

Non-standard options include the addition of up to 64GB per channel data recording at the bit level and UDP data broadcasting of the received telemetry. The receiver can be configured to support Multisymbol PCM/FM, SOQPSK, GMSK, Analog FM Video with or without NTSC de-emphasis, BPSK, QPSK, OQPSK, AUQPSK, PCM/PM, and Multi-H CPM. Data rates up to 60Mbps are supported. The unit has a very flexible and useful internal data/IF modulator and bit error reader/frame synchronizer lock indicator for use in system loopback tests. Adding an external tunable up-converter makes this feature a very powerful tool itself.

2 // A functional block diagram of the LS-28-DRSM showing some of the standard inputs and outputs

The unit constantly performs maintenance monitoring of various environmental parameters and alerts the user to out-of-boundary conditions. The software logs the user settings and important receiver performance parameters as a function of time at up to a 10Hz rate.

If the user wants to convert from receiver mode to a dual-channel bit synchronizer personality, that change can be commanded via software. The unit will be converted to a dual-channel bit sync while the GUI is transformed for that operational mode. The bit sync function operates to 30Mbps and provides several options for PCM code conversion.

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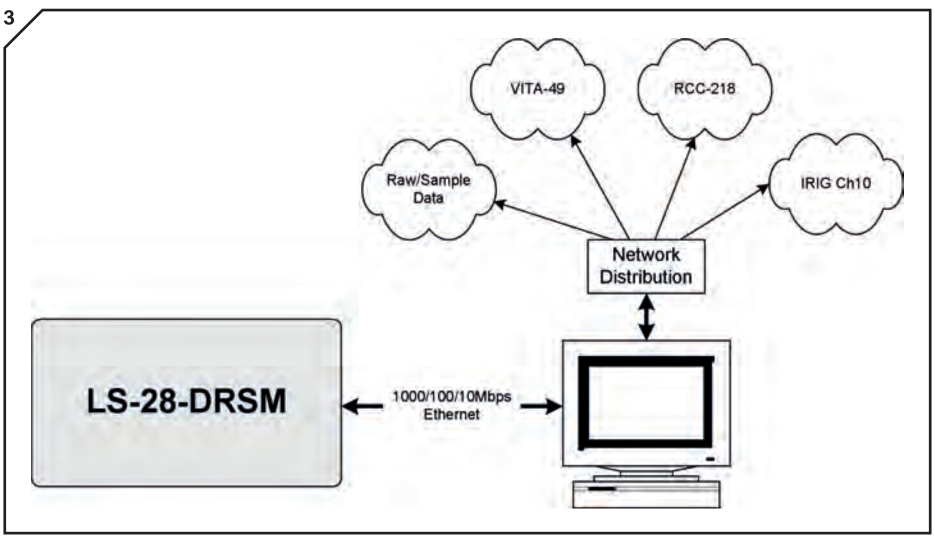


3 // The processing engine LS-28-DRSM can be part of a network-centric design

The LS-28-DRSM provides the capability to decommutate data from any input source (RF, IF, baseband). The framed data is then broadcast via UDP packets. These packets can be brought in via the network auxiliary input of the Lumistar Data Processing Software (LDPS) suite of tools for real-time display, archive, playback and simulation of telemetry data.

The LS-28-DRSM is capable of handling many modern coding and digital link enhancement schemes, such as Viterbi, Reed-Solomon, LDPC, Space Time Coding and Adaptive Equalization. Each of these has its own special niche, applications and merits (as well as demerits) in modern telemetry flight testing and space telemetry applications.

REMOTE SPECTRUM MONITORING

When configured for remote spectrum monitoring applications (Figure 2), each LS-28-DRSM RF section can be configured with 12 independent RF channels (six per channel x two channels) from 70MHz to 7GHz. Each channel is sampled in a 50MHz bandwidth at the second IF of the receiver, digitized, packetized and converted to the VITA-49 standard for transmission across the LAN. This enables a complete digital reconstruction via software of the RF signature at all remote sites that require 24/7 spectrum monitoring. Special software for this application will display each site's spectrum in real time, archive the spectrum as a function of time, and provide for user-identified alarm conditions when certain preset limits are exceeded.

SIGNAL ACQUISITION NETWORK APPLIANCE

The LS-28-DRSM can be configured in a role as a generic analog-to-digital acquisition unit for RF, IF and low-frequency signals up to 30MHz (Figure 3). Each channel of the module contains two sampling subchannels operating independently: a channel for intermediate frequencies between 1MHz and 100MHz, and a DC-coupled channel covering frequencies up to 30MHz. The intermediate frequency sampling sources include RF and frequency down-converted sources, as well as external sources, and provide AGC if required. The low-frequency input acquisition port contains provisions for signal offset, AGC controls and software selectable input impedances. Once the desired signal envelope has been established, the signal is digitized at up to 250MS/s by the intermediate frequency processing channel or up to 125MS/s for the low-frequency channel. Each subchannel supports 12bit resolution at the ADC. This sampled data can then be further processed in any number of ways, recorded, and/or streamed via the network port based on user requirements.

COMMAND VERIFICATION RECEIVER

The LS-28-DRSM can be configured to provide the functionality of a Command Verification Receiver. This is required for use in Command Destruct applications, where verification of the quality of the transmitted command signals is required. The unit can be configured to receive two channels of UHF command signals, typically between 350-450MHz. These signals contain up to four low-frequency FM modulated 'tones' in accordance with the IRIG 208 standard. The command receiver will demodulate the tones and provide discrete tone frequency values and deviation as per the standard's requirements. The compliance of the tones is then displayed via software GUI. The software can be configured to provide alerts when the received tones are non-compliant.

Owing to the open-ended architecture of the LS-28-DRSM series product, many more personality applications are conceivable and achievable. \\

Bryan Graber is president and CTO, and Mark McWhorter is vice president of sales and marketing for Lumistar

ADDITIVE MANUFACTURING WORKFLOWS

Simulation uncertainties arise from different assumptions made in model creation. Mid-stage software validations improve confidence and optimize the design of additively manufactured aerospace components

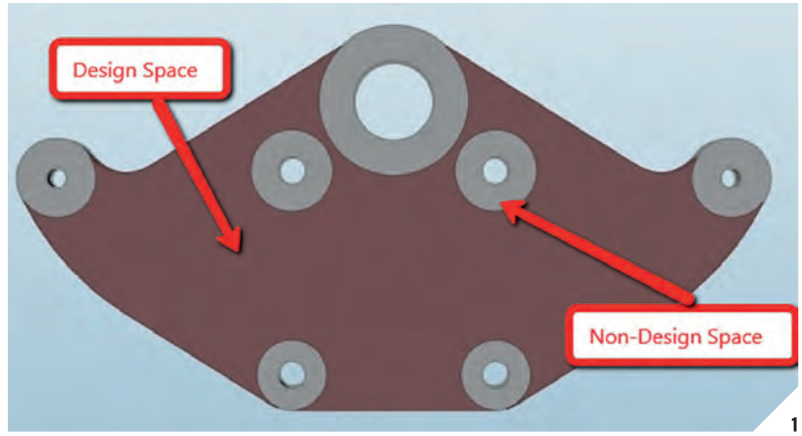
// SRIDHAR RAVIKOTI AND MEGAN LOBDELL

The aerospace industry is implementing 3D printing (additive manufacturing) on a selective basis, particularly for one-off and small-lot production, and to produce parts that cannot be made using conventional manufacturing processes. With 3D printing there is the incredible possibility to build a solid model, optimize its shape by generating organic structures, and then directly print it to make a ready-to-use part. A critical step is to ensure that the part will perform as simulated. This is because simulation includes uncertainty from the assumptions of the model. This uncertainty is often left untested until the prototyping stage. Altair Engineering and DatapointLabs collaborated on a project to introduce a mid-stage validation step to the design workflow to measure the simulation accuracy before parts are made, bringing confidence to the engineer's model.

With the advent of 3D printing and additive manufacturing (AM), designs previously thought difficult to produce can be generated quickly, efficiently and without tooling. In modern light-weighting strategies that involve geometric optimization, the goal is to generate designs that meet the original performance requirements but with less material. Whereas over-design used to be acceptable to prevent part failure, a key requirement of the new scenario is to ensure that the optimized part does not fail. For this strategy to succeed, it is necessary that the simulation be accurate up to failure.

A great complement to 3D printing is the topology optimization technique that generates organic shapes, adding material along paths that are essential to support loads. Because of the design freedom offered by manufacturing process, the shapes generated by topology optimization can be easily manufactured without compromising on the performance gains typically seen with traditional manufacturing methods.

Altair's OptiStruct, a mature technology for topology optimization that provides engineering direction to material placement, has been used to perform analysis and to generate optimized shapes.



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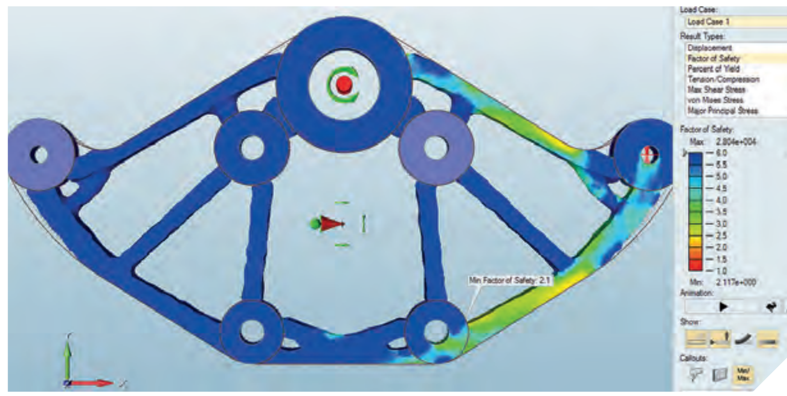

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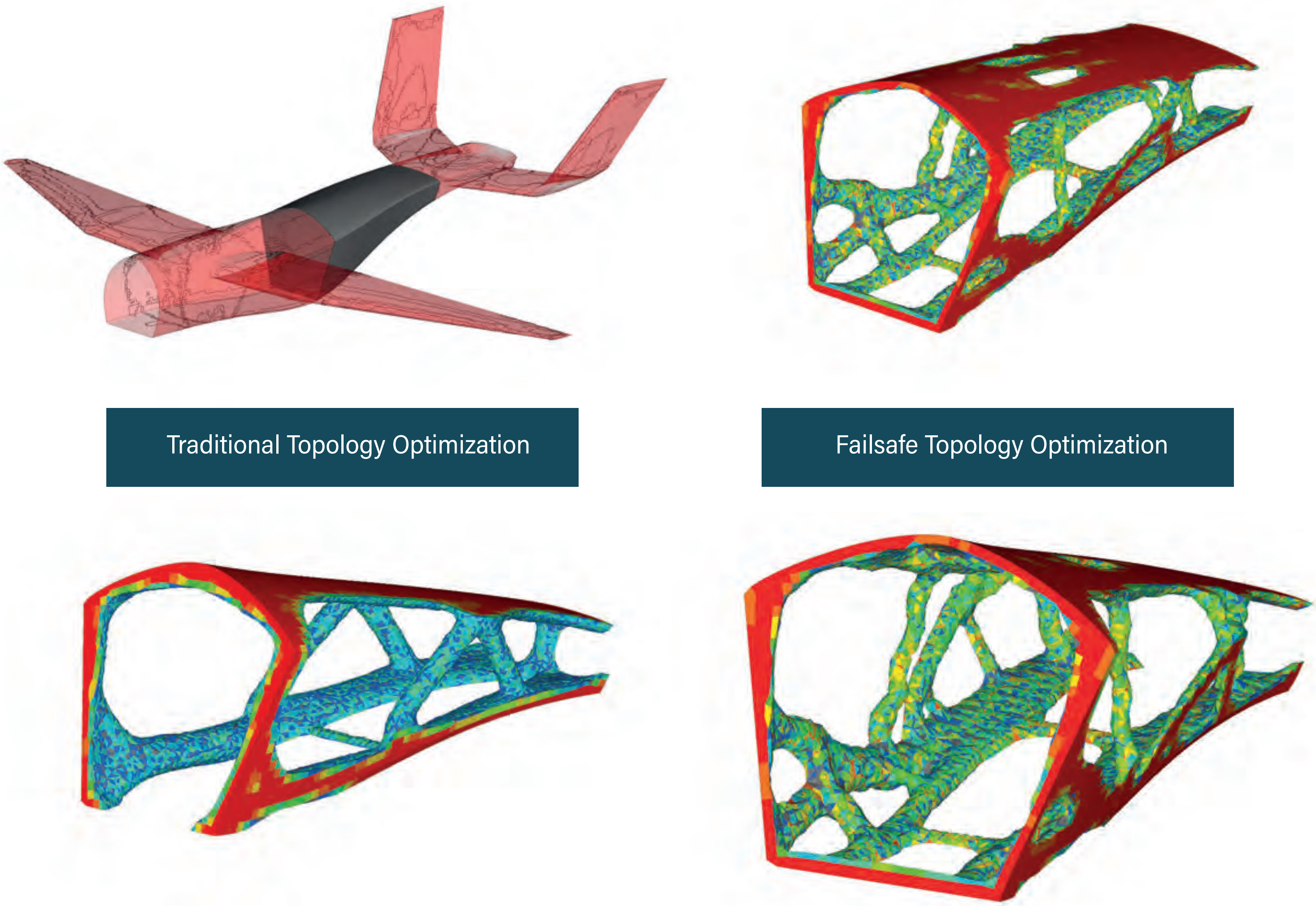
1 // Original bellcrank design set up for topology optimization based on design spaces

2 // Topology optimized bellcrank design

3 // Smooth Result Interpretation using polyNURBS technology in solidThinking Inspire

OptiStruct also includes an innovative fail-safe topology optimization method for general 3D structures. Fail-safe robustness of critical load-carrying structures is an important design philosophy for the aerospace industry. The basic idea is that a structure should be designed to survive normal loading when partial damage occurs. Such damage is quantified as complete failure of a structural member, or partial damage of a larger structural part. When generating topological designs, the structure is designed to have redundant load paths.

Traditionally, the design process involves much iteration between the designer and the analyst, where the designer submits a



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“THE SIMULATION CALCULATED A SIMILAR FAILURE LOAD TO THAT RECORDED IN THE PHYSICAL TEST”

4 // Failsafe topology optimization in OptiStruct

design to the analyst, who completes the analysis and sends recommendations back to the designer. The process is repeated until a valid design meets the analysis criteria. It is then handed to the manufacturing team, which may have additional constraints or concerns, and iterations then continue. AM, coupled with topology optimization, allows the design-and-analysis and manufacturing iterations to be greatly reduced or even eliminated. To ensure that the part will perform as simulated, a mid-stage validation is conducted on a standardized part before creating the final product. This is because it is often difficult or even impossible to accurately test and replicate the real-life boundary conditions quantitatively of the product with adequate fidelity.

This workflow, as shown in Figure 7, may help to reduce the time required to design, analyze and produce an aircraft component, while also greatly reducing its weight. The workflow was put to the test with a Cessna 172 rear elevator bellcrank, as shown in Figure 1. The goal was to optimize the part for weight based on the maximum allowable load input, while ensuring that it has a reasonable margin of safety and meets the maximum deflection constraints.

Density and stress-strain curves were measured and the material models required for simulation, representing both elastic and plastic behavior as well as the modulus and ultimate strength, were developed using Matereality’s software Workgroup Material DatabasePro and CAE Modeler. Materiality is an affiliate of DatapointLabs.

Prior to the optimization, a mid-stage validation of the simulation was performed on a 3D-printed Cornell bike crank, which has features designed to probe the quality of the simulation. Using digital image correlation (DIC), images of the strain field on the face of the bellcrank were gathered to compare with the simulated strains to evaluate the fidelity of the simulation to the test. The elastic response behavior and failure validation were simulated in Altair’s structural analysis tools OptiStruct and RADIOSS. A picture of the broken crank and the simulation image were compared. Not only did they break in the same locations, but the simulation calculated a similar failure load to that recorded in the physical test.

With a measure of confidence in the simulation now established, topology optimization of the part was done to identify the ideal material layout. The resulting conceptual design achieved a mass reduction of 45%, which was excellent for any structure and especially for aerospace structures, where minimizing weight is critical.

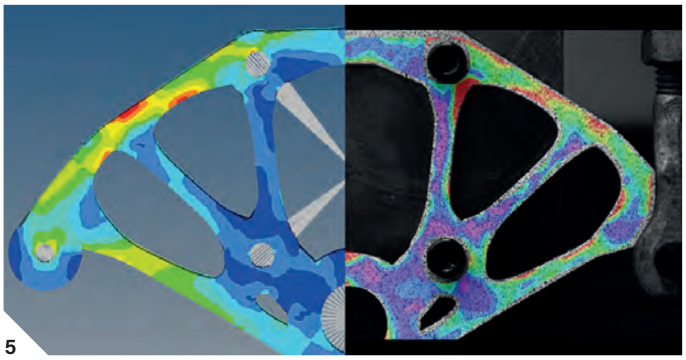
A finalized concept design was generated, as shown in Figure 2. The problem remained of how to convert that concept to a feasible geometry for manufacturing and CAD purposes.

5 // Surface VonMises strain comparison from simulation and test

6 // Testing the topology-optimized AM bellcrank

7 // Workflow of mid-stage validation to improve simulation accuracy with testing data

"INSPIRE REDUCES THE TIME IT TAKES TO CREATE GEOMETRY TO HOURS OR EVEN MINUTES"



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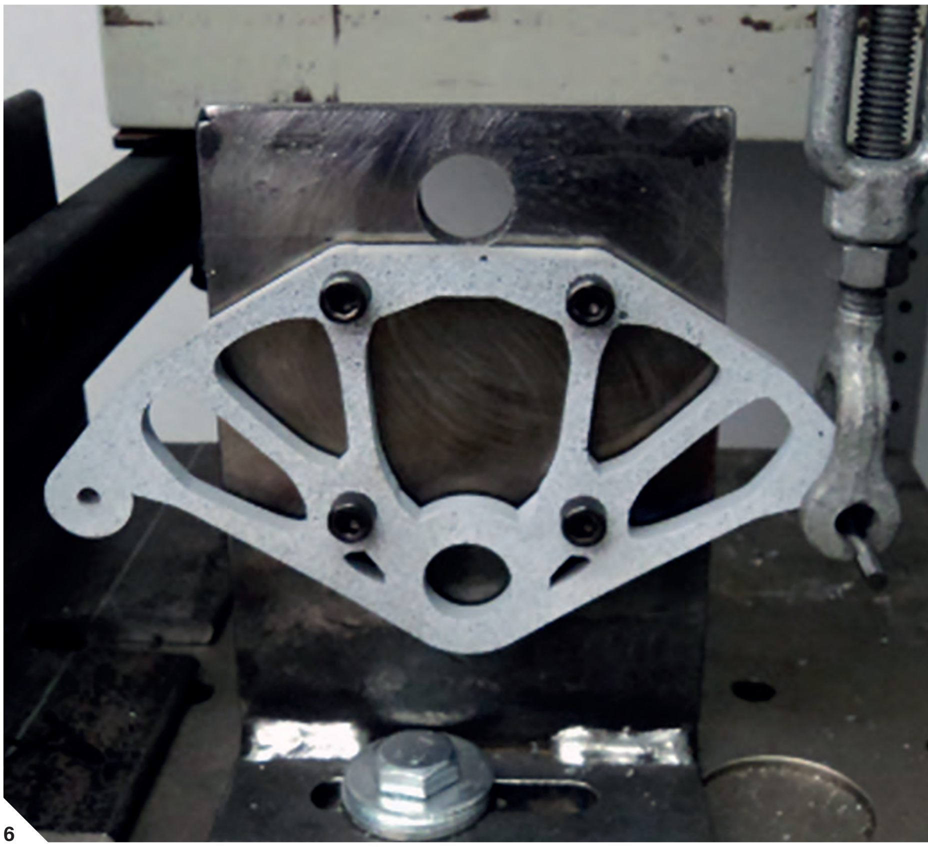

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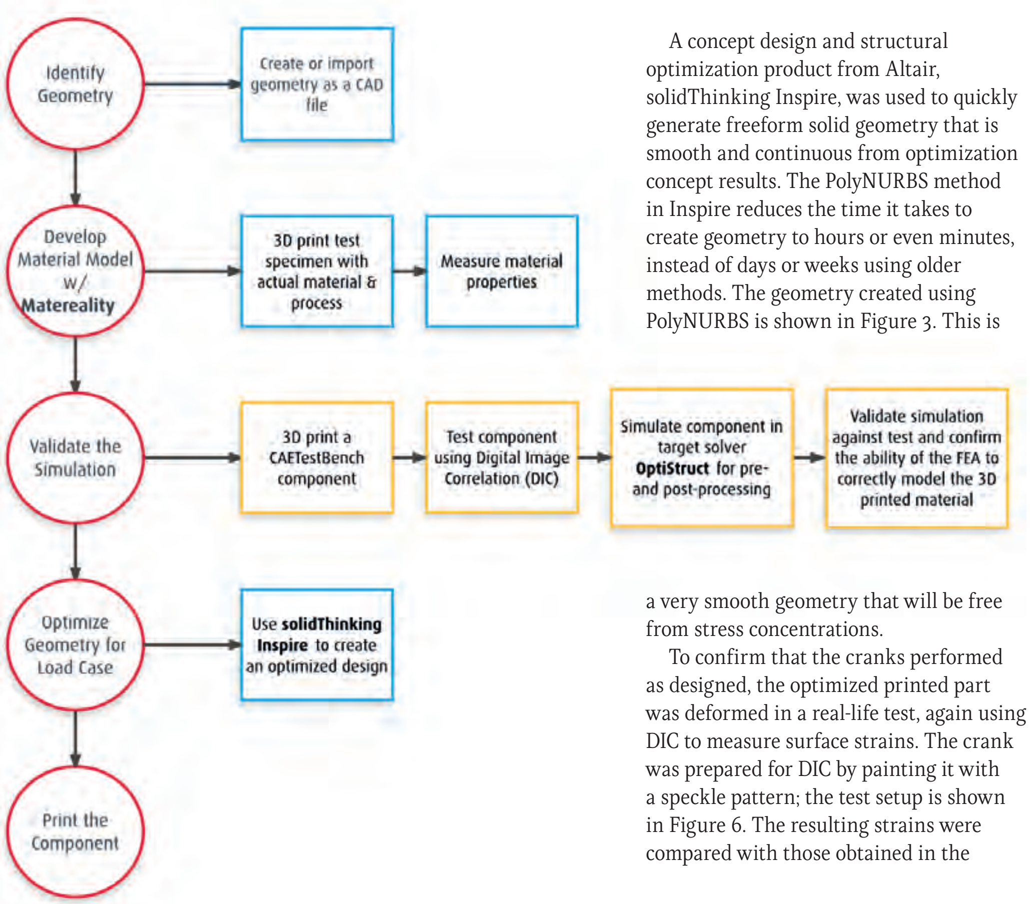

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A concept design and structural optimization product from Altair, solidThinking Inspire, was used to quickly generate freeform solid geometry that is smooth and continuous from optimization concept results. The PolyNURBS method in Inspire reduces the time it takes to create geometry to hours or even minutes, instead of days or weeks using older methods. The geometry created using PolyNURBS is shown in Figure 3. This is a very smooth geometry that will be free from stress concentrations.

To confirm that the cranks performed as designed, the optimized printed part was deformed in a real-life test, again using DIC to measure surface strains. The crank was prepared for DIC by painting it with a speckle pattern; the test setup is shown in Figure 6. The resulting strains were compared with those obtained in the optimization simulation. Figure 5 shows a comparison of the digital image correlation measured strains and the those predicted by the OptiStruct FEA model. There is very good correlation between test and simulation for both peak strains and strain pattern.

This bellcrank project clearly illustrates the workflow of design, analysis, optimization, build and test for an aerospace component. Incorporating a mid-stage validation into the production workflow is required to confirm the efficacy of the simulation tools and material model prior to use in real-life parts. The produced part will generally have lower weight through an optimized design that will not increase manufacturing costs. Additive manufacturing coupled with topology optimization provides great opportunities to the aerospace industry through these benefits. This workflow process can also be used as the basis for certification and qualification of additively manufactured aerospace components. \\

Sridhar Ravikoti is a marketing director at Altair; Megan Lobdell is an engineer at the DatapointLabs Technical Center for Materials

IDOF: INSTANT DEGREES OF FREEDOM

Normal means of calculating power spectral density are subject to inaccuracies due to time delays, a high variance between estimated values and the actual PSD value. iDOF solves these issues

// JOEL MINDERHOUD

Power spectral density (PSD) estimation is a critical tool in the vibration test engineer's toolbox. During a random vibration test, Gaussian time-domain data is transformed into frequency-domain data using the fast Fourier transform (FFT). Specifically a set of time-domain samples is transformed into a set of frequency-domain data using the FFT, and with this frequency-domain data, PSD is estimated.

Due to the nature of randomness, the PSD estimate generated from one set of sampled time-domain data is volatile, with high variance between estimated values and the actual PSD value. An effective way to reduce this volatility and decrease the variance between the estimated and actual PSD is to partition the total sampling period into equally sized time periods (frames), transform the samples from each frame using the FFT, calculate the power of these FFT values, and then average the power values from each set using the arithmetic mean. This is generally known as Welch's method. This method of FFT averaging requires a considerable amount of time to gather, transform and average the data, which is inconvenient to engineers who wish to know as quickly as possible whether the test and product are and will remain within tolerance limits, since failure to be within tolerance limits may indicate that the test is over-testing and perhaps damaging the product. The concern for meeting tolerance arises with respect to changes in the level of the test. Methods of PSD estimation have been offered as a solution to meet tolerance after a change in level, but some methods – even a common one – lead to inaccuracies.

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

This method is inaccurate, since it assumes that the ramped-up data will be a factor-multiple of the lower-level data, and that the behavior of the product at high level would exactly mimic that of the product at low level. This is not a justifiable assumption, since changes in level of the product being tested cannot be expected to exhibit behavior exactly like that of a lower level. Resonances, for example, can shift with an increase in level. This method masks the true behavior of the product at a higher level, which undermines the very purpose of a vibration test (see Figure 1).

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

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

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

"INSTANT DEGREES OF FREEDOM – A METHOD OF PSD ESTIMATION DESIGNED TO RAPIDLY REDUCE ESTIMATION ERROR"

When it comes to error in the PSD plot (the difference between the control and demand curves), there are two sources: control error and estimation error. Control error refers to the discrepancy between the actual PSD of the data (signal) and the desired demand PSD. Estimation error refers to the discrepancy between the estimated, plotted PSD and the actual PSD of the signal.

For instance, suppose one resets the PSD estimation's averaging during a test (without changing level). It won't affect the signal, and so the actual PSD of the data doesn't change, yet the PSD plot becomes very ragged until enough new data has been accumulated to average out and accurately estimate the PSD.

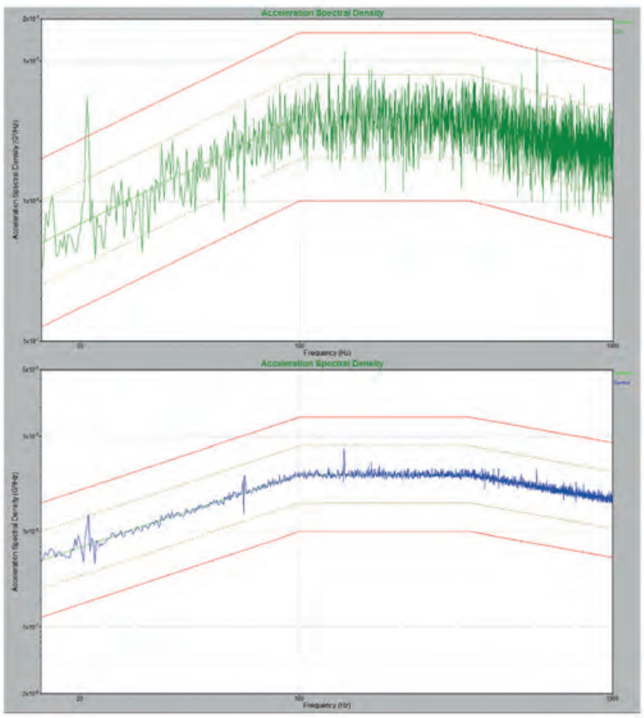
The error evident in this raggedness is estimation error, since resetting the averaging doesn't affect the actual PSD of the signal and therefore the error between the actual PSD of the signal and the demand PSD does not change. This is an example where, although the data plotted on the screen has large variance, the control may be very good, with only a small amount of control error.

However, consider the PSD estimation method involving the multiplication of low-level data. During a change in level, the actual PSD of the signal (i.e., the signal) undergoes a major change – including shifts in resonant frequencies – since the signal is changing (increasing in power). Yet the inaccurate PSD method doesn't indicate any changes in the PSD plot during this change as well as at the higher levels, although this method gives the appearance of minimal error on the plot, there is great difference between the actual PSD of the signal and the estimated PSD shown on the plot. In this case, there is both a large control error and a large estimation error, and the estimation error offsets and masks the presence of control error.

Estimation error arises from the inherent properties of PSD estimation as described by chi-square statistics – from the fact that the PSD estimation estimates a random signal. Control error concerns the signal and arises from resonances in the signal or other noise added by the system to the signal that takes the controller time to accommodate. It is the control error that interests and most concerns the test engineer. Estimation error occurs as a matter of fact when estimating the PSD of a random signal. Estimation error is inversely proportional

1 // PSD estimation using iDOF at full level (bottom) compared with separate signal analyzer using traditional averaging (top)

2 // PSD display using multiplication method (top) compared with separate signal analyzer (bottom)



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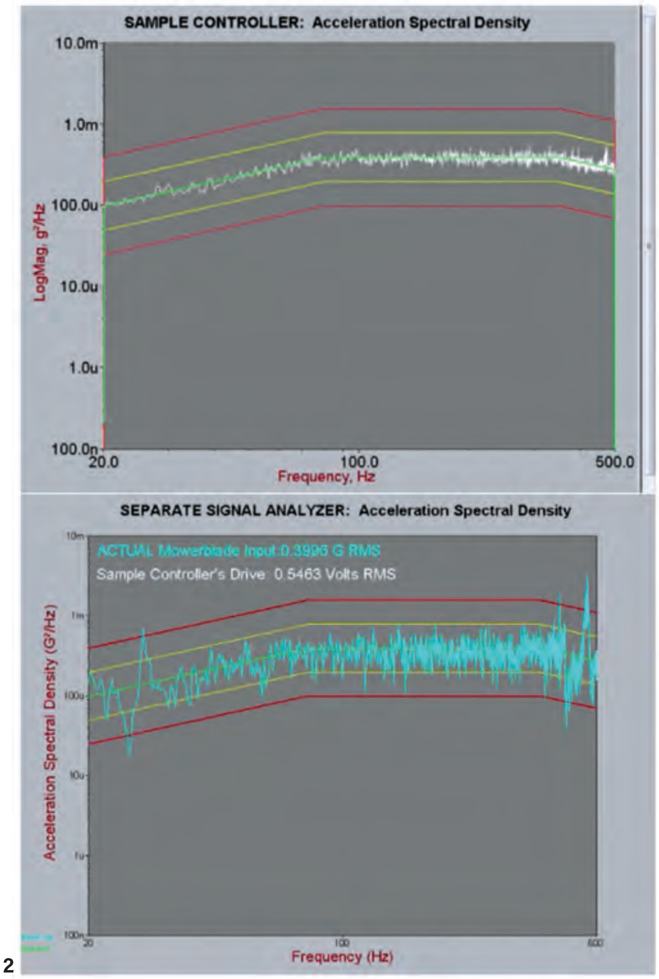

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"IDOF GIVES THE TEST ENGINEER A PRECISE VIEW OF THE SIGNAL'S ACTUAL PSD"

to the number of frames averaged – hence it is largest at the beginning of a test and at changes in level when averaging is properly reset. Even if the signal were perfect and there was no control error, there would still be estimation error in the PSD plot. That error would decrease inversely proportionally with degrees of freedom. Furthermore, the presence of estimation error does not imply the presence of control error, since estimation error should not concern the control of the signal.

However, there is a method by which estimation error can be confidently removed: iDOF. It does this in a manner that preserves control error and confidently removes estimation error, enabling the user to see control error more clearly. iDOF goes to work soon after test startup and after a change in level (at which change averaging is reset). Important to note, iDOF does not touch the control itself (evident in the fact that it removes only estimation error). iDOF does not affect the signal being sent from the controller to the system, but it does clarify the estimation of the actual PSD of the signal. Hence, the control trace – the estimation of the actual PSD of the control signal, not the control signal itself – is displayed clearly, with less raggedness.

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

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

Joel Minderhoud is a research engineer at Vibration Research

EFFICIENT FUNCTIONAL TESTING OF FLIGHT ATTENDANT PANELS

Verification of Flight Attendant Panels (FAPs) requires an interdisciplinary approach. TestPlant and Vector have combined their domain tools for efficient testing of the entire system

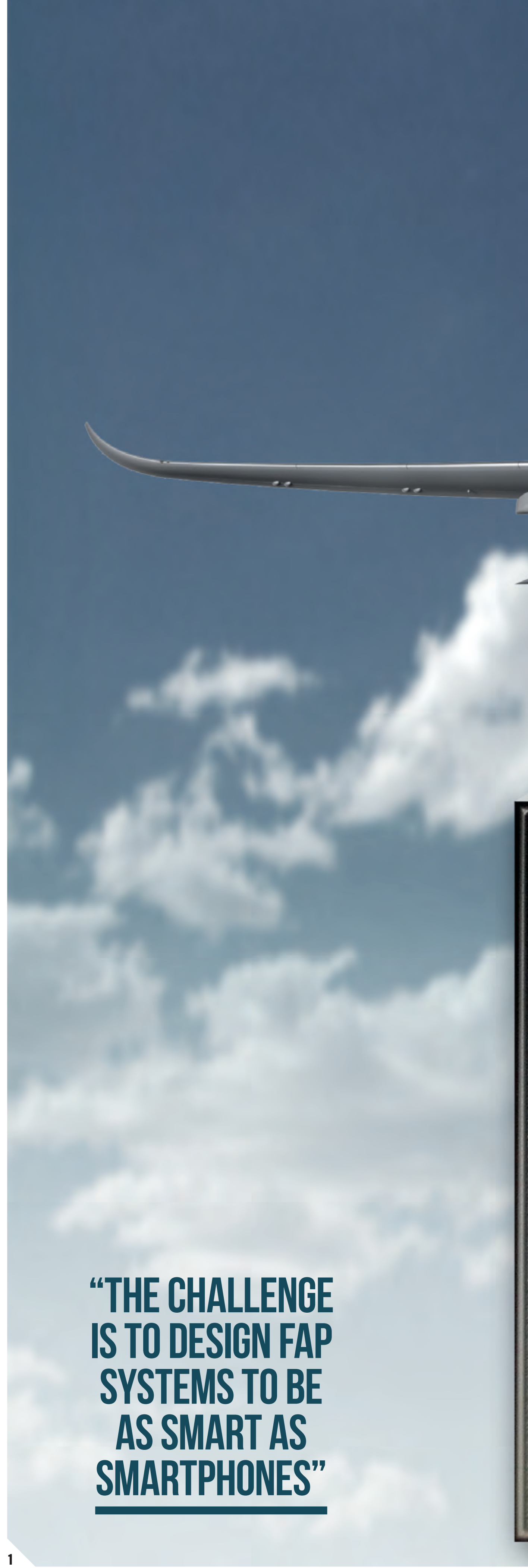
// SEBASTIAN MEZGER AND MINGZHI DENG

Ever since Flight Attendant Panels (FAPs) were first introduced in the Airbus A320 series, the number of checking and monitoring functions which they control has grown regularly (Figure 1). Improved touchscreen technologies are continually making the human-machine interface more efficient and convenient. In modern aircraft, the crew uses FAPs to control and monitor many cabin functions, among them lighting, announcements, door status indication, smoke detection and temperatures. The units are also used for functions relevant to maintenance, for instance to add entries to the digital cabin logbook used to log faults. Furthermore, the FAP indicates safety information such as smoke detection or emergency signals. Easy, efficient and reliable operation of FAPs with graphic user interfaces plays an important role in the airlines' satisfaction with the units.

Quality assurance measures must be adapted to meet the increasing prevalence of software-based user interfaces. Complex logic must be applied, especially in the operation of embedded systems, which pose new challenges to the development process. Trends such as extending functionality by adding new software components or flexibly adapting the user interface can further increase this complexity. Consequently, the test phase is assuming growing importance in the development of user interfaces.

To properly address this increasing importance, it is necessary to validate functions in the early phases of development. Often the target hardware is still unavailable or at least incomplete by the time testing needs to start. Frequently, the validation must be performed in a purely virtualized environment or on an isolated subsystem using remaining bus simulation.

Desirable user interfaces are characterized by visualizing the underlying cabin applications in a way that is both clear and easy to understand – despite their complexity – and by offering intuitive and simple operation (usability). The challenge is to design FAP systems to be as smart as smartphones. This leads to highly responsive touch-based infotainment user



"THE CHALLENGE IS TO DESIGN FAP SYSTEMS TO BE AS SMART AS SMARTPHONES"

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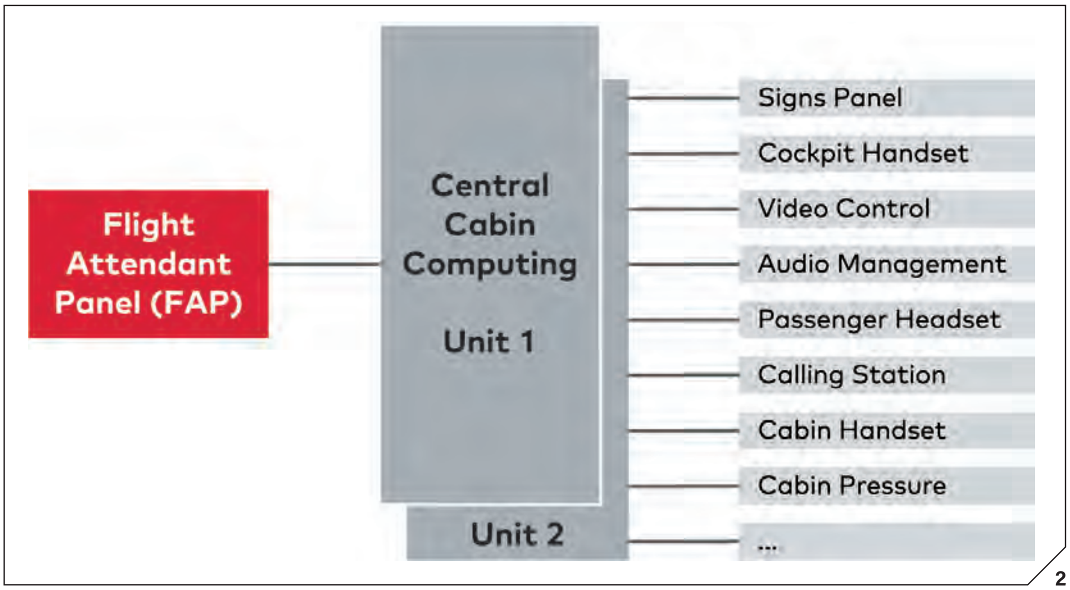
1 // Flight Attendant Panels, an essential part of modern aircraft, need reliable quality assurance and testing before aircraft test flights begin



2 // The FAP serves as a central control and display element for a wide variety of cabin functions

interfaces with a broad range of functions, and these must also be validated. The customer always expects the FAPs to show state-of-the-art technology in its operating concept and supported periphery. The units must also lend themselves to reliable software updates at regular intervals. In turn, these constraints place stringent requirements on testing that should be repeatable, automatable and maintainable.

INTERDISCIPLINARY APPROACH

To satisfy these requirements, an interdisciplinary approach is needed that combines the tools from both GUI and ECU testing in order to assure comprehensive verification in all development stages.

eggPlant Functional, the software from TestPlant for functional GUI tests, enables testing of embedded software applications via the user interface. This approach assures greater testing depth compared to testing on the program code or functional level. Here, test automation utilizes image and text recognition algorithms to detect switch surfaces and displays. For instance, if a surface switch should be activated, its position is identified by image recognition, and a button push is initiated. Remote control mechanisms such as Virtual Network Computing (VNC), Remote Desktop Protocol (RDP) or Keyboard-Video-Mouse (KVM) over IP (Internet Protocol) are used on the system level to transfer screen contents and initiate user interactions. VNC and RDP are protocols commonly used in the PC area to transmit screen contents as well as keyboard and mouse inputs. KVM switches are typically located on the hardware level to implement the same functionality in transmitting input and output information. This makes it unnecessary to modify the testing software to achieve testability.

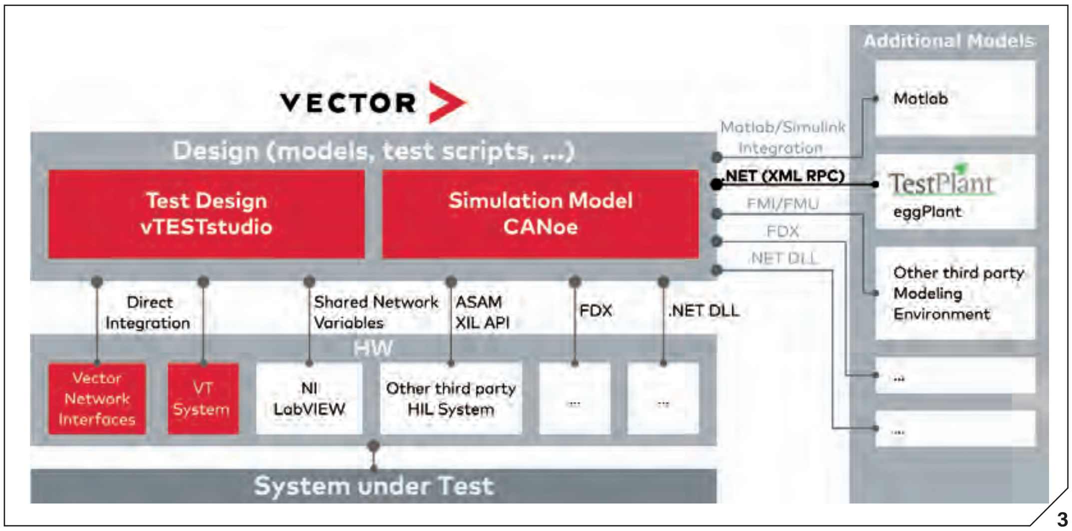
Such a non-invasive approach ensures that changes which would otherwise only be performed to test the software do not have any effects on the actual test. Any ECUs can be checked using this approach, because remote control mechanisms now exist in all commonly used operating systems (Android, iOS, Linux, QNX, VxWorks, Windows, etc.). eggPlant Functional is operated as a distributed system, in which the host application with test flow control is executed on a conventional PC. Only the remote control component is needed at the ECU under test. By using different interfaces, eggPlant Functional can interact with the systems of other test automation suppliers, and has been designed to be an open system.

CANoe (oe = open environment) software from Vector handles the remaining bus simulation for the ECU under test and the analysis of bus parameters. In addition, it provides a test environment that includes a test sequencer and test reporting. The tests themselves are created in the Vector tool vTESTstudio, an authoring tool for editing test flows for embedded systems. Programming language based methods (CAPL/C#), spreadsheet-based methods or graphic test notation and test design methods are available for this purpose. CANoe was explicitly designed to be an open environment, and it offers numerous interfaces for linking to external programs (Figure 2). These include Vector's own UDP-based Fast Data Exchange (FDX) interface, the Functional Mockup Interface (FMI) and MATLAB. It is also possible to integrate external DLLs. The latter is used to link eggPlant Functional to CANoe. eggPlant Functional offers access to external applications over an XML-RPC interface (Extensible Markup Language Remote Procedure Call); this is executed by eggDrive in a mode without a graphic user interface.

The interface lets CANoe call functions and test scripts in eggPlant and read out individual (partial) results of the overall test report. TestPlant offers an implementation in the form of a .NET assembly for use of the XML-RPC interface. This makes it possible to link to the combination of CANoe and vTESTstudio (Figure 3). Encapsulation of the necessary calls in a C# test library and mapping of the test results to the CANoe test report results in an easy-to-use interface for combining CANoe and eggPlant Functional. The test designer creates the ECU tests in a familiar environment such as vTESTstudio and accesses the functions of eggPlant Functional in the same way as the functions of CANoe are accessed.

BENEFITS

The integrated approach of Vector and TestPlant gives the user a test environment in which, in addition to the ability to



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stimulate and analyze parameters transmitted over the databus in the airplane, the FAP's graphic user interface can also be monitored and stimulated. From the perspective of the test developer, the level on which the information is accessed does not matter. Similarly, one advantage of CANoe is that testing is performed independently of the bus physics. It is only necessary to interchange the hardware interface to match the bus system being used. Consequently, the same models can be used to test the next generation of FAPs, even if a different bus system is used.

Since it is also possible to run existing eggPlant Functional test scripts, scripts from the pure user interface test can be used again in an integrated functional GUI test. The tools that the domain specialists already have and are familiar with can also be used in a combined application case. Such an approach increases the depth of testing or degree of test automation and ensures in-depth and extensive functional testing of an ECU, including in cases where there are frequent software releases. Even in early development stages, such a test setup enables validation of an isolated ECU including the user interface. CANoe is used to simulate ECUs that communicate with the ECU under test and do not need to be present in real form. Functional GUI tests thereby enable validation with modest hardware resources at a very early time.

This test setup is also ideally suited for creating a development environment with continuous testing. It can be used to validate daily builds, for example, enabling quick responses to any problems in new software releases. It lends itself to frequent software releases and short development cycles and ensures timely reactions to new requirements and constraints.

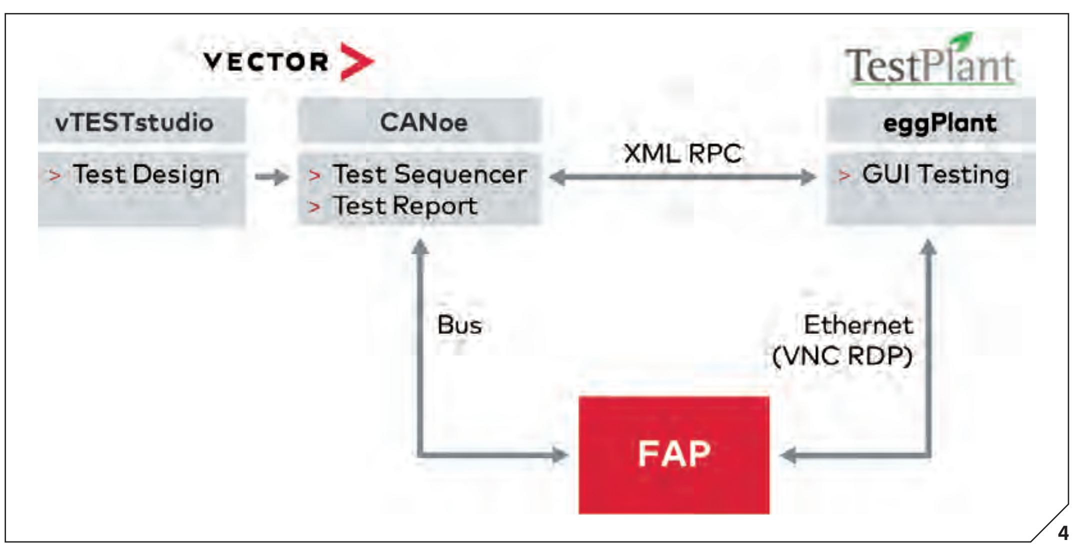
3 // CANoe offers an open environment with various interfaces to third-party tools

4 // Toolchain for integrated functional GUI testing of a FAP

SUMMARY

Software-based embedded systems that are operated via graphic user interfaces are becoming increasingly more important in airplane development. To meet quality assurance requirements, it is not only necessary to test the individual software components but also their user interfaces. Therefore, the goal is to verify the functionality of the embedded systems completely and reliably in automated testing. The test automation tools eggPlant Functional and CANoe come into play here. With their open interfaces they represent a simple tool combination that is ideal for such testing. Domain specialists can implement tests in their familiar environment and then integrate the tools into an overall test suite. This eliminates the effort involved in creating additional tests. It also enables shorter development cycles with frequent software releases, and this produces a clear competitive advantage for the aircraft manufacturer and the supplier. \\

Sebastian Mezger is team and project leader with Vector Informatik, and Mingzhi Deng is a technical consultant at TestPlant



4

SATELLITE AND SPACECRAFT VIBRATION TESTING CONTROL

Critical vibration testing requires accurate, reliable controls with advanced safety features to protect valuable flight hardware and is essential for successful qualification

// **THOMAS REILLY**

Rigorous, safely-controlled vibration testing is required for spacecraft and satellites prior to launch. This testing is designed to qualify the structure against the various static and dynamic loads during launch. Advanced safety features have been developed and proven to reduce or eliminate testing anomalies, and even protect the test article against external events such as a power outage.

TESTING METHODS

There are a variety of tests methods that are used to simulate the various load sources encountered.

Random vibration testing is used to verify strength and structural life by introducing random vibration through the mechanical interface. Random tests are typically performed in the frequency range of 20-2,000Hz.

Sinusoidal vibration testing includes testing at low levels to verify the natural frequency and at higher levels to verify the strength of structures. Responses are monitored and input forces are reduced or limited as necessary (called notching) to ensure that the target responses or member loads are not exceeded.

Pyrotechnic shock tests are used to verify resistance to high-frequency shock waves caused by stages separation. This can include introduction of high-energy vibration at frequencies up to 10kHz.

Sine burst testing involves short-duration constant-amplitude sine excitation. This is a quasi-static load to validate the strength design for flight and can be used as an alternative to static loads or centrifuge testing.

The Data Physics Vector single-shaker controller and Matrix multishaker controller offer a feature set that addresses all requirements specific to spacecraft and satellite testing.

SWEPT SINE CONTROL

Swept sine testing is the most difficult of the tests required for qualification of spacecraft and satellites. The primary objective of swept sine testing of spacecraft and satellites is to verify the strength of the primary and secondary structures. Qualification tests consist of one sweep through the required frequency range, typically 5-100Hz. Some tests will be up to 150Hz. This sweep is repeated in three orthogonal axes. The amplitudes of the sweep are dictated by the launch vehicle.

Swept sine control requires tracking filters to accurately measure the amplitude and phase of the sinusoidal signal. Data Physics has implemented high-quality digital track filters in each input channel. Tracking-filter type (fixed or proportional bandwidth) and bandwidth are user selectable to optimize the tracking filter for the frequency range and sweep parameters. Swept sine testing of spacecraft and satellites is typically done with very high sweep rates, up to four octaves per minute, to minimize the number of cycles at resonance frequencies. The combination of fast sweep rate and low-frequency, lightly damped resonances is particularly challenging for a vibration control system.

Notching, or reducing the vibration amplitude over specific frequency ranges, is used to prevent excessive loading of the spacecraft or satellite structure. The levels are typically determined by coupled loads analysis using mathematical models of the launch vehicle and spacecraft.

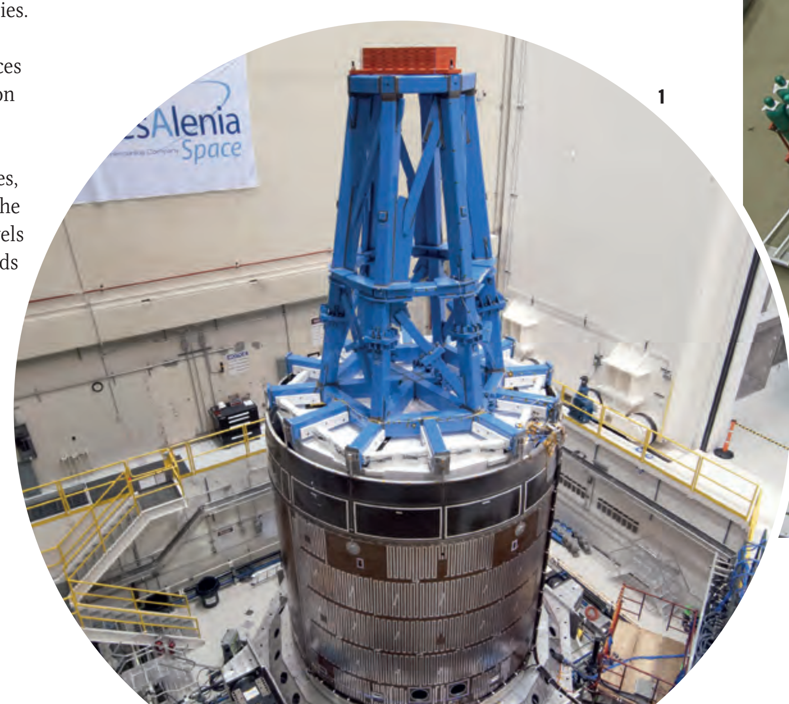
Primary notching is used to limit the forces and moments at the interface between the spacecraft and the launch vehicle. Secondary notching is used to limit acceleration levels at specific locations on the satellite or spacecraft.

Testing in each axis starts with a low-level 'signature' sweep to determine resonance frequencies. This data can also be used when adjusting the limit profiles used to notch the test. Sweeps are repeated at higher levels until the full test level has been reached. At each level, vibration responses at critical locations are checked and profile levels are modified as necessary.

ADVANCED SAFETY FEATURES

Protection of valuable spacecraft and satellites is paramount to successful vibration qualification of them. Several new safety features are incorporated in the Data Physics sine vibration controller that was used for testing of the James Webb Space Telescope at NASA Goddard Space Flight Center's Large Vibration Test Facility (LVTF).

Pretest feasibility A low-level random signal is used to excite the structure prior to each run to verify the test hardware and compute the frequency response function between the drive



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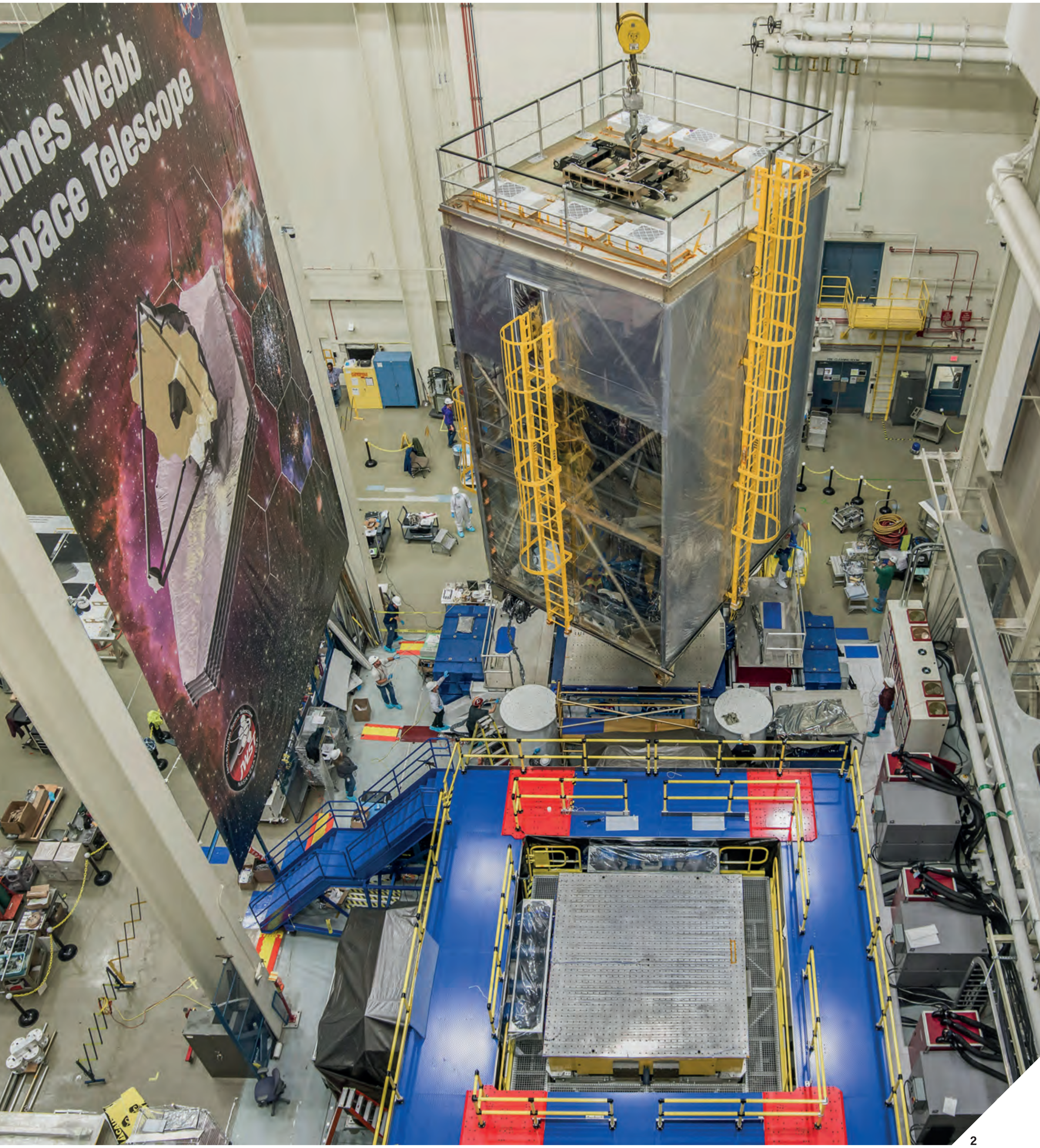
1 // The European Space Agency dynamic model of the Orion service module at the mechanical vibration facility at NASA Plum Brook Station (photo: NASA Plum Brook)

2 // The James Webb Space Telescope is transferred from the horizontal table to the vertical table at NASA Goddard Space Flight Center (photo: NASA GSFC)



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signals and all input channels. Reference and limit profiles are used with the pretest frequency response function data to predict the levels that will be reached during the sine sweep. Channels that might reach their limit profile levels, resulting in notching of the drive, are identified. The pretest feasibility checks provide warnings of potential over test situations and can identify configuration problems prior to test runs. Before each test run, the frequency response data from the pretest can be overlaid with previous runs to identify any changes in system response. Differences in the frequency response function can be used to indicate possible problems. These could be anything from shaker, sensor or signal conditioning problems to structural failure of a component of the test article.

Safe shutdown Abrupt shutdown of a vibration test can cause damage to a test article by producing a high amplitude transient in sensitive equipment. The safe shutdown feature ensures a smooth controlled shutdown for any test failures. This includes failures detected in signals measured by the controller or external failures detected by other systems.

The Data Physics controller at NASA Goddard Space Flight Center is connected to interlocks in the shaker, amplifier and slip table. Any failure of these systems initiates a controlled shutdown. This includes complete loss of facility power. In all shutdown conditions, the controller will smoothly ramp down the test level to zero over a user-specified duration. This feature is implemented to achieve very low latency between detection of the external shutdown signal and initiation of the shutdown. Low latency prevents further damage to valuable test articles caused by continuing to excite the test article after a failure has occurred.

Predictive limiting This is useful for dealing with low-frequency, lightly damped resonances. Limiting can be difficult when sweeping is conducted at high rates. The predictive limiting feature makes use of the pretest frequency response function to predict the frequencies at which limit profiles will be exceeded and will improve the performance of limiting at those frequencies.

MULTISHAKER SWEPT SINE TESTS

Vibration testing of spacecraft and other large payloads may require the use of more than one shaker to provide sufficient force to achieve the required acceleration levels. When using more than one shaker, multishaker control is necessary. The Data Physics Matrix controller is capable of both multishaker, multi-axis and multishaker, single-axis testing.

Sine testing of spacecraft is performed using sequential single-axis testing using multiple shakers requires the controller to measure and control all unconstrained degrees of freedom. For example, if a 6DOF table is used for multishaker single-axis testing, the controller must actively control all unconstrained degrees of freedom. This means actively reducing any cross-axis and rotational vibration while generating the desired in-axis vibration. An array of triaxial control accelerometers, measuring all unconstrained degrees of freedom is used as a control.

The Data Physics Matrix multishaker controller is used at the Mechanical Vibration Facility (MVF) at the NASA Space Power Facility at Plum Brook Station. The shaker table in the MVF is the highest capacity and most powerful shaker system ever built for spacecraft testing. Built by Team Corporation, the MVF incorporates 16 vertical shakers and four horizontal shakers driving a table that is 22ft (6.7m) in diameter. The table handles test articles with mass of up to 75,000 lb (34,019kg). The table is driven through hydrostatic spherical couples that enable a full 6DOF of vibration. The table's unique ability to produce vibration in all three axes enables sequential single-axis testing of large spacecraft without having to remove the spacecraft and reconfigure the table. The MVF recently completed vibration testing of the European Space Agency's dynamic model of the Orion Service Module.

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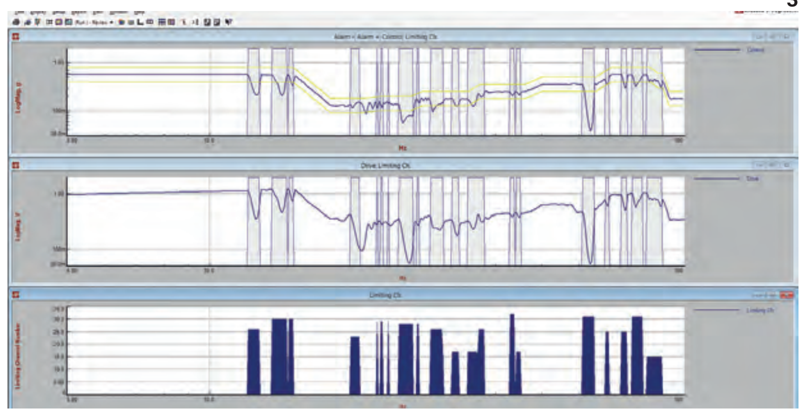

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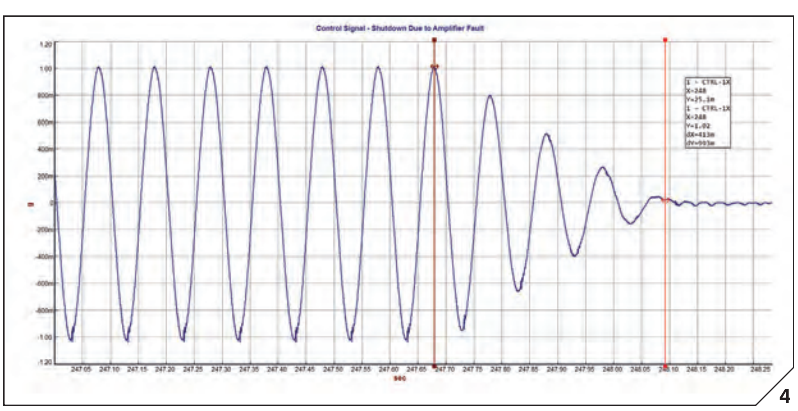


3 // Data Physics Vector sine control output showing frequency bands with limiting

4 // Accelerometer response on table during safe shutdown after an amplifier fault

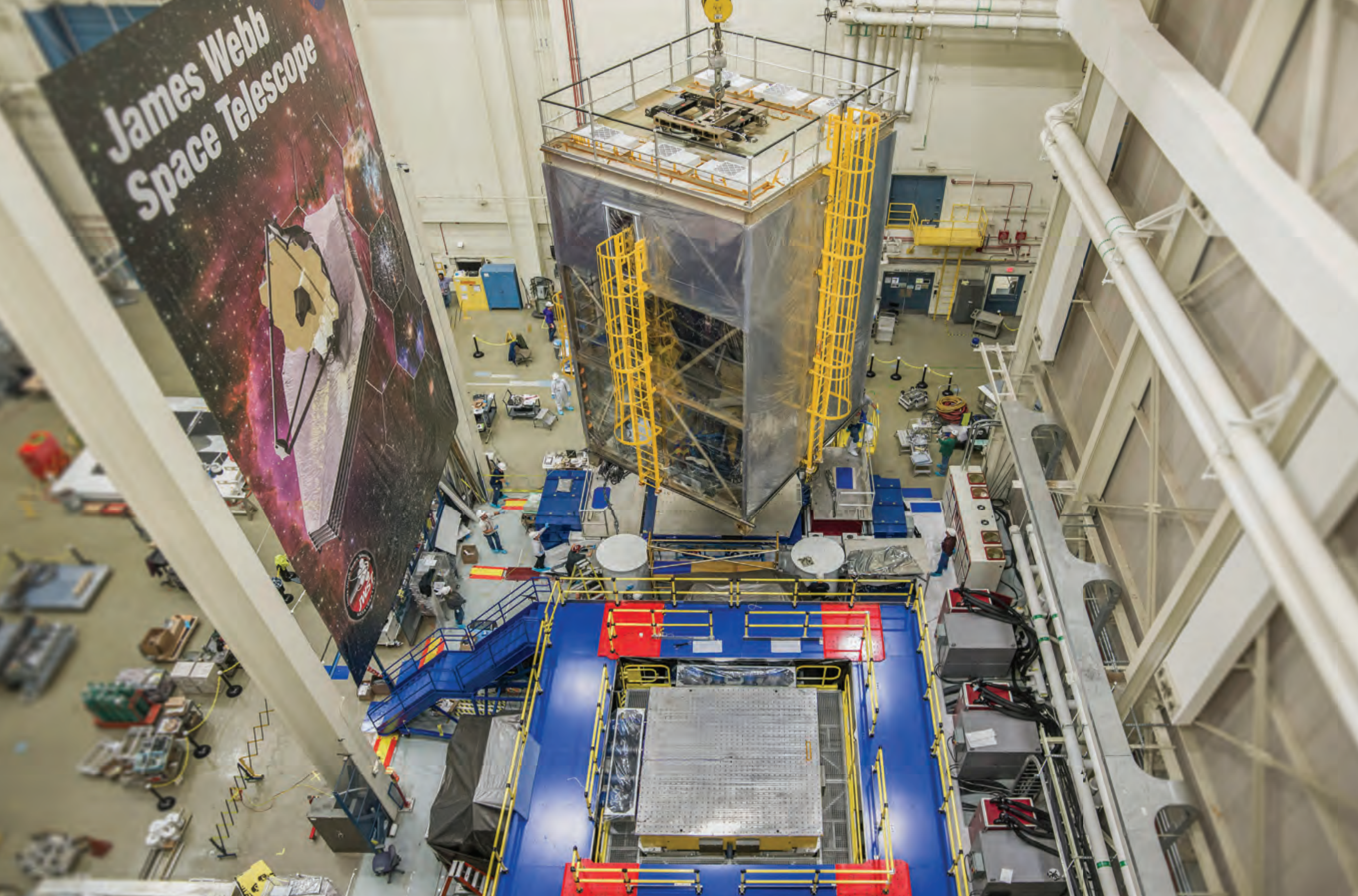
ACQUISITION AND ANALYSIS

Testing of large structures requires hundreds of measurement channels to measure the dynamic response of the test article. This data is analyzed between runs and compared with models. An independent system capable of acquiring and processing sine data is often required. Data Physics offers SignalCalc Sine Reduction software for simultaneous recording and processing of hundreds of channels of sine data using digital tracking filters.

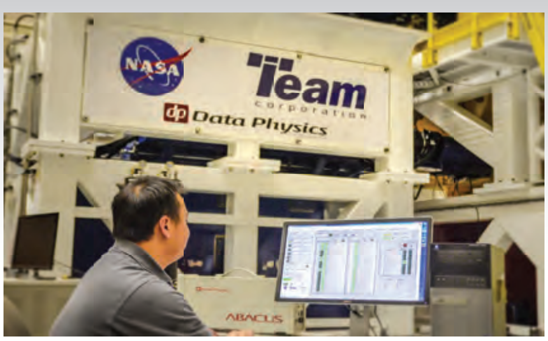
The Sine Reduction software uses a signal from a constant output level adapter (COLA) in the vibration controller to determine the instantaneous sweep frequency using a tachometer channel. Each measurement channel can be processed as filtered (fixed or proportional tracking filter), RMS or peak. This data can be compared with user-defined tolerances for each channel. If a channel exceeds its tolerance, a signal can be send to the Data Physics controller to initiate a safe shutdown, providing additional protection of the test article.

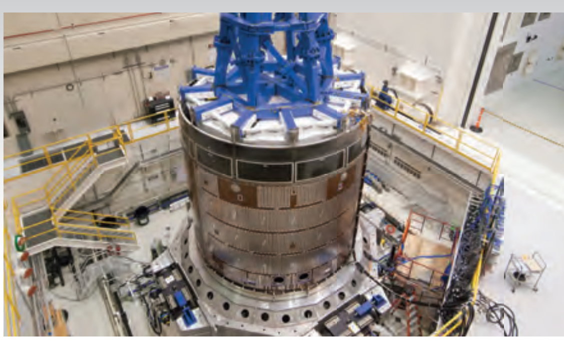
A Notching Prediction tool is also available. This tool can be used with measured data from low-level sine sweeps to predict the manual notching of the test reference profile that will be required to ensure that the response levels on that measurement channel remain within acceptable limits when the test is increased to full level. \\

Thomas Reilly is director of product management at Data Physics


James Webb
Space Telescope


Team


NASA
Team
corporation
Data Physics



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TEST LIKE YOU FLY, FLY LIKE YOU TEST

Gantner Instruments' latest Q.series data acquisition system has been designed to meet the increasing need for advanced rocket engine test equipment

// STEPHAN PLOEGMAN

Today, countries and companies small and large battle for a place in suborbital outer space. Plenty of factors are making space missions cheaper and more feasible: the miniaturization of electronics, the development of stronger and lighter materials, and cutting-edge rocket engine designs. Startups and semi-professional rocket societies, often student-driven, bring innovative technology, products and services to life that help to reduce the cost associated with getting into space.

Students for the Exploration and Development of Space at the University of California San Diego (SEDS UCSD) became the first university research group in the world to successfully design, test and launch a rocket powered by a 3D-printed engine. Complex parts made with 3D printing have the potential for considerable cost savings. The Vulcan-1's engine contains an internal structure of 'channels and chasms', which optimize the efficiency of the combustion, and could only be produced through 3D printing.

This year, one of the world's most promising new rocket companies successfully launched its first carbon-fiber rocket with 3D-printed engine to space from New Zealand's Mahia Peninsula. Composite material has the potential to make rockets lighter and tougher than their metallic counterparts. The Inholland University Delft, in the Netherlands, is known for its research work in lightweight composite structures. In 2015 this resulted in the launch of its first carbon-fiber rocket, the Aquilo, which turned out to be 45% lighter than one made of conventional materials. Together with NERO (Dutch Federation for Rocket Research), the team recently developed and tested a solid-fuel engine with a lightweight glass-fiber reinforced aluminum casing. During the static fire test, the PB51 engine generated a total impulse of 4,400Ns with a burn time of close to four seconds.

Delft is also home to one of Europe's most successful university student rocket societies, Delft Aerospace Rocket Engineering (DARE). In 2015, DARE broke the European altitude record for experimental rockets with the launch of Stratos II+ to 21.5km (13.4 miles). The DHX-200 Aurora engine had a total impulse of 180kNs and a burn time of around 23 seconds. Prior to launch, the engine has been static test fired 14 times at the facilities of TNO Rijswijk in the Netherlands and DLR Trauen in Germany. DARE recently presented the Stratos III that comes with an engine that has a 3D-printed titanium nozzle and a carbon-fiber composite combustion chamber. The mission is for Stratos III is simple: to improve the current European student altitude record for rocketry, which is currently held by HyEnD, a student team from Germany, at 32.3km (20 miles). But they do not leave it at that. DARE is pursuing the goal of becoming the first student rocketry society in space. The team is currently test firing its improved engine design, a 4kN hybrid rocket engine to lift the Stratos III to a record-breaking altitude.

2

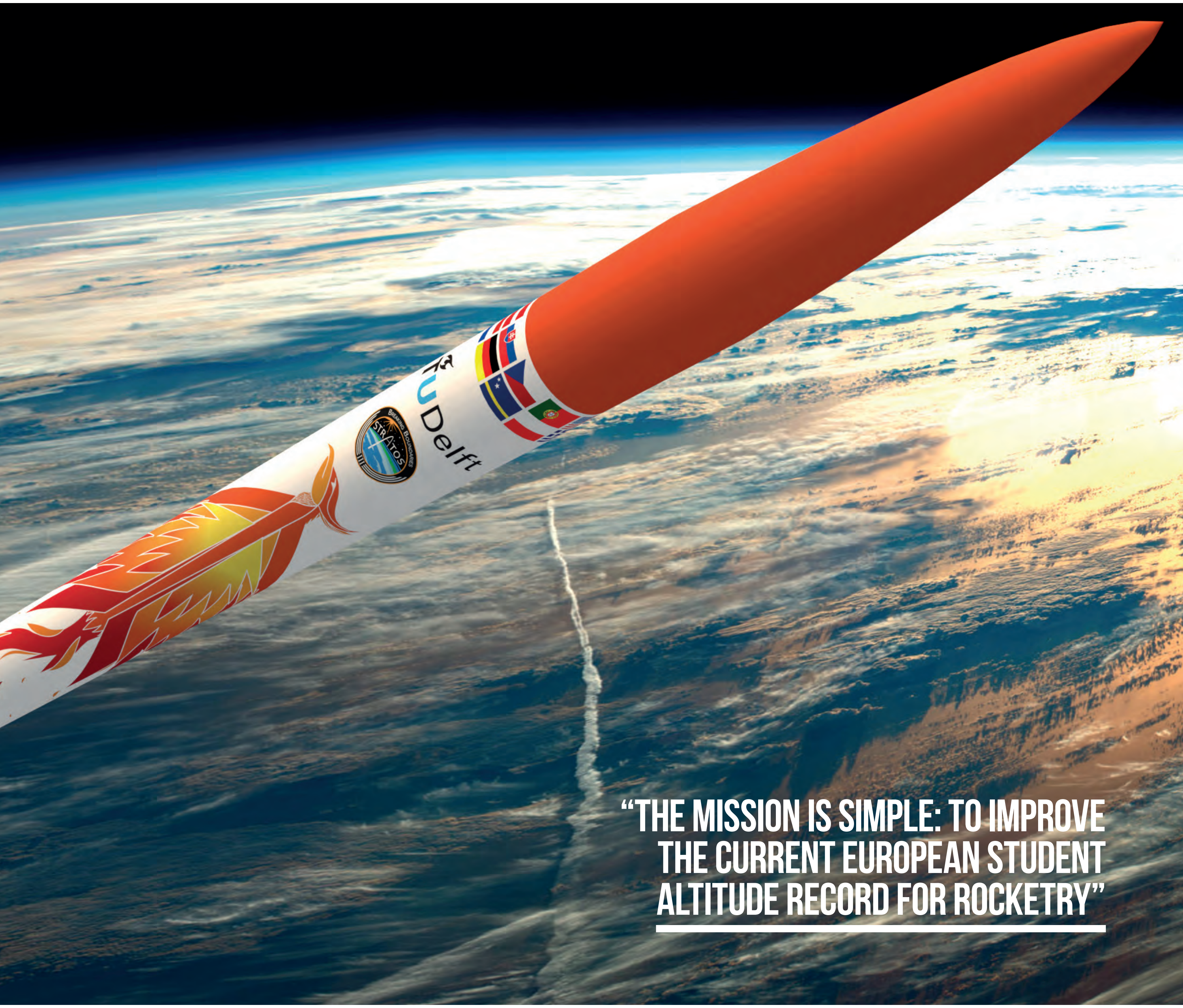
Whether an engine for experimental rockets or for commercial spaceflight, adequate testing is critical to the success of each launch program. Because of the cost and risk associated with developing and testing an engine, a reliable test setup is vital. Maintaining system consistency and accuracy in a harsh environment is putting stringent requirements on the data acquisition equipment.

ACCURACY

Accuracy, flexibility and reliability characterize the Q.series, making it the

1 // The Q.raxx data acquisition system

2 // Simulated view of DARE's Stratos III rocket



"THE MISSION IS SIMPLE: TO IMPROVE THE CURRENT EUROPEAN STUDENT ALTITUDE RECORD FOR ROCKETRY"

data acquisition system of choice for world's innovation-leading engine manufacturers. Some of the most important parameters to be measured during static fire tests are thrust, temperature, pressure, flow rate and vibration.

Thrust force measurement is typically accomplished using a moment/side load compensated strain gauge beam or load cell. The Q.series strain measurement with low signal drift minimizes measurement uncertainty and ensures repeatable test results for reliable thrust measurement and accurate propulsion system performance assessment.

Temperature is also important to determine engine performance. The Q. series system features built-in disturbance depression and adaptive linearization for precise temperature measurement. Triple galvanic isolation up to 1200V, intrinsic safety barrier compatibility and stable cold-junction compensation ensure high accuracy even in the harshest environments. The combustion chamber pressure also determines the performance of a rocket engine. Typically, static and dynamic pressures in the combustion chamber are measured during fire testing.

The Q.series comes with a galvanically isolated universal measurement module that can be configured for pressure transmitters with bridge or conditioned 4-20mA output.

Accurately measuring the rate volume of an engine's fuel/oxidizer consumption is critical for measuring performance parameters of the rocket, such as specific impulse – the ratio of fuel mass consumed to thrust produced per second. Specific impulse measurements determine payload

3 // A PB51 static fire test

size and mission fuel requirements. A flow meter in the fuel lines monitors fuel/oxidizer consumption during static fire testing. The data acquisition system must be capable of high-speed measurement to capture rapid changes in fuel flow. The Q.series allows for fast and precise frequency measurement for both analog and digital flow meters.

Vibrations can have a powerful effect on a rocket's avionics, hardware, and any payload on board. The vibration that is produced by an engine is called thrust oscillation. Typically, integrated electronic piezoelectric (IEPE) sensors are used to measure the thrust vibration signatures. The Q.series features per-channel adjustable measurement ranges and filters for accurate vibration analysis. Real-time fast Fourier transforms (FFTs) allow for instantly detecting the vibration signatures produced by the engine while under test.

"OPEN-STANDARDS SUPPORT MAKES IT SIMPLE AND EASY TO INTEGRATE THE Q.SERIES INTO A SMART NETWORKED SYSTEM"

FLEXIBILITY

The system architecture is fully scalable from a few channels to 1,000+ channels, with the flexibility to mix and distribute modules for both light instrumented subscale component testing and heavy instrumented full-scale engine testing. The system can operate standalone using Gantner Instruments' latest GI.bench test software. Or the open-standards support makes it simple and easy to integrate the Q.series into a smart networked system, either via REST API, Data Distribution Service (DDS) or fieldbus protocols such as EtherCAT, PROFIBUS or Modbus TCP.

The Q.series hot swap feature enables simple expansion, modification and service without the need to shut down or reconfigure the system or its interfaces, ensuring high system uptime.

RELIABILITY

Engine testing generates a lot of data, especially when engine transient responses must be recorded. Scan rates can range from 10Hz to several kilohertz depending on the parameter or type of test.

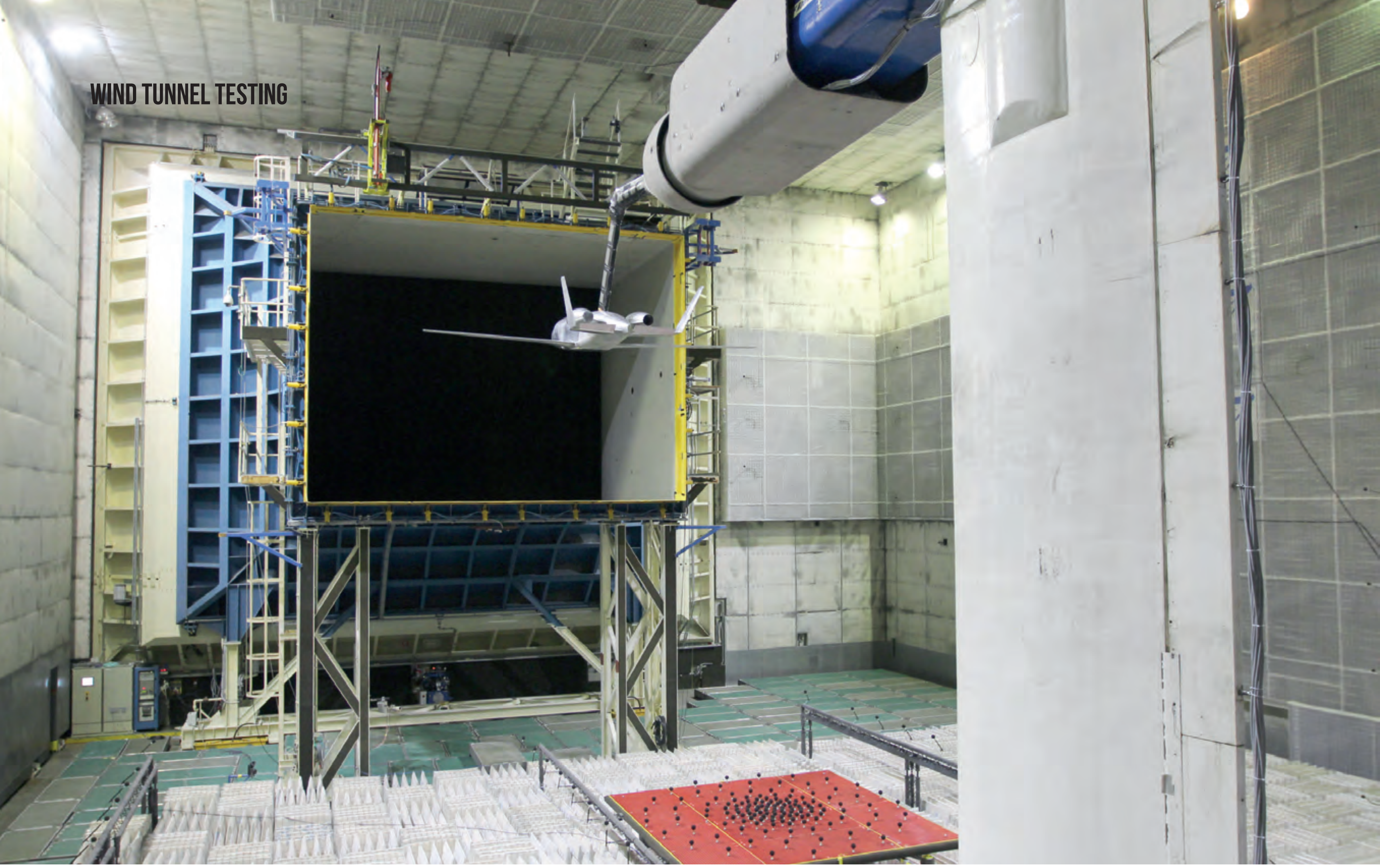
The Q.series enables the creation of up to 20 dataloggers. Each datalogger can be configured to record a different data set at a specific logging rate and different logger type, for continuous, triggered or event-based logging. For example, a supervisory system can be used to trigger a logging action with a pre- and post-trigger time. In parallel it is possible to configure a logger that continuously records data to a circular data buffer. File name, size, destination and protection level are fully configurable for each datalogger.

For mission-critical data acquisition applications, Gantner has developed fully redundant measurement modules that, even if the primary signal conditioning circuitry fails, the data recording will continue via the redundant circuitry. To be certain that not a single sample is missed, the Q.series system features three levels of redundancy for assured data availability. Measurement data can be broadcast in parallel with an online database, as well as to an FTP backup server. Both data ports are continuously monitored. If a broadcast fails, the Q.series system will automatically start logging data to its local disk.

Data skew in a multichannel, distributed data acquisition system is one of the major uncertainties during a test program. Often measurement modules need to be synchronized by means of field-programmable gate array (FPGA) programming, inaccurate network time protocols, or extra module-to-module synchronization lines. The Q.series data acquisition system comes with built-in, hardware-based synchronization between the modules. Even when a system is distributed over long distances we ensure precise time synchronization with a maximum jitter of 1µs, eliminating long cable runs.

Gantner's know-how is reflected in all its products and associated services. Despite today's fast-changing industry, the company stays focused on what matters most: high-quality data that users can rely on. \\

Stephan Ploegman is business development manager for aerospace at Gantner Instruments



1

ENGINE INTEGRATION AND NOISE SHIELDING

Wind tunnel testing can provide environmental advantages by assessing engine locations for decreased noise and for stability and control testing

// GEORG EITELBERG AND HERMANN HOLTHUSEN

The aspect of noise emission, especially at low flight speeds in the vicinity of human settlements (airports) has to be considered when evaluating any novel propulsion integration concepts. This includes noise shielding configurations.

Although rear fuselage mounted engine configurations are well established, the mounting of engines in such positions where either noise shielding or the combination of noise shielding together with the benefit of boundary layer or wake ingestion (BLI/WI) and re-energizing can take place, may affect the control and stability of an aircraft.

The advantage of BLI/WI engines could be twofold: the interaction of engine flow with that around the airframe might increase system efficiency and sound propagation can be given directivity according to requirements. A smaller step in directivity control is to place fuselage-mounted engines in a location where some of the emitted noise is reflected upward, thus shielding the ground from acoustic emissions. A pioneering study at German-Dutch Wind Tunnels' large low-speed facility (DNW-LLF) into this aspect was performed by Dassault Aviation together with ONERA with the support of the EU CleanSky research program.

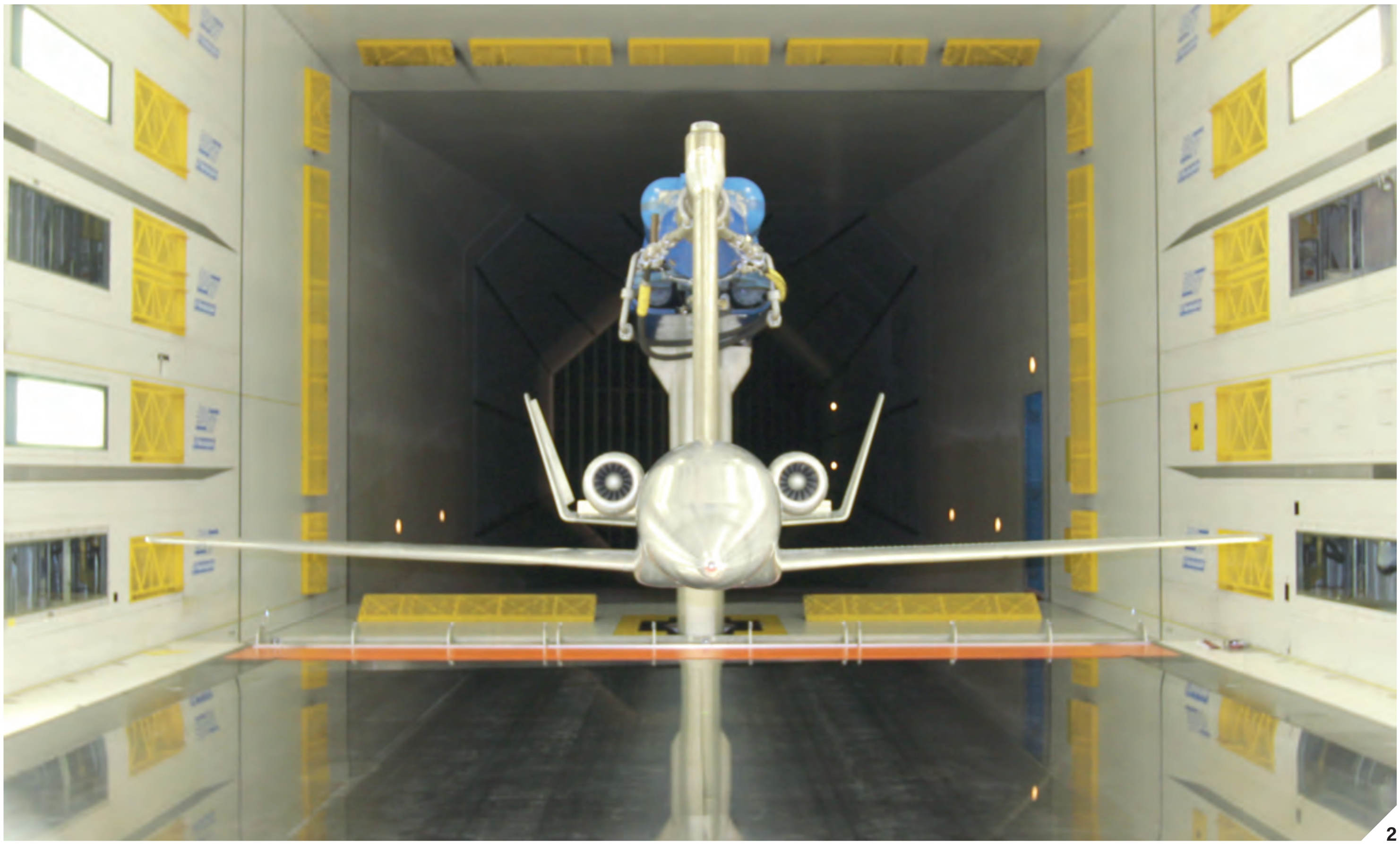
THRUST AND NOISE SHIELDING

For aerodynamic effects, the focus of the simulation is on the fan flow. The slipstream of the fan is the part that is closest to the aerodynamic surfaces and the fan pressure ratio together with the bypass ratio determines the characteristic interactions. The thrust (and power) in a wind tunnel simulation is scaled with the size of the model squared, providing for thrust coefficient similarity in a wind tunnel test, assuming sea level conditions and that the flight speed can be duplicated. This scaling places high requirements on the power density of the engine simulator drive, since the available volume scales with the third power of size. Although electric drives are continually being improved, the current pneumatic technique to drive engine simulators is still the best method to obtain reliable, scaled data.

For noise shielding studies, not just the thrust needs to be scaled properly to provide similarity with the flight performance of the real airplane. The characteristic

1 // Noise source localization in the open test section of DNW-LLF

2 // Noise shielding configuration of the Dassault low-sweep business jet



2

wavelength of the noise also needs to scale appropriately with the size of the shielding elements. This requirement is fulfilled when the product of the Strouhal number

$$Str = \frac{f_{acoustic} \cdot L}{u_{\infty}}$$

where $f_{acoustic}$, as shown in the formula above, is the frequency of the emitted noise, L is the characteristic size of the shielding element and u_{∞} as shown in the formula above, is the free stream velocity, and the Mach number

$$Ma = \frac{u_{\infty}}{a}$$

where a is the speed of sound, is conserved in the experiment.

Since noise is predominantly a concern in the vicinity of airports, the Mach number in the experimental simulation has to remain low. This is a challenge for obtaining an audible signal in a wind tunnel. For Strouhal number scaling, the dominant frequency is that of the fan blade passing frequency (BPF). The Mach number similarity also assures that the frequency shift due to the convective transport of noise (the Doppler effect) remains similar.

SCALING FOR GROUND EFFECT

The ground proximity effect was been well studied in the early years of airplane development. The rule of the thumb is it increases lift when the product of the lift coefficient, c_L, as shown in the formula below, and the aircraft span, b, is large compared with its elevation, h, above ground:

$$\frac{c_L}{h/b} \gtrsim 20$$

Newer results reveal that the actual values for this ratio and the effect will vary also according to the detailed configuration. The different behavior when the high lift elements are deployed, and if the tail plane is a high T-tail or low U-tail, can be surprising. Instead of extra lift, a suction force can be generated and hysteresis effects can occur.

The details of the above complications often get lost in conventional wind tunnel tests because of the presence of the tunnel wall boundary layer. There the momentum is already lost in the flow before it reaches the lower surfaces of the aircraft models.

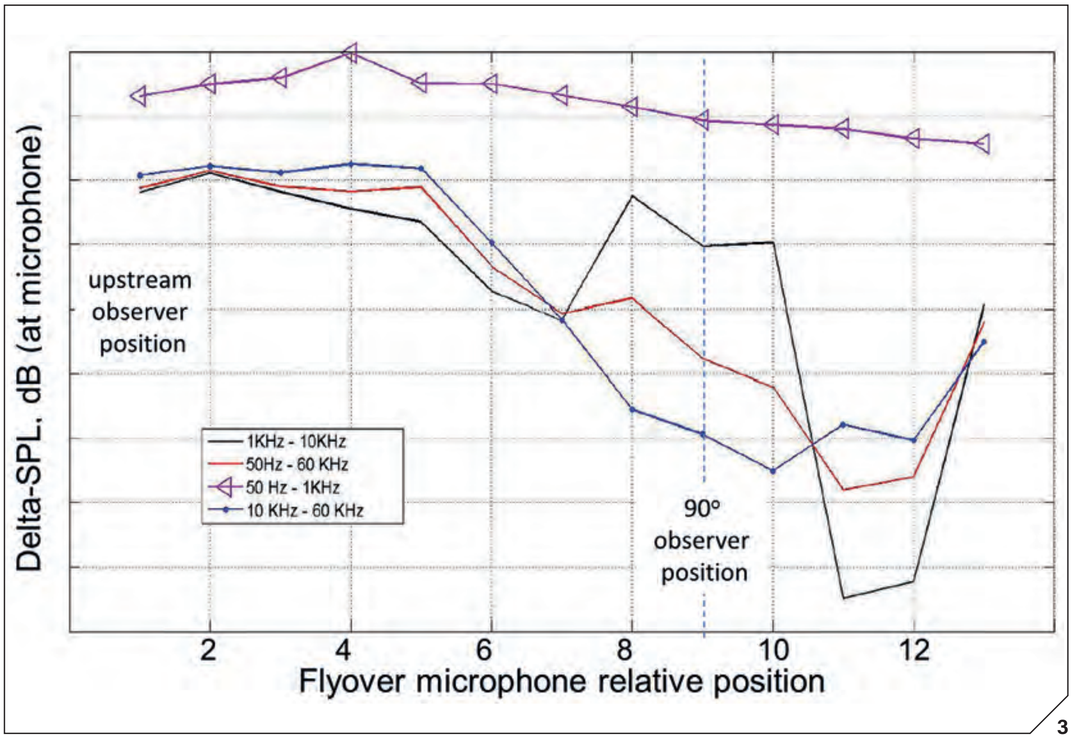
ENGINE INTEGRATION CAPABILITIES

DNW has Turbo Powered Simulator (TPS) engine simulator units available for a wide range of model scales. The TPS specifications have evolved following the trends of the real aircraft engines. DNW has developed its own supply capability for TPS units in order to be able to match any new engine specifications. The currently available power ranges from 60-350kW and the nominal fan pressure ratios range from 1.4 to 1.75, enabling the simulation of established configurations as well as the modern new generation of aircraft propulsion.

ACOUSTIC CAPABILITIES

Dedicated to the measurement of aeroacoustic effects, the DNW-LLF recently underwent an upgrade of its acoustic properties. Existing noise sources were either removed or their shielding was improved. The result is such that the background noise is barely audible and dominated by the shear layers in the open test section configuration. In case of the fan noise of the engine simulators at the BPF, the resulting signal-to-noise ratio is in the order of 30dB at the nominal operating conditions of u_{∞} (as in the formula above) = 60m/s and the BPF = 9,500Hz.

For quantification of the acoustic characteristics of aircraft models, a range of possibilities are available at DNW. In the open test section configuration, out-of-flow arrays (two of them are available, with 144 microphones and 4 x 4m^2 apertures each) are utilized for noise source localization as in Figure 1. Traversable in-flow arrays and lines of far-field microphones outside the flow can be used for source directivity studies, depending on the test goals. A



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3 // Installation effect: integration on different frequency bands

similar approach can be adopted in the closed test section, with wall-mounted phased arrays of 1 x 1m² aperture.

GROUND PROXIMITY TESTING

The tests, with the project acronym PLAAT for 'Powered Low Speed Aeroacoustic and Aerodynamic Testing', were performed on a model developed by Dassault Aviation for acoustic shielding of noise emissions as well as for the stability and control testing of the shielding configuration. This low-sweep business jet was representative of a 'green' low-emission Falcon concept, with laminar wings and U-shaped acoustic shielding empennage. It was scaled to make optimal use of the existing engine simulators with a 7.8in (19.8cm) diameter, resulting in an approximately 1:5 scale model of the business jet.

The previously discussed scaling for the ground effect is a good guideline for conventional configurations of high aspect ratio wing aircraft. Here it is important to note that the ground effect can only be effectively quantified for free flight conditions, when the runway is also properly simulated, i.e. the momentum of the flow underneath the aircraft model is conserved in a manner similar to an approach flight. In the DNW-LLF, the belt can be operated at up to 80m/s, corresponding to the realistic relative velocity between an aircraft and the runway.

The combination of the six-axis positioning mechanism with the dorsal sting model support and the moving belt for the wind tunnel floor enables testing for different landing conditions. Particularly important is the testing of the in-ground effect corresponding to different side wind conditions, i.e. model at yaw. The hysteresis effect of lift and drag dependency on the initial conditions is still not accessible to numerical calculation.

NOISE SHIELDING TESTING

The test in the open test section, even though not as easy to correct for the finiteness of the test section as a closed test section, is required for acoustic access. The acoustic access enables DNW to apply the measurement systems required to localize the dominant noise sources on the aircraft as well as to characterize the far field distributions of noise levels. The latter reflect the directional characteristics of the existing noise sources. In the PLAAT test, the dominant noise source was the engine simulator, of which the fan noise was of particular interest.

SHIELDING EFFECTS AND SOUND FREQUENCY

The far field noise patterns were evaluated for three configurations: the tail-less configuration for reference, the cross-tail and the U-tail configuration of a business jet designed by Dassault.

Although the engine simulator was originally designed only with the fan thrust similarity requirement, the Strouhal number similarity with modern high bypass ratio engines was a convenient by-product of the number of fan blades of the TPS. DNW's 15-blade fan simulator is operating at Strouhal scaled frequencies not far from those of full engines with, say, 18 blades. In all configurations the engine simulators were operated near their nominal conditions, yielding a BPF of approximately 9,500Hz.

The resulting far field acoustic data clearly demonstrates the feasibility of the shielding approach to reduce noise emissions toward the ground.

The difference in the sound pressure level (SPL) distribution for different frequency bands, however, displays interesting dependencies. Although the shielding is effective for all the frequency ranges evaluated, not all frequencies are affected in equal measure, as can be observed in Figure 3.

The frequency dependence of the shielding effect points clearly to the need to give careful consideration to the scaling requirements as discussed above. Reflections and diffraction effects need to be represented in an adequate manner to provide realistic verification of performance.

The support of the EU CleanSky program and the collaboration of Dassault Aviation and ONERA are gratefully appreciated. \\

Georg Eitelberg is director and Hermann Holthusen is project manager at the DNW

CT SCANNING WITH SUBPIX AND RING ARTIFACT REDUCTION

Non-destructive testing using CT on aerospace components and assemblies can now be done more accurately

// KEVIN BRESNAHAN

1

Over the past few years, the non-destructive testing industry has seen a rapid improvement in image quality and throughput using computed tomography (CT) to inspect and test aerospace components and assemblies. By using a computed tomography system, testing components is now becoming more commonplace in lieu of past techniques, such as destructive cross-sectioning. The result of the CT scan is a 3D model of the part that can be virtually cross-sectioned in multiple axes to reveal the problem or confirm the lack of a problem in the scanned region of interest.

Based upon new technological developments, the quality engineer can now increase the resolution of the CT scan while maintaining the same field of view using a technique called subpiX. This enables the engineer to scan the same region of interest while achieving better resolution to show smaller discontinuities that may be present. This technology is especially useful when employing a mini-focus, high-energy x-ray tube during the scanning process.

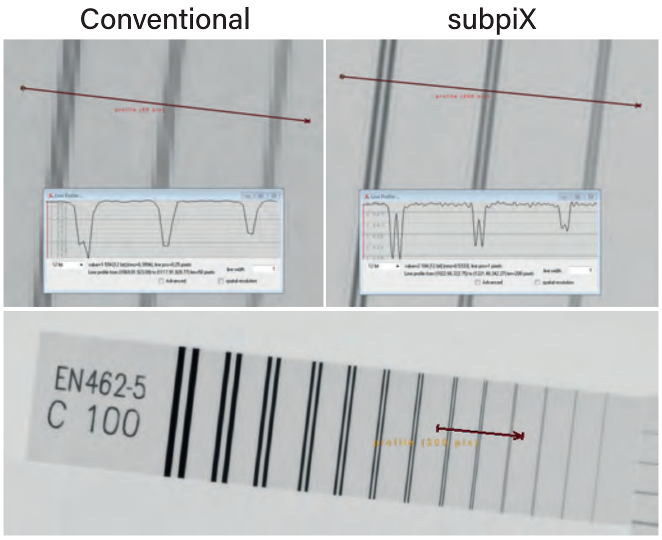
Traditionally, the use of a mini-focus tube was limited by the focus spot size and geometric unsharpness. This can be a common issue when the magnification required to achieve the proper resolution is not possible due to the unsharpness caused by the large focus spot size. By offering the end user the ability to slightly shift the digital detector array behind the part in question, the resolution can be improved (typically doubled) without adjusting the magnification.

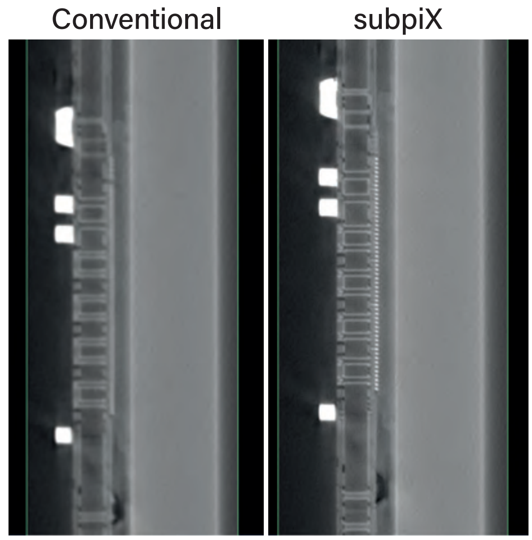
An additional benefit of using subpiX is an increased signal-to-noise ratio and increased contrast-to-noise ratio. This technology can also be used when the end user does not specifically want increased resolution, but they would rather increase the field of view size without sacrificing resolution. This can potentially increase the throughput capability as a sample that normally requires multiple higher magnification CT scans can now be completed with one lower magnification subpiX scan. This technology is very useful in the aerospace testing world, where testing must be performed very quickly and the outcome of a part must be determined immediately.

1 // The X3000, which uses subpiX and ring artifact reduction technology, can be configured for scanning thick aluminum castings or can focus down on a gold bond wire the thickness of a human hair

Using subpiX and a mini-focus-enabled system, an operator can run at higher frame rates on the digital detector, allowing for a faster acquisition of a larger area. This provides more useful data and information to enable an informed decision on the integrity of the tested part.

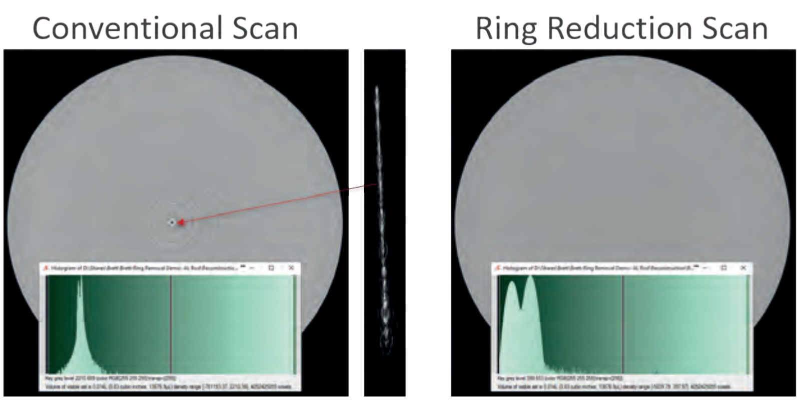
"SUBPIX ENABLES THE ENGINEER TO SCAN THE SAME REGION OF INTEREST WHILE ACHIEVING BETTER RESOLUTION

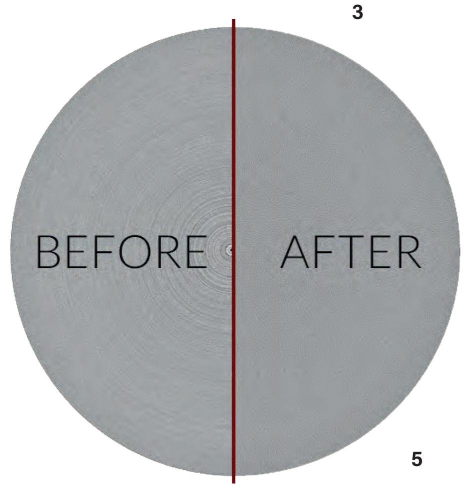




2 // The lower image is a duplex wire gauge used for obtaining spatial resolution data. The red line shows the width of the scans. Top image (l) uses standard DR software. The subpiX software (r) shows a clear distinction between the wire pairs

3 // A scanned image of an electronic device. Left side used standard DR software. Right side is the same device scanned using subpiX software





4 // A ring artifact is shown by the red arrow in the conventional scan (l). Ring Artifact Reduction (R) shows removal of the anomaly

5 // A side-by-side comparison of scans shows removal of the artifact in the center after ring reduction

With the advent of subpiX technology, additional innovations have been developed using similar hardware and software technologies. An important recent development refers to ring artifact reduction. This allows the system operator to considerably reduce a common artifact that can obscure the proper interpretation of scanned aerospace components. This artifact is due to the center axis of the part rotation during the CT scan, or it can be caused by over- or under-performing pixels on the digital detector array. This type of artifact is most prevalent when there is a lower signal-to-noise ratio in the image. The hardware and software solution leads to higher quality images and increased identification of potential discontinuities within the part.

In addition to reducing the artifact within the image and providing a higher quality image, using ring artifact reduction technology enables the operator to reduce acquisition time during the gain and offset steps of a CT scan.

Gains and offsets are used to calibrate the detector to a uniform background level and eliminate pixel brightness variations at different x-ray intensity settings. Reducing time invested in the gains and offsets and relying on the ring artifact reduction technology leads to a decrease in the overall time required to run that scan, which then increases the throughput of the CT system on the manufacturing floor. The ring artifact reduction software shifts the detector in the X-axis and Y-axis as the scan is acquired to eliminate the fixed detector noise.

Ring artifact reduction technology will also allow the CT operator to fix or mount the part for inspection closer to the x-ray source without having to worry about where the ring artifact will appear within the scan.

By using these new types of technology, the aerospace engineers, quality professionals and CT operators can increase resolution, increase field-of-view size, and increase throughput from a computed tomography scanning machine. This will allow for an increased number of parts to be inspected, as compared to using past methods that may need to alter the sample or may remove the ability to find the problem within a part.

The X3000 system has just been released by North Star Imaging (NSI) in response to customers needing a compact system with unique capabilities generally available on a larger X-ray or CT system.

NSI's applications specialists can help select the best X-ray source and detector for the customer's needs. The system is 263cm (8.6ft) wide x 132cm (4.3ft) deep x 201cm (6.6ft) tall and has a maximum energy of 240kV with a geometric image magnification of up to >3000 times. From thick aluminum castings to gold bond wires, the X3000 will meet your needs. \\

Kevin Bresnahan is western US business development manager with North Star Imaging


When failure is not an option...
CT scan of a
turbine blade
our technology helps eliminate the possibility
We build World Class Industrial Digital X-ray and
3D Computed Tomography Systems so you can
develop the world's best products.
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NSI
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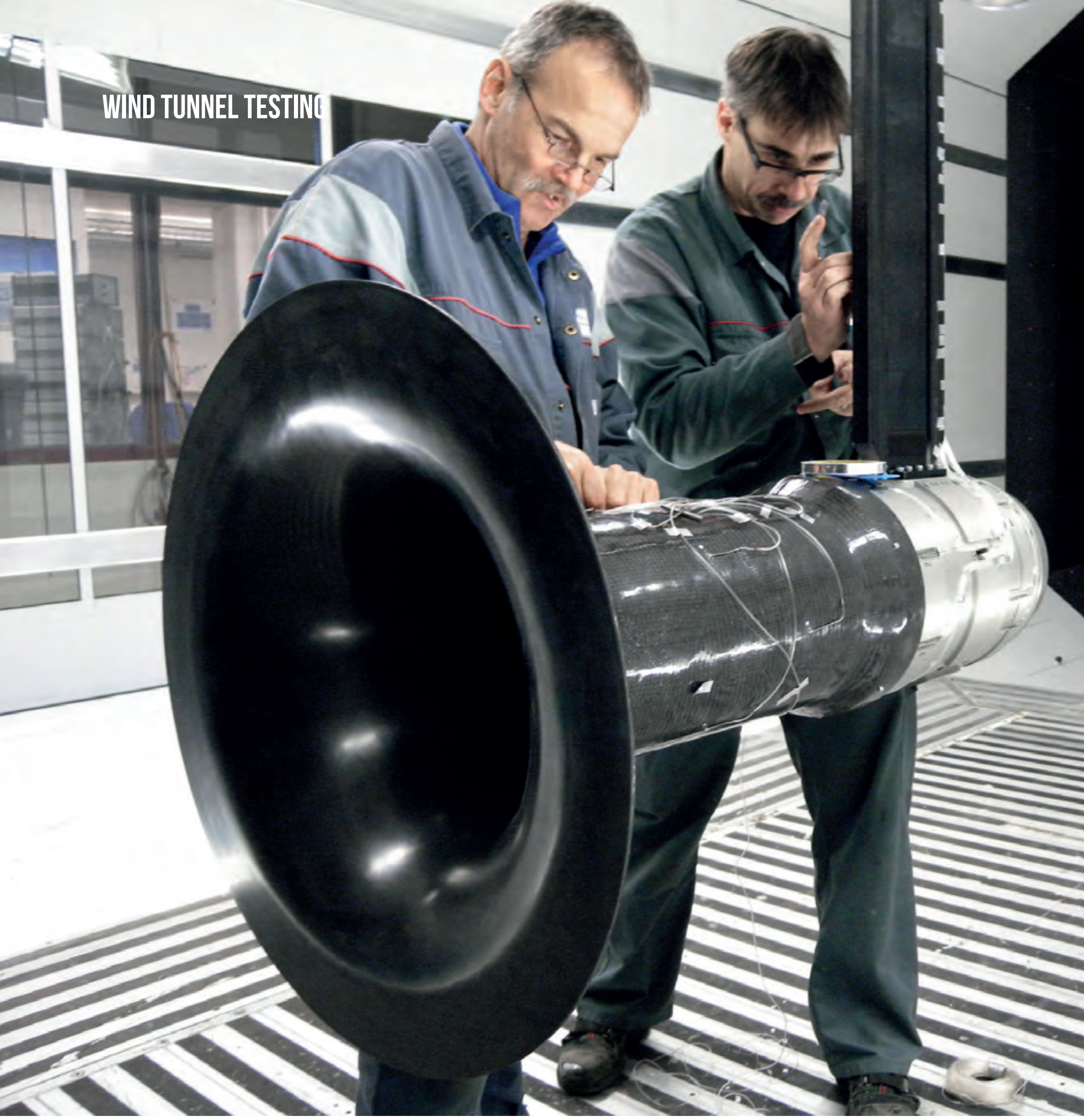
4nsi.com/ati | +1 (866) 754-4902 | sales@4nsi.com



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TURBOFAN-POWERED MODEL IN LWTE

In the Green Regional Aircraft platform of the European aeronautical research program Clean Sky, technologies are investigated to reduce the ecological footprint of future aircraft

// **ANDREAS HAUSER**

For EU research into cleaner technological options, two specific aircraft configurations have been studied in more detail – one powered by modern turbofan engines, the other by more conventional turboprops. A consortium led by IBK was awarded the task to build and test corresponding wind tunnel models in the RUAG Large Subsonic Wind Tunnel Emmen (LWTE): the Experimental Subsonic Investigation of a Complete Aircraft Propulsion system Installation and Architecture powerplant optimization (ESICAPIA) project dealt with the turbofan powered aircraft model and Low Subsonic Investigation of a large complete Turboprop Aircraft (LOSITA) with the turboprop. RUAG, as a member of the consortium, was responsible to provide the power simulation system for both models and to perform the wind tunnel tests. While the simulation of propellers has been standard in RUAG's wind tunnel for many years, a turbofan presented some new challenges.

The development of the RUAG Turbo Fan Simulator (TFS) was started by building a first proof of concept unit, based on the hardware available from the counter-rotating open fan tests performed in 2010. As a consequence, this first demonstrator featured a counter-rotating ducted fan. The geometry of the nacelle and the core were not representative of a real engine, nor was the demonstrator suitable for use in a wind tunnel application. The primary goal was to validate the design process for the fan and to confirm performance prediction.

In the meantime, specifications for the ESICAPIA model were finalized and the development of a TFS unit for wind tunnel

1 // Mass flow calibration of the turbofan engine

2 // The 'mini' turbo fan simulator was built with a fan diameter of 170mm

3 // The original TFS – 250mm (9.8in) – was designed for large-scale models

4

4 // Green Regional Aircraft model equipped with turbofan engines developed and manufactured by the ESICAPIA consortium

(Image: IBK, RUAG, University of Bristol, EUROTECH)

testing applications could be initiated. It quickly became clear that the mass flow requirements could be achieved using a single-stage fan, which was a tremendous benefit in terms of complexity. In order to reduce the risks, it was decided to power the TFS with one of the two motors used for the counter-rotating open fan. The reduction in length allowed a design of the TFS that would fit into a nacelle with no geometrical deviation from the original.

In propeller-powered aircraft, the thrust-drag bookkeeping methodology is rather straightforward. Direct thrust is measured by a rotary shaft balance in the hub of the propeller. For a TFS unit, an a priori calibration must be used to relate the thrust to internally measured parameters such as mass flow, temperatures and fan pressure ratio. An isolated setup was designed to obtain the corresponding data. The TFS unit is attached to a balance and installed in the wind tunnel. A non-metric fairing shields the balance, the strut and the TFS. Only the thrust directly generated by the TFS is measured in this setup.

The first TFS unit was tested in the wind tunnel during the summer of 2015. Initial performance did not match the expectations. The problem was traced to an error in the design of the stator. After a redesign, the expected mass flow of 4kg/s (8.8 lb/s), enough to cover the requirements of ESICAPIA, could be achieved. The remaining two TFS units were also calibrated and put into storage, awaiting their use on the model.

Wind tunnel tests of the ESICAPIA model were performed in the last quarter of 2016. The TFS unit was integrated into the scaled nacelles and installed on the model. In an extensive test campaign, an aerodynamic database of the airplane, including power effects, was generated. The TFS units performed flawlessly for the full duration of the test.

The TFS developed for the ESICAPIA model, with a diameter of 250mm (9.8in), are too large for most of the models that are normally tested in RUAG's large wind tunnel. Therefore, the next logical step was to reduce the size. Again, the enabler for the 'mini-TFS' was a new generation of hydraulic motors of yet smaller dimension and higher power. The proof of concept unit with a fan diameter of 170mm (6.7in) is a completely new design that promises to deliver 3kg/s (6.6 lb/s) and is being readied for the first tests. \\

EU HORIZON 2020

ESICAPIA/LOSITA have received funding from the European Union's Horizon 2020 research and innovation program under grant agreements CS-GA-2013-01-LOSITA-620108, CS-GA-2012-02-ESICAPIA-325954

Andreas Hauser is department manager for aerodynamics at RUAG

1

ADVANCES IN HIGH-SPEED IMAGING

Aerospace testing applications often need high-speed image recording in challenging situations – recent technological advances have made choices easier

// DOREEN CLARK

Comprehensively testing designs in aerospace can be complex and difficult. High-speed imaging lends a helping hand to understanding the dynamics of designs by providing valuable information that may be otherwise difficult or impossible to gather. However, high-speed imaging has its own inherent issues: it can require incredible amounts of light; it can generate large amounts of data; and it can incorporate trade-offs in camera size or features, for example, to achieve core frame rate and image-quality capabilities.

Vision Research, designer and manufacturer of Phantom cameras, has introduced cameras and features to help address issues found in high-speed imaging, making the technology more useful for the demanding testing needs found in aerospace.

EXPOSURE INDEX

Light is a key element in high-speed imaging. The higher the frame rate, the more additional light is required, so a camera's light sensitivity, typically reported as its ISO rating, is important. The sensitivity is a derivative of the sensor design and processing. Besides the native sensitivity, image processing can be applied through software to lighten images. However, this kind of post-processing can be time-consuming, and large adjustments can add noise and lose detail in the image, rendering it less useful. Exposure index, available in almost all Phantom high-speed cameras, helps alleviate that.

Following the same concept found in many DSLR cameras, Phantom cameras have eight preset options to increase the effective ISO of an image while adding minimal noise. The options are based on adjustments of an image's tone curve, rather than adjusting the gain or gamma, and making it possible to use higher apertures and to see details otherwise hidden in the shadows.

10GB ETHERNET

High-speed applications generate a considerable amount of data, and while that data can be critical in testing, the sheer quantity can make it challenging to download from the camera. For this reason the Phantom 'Ultrahigh-Speed' cameras, which have up to 288GB of memory, have 10Gb Ethernet as a standard feature, and as an option in Phantom VEO cameras. 10Gb Ethernet provides up to 500MB/second download speed to an optimized system, considerably reducing download time compared with 1Gb Ethernet.

1 // The Phantom Flex 4K-GS can record up to 1,000fps at full 4K resolution and an optional in-camera ProRes 422 HQ codec cuts storage requirements by half

2 // Sample images show the exposure index range of the v2512 at 99,000 fps. The lowest exposure index (l) is 8,000 and the highest (r) is 40,000.

PROGRAMMABLE I/O

Some testing applications require flexibility in managing signals to capture critical details. To address this, Vision Research introduced a powerful new feature called Programmable I/O with the Phantom VEO family. This concept goes beyond the standard selectable AUX ports found on cameras and other test equipment. The Programmable I/O internal pulse processor, in addition to assigning different signals, enables users to modify the actual signal characteristics to interface with external devices, something not possible before. In most cases, parameters such as signal polarity, filter time, signal delay, and pulse width

2

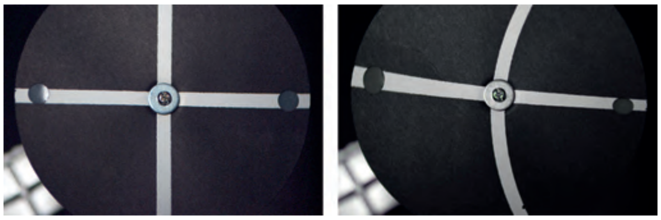
3 // The Flex 4's global shutter image (left) shows quickly moving and rotating events without producing classic rolling shutter image (right) with distortion artifacts

can be adjusted. Setting these characteristics is referred to as pulse processor control.

FLEX 4K-GS

Often, the observation of fine details from a distance requires higher pixel resolution than typically found on high-speed cameras. In response to this need, the Phantom Flex4K-GS camera has been developed. This modification of the well-known and highly acclaimed 4K resolution media camera means that research and development now has access to image quality not previously available. The key component is the switch from a rolling shutter (low noise, improved visual quality for cinema) to a global shutter. Global shutters enables viewing quickly moving and rotating events without producing classic rolling shutter image artifacts (e.g. the bending of helicopter rotor blades). Like the media camera, the Flex4K-GS will deliver 1,000fps at 4K resolution (4096x2160), 1,900fps at 2K resolution (2048x1152), and 2,930fps at 1280x720.

3



MIRO N-SERIES

The aerospace industry is heavily influenced by structural size requirements for a variety of projects. For these applications the tiny Phantom N-Series is the best option for recording hard-to-access events. At just over a 1in cube (32 x 32 x 29mm) this camera can fit in the smallest spaces and still deliver quality images to researchers. At full resolution (768x600), this tiny, but powerful device can deliver 560fps and can reach over 9,000fps at lower resolutions. Another benefit of the N-Series setup is that the camera head is attached to a base at the end of the connection cable.

Using CoaXPress (CXP) protocol ensures that every image is safely stored away from the camera head via the connection cable. This becomes extremely important in potentially destructive environments.

The separate base means that all the required data and images are safe if the head is destroyed. The camera head is easily replaceable in the field and does not require lengthy downtime. \\

Doreen Clark is a senior product manager with Vision Research

1 // The AstroNova Daxus is a small yet powerful data acquisition device which can be used as a standalone unit or stacked for high channel count jobs

A MODEL OF EFFICIENCY

A distributed data acquisition system efficiently enables engineers to acquire large amounts of data from physical measurements at the source while monitoring and analyzing the data over a network or via cloud services

// **DAVID KORTICK**

The need to record data from many sensors in different areas and at high sample rates presents many challenges for today's aerospace test engineers. The number of channels and types of signals used for physical measurements are increasing and data acquisition systems must be capable of processing this large amount of data efficiently. A distributed, networked data acquisition system with local processing and storage provides the flexibility required to meet these acquisition challenges.

LOCAL SIGNAL PROCESSING AND STORAGE

The latest distributed data acquisition systems, such as the Daxus family from AstroNova, provide modular signal conditioning for a wide variety of measurements including temperature, pressure, strain, voltage, current, counters, timing and control signals. More importantly, this conditioning must be local to the sensors to avoid long cable lengths that can result in a cumbersome test setup and introduce measurement errors. The signal conditioning must also provide sufficient channel-to-channel and channel-to-chassis isolation to avoid measurement pitfalls such as ground loops and channel crosstalk.

One of the most effective ways to reduce the burden on the network is for the data acquisition system to handle the majority of the data processing. This avoids having to send high-bandwidth sample-by-sample data streams back to a centralized processor. Digital signal processing (DSP) is one of the tools that allows the Daxus and similar systems to efficiently process large amounts of data and present a network-friendly waveform representation that does not consume high bandwidth. For example, a user may require a low-pass filter with a Butterworth topology and a cutoff frequency of 34Hz. DSP capabilities including filtering (low-pass, high-pass, band-pass and band-stop), root mean square (RMS) conversion, integration, differentiation and other functions are available. With a DSP implementation at the data source, the user can easily configure this specific filter so that the raw data is processed before sending it over the network.

Data processing can also include counter functions and derived channels. As with DSP functions, these algorithms are handled by the data acquisition system itself on the raw data, so only the resulting calculations and waveforms are recorded or sent over the network. Typical counter functions that are often used in aerospace testing are frequency, duty cycle, event counter, pulse width, period, edge separation and quadrature. Derived channel functions use specific inputs and perform inter-channel math processing to create new channels for specific purposes, such as power calculations.

With a local storage medium, such as the dedicated hard drive or solid-state drive on the Daxus system, there is no concern for the level of network traffic that would impede a high rate of data collection. Writing of the data to the drive is a direct process and is not affected by network latencies. Moreover, the efficiency of this process allows the user to review older data at the same time newer data is being collected.

SYNCHRONIZATION

A crucial aspect of using a distributed data acquisition system such as the Daxus is the ability to synchronize acquired data. Within the units themselves, this is typically accomplished by using individual analog to digital converters (ADC) that share a common clock for sampling the waveforms. This is a well-known method that provides precise timing and is only affected by the accuracy of the clock and the specifications of the ADC selected. This method also works well for multiple systems close together, when a sample clock can be shared. The benefit of this type of synchronization is actual sample-by-sample synchronization.

A more difficult process is to synchronize data from multiple systems that are in different places, as is the case with the distributed model. System clocks can vary greatly, and with multiple systems there can be a tolerance stack where the worst-case error of each unit has to be taken into account to determine an overall synchronization accuracy for the entire system. Fortunately there are methods of using external time codes and protocols that mitigate the error associated with using multiple systems.

One of the most popular methods is to use timing formats such as the Inter-Range Instrumentation Group (IRIG) time code. This uses a time code structure that is recorded along with the other sampled data. By recording the same time code among different data acquisition units, the time of any given sample can be determined down to the accuracy of the selected time code. The drawback to this type of synchronization is that a typical IRIG B signal is amplitude modulated and distributed over coaxial cable, meaning that cables from the time source have to be run to every data acquisition unit.

Another synchronization technique is to use GPS signals. Similar to IRIG, the time is recorded along with the data and can be determined down to a single sample point. GPS timing is a good solution for outdoor applications or where a GPS antenna can lock onto the signals from the various GPS satellites. A major benefit of this type of synchronization is that you have not only timing information but also location information, which can be just as important for some types of testing.

For a distributed data acquisition that uses Ethernet networking, the network time protocol (NTP) is another useful method or synchronizing time between systems. NTP is a standardized network protocol used for clock synchronization. It uses is a client-server model where the clients (the data acquisition systems) communicate with an NTP server to obtain the precise time. The accuracy is typically 1-10ms, but can be greater due to network latencies. Another implementation is to configure a distributed system as an NTP server with all other units as clients. This can increase the synchronization accuracy in smaller networks that have less traffic.

MONITORING, REVIEW, ANALYSIS

Transferring acquired data over the network can be accomplished in real time and/or post-acquisition. Real-time monitoring is well suited for longer-term testing where the data and test results must be monitored. Data can be streamed point-to-point or as arrays. Another technique is to use a minimum/maximum algorithm to represent the waveform. This is much better suited to higher speed signals where the engineer needs to monitor for any transients or spikes on a waveform, or wants to see the envelope of a signal. This method has the benefit of preserving the amplitude of the signal regardless of the data transfer rate over the network.

A main benefit of having data recording at the source unit is that if the network or cloud becomes unavailable, the data acquisition system continues to record. For post-acquisition transfer, the software should provide an intuitive graphical user interface and advanced visualization methods that allow the engineer to easily select all or any portion of the recorded information to be transferred. Applications such as verification and validation testing, for example, usually require the entire test data file to be archived. Other applications such as research testing or trouble-shooting problems, where only a portion of data around an area of interest may be required, are also served well by this method.

Measurement of parameters and signal analysis can also occur both in real time and post-acquisition. A simple measurement may take the form of a set of horizontal or vertical cursors to determine amplitude variations, time intervals, minimum and maximum values, or an average value from the entire test. Different types of analysis can easily be employed, such as fast Fourier transforms, RMS conversion, post-capture filtering or additional derived channel equations.

"A CRUCIAL ASPECT OF USING A DISTRIBUTED DATA ACQUISITION SYSTEM SUCH AS THE DAXUS IS THE ABILITY TO SYNCHRONIZE ACQUIRED DATA"

CONCLUSION

Having local data acquisition at the source while being able to monitor, review and analyze from anywhere is a must for today's aerospace test environments. A good example of a distributed data acquisition application is a test cell where the unit under test may be in a closed chamber. The data acquisition unit is connected to the various sensors and signals on the test article and also to the test cell network via Ethernet or wireless. Real-time test data can be monitored, reviewed and analyzed by local personnel as well as transferred via network or cloud services to off-site engineers. Local storage provides enough capacity for the full test cycle. The system takes the data transfer burden off the network, providing only the data necessary to make decisions as the test progresses. Multiple test cells can also be monitored simultaneously due to the distributed nature of the system.

AstroNova's Daxus family of distributed data acquisition systems provides everything needed to condition, sample, process, store and transfer data efficiently through a network or cloud services. \\

David Kortick is product development manager with AstroNova

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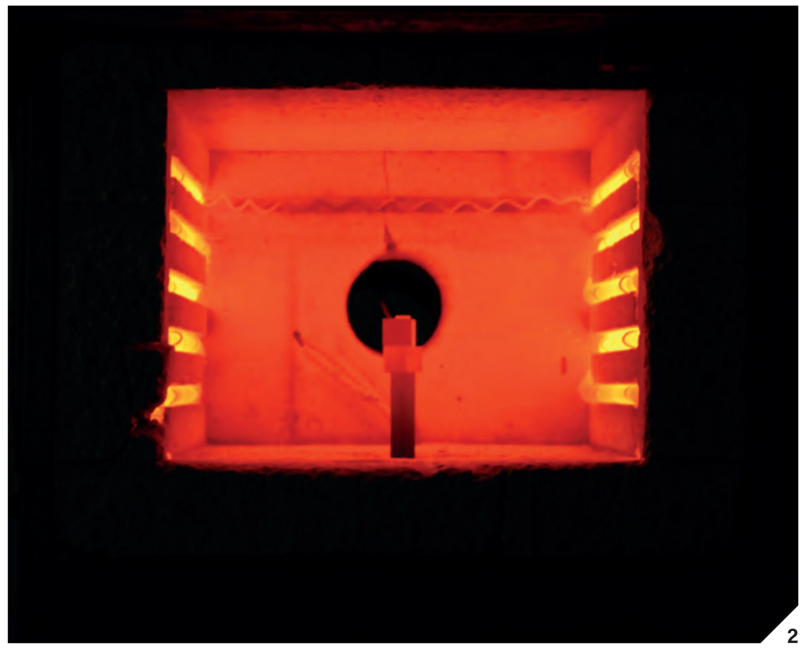

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SENSORS FOR ULTRA-HIGH TEMPERATURES

In a design breakthrough, a patented technology has created an accelerometer that operates at high temperatures and offers a long working life

// PABLO FERREIRO

High-temperature aerospace accelerometers work in harsh conditions, and users expect high performance and long-term durability from their sensors in such environments. Material selection is a critical, yet difficult, area involved in the design and manufacturing of high-temperature accelerometers. These design constraints led to the research and development of patented technology that culminated in Dytran Instrument's Model 3335C accelerometer. The 3335C combines all known advances in high-temperature sensor technology in a small, powerful, hermetically sealed sensor that operates at up to 1,200°F (649°C) through the use of Silver Window technology.

MATERIAL CHOICES

There is a common denominator when reviewing the typical available piezoelectric crystal and ceramic materials available for high-temperature sensor design – the loss of oxygen at elevated temperatures. Oxygen depletion occurs during the operation of piezoceramic sensors at these high temperatures, which lowers insulation resistance. The solution to this design issue is to allow oxygen back into the piezoelectric crystals. However, given the current restraints of the sensor housing environment, this solution is not feasible. The metal sensor housing chemically traps oxygen released from the crystals, forming a metal oxide and permanently making the piezoelectric crystals operate with lower insulation resistance, even at lower temperatures.

Some manufacturers pre-oxidize all their metal parts to avoid oxygen getting to the internal surfaces; others open vents into the sensor to allow environmental oxygen into the piezoelectric crystals. But these openings or vents also allow in corrosive gases or other contaminants from a harsh environment into the sensor's housing.

Other techniques are more elaborate, with porous metals to allow gas interchange or chemicals – such as manganese dioxide (MnO_2) – that release oxygen at high temperatures, but demonstrate similar shortcomings. The porous metals can allow corrosive gas ingress, and use of MnO_2 is also problematic as the internal oxygen supply will eventually run out as it is consumed by the crystals or the internal metal parts.

SILVER WINDOW TECHNOLOGY

Dytran Instruments developed a technology to overcome and address the factor of oxygen depletion that affects all piezoelectric materials. The technique solves all the material selection shortcomings as it produces a constant supply of oxygen to the interior of the sensor housing that it is activated only when operating at high temperatures. The technology incorporates a patented metallic Silver Window that allows diffusion of oxygen from the exterior of the housing and forms an integral part of the metal housing of the sensor. Additionally, silver metal operates perfectly in high-temperature environments, as the silver deoxidizes with high-temperature exposure. A sensor made with the Silver Window technology is still hermetically sealed, as the silver metal allows diffusion only through the metal matrix and the sealing of the sensor is hermetic in nature.

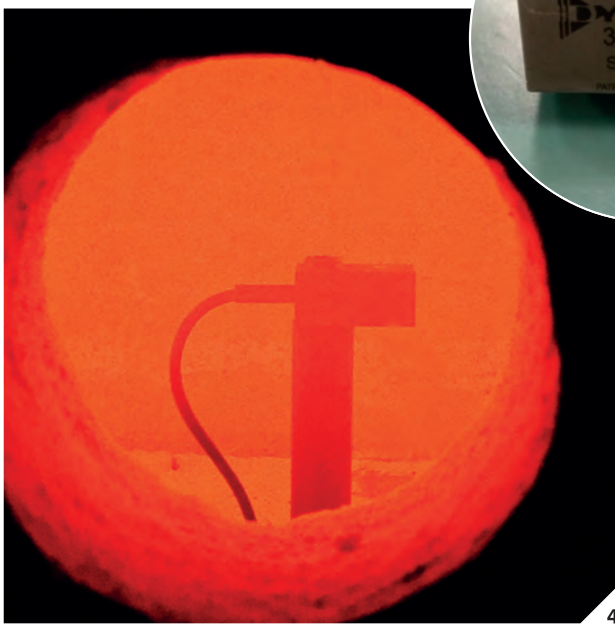
Another substantial advantage of Dytran's patented technology is the feasibility of making the design small enough for any high-temperature, hermetically sealed sensor. All sensors fabricated with the Silver Window could be made with the smallest dimensions achievable, because the increase of oxygen availability to the piezoelectric crystals allows for designs with smaller crystals.

1 // Model 3335C top view. The Silver Window is at the left, the connector (right side) is 10-32 UNC, terminated and isolated from the cable sheath

2 // Model 3335C testing at 1,400°F (760°C)

3 // Model 3335C front view. The Silver Window is located at the top

4 // Dytran model 3316M3 during high-temperature testing at 1,000°F (538°C)



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Sensor assemblies are more robust and better able to resist thermal shocks, a common failure of competitors' sensors. Furthermore, sensors using the Silver Window have better low-frequency behavior, as the insulation resistance is higher than with comparable sensors. There is only one manufacturer in the world using Silver Window technology, as it is patented by Dytran Instruments. Dytran's model 3335C, an ultra-high-temperature charge mode accelerometer, has the highest frequency response of any accelerometer on the market and can survive temperature excursions beyond 1,200°F (649°C) and is tremendously robust against thermal shocks.

Dytran Instruments is vertically integrated and manufactures instruments from the machined parts up to the complete sensor, isolating bases and hardline cables. Accelerometers and instruments operating at temperatures over 700°F (371°C) and up to 1,200°F (649°C), use Silver Window technology. The sensors have isolating bases to avoid signal ground loops and robust hardline cable interconnects to survive the harsh environments encountered, enabling them to transmit a reliable signal to the data acquisition unit. The main testing applications for the high-performance sensor are gas and steam turbines for power generation and aircraft, nuclear power plants, exhaust and catalytic converter studies, rocket engines, and any ultra-high-temperature vibration testing environment. \\

Pablo Ferreiro is a research and development engineer with Dytran Instruments

ELECTRONIC WARFARE TESTING FOR OPERATIONAL SUPERIORITY

Testing modern electronic warfare systems requires an open range to exercise a wide array of possibilities for relevant and realistic test, training and exercise scenarios

// JONAS LINDE

2

Electronic warfare (EW) has played an increasingly important role in military flight since World War II, with its early jamming of basic radars and navigational aids, right up to today's complex self-protection and disruption systems.

The importance of EW on today's battlefield has recently been underlined by the very efficient use of various electronic warfare techniques by the Russians in the Ukraine and Crimea conflicts. The geopolitical situation has also passed a crossroads and more nations are now refocusing their defense policies toward homeland defense and are gearing up to be able to (once more) face a symmetric battlefield of the future.

This means that capabilities such as air interdiction (AI) into highly congested airspace with advanced, hostile and uncooperative EW threats are now being (re-)developed. However, since the end of the cold war era, many nations have allowed their capability to fight an intense conflict against a technologically advanced adversary to decline.

REBUILDING CAPABILITY

Sweden and many other nations are trying to sharpen their EW capabilities. This has led to new tactics being developed, new equipment being bought and fielded, and to growth in the number of exercises with an electronic warfare focus, to increase the readiness of front-line units.

1 // Gripen fighter jet deploying flares

2 // Live GBU at Vidsel Test Range

3 // Vidsel Test Range

4 // Chaff being dropped from a Lancaster bomber

From the perspective of the Swedish Defence Materiel Administration Test & Evaluation Directorate (FMV T&E), the changes in defense policies and the emerging increase in defense spending in Sweden and Europe influence the agency in several ways. Some notable areas are an increased demand for EW competence at FMV Flight Test Centre (FMV FTC), and also an expanded interest in performing EW focused test and exercises at the FMV T&E operated Vidsel Test Range (VTR). The development in demand is driven both by the defense industry and military organizations' need to perform complex EW trials and live exercises.

FMV FTC and VTR have been active in the EW-domain for many years. FMV FTC has gained a lot of expertise in the field from the T&E of the various Swedish fighter projects as well as from a number of helicopter, transport and special mission aircraft. VTR offers a wide array of possibilities when it comes to test, training and exercises and, most importantly, allows industry projects as well as military units to go live on their electronic warfare systems. This includes chaff and flares, and communication and navigational jamming of both platforms and weapon systems.

EW DIVISIONS

EW is normally discussed within the community in terms of three areas – electronic attack (EA), electronic protection (EP) and electronic warfare support (ES). Operations in recent conflicts have underlined the importance of mastering all three fields of EW to achieve operational superiority in other warfighting domains. FMV T&E is monitoring and evaluating ongoing development and has the means to translate it into relevant and realistic test, training and exercise scenarios.

The knowledge needed to develop and stage relevant EW test and training scenarios lies with the subject matter experts – the experimental test pilots and flight test engineers at FMV FTC. However, they are supported by an advanced set of infrastructure, including a vast array of EW threat system, radars and stimulators. Best of all, they are able to stage and carry out the scenarios in the real world at VTR, Europe's largest overland test and training range.

LIVE TEST, TRAINING AND EXERCISE

VTR, due to its remote location and vast restricted air and ground space, enables the execution of very complex EW scenarios that can include almost any aspect of modern EW operations. The operations in eastern Ukraine have pointed out three critical items that need to be accounted for and taken care of in setting up an EW scenario to test new equipment or to train forces and develop tactics for symmetric battlefields.

EW operations in Ukraine have seen a greater use of various techniques to jam GSM signals and HF/UHF (terrestrial and aircraft) radio channels, mobile terminals, trunked radios and GPS systems. At VTR, defense industry and military units can test systems and equipment, and train in tactics to continue operations during these harsh electromagnetic conditions.

From a training and exercise point of view, another critical item is to be able to design and deliver training and exercise scenarios that involve a surprise factor. VTR, with its vast ground space and good road infrastructure, facilitates and supports employment of dynamic scenarios where the various threat systems and jammers are relocated during the execution of the scenario.

The third important item that needs to be addressed to achieve an operational EW capability relevant to the future symmetric battlefield is end-to-end testing, training and exercise. This means being able to plan and carry out a scenario that incorporates all three aspects of EW, including delivery of live kinetic effects on representative targets using anti-radiation missiles or other weapon systems while undertaking evasive maneuvers and deploying chaff and flares and other electronic countermeasures. The vast restricted air- and ground space at VTR, as well as its remote location, deliver the physical conditions to host such advanced scenarios. The above mentioned array of EW threat systems, including different fighter, acquisition, tracking and surveillance radars, as well as the airborne jammer and threat system simulator Astor III, gives a plethora of systems that can occupy the scenario.

A DECISIVE OUTCOME

The Russian-backed insurgents in the Donbas region of Ukraine have showed how decisive is employment of advanced EW tactics. During the conflict, command-and-control networks were damaged or destroyed through jamming radio communications, radar systems and muting GPS signals. These operations severely hampered the Ukraine forces. This underpins the importance of EW T&E to secure the functionality and operational readiness of equipment and troops and underlines the paramount importance of realistic training and exercises for military units that are expected to operate during harsh electromagnetic conditions. \\

Jonas Linde is the director of marketing and senior test flight engineer at FMV, Swedish Defence Materiel Administration

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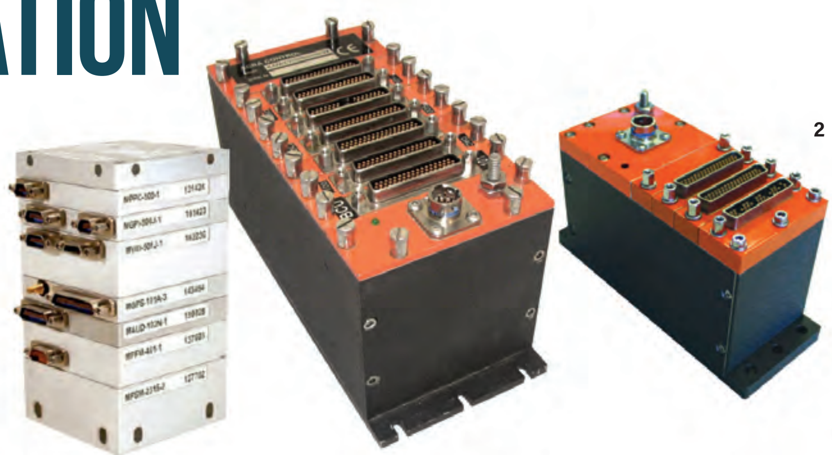
FROM COMPONENTS TO FULL INTEGRATION



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Flight test hardware, sourced as components from multiple suppliers, makes integration challenging and complicates the purchasing and support process. A better way is fully integrated flight test systems from a single source

// **ALBERT BERDUGO AND DAVID BUCKLEY**

In a typical flight test application, the flight test engineer must identify the various components needed to satisfy their test regime's unique requirements, including data acquisition units (DAU), gateways, transceivers, recorders, cameras, managers and switches. These components then have to be sourced, often from multiple suppliers. It is not unusual for flight test component customers to acquire their DAU from one vendor and their recorders and switches from another. The engineer next must face the challenge of integrating these heterogeneous test components. What's more, if a problem emerges during the test phase, the engineer might have to deal with multiple suppliers in order to get the issue resolved.

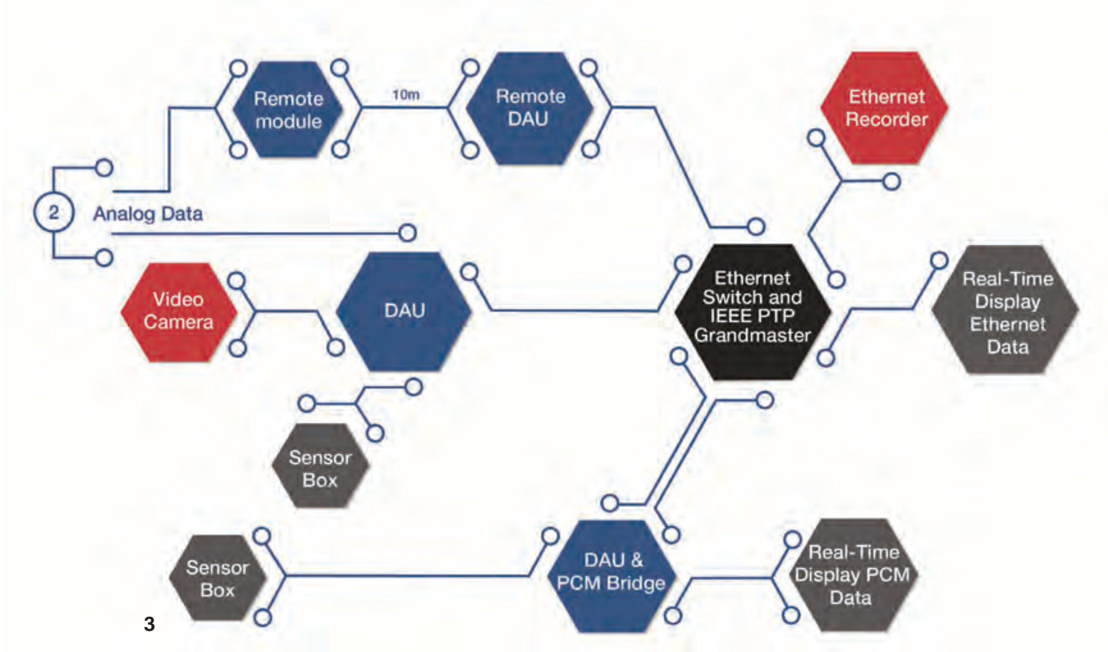
These latter phases of the flight test system design process can all create delays, which are the major source of risk to programs because delays keep the test platform on the ground instead of in the air. A better approach would be for flight test components to be sourced from a single supplier. This would enable a fully integrated system-level flight test solution freeing the customer from integrating various components, all sourced from multiple vendors. Instead, the single-source vendor would take on the full responsibility of providing a completely seamless set of interoperable products. Even better, if a problem arises, the flight test engineer only has to deal with a single point of contact to resolve the issue, instead of multiple suppliers. This should minimize any delays.

Curtiss-Wright, through its recent acquisition of Teletronics Technology Corporation (TTC) and its integration with its data acquisition product line for aviation and space platforms, is striving to make the single-source fully integrated flight test system solution a reality. Curtiss-Wright now supports more aerospace flight test customers, platforms and programs than any other organization around the world. With its increased resources and global reach, the company is able to continually improve quality and expand the availability of its customer support, while bringing even larger system-level solutions to market. The combined product families have all of the component-level products needed to integrate a complete system-level solution: DAUs, gateways, transceivers, recorders, cameras, managers and switches.

1 // Ethernet interfaces allow recorders like the Curtiss-Wright ADSR to more easily be integrated into other architectures

2 // Integrating DAUs from different product lines is simplified with common software support

Some flight test engineers will have a strong preference for which setup software they prefer to use. For example, TTC products use TTCWare setup software, while existing Curtiss-Wright data acquisition products use DAS Studio. Recognizing that very real preferences will exist, Curtiss-Wright is taking selected products and updating their ability to support TTCWare and DAS Studio software. This will enable flight test engineers to select the development environment that they feel most comfortable with, providing them with a fully integrated system solution taking full advantage of the benefits of both product families. Curtiss-Wright's miniature Axon DAU, scheduled for release in 4Q2017, can be can be configured from



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both TTCWare and DAS Studio setup software. A fully integrated flight system solution also simplifies program logistics with a single purchase order.

An example of a single-source end-to-end integrated data acquisition system was demonstrated at various conferences in 2017. The typical flight test system demo had several inputs: video, analog data, accelerometers, pressure sensors, bridge gauges and temperature sensors. It output bulk data to an Ethernet recorder, and output serial PCM data typical of RF telemetry, with data displayed graphically in real time. The demo system seamlessly incorporated many diverse elements including the Acra KAM-500 DAU, the high-performance TTC HDC-330 video camera, the next-generation Axon DAU, and the unique Axonite single module DAU that fits inside a volume of 8in³ (131mm³) and can operate 60ft (18m) away from Axon. It also integrated the Curtiss-Wright NET/SWI/101 switch and the TTC ADSR Ethernet recorder that can record 788GB of data at 150Mbps.

3 // Modern flight test instrumentation systems are getting larger, leading to more integration risks with multiple partners

Evolving flight test solutions from a component-level approach to a system-level approach delivers a value proposition that better addresses customers' problems.

It reduces their risk, and speeds time to deployment by delivering a fully integrated system based on proven, interoperable products.

Bringing together TTC and Curtiss-Wright's product families provides more resources to accelerate the development of advanced technologies. \\

Albert Berdugo and David Buckley are CTO and chief architect respectively in the Aerospace Instrumentation Group of Curtiss-Wright Defense Solutions

1

TESTING: A STEPPING STONE FOR INNOVATION

Successful collaboration in a comprehensive testing program led to the innovative redesign of an aircraft-qualified product

// DAVID SCHIFFMANN

Airlines and aircraft manufacturers are constantly looking for new ways to improve services. Having a great idea for something, designing, manufacturing and finally qualifying it in accordance with international aerospace standards, requires expertise, know-how and skill – as shown by this case study about an innovative product development.

Located close to Van Nuys Airport in Los Angeles, California, Dynamo Aviation (DA) is a leading manufacturer of custom engineered products. It serves aircraft manufacturers, airlines, operators, completion centers and MROs worldwide. Part of the company's mission is to exceed customers' expectations by finding new product solutions. Building on a reputation for design innovation, its engineering incorporates proven technologies that ensure optimal operating performance and product reliability. DA specializes in the design and manufacture, among other items, of galley equipment such as water heaters, for a range of aircraft platforms.

Working to improve one of its clients' water heater assemblies, DA was looking for the right partner to assist in the project. More precisely, it was looking for a partner with the ability to test and qualify an innovative glass immersion heater.

Peter Rabadi, vice president of business development at DA, explains that a passion for aviation is vital for testing and qualification, saying, "The products we manufacture are basically an expression of our values and philosophy. Every new product we introduce to the market has to be tested in a way that guarantees safety and reliability in combination with our innovative design.

"Our partners should not only test and qualify our products; they should be able to understand how an aircraft works, which environmental impacts a given component experiences once it is installed and used in a flight situation and, most importantly, they should be able to provide our engineers with detailed information if a unit fails during testing. They have to be passionate about the work they do."

1 // Dynamo Aviation (DA) glass immersion heater

Internationally renowned for a holistic approach in aerospace testing, from qualification to technical documentation, DAUtec has established a strong reputation in the aviation design and manufacturing community. The company's enthusiasm for aviation gives it a real competitive advantage. Founder and managing director Hans-Jörg Dau says, "Every member of this organization is a specialist with expertise in one of the many professions of the aerospace industry."

Dau also works for the German Federal Bureau of Aircraft Accident Investigation as an accredited investigator. The know-how he obtained in this position is shared throughout the company and provides valuable insights, especially in regard to new product development.

One of DA's customers recommended DAUtec as a partner for this project and initiated a collaboration. This began with an analysis to find the root cause of the failure of a water heater assembly installed on various aircraft. DAUtec analyzed a defective unit and identified corrosion

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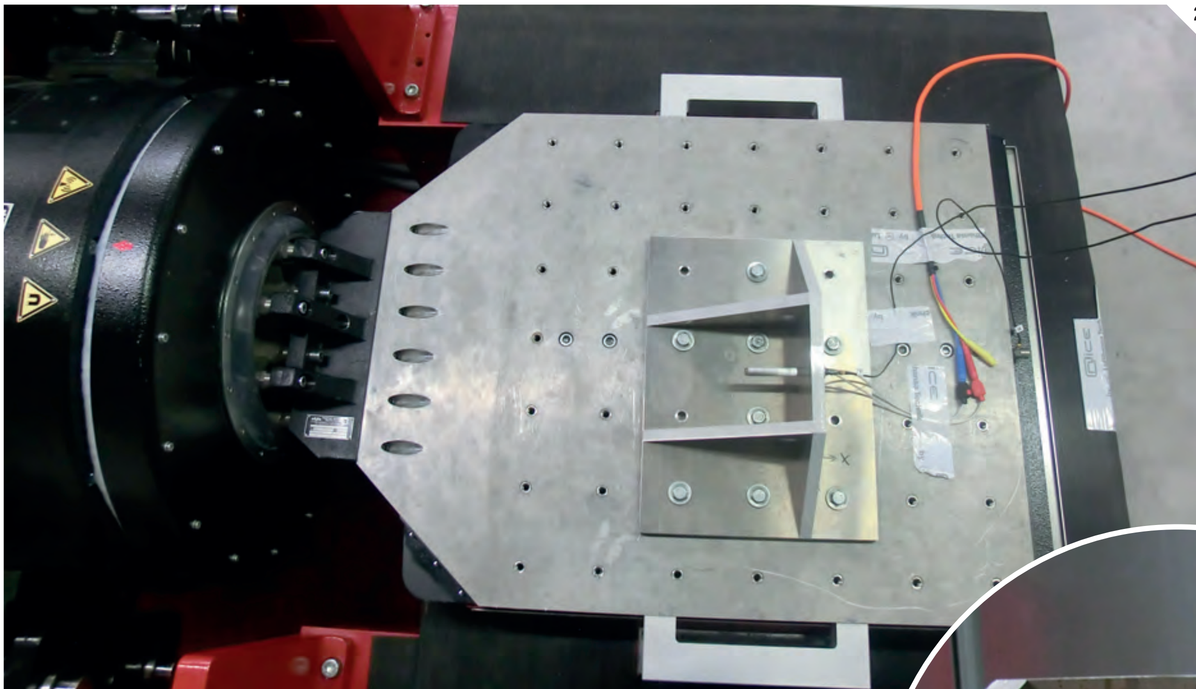

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caused by chlorinated water as the main reason for the breakdown of the immersion heater. Analysis at a more detailed level showed micro cracks on the surface of the metallic heater, through which water penetrated, causing an electrical short.

This information enabled DA to create an improved design by choosing a different material to eliminate the threat of corrosion and ultimately the risk of a short circuit. After manufacturing a functioning prototype, DA returned to DAUtec to perform the testing and qualification.

DAUtec discussed in a Similarity Report what DA would need to do to qualify its heater for use in an aircraft. The technical results showed that the old heater could be replaced by the newly designed heater. The report consisted of a geometrical comparison, an electrical resistance comparison and a performance test. Furthermore, DAUtec advised DA to carry out additional tests to simulate certain inflight situations to get a better impression of how reliably and safely the unit performs under the critical conditions occurring while the aircraft is in operation. Other testing simulated decompression, overpressure, normal surge voltage (AC), inrush current, voltage spikes and vibration. These demonstrated that the material used for the new design would meet safety requirements.

2 // Immersion heater installed on shaker for x-axis vibration

3 // OEM and DA immersion heater prepared for performance testing

4 // DA immersion heater in operation during vibration test (z-axis)

The testing results indicated that using glass for the new heater would be better because it eliminated the voltage potential difference in the unit, which led to galvanic corrosion. DAUtec's services for DA included photos, diagrams and test curves showing the results of the testing. The qualification was validated by an airworthiness qualification engineer who summarized and evaluated all the results in the test report.

This example shows how sound collaboration led to an innovative product with better performance, that also ensures greater reliability and improved safety for passengers flying in the retrofitted aircraft.

The foundation of DAUtec's services is the expertise and experience of its airworthiness qualification and test engineers. A specialized laboratory with state-of-the-art equipment (electromagnetic compatibility, climate and highly accelerated stress screen (HASS)/highly accelerated life test (HALT) chamber, shaker and autoclave) provides the right conditions to perform tests as prescribed in the generally accepted standards for airborne equipment (e.g. RTCA DO-160, MIL-STD-810).

The company's broad portfolio in avionics includes acceptance test procedures, preparation of test reports and other documents such as the Declaration of Design and Performance (DDP). DAUtec also consults with the Luftfahrt-Bundesamt (LBA) for civil and military aircraft systems and equipment and has qualified equipment and components for cabin interiors, galleys, fuel systems, avionic power plants and in-flight entertainment systems. \\

David Schiffmann is engaged in business development with DAUtec

1

GROUND VIBRATION TESTING

'ICP' accelerometers address specific technical needs, are conveniently mounted and handle a range of operating environments

// **MARCO PERES AND RICHARD BONO**

All vibration testing applications have slightly different goals and constraints and thousands of different sensors are available. When choosing an accelerometer, frequency, amplitude (*g* range), resolution, packaging, connectors, mass and the installation environment must be considered. The best technical and economic choices arise from contacting vendors to obtain a knowledgeable, professional recommendation.

In modal analysis applications for aircraft or spacecraft, the operating conditions that must be considered are: low acceleration signal level, low frequency, high channel count, and the need for long cables. When choosing modal accelerometers, the top considerations are: resolution, low frequency, amplitude and phase, small size, specialized or flexible mounting, transducer electronic data sheet (TEDS) and low cost per channel.

Low signal levels and the need for long cable leads make modal applications ideal environments for PCB's ICP accelerometers. Low impedance and constant current operation provide an amplified output that ensures lower signal levels have immunity to environmentally-induced noise. The specified resolution of an accelerometer defines the noise floor of the measurement channel. This best case estimate could later be degraded by high impedance signal issues from long cable errors, such as triboelectric cable motion and insulation resistance associated with charge output (pC/*g*) accelerometers.

Accelerometer mass and sensitivity are proportional (i.e. it takes more seismic mass inside an accelerometer to increase the sensitivity and improve resolution), so a general guideline is to select the best resolution available in a moderately small package. A typical example has 100mV/*g* sensitivity, a fraction of a milli-*g* resolution, and a mass of 5g or less. This minimizes the mass loading effect of the sensor while still giving reasonable resolution and a lower cost per channel.

Channel-to-channel phase matching of modal accelerometers is also important. If they are not in phase with each other, then the pre-test computer-generated global parameter estimation will not match the measured frequency response function (FRF). It is also advisable to instrument all desired measurement points simultaneously which also provides consistency in the mass distribution of sensors on the test structure.

The old method of roving a small set of accelerometers around a structure runs the risk of shifting certain component resonances as they are loaded and unloaded with the variable mass of the roved set of sensors. Inconsistent FRF will result, challenging pre-test parameter estimation models that expect resonances to have consistent, global properties. Measurement takes a snapshot in time of data, ensuring that other variances (for example, visco-elastic properties that can change with temperature) are consistent in the database. An additional benefit of instrumenting all measurement points is the reduction of setup time.

Modal array accelerometers were developed to address not only specific technical needs, but also those such as convenient mounting and large channel cable management. When handling hundreds of sensor channels, an organized, modular cabling system and automated

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1 // Tri-axial ICP modal accelerometer wing mounted with an electrically isolated base

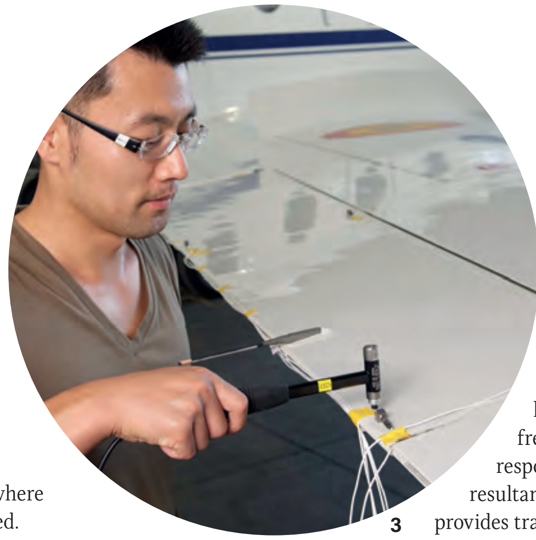
2 // Modal shaker, with through-hole armature, stinger and force sensor mounted under a wing

(Photos: Belgian Defense)

channel management is extremely important. Without a focused effort, time is wasted setting up, troubleshooting and managing the instrumentation process. This could be spent in actual measurement and analysis, where the true value added is created.

The TEDS function exemplifies automated channel management by storing digital data (sensor model number, calibration value, etc) inside the analog accelerometer, making it available for recall during setup.

A simple reverse bias scheme applied to the two-wire ICP signal toggles the sensor into digital mode, establishing communication with a TEDS-enabled signal conditioner or FFT analyzer. This is a time saving when the test article is a high-value asset such as an aircraft or satellite.



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3 // Modally Tuned impulse hammer in use on airplane aileron

(Photo: Belgian Defense)

PCB's Modally Tuned impulse hammers easily deliver impulsive forces of known amplitude and frequency. Combined with response accelerometers, the resultant motion of the test specimen provides transfer characteristics and structural health determination. Impulse hammers are useful on full-scale aerospace structures and components such as turbine blades, electrical components and other subsystems.

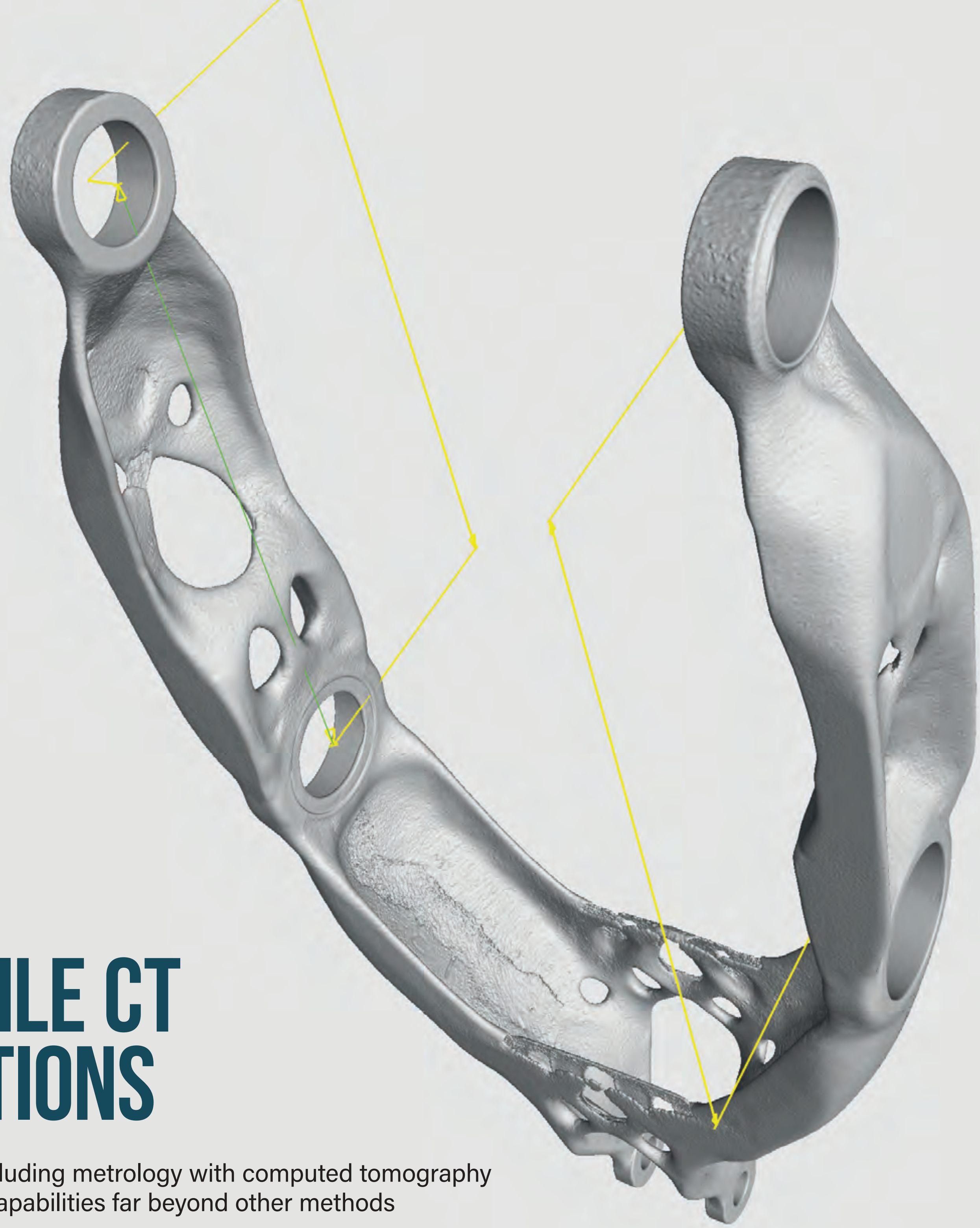
The Modally Tuned impulse hammer design has been refined to eliminate its own resonances that may corrupt the test data.

Hammer selection involves determining the size and mass of the hammer that will provide the force amplitude and frequency content required for proper excitation of the structure under test. Each hammer's calibration frequency indicates the frequency content of the force impulse that is achievable using the supplied tips. An extender mass provides additional tuning by concentrating more energy at lower frequencies.

Hammer test limitations are the single impulse force and frequency content.

Piezoelectric force sensors and impedance heads are well suited for measuring input forces. Impedance heads are single sensors measuring both force and the driving point acceleration response. This is a critical measurement in experimental modal analysis for accurate modal scaling and it is recommended that impedance heads be used in most cases. \\

Marco Peres is application engineer and Richard Bono is co-president at The Modal Shop



VERSATILE CT INSPECTIONS

Quality assurance including metrology with computed tomography provides inspection capabilities far beyond other methods

// PATRICK MÖSER

The aerospace industry places a special emphasis on developing new materials and production methods that can lead to lower weight and cost reductions. Additive manufacturing (AM) is one such process in which component parts are built out of an amorphous initial material based on computer-generated data models. This makes AM particularly useful for meeting requirements for lightweight engineering in the applied fields of aerospace and automotive industries, and in medical technology. AM provides opportunities for weight reduction and consequently to economic efficiency, especially for smaller and medium batch sizes. Dispensing with supplementary machining tools and similar auxiliary aids enables faster lead and throughput times.

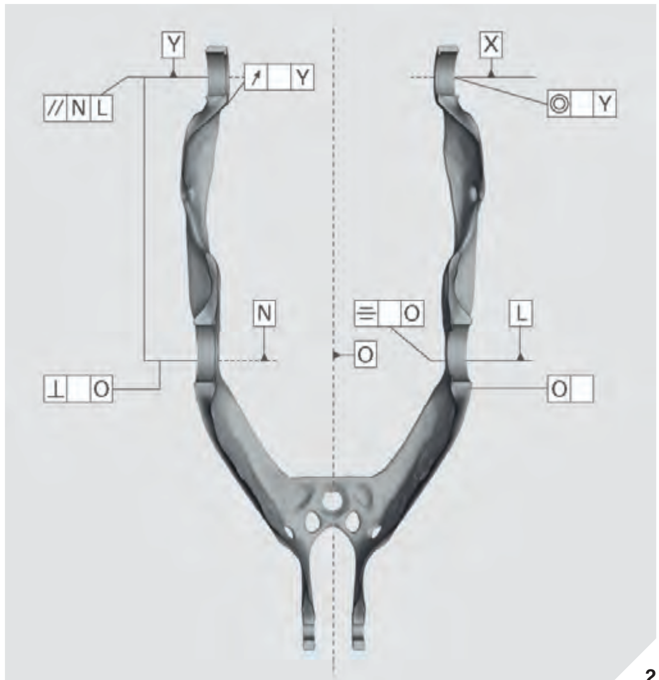
However, the high demands placed on quality in these industries calls for special attention to be paid to inspection technologies and manufacturing process control. Every part bearing a relevance to safety – starting with the raw material straight through to the final product – must be monitored end-to-end while ensuring its flawless accuracy. Conventional testing and inspection methods frequently reach their limits within the framework of additive manufacturing processes.

1 // 3D computed tomography measurements and analyses of volumes for deformation, symmetry, parallelism, axial run-out and perpendicularity. In this case a helicopter bellcrank is shown

(All images: TU Hamburg Institute of Laser and System Technologies and Liebherr Aerospace Lindenberg)

CT CAPABILITIES

Computed tomography (CT) makes it possible to obtain a non-destructive, three-dimensional look into the part to be inspected. CT creates a digital 3D visualization of the work piece's volume, including all inner geometric and structural information necessary to assess the part's quality. All the data material that forms the basis for full-body part testing and inspection is generated with one single scan. Examples here include porosity, surface quality and deformation. Precise pore and wall-thickness analyses along with exact settings of shape and position parameters are possible and the tiniest



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deviations and part defects existing across all interior and exterior surface areas can be captured and localized.

2 // Coordinates and feature relationships, which are measured with computed tomography

HELICOPTER BELLCRANK

A bellcrank to incorporate the rotor blade of a helicopter was produced via additive manufacturing from a titanium-aluminum alloy. The driving factors were a reduction of the part's weight while retaining identical mechanical attributes along with a resulting possible reduction of production costs.

Optimizing the design structures enabled the AM method utilized to achieve a weight reduction of around 30%. Quality control played a mandatory role due to the part's importance to safety. Factors to be considered as particularly crucial to quality were deformations like the parallelism exhibited by the crank arms, yet this equally applied to precision bores and their diameters. The size, location and geometry of remaining gas inclusions made evaluations possible pertaining to the part's fatigue strength, as well as regarding machining process reproducibility.

CT SYSTEM FOR INSPECTION

The high-resolution Yxlon FF35 CT computed tomography system was the ideal solution for this sophisticated inspection task, using a water-cooled 225kV microfocus tube and a high-resolution flat-panel detector. Maximum system stability and optimization of the imaging chain enable the precise surface identification necessary for metrology down to the smallest subregions of the three-dimensional grid.

The volumetric model generated from the high-precision CT scan in the STL data format represents the basis for multiple analyses. In addition to acquiring dimensional characteristics, of the part with CT, evaluating the 3D data provides critical information. This includes overall part porosity, pore volume, size, numbers or the pores' projected area. It can also provide information about the distances from defects to selected reference surfaces. These defects can receive colored markings as to volume or in cross-section, or they can be depicted in isolated form.

As a method of non-destructive testing and inspection for additive manufacturing, computed tomography provides a data density and an information quality that optical or tactile methods are either unable to supply, or only to a limited extent. Among current methods of testing and inspection, the degree of detail from CT is therefore unique.

The benefits of CT for users range from the pure Okay/Not Okay assessment of single items all the way to integrated solutions in production environments for controlling upstream and downstream manufacturing processes.

As a result, the possibilities of CT go far beyond evaluating the individual quality, appearance or workmanship of a part. This, in turn, can make an essential contribution on behalf of technologies in Industry 4.0. \\

Patrick Möser is a product marketing analyst at Yxlon International

"EVERY PART BEARING A RELEVANCE TO SAFETY – STARTING WITH THE RAW MATERIAL STRAIGHT THROUGH TO THE FINAL PRODUCT – MUST BE MONITORED END-TO-END"

A MIGHTY WIND

A signal conditioning solution for wind tunnel testing at the TDT

// DOUGLAS FIRTH AND NANCY HOLZNER

The Transonic Dynamics Tunnel (TDT) at NASA Langley in Hampton, Virginia, is a continuous-flow wind tunnel used to study aeroelasticity on fixed and rotary-wing aircraft at transonic speeds. The facility uses air or the higher-density R-134a as its test medium. With a test section 16ft high by 16ft wide (4.8m x 4.8m) by eight feet long (2.4m), the TDT is used extensively for a wide variety of tests, including propulsion systems, free flight, flutter, buffet, aeroacoustics, and tests that involve real-time control, such as flutter suppression. For more than 50 years nearly every US-built launch vehicle, high-performance military aircraft and commercial transport aircraft has been tested in the TDT.

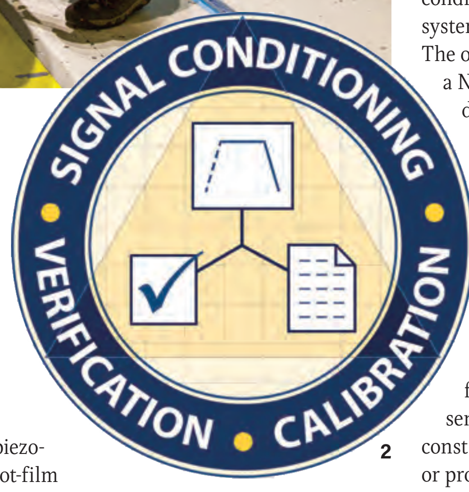
Testing in the TDT requires the acquisition and display of 512 channels of static and dynamic data. This must be simultaneously acquired, stored, analyzed and provided to a real-time control system for model control. A variety of sensors, such as strain gauges, silicon diaphragm pressure sensors, piezo-resistive accelerometers and hot-film anemometers are used to measure model response during test. Actuators are used when model control is desired.

Time correlation of sensor data is often critical to understanding dynamic model response, particularly when the coherence between two sensors must be determined. The measurement system must have outstanding channel-to-channel matching properties, even at different programmed gain settings, to avoid introducing artifacts during coherence analysis. The measurement system transfer function must be adaptable to a transient or steady-state test requirement.

With a system of 512 sensors, automated techniques are required to verify measurement system performance prior to each test, including sensors and cables when practical. With relatively long test durations, the continuous monitoring and display of sensor excitation and sensor resistance during the test are highly desired as a way to verify sensor health. Fully automated, traceable annual calibration of the system is also required.

To compare signal conditioning vendors, NASA purchased small evaluation systems and put the hardware through a series of rigorous qualification tests. They included DC and AC gain accuracy, DC excitation accuracy, DC stability, broadband and spectral noise, wideband and filtered frequency response, transient response, passband flatness, and amplitude and phase match.

NASA chose the 28000 Signal Conditioning System from Precision Filters Inc. (PFI) to provide the analog signal conditioning for the 512 sensors installed on the test model. The system requirements are supported by the PFI 28124 quad-channel transducer conditioner card, and the 512-channel system is housed in just 84in of rack space. The outputs of the 28124 card are routed to a National Instruments PXI analog-to-digital converter system. Cabling to the sensors and the A/D system is done via the rear of the 28000 chassis. Signal conditioning cards can be inserted and removed from the chassis without disconnecting the input/output cables.



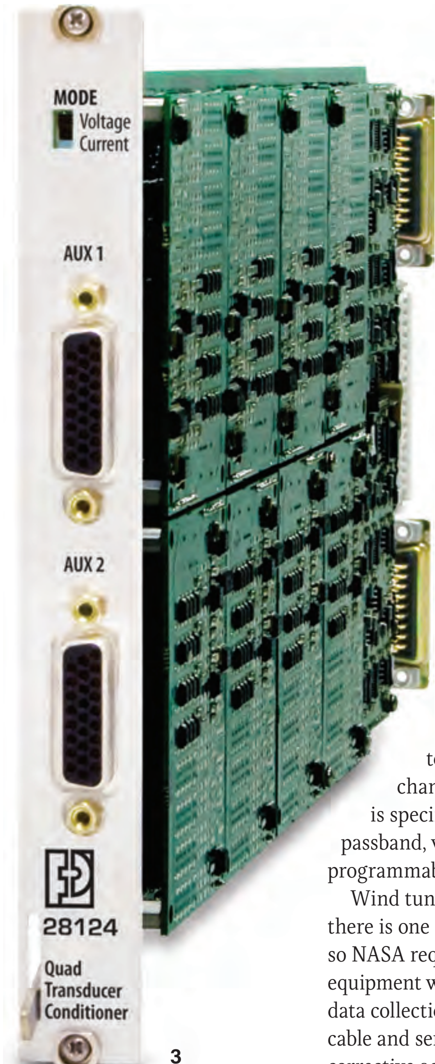
The 28124 card provides a high-performance, high-density, fully programmable, universal solution for conditioning the wide array of sensors that NASA uses. It provides constant voltage for bridge-type sensors or proprietary 2-wire/4-wire (Kelvin connection) constant current excitation for variable resistance sensors, such as dynamic strain gauges or RTDs.

Three independently buffered outputs per channel are supplied. One is routed to the PXI A/D system, another is used by engineers to perform real-time analysis and model control, and a third is for the customer-supplied data acquisition system and for critical tunnel parameter and channel data. Each output supports ground sensing for driving grounded single-ended loads without introducing ground loops and may be independently programmed for filtered or wideband operation.

PFI's flat/pulse filter technology lets the user set the signal conditioner's frequency response characteristic under program control. For transient tests or those where time-domain wave shape preservation is important, the pulse mode characteristic is

1 // Setting up a test of the Space Launch System rocket in the Transonic Dynamics Tunnel

2 // Reliable data acquisition relies on three principles: conditioning of the signal, equipment that can autocalibrate and verification of the system before testing



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3 // A Precision Filters 28124 Signal Conditioning system card

used. Pulse mode provides linear phase response, which is required for time-domain wave shape reproduction and for outstanding transient response with low overshoot and ringing. For frequency-domain analysis, selecting the flat filter characteristic results in excellent transfer function flatness and a sharp, selective filter response. The 28124 conditioner card features outstanding channel-to-channel amplitude and phase matching characteristics – even when the amplifier is programmed to different gains on different channels. Matching of 0.1dB and 1° is specified throughout the filter's passband, with cut-off frequencies programmable from 1Hz to 100kHz.

Wind tunnel testing is expensive. Often there is one chance only to collect the data, so NASA requires high-performance equipment with features that ensure valid data collection. Quick, easy visibility of cable and sensor health enables timely corrective actions that can save crucial data. Built-in test hardware and software allow the user to run a series of automated sensor and cable health checks. PFI's proprietary dynamic shunt calibration techniques verify sensor resistance and roll-off effects due to cable capacitance.

All test and measurement systems require periodic calibration. Typically this means that test systems are dismantled and cards removed and shipped either to an in-house calibration lab or back to the manufacturer, which can cost 30 days of downtime. Because NASA's test schedule doesn't tolerate a month per year of downtime for equipment calibration, it requires automated *in situ* calibration. PFI meets the challenge, with built-in test hardware and software that enable performance of NIST-traceable calibration tests on-site – without removing the system from the equipment rack.

Wind tunnel testing at the TDT is complex and variable. Precision Filters' 28000 Signal Conditioning System has the accuracy, flexibility and reliability to meet all demands. \\

Douglas Firth is president and Nancy Holzner is a technical writer with Precision Filters

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DIAAMOND-S ARE FOREVER

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A research project has developed novel, automated, non-contact technologies for NDT of carbon-fiber-reinforced structures

// MIGUEL TORRES

Since 1957, the Spanish company Tecnatom has been engaged in developing applications of NDT for structural assessment of components. The company has been participating in the DiAAMond Consortium (Development of Non-destructive Inspection Approaches for Automatic detection and MONitoring of Damage evolution), a European Union project to develop innovative NDT techniques to monitor on-line carbon-fiber-reinforced polymer (CFRP) damage found during structural tests (ST) execution.

Another prominent participant in the consortium was Centro Avanzado de Tecnologías Aeroespaciales-CATEC, (Center for Advanced Aerospace Technologies), which is a close partner of Tecnatom in the development of several innovative solutions in the NDT field, including in the DiAAMond project.

Previously, conducting these tests meant only ultrasonic (UT) conventional manual inspection was carried out. This project has demonstrated novel NDT techniques for the real-time evaluation of structural tests, such as non-contact laser, ultrasonic or air-coupled UT, and other techniques, for example, infrared thermography and laser shearography.

DiAAMond demonstrates that selected NDT instrumentation will be able to automatically perform the data acquisition and analysis, without human intervention, while transferring results to the structural test control system in real time.

A demonstrator was validated at subcomponent level and in a realistic scenario, having been applied to six work packages from May 2014 to October 2016.

Work Package 1 (WP1) selected suitable NDT techniques for hybrid CFRP with dissimilar material joints structures. Several tests over different specimens were performed at laboratory level, to check the more suitable NDT techniques and the automation principles to be applied.

WP2 designed an automated NDT monitoring system developed in two stages. First was a design for a preliminary prototype and the second stage was for the final application.

The development of the automated NDT system and its integration followed in WP3. This was also a two-stage process, commencing with validation of the preliminary prototype and then validation of prototype. One key element of WP3 was the demonstration of the prototype on flat panels and large coupons.

1 // View of the cockpit demonstrator used during NDT evaluation

2 // General view of the configuration of the automated NDT system developed

3 // Screenshot of the operator interface developed, showing evaluated areas

4 // Example of the evaluation interface, showing data from a defect detected

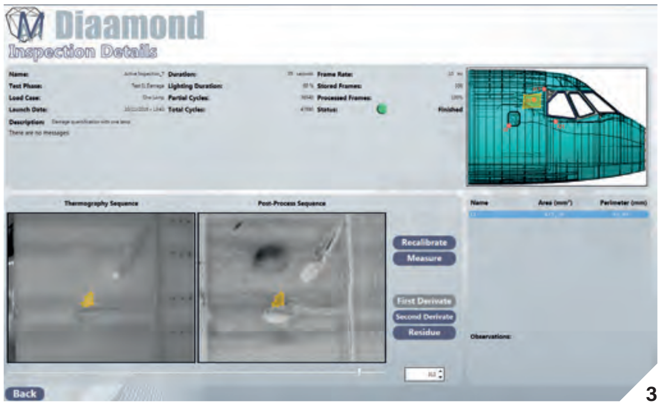
Final validation tests at the end of the project used a prototype unit and a cockpit structure provided by Topic Manager.

WP5 pointed to enhancements needed for industrialization of the prototype. It was performed taking into account the results achieved in WP4 with the prototype developed and future potential lines of development. The working package produced an *Enhancement For Industrialization Report* as a deliverable.

Finally, WP6 disseminated the results, and this article is part of it.

Of the milestones achieved, it is important to highlight the selection and implementation of the most cost-effective NDT technique. A second important milestone was the validation of the final system based on experimental results.

Out of the NDT techniques tried in the project, infrared thermography was chosen as a base. Passive thermography was used to monitor in real time the structural tests during loading of the structure. Active thermography was used when structural tests were stopped, to assess and evaluate damage in more detail (scheduled and non-scheduled inspections). Different algorithms have been tested and implemented for each, allowing filtering



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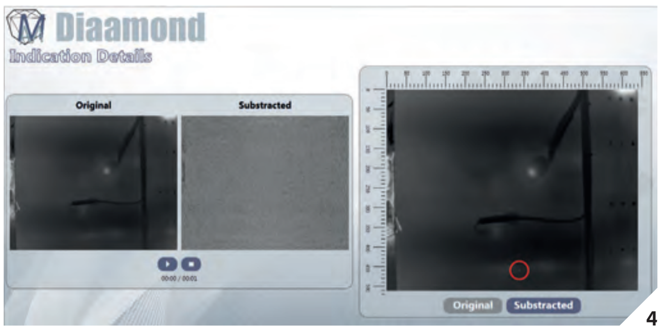

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only on the relevant information (passive) and to post-process the data to ease the evaluation process (active).

Software development had a huge number of additional tools developed, such as Inspection Area Mapping, a Comparison Module for NDT registers (IRT, visual, UT, etc), and for auto-calculating the Evolution Curves of Damage Index.

There are several benefits of this project. Environmentally, the NDT technology chosen is the optimal and most cost-effective one. It requires no coupling and so does not need to use water. The underlying technology (infrared vision) is not intrusive. The technology developed eases the process of building complex aircraft structures with CFRP material which will allow lighter aircraft, resulting in lower fuel consumption.

The work performed demonstrates the maturity of this technology. The whole process of NDT monitoring during structural tests has been tested and probed, and data recorded in real time of the 'indications' found. Remote control of the NDT system was developed, as was the changing of several parameters of the inspection process.

Closer collaboration with industrial manufacturers will improve the database for damage indices with real parameters. New improvements in mapping tools will be achieved. Finally, it will be necessary to improve integration between the NDT system and the structural test platform.

Tecnatom brings to the Consortium its background in the application of NDT for quality assurance during the manufacture of complex composite aero parts. \\

Miguel Torres is a business development manager in Tecnatom's Directorate of Technology and Product Development

EXTREME ENVIRONMENTS TESTING WITH F-GAS COMPLIANCE

Future-proofed for pending gas regulations, these environmental simulation chambers come as standard models or customized for users' needs

// RÉGIS PERRAUX

The new Climats Excal² line of environmental simulation test chambers offer excellent performance and are compliant with the new F-gas regulations that are progressively being introduced leading up to 2030. The range uses newer, more environmentally friendly gases; feature a new, more compact compressor; and offer extended temperature ranges. The machines underwent two years of research and development before being introduced to the market.

F-GAS COMPLIANCE

The F-gas Regulation (EC) No 842/2006, which came into effect on January 1, 2015, prohibits purchase of certain refrigerating machines that use gases or techniques that pose an environmental hazard from their global warming potential (GWP). GWP is an indication of the harmfulness of a gas relative to the greenhouse gas effect equivalent to one molecule of carbon dioxide (CO_2) over a given period of time. In real terms, 1kg (2.2 lb) of CO_2 represents a GWP of 1. The higher this number, the more harmful the fluid or gas.

The implementation of this European standard is not yet complete, but on the first day of 2030 the legislation will fully prohibit the maintenance of machines using fluids with GWP higher than 2,500 CO_2 equivalent.

FUTURE-PROOFING, NOW

Before being confronted with this deadline, it is better to invest in devices that are already compliant with, or even exceed, the new regulations. In the field of extreme environment simulation, Climats has already positioned itself with the new Excal² machines, which use R449A gas. In equal quantities, this gas has over 99% of R404 specifications, but with a 65% reduction in GWP.

For users, the consequences are twofold. The first is that the use of this gas makes it possible to comply with the new regulations. With a GWP of 1397, R449A gas gives an advantage in terms of maintenance. Machines that have a maximum charge threshold below 50 metric tons equivalent CO_2 require only an annual inspection. Machines in the Excal² line can therefore keep the same load of calorific fluid without generating any extra inspections compared with the use of R404A refrigerant gas.

1 // The Climats Excal² environmental test chambers offer future-proofing against refrigerant gas regulations and have a number of efficiency improvements developed over two years of research

MORE IMPROVEMENTS

The new Climats line does not just change the fluid, but it also benefits from a more compact compressor, making the machine more efficient. "With twin-compressor models, our machines can drop temperatures by up to 25°C (77°F) per minute," says technical manager Christian Morillon. The complete reworking of the cooling conditioning system, which can be used at 50Hz or 60Hz, also makes it possible for Excal machines to be 10-15%

lighter and occupy up to 20% less floorspace. These new specifications make it possible for the two lightest units, the 140-liter and 220-liter models, to pass through any standard door – a real plus for small facilities and laboratories.

The developments in the line also covered the machines' ergonomics, to make use and maintenance easier. "This involves several new features," says Morillon. "First, we have highlighted the various man-machine interaction zones, so that users intuitively understand how to stand to use our tools and keep them in good condition."

Similarly, the specific boards for measurement instruments are positioned together for easier access without impacting the other parts of the machine. The Excal² models are fitted on rollers and slightly raised so that they can be moved around a factory. Additionally, all supply connections have been grouped on two separate panels; water and air are on one and electricity is on the other. The machine is fully compatible with all computerized monitoring tools and benefits from standard operating system auto-check.

Furthermore, the Climats product line is mostly modular depending on requirements. Customization, covering non-standard specifications, represents a large part of the company sales. However, most of the machines sold are assembled from a base of 250 standard models covering volumes from 140-1,800 liters. This mass-production capability allows the company – based in the Bordeaux region of France – to deliver a machine within six weeks of ordering. \\

Régis Perraux is the sales and marketing director at Climats

STANDARD SPECIFICATIONS

- Humidity control from 10-98% at temperatures between +10°C (50°F) and +95°C (205°F) with minimum dew point limited at -5°C (23°F)
- Simulation of climatic environments between -90°C (-130°F) and 250°C (482°F)
- Test cabinet sizes from 140-1,800 liters
- Each cabinet size benefits from 10 to 15 compressor sizes
- Mass production relies on 250 standard models

DEVELOPING A NEW BOOSTER

Engineering large CFRP components requires high precision in the heat treatment temperature controls to ensure the finished parts have the correct material properties

// REINER WIESEHÖFER

Ariane 6 is the new launcher from the European Space Agency (ESA); its first launch is scheduled for 2020. The ESA collaborated with MT Aerospace and its partner, the German Aerospace Center (DLR), to develop the solid fuel booster. DLR used an annealing furnace from Vötsch Technik to anneal the large components. This furnace offers high temperature precision and therefore guarantees the required reliability of the process.

ECONOMIC REQUIREMENTS

Ariane 6 is equipped with up to four boosters, which, as solid fuel tanks, are each filled with 135 metric tons of fuel. Until now, the boosters have been made of steel, which had a couple of drawbacks. For one, it was relatively heavy; and secondly, its production was complex and expensive. To avoid these drawbacks, the new boosters are being made of carbon-fiber reinforced polymer (CFRP), achieving excellent material properties in a simplified process with considerably reduced process costs. CRFP components are much lighter than steel components and therefore they increase the rocket's possible payload, which, in turn, improves the economic efficiency of each flight. The Vega-C launcher, which will use the booster as the main drive, also reaps the benefits of the new Ariane booster.

MATERIAL PROPERTIES

On the one hand, the material properties of composite materials depend upon the selection and quality of the components. For this reason, carbon fibers and resin matrix are tailored exactly to the booster's requirements. On the other hand, the precise observation of the defined process parameters, in particular temperature control in the furnace, plays a crucial role in the quality of the component. In order to check the booster's production process, the booster shell was produced in advance at its original diameter – but only half the length. This size was sufficient for the developers to be able to intensively examine the production process and the material properties.

OPTIMUM PRODUCT QUALITY

It is produced using a dry wrap procedure, in which dry carbon fibers are wrapped around a pin. Then, an infusion installation is fixed around the component and vacuum-drawn in order to ensure the resin flow in the component and to prevent air pockets. The resin matrix is transported from outside into the furnace via infusion tubes in the side openings on the furnace wall. It is infused in the component at the defined temperature in the furnace. The highly fluid resin inherently follows the pull of gravity; however, the booster must have an even wall thickness and therefore needs the even distribution of resin all around. This is solved by using a special rotation device in the furnace. It rotates the booster evenly and in doing so prevents the resin from running downward. For this, an axle is fed from outside through the furnace door that connects a motor to the rotation device. For the hardening process, the temperature is increased from the infusion temperature up to the hardening temperature using a predefined temperature ramp. The precisely defined heat with a temperature precision of ±2K ensures that the crosslinking occurs exactly as required and planned.

Clemens Schmidt-Eisenlohr, research associate at DLR, explains, "The huge size

1 // The tempering and curing oven for producing the booster sections of the Ariane 6 rocket

(Vötsch Industrietechnik)

of the component made the special application a real challenge. Vötsch Technik took on this challenge with dedication, designing the furnace controls so that the temperature distribution conformed with the requirements, even in the end areas of the furnace, which was full to maximum capacity."

PROVEN FURNACE TECHNOLOGY

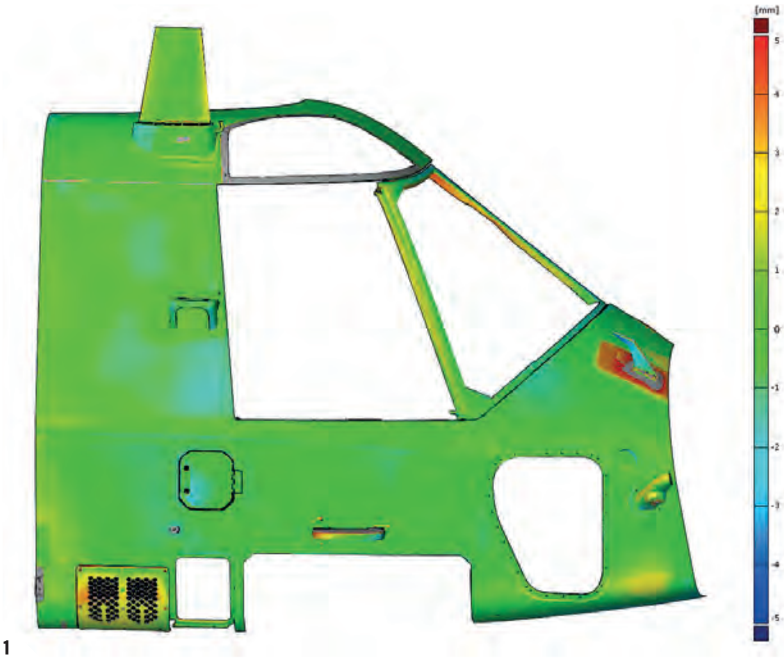
The used VTU 500/450/850 hardening furnace had interior dimensions of (WxHxD) 5,000 x 4,500 x 8,500mm (16.4 x 14.8 x 27.9ft) and an interior volume of more than 190m³ (6,710ft³). The furnace works using particularly powerful fans. They ensure a high circulating air output, transport the heat quickly and evenly to the product, and enable high heating rates. The system is controlled using a touchpanel via the simple-to-operate Weiss Technik 'S!MPAC' controller. To meet the special requirements of DLR, the furnace was equipped with a series of special specifications. Alongside the rotation device, these specifications include the side feedthroughs that make it possible to transport resin from outside into the furnace. Products are fed into the furnace at ground level and without carriages or other equipment. That provides clear benefits, especially during development, and allows for more component flexibility in handling.

Björn Wieler, system engineer at MT Aerospace, adds, "In research and development projects, there are often special requirements. Existing technology has to be quickly adapted or modified. Vötsch Technik met all the requirements in the shortest time and to our great satisfaction, so that we were able to produce the boosters as we wanted."

The ESA coordinates European space activities – including overseeing the design and construction of the new Ariane 6 launcher. The agency commissioned aerospace technology specialist MT Aerospace to build the new booster. The company is a long-standing development partner of the Augsburg, Bavaria-based German Aerospace Center – Center for Lightweight-Production-Technology (DLR-ZLP).

The large, versatile furnace modified for the Ariane booster and described here is one of a number of furnaces in operation at the DLR. Not only is it used for the Ariane project, but it has also already proven its worth in other, extremely varied projects featuring large-dimension components.\\

Reiner Wiesehöfer is authorized officer at Vötsch Technik Business Unit Heat Technology



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SCANNING TO THE SMALLEST DETAIL

Supporting military helicopter maintenance in real-world conditions required optical 3D metrology to build full-size training rigs – which saved time and money, and provided a high level of precision

// **KATRIN STENEBERG**

Keeping military helicopters deployed for as long as possible means maintenance needs to be carried out quickly and reliably. This requires specialized hands-on training for maintenance crews at regular intervals – ideally using the actual helicopters. However, this is usually a problem. NATO NH90 transport helicopters are usually out on assignments so they are virtually never available for maintenance training. To keep the training program updated and on track, the German and French armed forces turned to Reiser Systemtechnik. The company, based in Upper Bavaria, is well-known for its expertise in building training mock-ups that replicate complex military systems. The armed forces ordered five helicopter mock-ups – also known as rigs – for the training program: four army versions and one navy version.

The rigs are full-size scale models of the actual helicopters. They are made of fiber composites and aluminum, and are fitted with ancillary equipment of relevance to training. Crews can practice maintenance procedures, including component and system replacements, as if they were working on the helicopters themselves. All the maintenance jobs are performed in strict accordance with the military maintenance manuals, which means that the training rigs must be exact replicas of the helicopters – right down to the smallest details. The training enables crews to carry out maintenance much faster, and it reduces the number of mistakes that could arise when ancillary equipment is replaced. "We offer our customers the advantage of availability, because unlike the helicopters, the training rigs cannot be deployed for flight missions. What's more, using the training rigs is a lower-cost alternative to using the original NH90 helicopters," says Dr Martin Wilke, head of Projects and Systems Engineering at Reiser.

The first step of the project involved a study to determine the precise training

1 // During final assembly of the training rigs, the outer shell or 'skin' is inspected for possible deformations. The full-surface measurement data is compared with the CAD data set. Deviations from CAD are highlighted in color and easily recognizable as problematic areas, enabling specific improvements to be made in manufacturing

2 // The NATO NH90 transport helicopters are almost constantly in service – and so are seldom available to maintenance crews for training purposes. Thus full-scale training rigs are built to fill this gap

requirements for the rigs. The requirement profile of the NH90 rig comprised more than 1,200 maintenance tasks. These included the removal, repair and installation of components essential to operating the aircraft.

In building the helicopter training rig, the ATOS Triple Scan 3D digitizer from GOM is used for non-contact scanning of all components, surfaces and ancillary equipment of the original helicopter – from the smallest screws to the largest airframe components, including both aluminum and fiber composite elements of all sizes. The three-dimensional scan data is then imported as an STL mesh to CAD systems for reconstruction (reverse engineering). Simulations are also carried out based on FEM computations.

During final assembly, another 3D scan is conducted to guarantee the correct positioning of specific parts in relation to each other, and to inspect individual components under load. "When checking

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3 // During final assembly of the training rigs, more 3D measurements are carried out with ATOS Triple Scan. The correct positioning of the individual components is also verified point-to-point using an optically tracked touch probe

the position of the helicopter airframe on the assembling jig, as well as the positioning of the exterior shell panels on the airframe itself, ATOS Triple Scan – with a measuring volume of 2,000mm and the GOM touch probe – delivered outstanding results," explains Sylvain Rid, project manager, NH90 maintenance training rig. "We have drastically reduced the time needed for assembly, and have given a major boost to precision."

During the procurement process, Reiser considered systems from two other manufacturers, in addition to GOM. "Neither of those products met our requirements in terms of precision and versatility, for both extremely large and extremely small objects," explains Wilke. In contrast, the GOM system satisfied every requirement, for example, when it came to point-to-point positioning inspection using the optically tracked touch probe, and for 3D surface scanning to detect possible deformations in the outer skin covering the airframe. Reiser demanded a system that would address all of its needs. "The versatility of the ATOS 3D digitizer, making it suitable for use in a wide range of customer projects, was a very important factor in our decision," says Wilke. What's more, the system's mobility and flexibility makes it an ideal choice for scanning on-site for suppliers and customers.

The first training rig has been completed and delivered to the German Air Force Training Academy in Fassberg. Four additional models will follow. Following initial testing, which also covered the NH90 engine, the feedback from the armed forces was very positive – the quality, effectiveness in training and realistic replication of the rig were all convincing. The project also met expectations in terms of cost-effectiveness because the training rigs enable considerable savings – original training helicopters would be up to 70% more expensive. Due to these factors, plans call for applying this new approach to other military and civilian systems that require maintenance training. \\

Katrin Steneberg is a GOM application expert

"USING THE TRAINING RIGS IS A LOWER-COST ALTERNATIVE TO USING THE ORIGINAL NH90 HELICOPTERS"

1 // Remote visual inspection of a helicopter gearbox using the portable MoVeo videoscope from Karl Storz

VISUAL INSIGHTS

UK MoD helicopter technicians are exploring and proving the benefits of remote visual inspection

// OLIVER SKIPPER AND JASON FREEMAN

Remote visual inspection (RVI) is defined as an inspection in areas that are wholly inaccessible. The remote part refers to the fact that the user or operator does not have direct access to the area/cavity of inspection. RVI technology enables an inspector to visually inspect these inaccessible areas to view parts of a pipe, engine, gear box, bearing, or a similar part or assembly. Without the use of RVI, the technician would have to completely disassemble the entire construction in order to inspect the area of interest.

To explore how best to avoid this, one UK technical team has experimented with endoscopic RVI for their Wildcat maintenance operations, ensuring day-to-day airworthiness and operational safety.

AW159 Wildcat helicopters are produced by Leonardo Helicopters and used by, among other organizations, the UK Army and Royal Navy. They are subject to a high level of daily usage and have to be in constant readiness to operate in challenging and extreme environments, from dry sandy deserts to wet and salty conditions, throughout their lifetime.

Helicopters have achieved this increase in performance levels with the aid of ever more complex mechanical, electronic and structural components. These are made possible through advances in new materials and manufacturing processes to provide a new generation of complex turbine blades, housings and mechanical components, which are subjected to periodic visual inspections.

CHALLENGES FOR TECHNICIANS

Stress and pressure on metal parts can lead to small cracks and, for instance, salt water can cause corrosion and rust. If inspections are neglected, it could result in mechanical failure in the worst cases. Helicopters and aircraft are compact and robust in design, which causes considerable challenges when unable to freely access some critical parts. Other parts are completely inaccessible for technicians without special equipment such as endoscopes, borescopes and videoscopes for visual inspection.

Through extremely small holes, the scopes assist inspection of the inner parts without disassembling the complete unit. Depending on the underlying inspection task and access ports, the technician can either use a rigid endoscope (borescope), videoscope or fiberscope with an articulating probe to quickly gain access to components prone to failure.

"Karl Storz advised and helped us with its application and product knowledge to validate which of the technical solutions best fits our current inspection needs and budget, ideally applying it for other general visual inspection tasks too," says Stuart Dando, AW159 Wildcat capability manager at Leonardo MW (LMW).

MOVING FREELY AND WORKING WITH ONE HAND

The helicopter division of LMW originally planned a visual inspection primarily in and around the lower fuselage areas, in particular the fuel system common overboard pipelines. In this particular case, the Karl Storz MoVeo videoscope with 4mm (0.16in) diameter probe and 3m (118in) working length was used. While working on a helicopter, it is important to have a battery-powered and portable system to be able to move freely and work with one hand. The minimal weight is a further benefit. Some inspections require technicians to work lying down or in uncomfortable positions and these features greatly aid the technician in producing a thorough and accurate inspection.

Use of the 4mm MoVeo probe enables access to the lower fuselage area between the fuselage and the fuel tank liners. The robust tungsten mesh assists in protecting the probe against sharp edges and supports the user during insertion. In addition, consequential damage on the probe can be minimized. A 5in (127mm) display on the scope panel allows for the collection of accurate data to see if any internal damage such as cracks, corrosion or rust are present. The true color image helps to differentiate these (e.g. rust versus dirt).

The result of the visual inspection by LMW presented a few, almost negligible, deposits of corrosion that are mostly invisible to the human eye. All findings were saved and recorded digitally and transferred via SD card to a PC for later detailed video and image-based documentation and review.

Additionally, the technician has to check the fuel tank the same way. By using the same equipment, the huge maintenance burden of defueling the aircraft, removing the fuel tanks and the fuel tank bay liners is eliminated. According to Jason Freeman, customer support directorate, Leonardo MW, the fundamental reason for the usage of RVI is to save time and therefore money. In this case a saving of 200-300 man hours and associated costs per helicopter was achieved by using the MoVeo equipment. By using the videoscope, the operator obtains detailed interior information and is therefore able to conduct effective and low-cost spare-parts planning.

“THE SCOPES ASSIST INSPECTION OF THE INNER PARTS WITHOUT DISASSEMBLING THE UNIT”

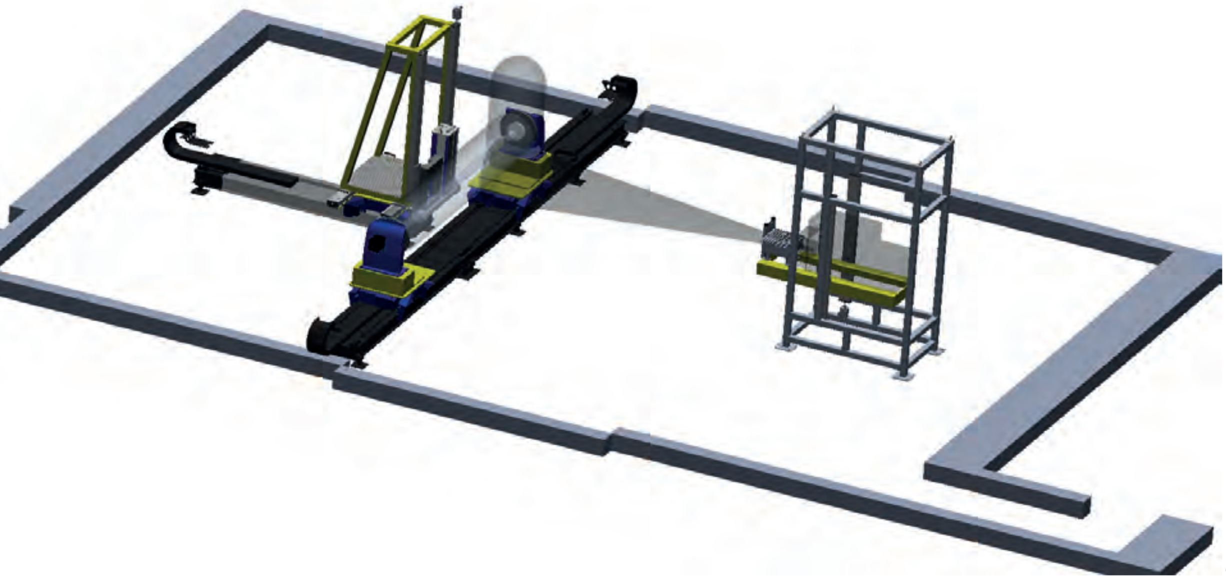
In the future, the requirement for cost savings will drive the RVI sector to perform more complex tasks in less time, saving money, and this drives the trend to integrate high-end endoscopic equipment with excellent images into daily operations.

Increasingly defects must be measured to enable a go/no go decision, but also, with subsequent measurements, to monitor the defect for propagation or further damage. Acceptable defect propagation can be monitored and documented over time, informing future inspections and providing valuable data for designing next- generation aircraft. As this sector is under constant development, video probe technologies – such as the Multipoint 3.0 Solution from Karl Storz – with see-and-measure functionality are becoming increasingly relevant in daily operations.

In the end, Leonardo delivered 62 inspected Wildcats to the MoD fleets (UK Army and Royal Navy) knowing that with the MoVeo videoscope equipment a lot of costs can be saved compared with disassembly inspections. “LMW will use this knowledge for future operations and associated economical value in our next MRO service project,” says Dando. \\

Oliver Skipper is country manager and RVI applications specialist (industrial) at Karl Storz, and Jason Freeman is in the customer support directorate at Leonardo MW

2 // Typical MRO borescope inspection can measure defects with full color image for clarity



HIGH-ENERGY IMAGING

A new high-energy camera system enables enhanced DR/CT imaging up to 9MeV for the inspection of aerospace material and high-density components

// GUY REIM AND JUSTIN EVERLY

Digital radiography and computed tomography (DR/CT) have been used for non-destructive testing (NDT) in the aerospace industry, with applications that span research and development, manufacturing, quality control and failure analysis. However, until now DR/CT systems were not able to effectively capture information from x-rays at high energy levels, thus missing some important inspection information.

Adaptive Energy has developed a new high-energy camera system for advanced DR/CT imaging for aerospace material and high-density component inspections. By capturing improved quality x-ray image information at high energy levels, the system improves both inspection accuracy and speed.

TRADITIONAL DR/CT CAPABILITIES

All DR allows radiographic images (x-rays) to be viewed and processed in digital format on a computer display, rather than as a radiographic film image. This enables more advanced and flexible processing, image enhancement, analysis, storage and communication of the images. CT, also called x-ray computed tomography, produces two-dimensional and three-dimensional images of an object derived from flat x-ray images.

These radiographic imaging techniques allow for accurate non-destructive inspection and testing of materials including metal, plastic and composites to identify defects and analyze characteristics such as dimensions, shape and density. DR and CT are highly effective for crack detection, inspecting for delamination, corrosion, component placement and weld strength, among other aerospace applications. For example, Adaptive Energy has created systems for inspecting the braze meniscus of honeycomb structures, and built a solution combining high-energy x-ray and linear diode array (LDA) digital radiography to inspect fuel and component placement in solid rocket boosters.

However, as useful as they are, DR/CT technologies have some limits. Standard digital array panel displays convert x-ray energy to light with scintillators to produce an image on screen. Conventional digital array panels have the capability to capture image data in the lower kilovolt range, and poorly capture high-energy image information above 450kV. The higher-level x-ray energy is not converted to light, it just passes through the digital array panel. This means that some critical material evaluation data is not captured. Fabricators have no way to know if there are structural issues with these components that remain undetected, and which will emerge only under live conditions.

HIGH-ENERGY DR/CT INNOVATION

Adaptive Energy has now developed an integrated camera system that can capture information at much higher energy levels. The new systems use x-ray line scan cameras with capabilities up to the 9MeV energy level to capture a full range of high-energy images. Built-in controls and operating software allow users to control the linear accelerator (LINAC) that moves an object being scanned, improving both image quality and capture speed.

These cameras offer a higher x-ray-to-light conversion rate than conventional DR/CT systems. Using various high-energy scintillating materials they can convert x-rays to light more efficiently, resulting in higher contrast images and the capture of more detailed information. The camera

1 // Schematic of the high-energy scanner camera system

2 // The high-energy camera units can be made at any length to suit a variety of applications. This one has a 36in active imaging area, allowing for easy manipulation on and around inspected items

3 // Aerospace applications of the LINAC high-energy CT imaging system include inspections of high-density materials, additive manufactured components, and enhanced whole body and tangential inspection

systems can be custom built at almost any length, and the simulators can be set up to optimize the energy being used for any specific inspection application or setting.

POTENTIAL APPLICATIONS

High-energy x-ray inspection and CT imaging is particularly useful in various additive manufacturing (3D printing) applications. One challenge with inspecting typical additive manufactured parts is that they create x-ray scatter noise, which decreases the imaging resolution for digital radiography and computed tomography. The new camera system's improved LINAC-to-image-detector synchronization, and the use of techniques to minimize scatter, greatly enhance the image contrast resolution.

These new camera systems can also be effective for a myriad of non-destructive testing settings, including whole-body inspection and tangential inspection. The line scan camera can be configured to best meet the specific x-ray application and imaging geometries for an application. Additionally, the camera systems offer the ability to choose scintillating material appropriate for the high-energy x-ray source, thus offering improved accuracy for applications in rockets and missiles, and with high-density materials.

Beyond providing improved imaging quality and information, Adaptive Energy's high-energy camera solution operates more efficiently, offering the benefit of decreased inspection time. With more data captured in less time, users gain both improved quality and improved productivity.

Adaptive Energy applies digital radiography, computed tomography and ultrasonic technologies, combined with innovative mechanical and robotic assemblies, to address mission-critical, time-sensitive non-destructive testing for government, aerospace, transportation, energy, materials and infrastructure industry requirements. \\

Guy Reim is CEO and Justin Everly is an engineer with Adaptive Energy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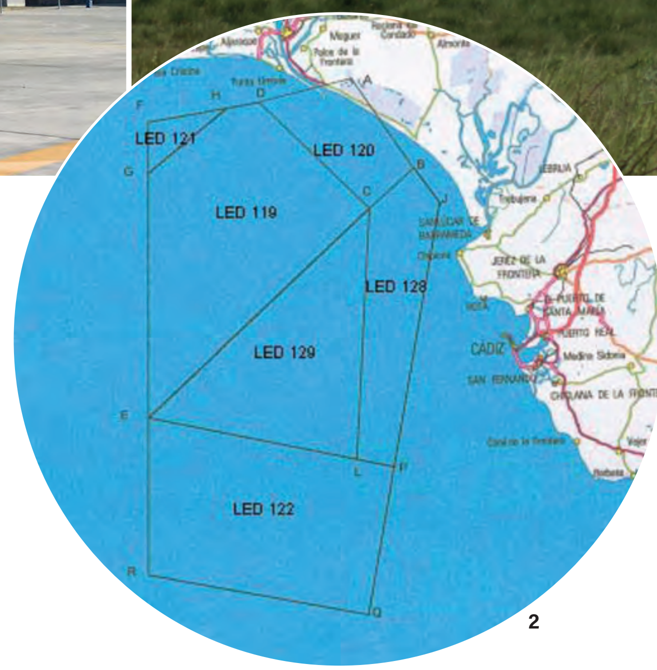

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OFFSHORE RANGES FOR UAS TESTING

Airworthiness assessments of unmanned aerial systems require infrastructure and test ranges, which INTA in Spain is developing, to support flight testing programs

// ANTONIO MESA-FORTÚN AND DR ANA CORRALES SIERRA

The absence of definitive guidelines for the certification and operating of unmanned aerial systems (UAS) means a process of investigation and experimentation is needed to achieve an acceptable safety level in these operations. Tests are needed to achieve the verification of the airworthiness of the UAS and the correct integration of manned and unmanned systems in the airspace. A test center suitable for the special characteristics of UAS is essential, as well as the personnel, equipment and technical knowledge.

Spain's National Institute for Aerospace Technology (INTA) is a public research establishment specialized in aerospace R&D. To perform flights with UAS in adequate conditions, INTA, with the support of the Ministry of Economy and the regional governments involved, is in the process of refurbishing and expanding two test centers: CIAR, in Castro de Rei, Lugo, and CEDEA, in Mazagón, Huelva. As well as infrastructure, INTA, as the airworthiness authority, provides technical support for the test flights.

Due to UAS characteristics, certification should cover the aircraft as well as the ground control station, equipment for launch and recovery (if needed), and communication between the various parts of the aerial system. The objective is to guarantee the same level of safety as for manned aircraft.

EL ARENOSILLO TEST CENTER

El Arenosillo Test Center (CEDEA) is an ideal environment for these kinds of tests. It has an area over the sea of approximately 50 x 100km (30 x 60 miles), where tests can be undertaken without interference from other aerial vehicles or shipping. In addition, the specific instrumentation available (radars, optronic systems, flight termination system, telemetry station and communications) allows the continuous monitoring and tracking of the aircraft, and real-time data, according to test program requirements.

The main disadvantage of the center is the lack of a runway for take-offs and landings; the UAS that operate in the area are launched by catapult and land by parachute. To overcome this issue, project CEUS is extending CEDEA to include a 2,000m (6,560ft) runway, platforms, taxiing strip, aircraft parking zone and suitable hangars.

1 // A new hangar for UAS test operation at the Center of Airbone Research (CIAR) in Lugo

2 // The El Arenosillo test area off the southwest coast of Spain

3 // An instrumented C212 INTA aircraft landing at CIAR. This center is able to support activities for manned and unmanned aerial platforms

4 // Working scheme for flight test with UAS

CENTER OF AIRBORNE RESEARCH

Once a UAS is certified, adding payloads – including calibration, classification of airborne equipment, integration, certification of the payload and data analysis – can all be performed at CIAR.

CIAR has recently been refurbished with repair shops and laboratories to carry out integration and payload testing. The project is now in its second phase, with the acquisition of the needed equipment – radar, control center and communications. The procurement of innovative products and services will ensure a continued high standard of cutting-edge technology is available.

In addition to UAS flights, CIAR undertakes research flights for INTA

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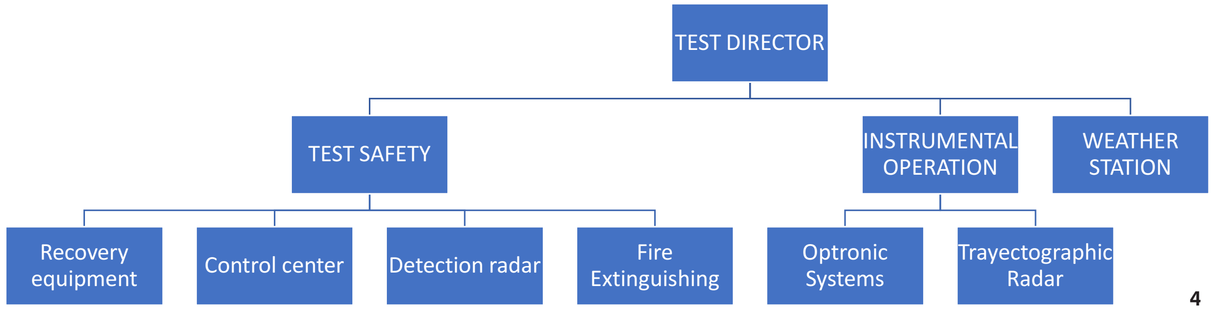

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with the aerial platform, such as flight campaigns to study the atmosphere (microphysics, aerosols, clouds, rain, ice formation, and microbiology), observation of the ground through remote sensing, testing new equipment and instruments, and the study of the airspace integration of manned and unmanned aircraft.

AIRWORTHINESS TECH SUPPORT

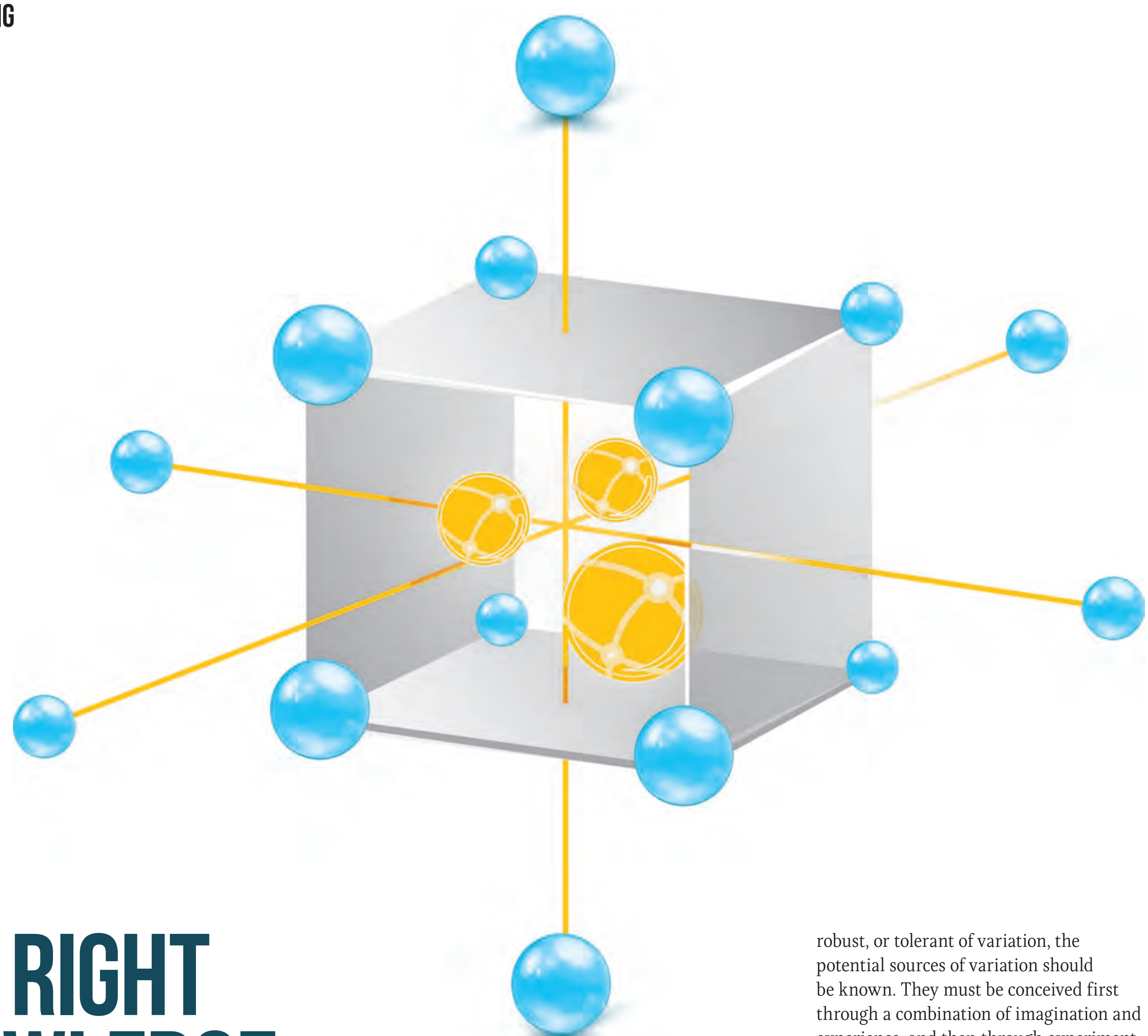
Emerging technologies involve risks that need to be mitigated. All the systems of the UAS must be analyzed to guarantee the safe working of those systems in all operating conditions that will be encountered throughout its operational life, in addition to functional analysis of its design and the evaluation of fail conditions. The design ought to guarantee a level of safety adequate to the critical nature of each flight condition

The authentication of this level of safety should be undertaken with ground and flight tests. The risks associated with each test should be analyzed, and prevention steps considered.

Highly qualified personnel at these centers will carry out tests with the support of the certification and airworthiness department and its specialists. Testing can cover areas such as environmental, propulsion, electronic warfare, human factors, software, aerodynamics, cockpit, structure, hydraulic system, avionics, instrumentation on board, electrical generators and distribution system, external lighting, automatic flight control system, ballistic protection, armament, electromagnetic compatibility, safety, communications, navigation, power plant and flight mechanics.

INTA's combination of infrastructure and capabilities provide a national network that covers all the requirements needed for the development and testing of UAS. \\

Antonio Mesa-Fortún is a test activities coordinator at the El Arenosillo Test Center, INTA, Spain. Dr Ana Corrales Sierra is a test activities coordinator at the Center of Airborne Research in Rozas, Spain



THE RIGHT KNOWLEDGE

Data is not the same as information and neither is sufficient to make decisions. For that, knowledge is required and test planning using Design of Experiments methodology helps

// ERIK REYNOLDS

The key to good test planning is designing experiments that offer the most decision-making power with the least expenditure of resources. This type of approach generally falls under the heading of Design of Experiments (DOE). Below we look at six questions that promote sound test planning using the DOE methodology.

WHAT ARE THE ESSENTIAL PERFORMANCE VARIABLES?

In any system under test there are many performance variables, but they can usually be narrowed down to an essential few. These are identified by determining the overall purpose of the system and why it is being put into service. Why is someone paying for its development, deployment and ongoing maintenance? Start with an exhaustive list of the possible performance variables, and then narrow them down through careful consideration of the design purpose.

WHERE ARE THE POTENTIAL SOURCES OF VARIATION?

Every system should have an intended operating environment, but in reality the world isn't as predictable as we would like it to be. Variation is everywhere, from the component production line to the software development process and even the weather and human operators. For a design to be robust, or tolerant of variation, the potential sources of variation should be known. They must be conceived first through a combination of imagination and experience, and then through experiment. Start by brainstorming a large list, but be careful when winnowing it down. First-order sources, which affect performance variables directly, can sometimes be predicted. Those that combine with one or more other sources of variation can have unexpected effects as well.

// To obtain the right knowledge, the right questions need to be formulated and these should be tested for relationships and appropriateness for the task at hand

WHAT RELATIONSHIPS MIGHT BE IMPORTANT?

The influence of sources of variation on performance variables is key to robust system performance. It also plays an important role in properly framing and scoping the tests that shed light on these relationships. To test all performance variables against the multilevel interactions among sources of variation is simply impractical. Even with a relatively small number of variables, the test matrix could soon be so large that it becomes unfeasible. How critical is the system under test? Are third-order interactions important, or would second-order suffice? Are relationships expected to be linear or non-linear? Answers to these questions drive what types of models should and should not be used.

All models are wrong, but some are useful. The key is finding those that are best suited for representing the causal relationships among your sources of variation and performance variables.

HOW APPROPRIATE ARE THE MODELS BEING USED?

The non-intuitive nature of probability and statistics can often handicap otherwise good test engineers when answering this question. For instance, do you know when regression models based on the normal distribution are appropriate? What about when they are not? It's also important to know which approach to take with regard to making knowledge claims based on collected data. Do you seek to confirm your hypothesis with your collected data? Are you trying to disprove it through finding the one instance where it proves false? Or are you, like most engineers, looking for regions where it is good enough to hold true reliably? Before testing, one needs to know how to tell the difference between a real phenomenon and a fluke.

COULD INITIAL EXPERIMENTS HELP SHAPE EXPERIMENTAL DESIGN?

Screening experiments are critical to planning a good test program as they can save time and money. Ironically they are often skipped due to budget concerns. Good screening experiments take a close look at a broad piece of the performance variable response surface to highlight areas for more scrutiny. They are like cartographers who map a new continent before the mountaineers arrive. Without them, one may think they have reached the top of the mountain, but they are only on a foothill. Screening experiments can also highlight surprising areas of concern that weren't considered in the conceptualization phase. If these aren't found in screening, one may not see them again until the system is fielded, and by then it's too late.

WHICH EXPERIMENTAL DESIGN BEST ANSWERS THE QUESTION?

Once the initial data from the screening experiments has been run through properly selected models, real test planning can begin. The interesting relationships and those of concern have been identified, and the bulk of the test budget can now be devoted to exploring those most important areas of the performance envelope.

By answering these questions, the DOE methodology will guide users in the wisest ways to spend their time and effort, helping to ensure that their design is robust – and that they have all the knowledge necessary to conduct proper test planning. \\

Erik Reynolds works with Intertek Consulting Services as a certified functional safety expert

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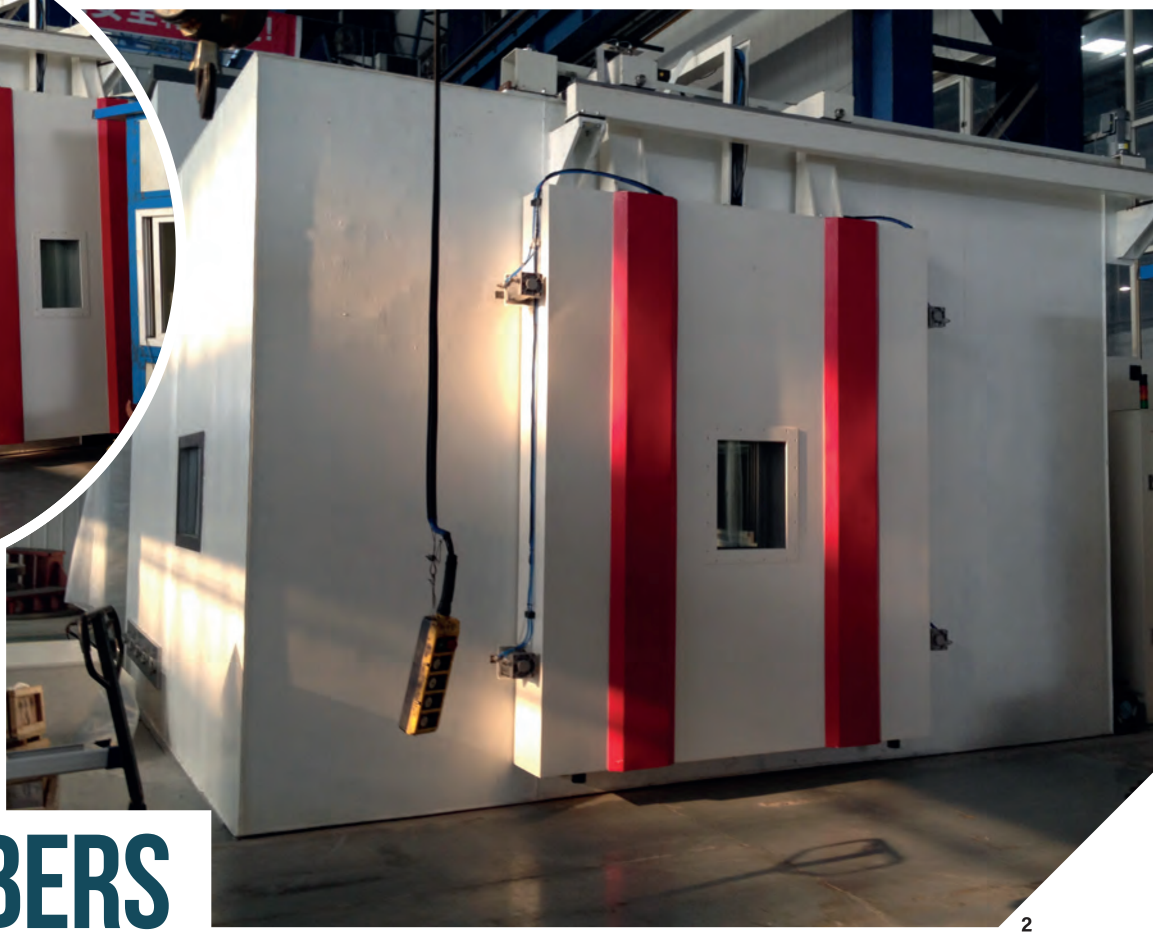

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ACCURATE TEST CHAMBERS

Safety, reliability and accuracy of conditions for testing are among the critical criteria that can be met by optimizing climate chamber designs with finite element analysis

// LEON CHEN, FRANK ZHAO AND LEE WANG

Hardy Technology's department of technical design in Chongqing received an order in 2015 for an altitude climate test chamber with a volume of 55m³ from a third-party testing organization of the Chinese government. While celebrating this winning bid, the designers started to think about how to produce an optimized design. Based on the concerns for safety and reliability, it was decided that the equipment should use an enhanced internal frame design. However, thicker steel plates and stronger ribs would increase the thermal load on the equipment, such that the heating and refrigeration rates would be affected, thus increasing the inefficiencies in energy consumption for operation.

Additionally, the 'thin' air at the simulated high altitudes would reduce the circulating air in the test space, which would extend the time to reach the required uniform temperatures and reduce the available time for the actual test.

Hardy engineers called on a number of relevant experts from Beihang University for help. A recent report using finite element analysis (FEA) of pressures on the structure of the chamber wall provided the optimal design suggestions.

Professors at the university also used fluid flow simulation software to provide optimized solutions for designing the air distribution in the space.

1 // View with an open door showing the ease of access for the Hardy 55m² climate chamber

2// The climate chamber exterior has several viewing ports and the rolling, suspended door allows ease of access.

Following the solution suggested by the professors, Hardy's design department rapidly finished the whole design. The equipment was delivered to customers on time and passed acceptance tests successfully. While simultaneously achieving the technical specifications required by the customer, an efficient, optimized design was created.

This equipment has an internally reinforced design. The inner wall uses 304 stainless steel with 6mm thickness and rectangle rib bar with 4mm thickness. Starting with an internal pressure at 1 atm, the pressure reduction rate is precise, taking 25 minutes to bring the chamber down to 50kPa (0.5 bar) while the system deviation is less than ±1kPa.

"THE PRESSURE REDUCTION RATE IS PRECISE, TAKING 25 MINUTES TO BRING THE CHAMBER DOWN TO 50kPa"

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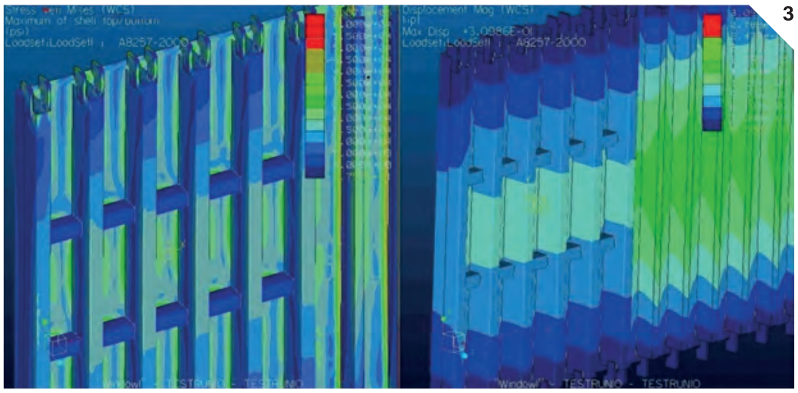

3 // A sample of the finite element analysis for an altitude chamber design

This also extends the lifetime of the vacuum pump. Two sets of pumps can be controlled to work together, independently or alternately, based on different working conditions. Two sets of cascade refrigeration systems (four compressors total) and multiple groups of heating elements are responsible for controlling the temperature of the test chamber space.

Hardy's patent (ZL 2009 1 0103747.9) – 'static balance' – is for a technology which controls the cooling capacity through the start/stop of pumps or compressors and will control each group of heating elements independently. These ensure the temperature changes at 2°C per minute with a system deviation at ±1.5° and a chamber power consumption at 90kW, during average working conditions.

This ensured the optimal control precision and best energy efficiency were achieved. Optimally designed air piping ensured that 30 minutes after reaching the setting temperature, the temperature uniformity was in the range of ±1.0° and the temperature fluctuation was in the range of ±0.4° in the test space.

The climate chamber is still operating to specification and continues to gather design and product data for the customer.

Hardy Technology has considerable knowledge of and expertise in computer-aided design simulation in the modern manufacturing industry.

Hardy moved to a new factory in June 2017 and continues to use CAD simulation to provide the best climate chambers and solutions for environmental testing. \\

Leon Chen is marketing manager, Hardy Technology Co; Frank Zhao is sales director and Lee Wang is project manager with Hardy Technology International

HIGH-SPEED INFLIGHT VIDEO STREAMING

High-speed streaming camera recording data during full flight time provides insight into unexpected events

// STEPHAN TROST

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High-speed video systems that record a complete flight from take-off to landing save money and provide insights into unexpected events. A cost-efficient way to achieve this is by recording test objects with rugged electronic cameras that stream data to local storage for later playback and analysis. Such systems can run standard 30fps cameras, as well as high-speed streaming units. An airborne-capable camera that reliably records all image data under severe environmental conditions and is experienced in an airborne environment is the core element of any video recording system.

THE CAMERA

The core of the camera is a sensitive state-of-the-art CMOS sensor that is embedded into a well-built thermally and optimally balanced design to avoid any thermal issues during operation. For data analysis, the preference lies on monochrome cameras where no RGB masking reduces spatial resolution as in color cameras. Of course, for general overviews, a color camera may serve the needs just as well.

Preferably the camera will have a single MIL connector, avoiding wiring multiple cables across the aircraft for power, data transfer, and other synchronization. In addition, a single shielded transfer cable dramatically reduces emission of EMI, often critical to an aircraft environment.

THE CONTROLLER

Today's user can connect the camera to a fixed installed airworthy PC for streaming the data without interaction of any crew member. Later, back on the ground, the data can be transferred by removable hard disks to or via Ethernet link to a central server for playback and analysis.

In the course of getting more computing power into tablet PCs, a new application of high-speed streaming cameras has become possible. The user – normally a flight engineer or crew member – has live images of the cameras on the screen and can control and pilot the recording. For immediate analysis, the operator can play back the sequence recorded in slow motion. Based on first analysis by the operator, he may decide to record another sequence with new parameters. Using a tablet computer, such changes of parameters – resolution, framing speed, trigger position, etc – are easily achieved with a few clicks, and the camera is soon ready to shoot the next recording.

1 // Modern camera and controller infrastructure substantially speeds up inflight high-speed video capturing procedures

2 // The H-EM controller 'TP-38X' can manage data from four cameras

HIGH-SPEED OR 30FPS RECORDING?

Naturally, today's high-speed streaming cameras offer many features for specific applications of the equipment. Some scenes require recording at standard speeds of 30fps while there are no fast movements. However, once the action starts, the camera may be easily set to high speed

3 // The Twintouch tablet with two H-EM cameras

"THE CAMERA MAY BE EASILY SET TO HIGH SPEED WITH JUST A FEW CLICKS"

with just a few clicks or even through an external signal from the aircraft. This eliminates the cost of mounting additional cameras at different frame rates needed for test purposes.

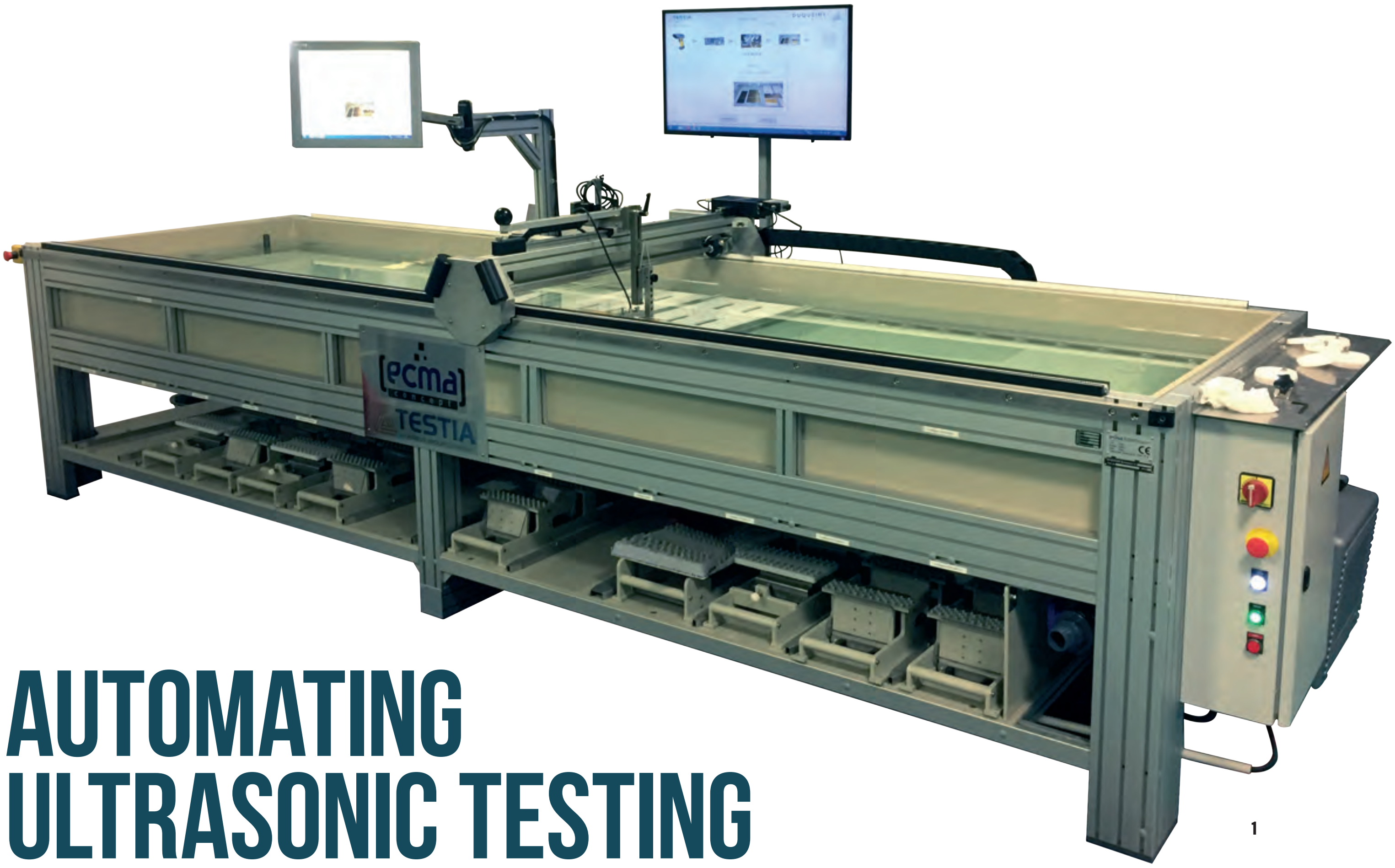
EXAMPLE OF TESTS

In a rotary wing aircraft, the analysis of rotor joints on both top and rear are observed during full flight time. The aim of the test is to understand the mechanical behavior of the rotor joints in different flight situations. One camera is mounted on a structure on the roof of the aircraft and focused on the scene of interest, while the other camera is mounted beside the tail rotor focusing on the joints. The single cable runs back to the cockpit, where a flight engineer has full control over the cameras, along with a live view on the tablet. After take-off, recording of both cameras is started with one single click, and individual sequences while exercising flight maneuvers are stored for later analysis. Furthermore, the system delivers synchronized image data of the tail rotor and main rotor. Later, the sequences are analyzed playing back on a simple PC for qualitative analysis. If required, the image data can be analyzed using motion analysis programs to get quantitative data as well.

CONCLUSION

Modern camera and controller recording systems speed up inflight, high-speed video procedures substantially and help to eliminate the need for extra standard-speed cameras. Taking this into account, along with the lower investment costs, these measurement systems are a powerful tool for a wide range of inflight tests. \\

Stephan Trost is the managing director for AOS Technologies



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AUTOMATING ULTRASONIC TESTING

Electronic and software solutions for ultrasonic NDT can lead toward greater automation and efficiency in the process

// **VINCENT BISSAUGE**

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Airbus A350 structure components suppliers are meeting demand by boosting their production capacity through the procurement of new production means, and/or by increasing their productivity. In the field of ultrasonic non-destructive testing (NDT) for composite components, the trend is toward automatic tests rather than opting for multiple technicians and equipment. Testia France offers various solutions that are suitable for customers' needs, from providing software assistance functions to a manual device through to conceiving complex automated cells.

To automate data collection and analysis, Testia relies on two technological building blocks that are flexible and customizable. The first is Smart NDT Tool, an electronic and software ultrasonic and eddy current platform, which can be set up both as a standard device and as a specific solution for a given procedure. The second is Ultis, software dedicated to ultrasonic testing data analysis, which can automatically generate reports. The combination of these two standard solutions combined with a customized and specific program is of great help to technicians in alleviating repetitive and time-consuming tasks and can do complex operations autonomously. Thanks to their adaptability, these assistance and software automation principles can be applied to numerous situations and can be adapted to various performance requirements, while taking into account budget constraints and technicians' concerns for ergonomics.

The impact of implementing automation solutions built on these technological building blocks can be seen in several examples below.

The first case consists of automating the data analysis only, while collecting it manually by means of an independent device. The technician collects the data before loading it into a specific program based on Ultis which then carries out the analysis, produces a report and gives preliminary results. This method leads to drastically reduced analysis time, halving the cycle time while reducing the risk of error, even when using a manual installation.

In several other cases of manual installations, adding the Smart NDT Tool platform to a master program brings an additional degree of automation. The operation is no longer entirely manual, but guided, thanks to step-by-step assistance, which the technician simply has to follow. This solution takes over the component's traceability from reading the barcode to issuing the report as well as looking after data archiving and creating an inspection follow-up file.

Automating data collection can go even further on some automatic devices or special machines. The use of motorized mechanical axles allows an automatic calibration on reference standards as well as the automation of data collection cycles. This cycle must be launched by the technician, but is entirely autonomous; the displayed results will allow the technician to authorize the expertise to carry on.

1 // Example of manual UT scanning system of composite parts with high software assistance

2 // Software GUI for a step-by-step preparation and calibration

3 // The step-by-step C-scan acquisition of a batch of 10 parts with a software GUI

3

"ULTIS ... CAN EVEN CARRY OUT COMPLEX OPERATIONS AUTONOMOUSLY"

Finally, integrating those solutions into a robotized cell overseeing the whole testing process is the highest level of system automation and autonomy. This solution when applied to high paced needs can be comprised of other end-of-manufacturing range processes. Experts continue to supervise operations and carry out the ultimate testing and validation steps that cannot yet be automated.

The view presented here, involving methods that consist of assisting and automating a test's different stages via software support, is versatile and progressive. Hence it can be applied to a manual device as well as a robotized solution; it can even be considered for gradually converting a piece of standard testing equipment into a competitive and ergonomic solution. Moreover, automation techniques seem to be more and more powerful, prompting us to consider developments for the not-too-distant future, such as a database management system that enables a statistical approach or even the integration of further AI algorithms to complete tests that are still essentially supervised by human overseers. \\

Vincent Bissauge is a technical sales engineer at Testia France

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RECORDING TOMORROW

Knowing what test engineers require in a data recorder has influenced the ongoing development of recording solutions

// MICHAEL SCHWEIGART

The WX-7000 series of instrument data recorders is designed to provide multichannel, high-bandwidth recording solutions for the testing and monitoring requirements of aerospace, defense and industrial acoustics/vibration-based applications. TEAC has been providing data recorders for the aerospace testing market since the reel-to-reel tape era and continues to develop and provide machines that use the latest and most reliable technologies.

In the past, PC storage capacities were small and data transfer rates were slow. In aerospace testing many signals are recorded at high sampling rates, but earlier computers did not have a high enough performance level to record the volumes of data. Instrument data recorders were therefore the main data acquisition system and the files created were analyzed on a computer after the testing was completed. Now the ubiquitous PC is the front end of the acquisition system, analyzing the data in real time, while the instrumentation data recorder has become the important backup system.

FEATURES AND CONNECTIONS

The TEAC WX-7000 series has many features that enable it to provide reliable data recording with protection from catastrophic data loss, including a wide dynamic range and high resolution. A unit can have 128 channels and synchronization between two units enables 256 channels to be recorded. The WX-7000 offers a longer recording time than is possible with tape recorder technologies.

Connection to sensors is eased by support for the transducer electronic data sheet (TEDS) standard, while data is stored on a reliable recording medium using an RDX server-grade removable disk. The operational interface is intuitive, using a 3.5in color LCD for user-friendly operation.

DATA SAFE STORAGE

To ensure failsafe recording, the WX-7000 closes the data file after every minute while recording. Even if an unexpected or mistaken power outage occurs, the recorded data is saved from the minute before the power loss and is available for playback after the event.

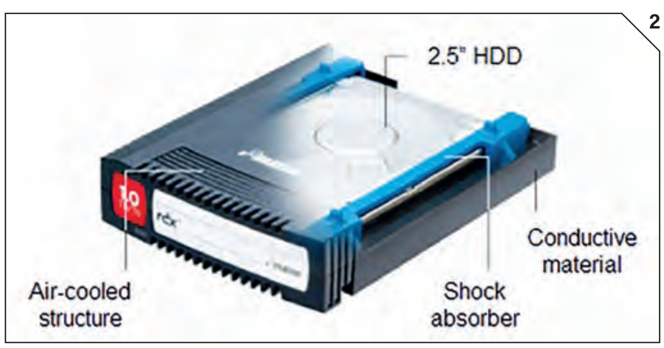
APPLICATIONS

TEAC WX-7000 data recorders have been used for developing the Japanese LE-X rocket engine. Vibration testing and analysis is one of the most important parts of development. If levels exceed certain thresholds, vibrations might lead to decreased engine efficiency and damage.

"IT PROVIDES RELIABLE DATA RECORDING WITH PROTECTION FROM CATASTROPHIC DATA LOSS"

1 // The WX-7000 main unit, shown with 16 channels, is configurable to 128 channels using eight 16-channel input/output cards

2 // Data is stored on an RDX server-grade removable disk



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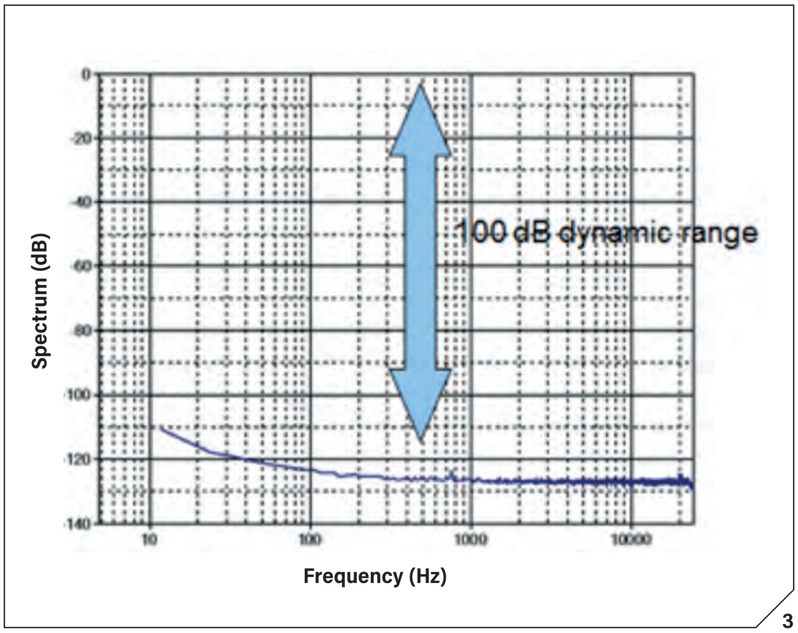


3 // The dynamic range of the WX-7000 is over 100dB

The test data collected can increase the reliability and durability of components, but they have to be performed under the same conditions as encountered in flight, such as extremely low temperatures, high nozzle pressures and high rotation forces when the rocket is launched. The time and cost involved in this kind of testing needs dependable and secure data recording.

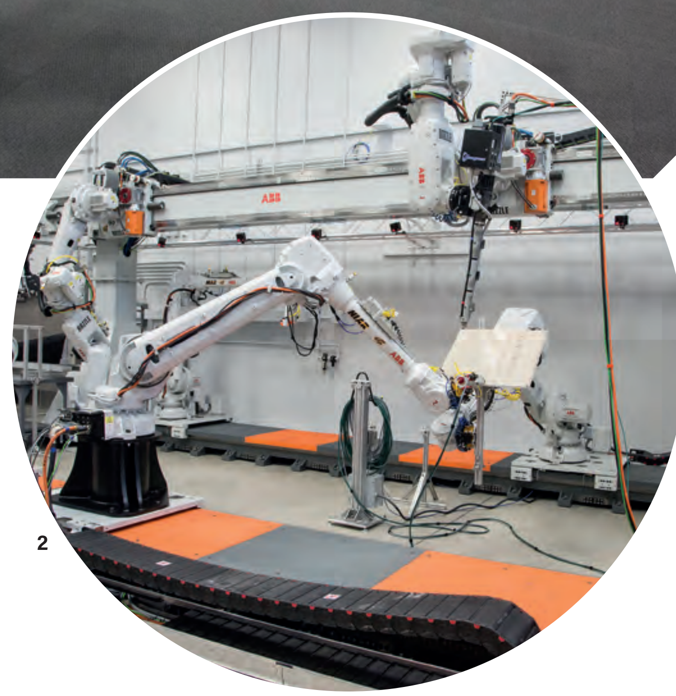
Turbomachinery and jet engine makers use the data recorders when testing for rotational balance to lessen shaft vibration, and they are also used during inspections. These applications employ the WX-7000 series with a PC front-end system running real-time analysis software. The recorded raw data is transferred to a PC via gigabit Ethernet in real time and to the WX-7000 to ensure safe data backup. \\

Michael Schweigart is division manager at TEAC Europe

FACTORY OF THE FUTURE

The 3DExperience Center combines advanced manufacturing technology, including a 3DExperience platform, reverse engineering, additive manufacturing and robotics, to shorten and streamline the manufacturing development process

// TRACEE FRIESS AND JEFF SMITH



The 3DExperience Center, a partnership between Dassault Systèmes (DS) and Wichita State University's (WSU) National Institute for Aviation Research (NIAR), was recently established as an interconnected community of researchers, corporations and laboratories designed to accelerate the ability to innovate – from initial requirements through production and into operations – while facilitating certification, the entire time.

Located in Wichita, Kansas, the center enables NIAR experts, known for their pioneering work in composites and the certification of 3D printed parts, to work with DS's expertise and solutions to help manufacturers digitally reinvent the way they approach advanced product development and manufacturing. It helps companies engage in advanced product development and the manufacturing of next-generation materials and technologies. Bringing together the virtual and the real, the center delivers unique capabilities to nurture novel ideas from initial concept to take-off.

"Together with Dassault Systèmes, WSU is fueling the future of aviation by providing new technologies and collaborative design methods for our students and enabling them to put theory into practice," says John Tomblin, WSU vice president for research and technology transfer, and NIAR executive director. "What we are striving for is to erase the thought that something is not possible. By combining virtual and real technologies, the sky becomes the limit. We want to challenge the future and make the impossible not only possible, but bring it into the real world."

The center's key components include the 3DExperience platform, customer collaboration rooms, the largest flexible cave in the world for 3D immersive reality, additive manufacturing, Multi-Robotic Advanced Manufacturing (MRAM), reverse engineering and inspection.

1 // The UAS model developed in 90 days

2 // Multi-robotic advanced manufacturing at the 3DExperience Center

The platform enables aerospace companies to work together simultaneously across multiple disciplines. Now program managers, engineers, manufacturers, testers and suppliers, together at every stage of the program, can understand design trade-offs, manufacturing constraints and program impacts.

Customer collaboration rooms accommodate teams of up to eight people. These rooms feature high-resolution screens, web conferencing and other collaboration tools, along with the full suite of solutions from DS.

The flexible 3D immersive reality cave delivers experiences as they are being designed, enabling manufacturers to

"WE ARE STRIVING TO ERASE THE THOUGHT THAT SOMETHING IS NOT POSSIBLE"

explore new designs and see the results of multiple simulations, including bird strikes and multi-physics analysis.

Additive manufacturing allows engineers to create custom parts as well as optimize standard parts for cost and weight – typically resulting in a 70% or more reduction in cost and weight.

MRAM makes it possible to explore any shape without restriction, reducing waste by up to 90%, and to optimize manufacturing techniques using the latest in robotics. MRAM can 3D print chopped fiber composite, mill, scan and execute many other advanced manufacturing techniques to accelerate production, lower the number of parts, and eliminate manufacturing waste.

3 // Virtual simulation at the 3DExperience Center

Reverse engineering and inspection enables engineers to scan complex parts to create new virtual representations, as well as to inspect new parts for certification and quality control.

DELIVER A SYSTEM IN 90 DAYS

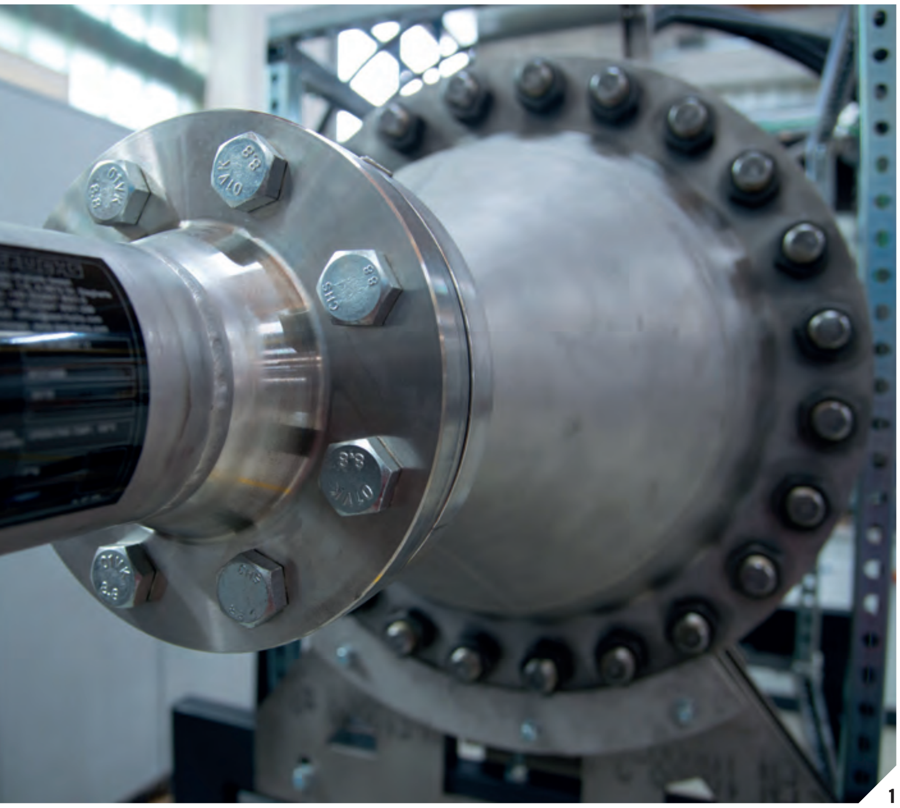
The first joint project at the 3DExperience Center was the development of a multi-mission, complex unmanned aerial system (UAS). The objective was to eliminate waste and shorten the development process. Creating the UAS with the 3DExperience platform and aerospace solutions, the team sought to reduce the delivery time of a UAS (normally two years from concept to take-off) to 90 days.

A team of DS and WSU experts, including graduate students, used the resources available in the 3DExperience Center and throughout NIAR to develop a fully autonomous 13ft wingspan UAV with electric VTOL, a gas pusher prop, and multiple configurations.

The UAS was developed and tested virtually and structurally while the center was under construction. It is now in preparation for its first flight.

With fully operational labs in place, Dassault Systèmes will use its business platform and software technology to remove time lags and mistakes, and implement advanced product development methods and processes in order to prove that concept-to-launch of similar projects can be achieved in 90 days. \\

Tracee Friess is director of communication, WSU-NIAR, and Jeff Smith is director, Aerospace and Defense Ideas Lab, Dassault Systèmes



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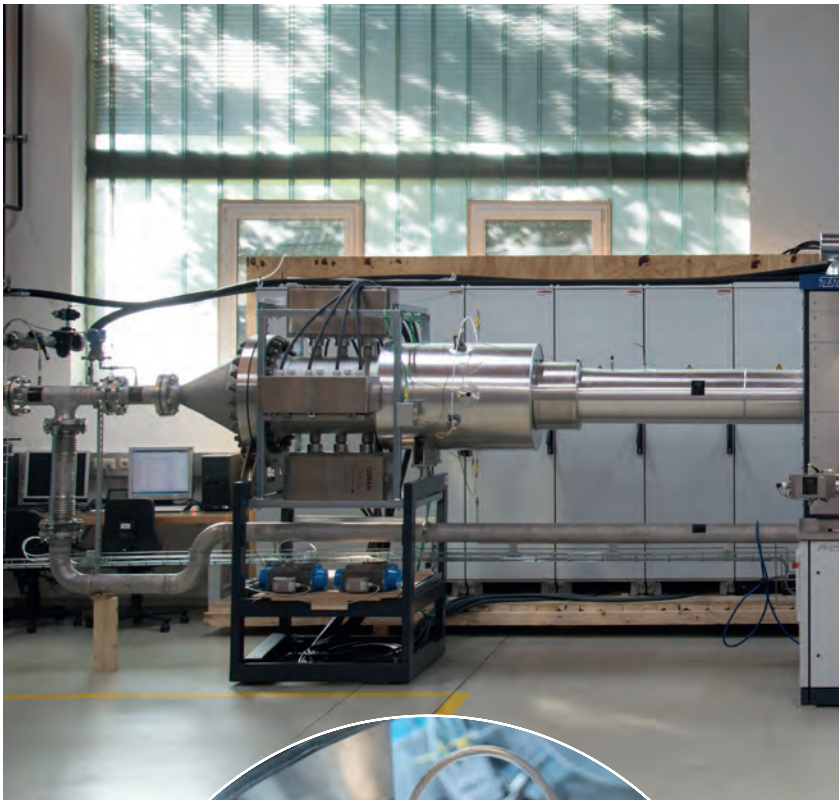


3

ACCURATE HIGH-FLOW HEATED TESTING

The Test-Fuchs PP250 pneumatic high-flow, high-heat test stand raises the bar for high-flow test systems around the world

// **ISRAEL RICHMOND**

Having passed its customer acceptance test with flying colors in June, the most advanced pneumatic high-flow, high-heat test stand yet is now being installed in Tulsa, Oklahoma. The PP250 High Flow Pneumatic Test System, manufactured by the Austrian company Test-Fuchs, is reliable and highly accurate, and designed for multiple scenarios that require a broad range of air flows. The system supports the testing of electrical and pneumatic control valves for bleed air and trim air applications for a multitude of aircraft and strictly follows the directives outlined in the maintenance manuals. Moreover a range of tests on various connectors and anti-icing valves can be performed with little effort, thanks to the test stand's user-friendly operation.

The overall system consists of high and medium-pressure air systems, the electrical heater and the test system itself. The compressed air supply gives the test system either high- or medium-pressure air flow, which is electrically heated and sent through the controlled testing loop.

The advantages of the PP250 include a compact and sophisticated design for reliable testing with excellent accessibility for operation and maintenance. The unit features a user-friendly interface and operation with customization possibilities, and benefits from custom in-house designed high-performance control valves.

The sleekly designed PP250 boasts features including 800°F (427°C) operating temperatures, 315psi (22 bar) operating pressures and flow rates of 250 lb/min (114kg/min). All three parameters are separately controllable, to support a variety of test objects with different test requirements and even at different supply pressures. The performance of the test

"THE PP250 IS DESIGNED FOR MULTIPLE SCENARIOS THAT REQUIRE A BROAD RANGE OF AIR FLOWS"

1 // The air intake and 1200kW electric heater

2 // The clean design of the Test-Fuchs PP250

3 // Customer acceptance tests at Test-Fuchs' headquarters in Austria

2

system and the precise accuracy of the parameters are greatly improved by the in-house designed valves. These operate with positioners and replaceable valve disks and feature excellent position feedback, <40ms valve actuation, 1/10,000th positioning accuracy over the operational range (a 20mm operating displacement would result in an accuracy of 2µm) and an integrated superimposed feedback control loop.

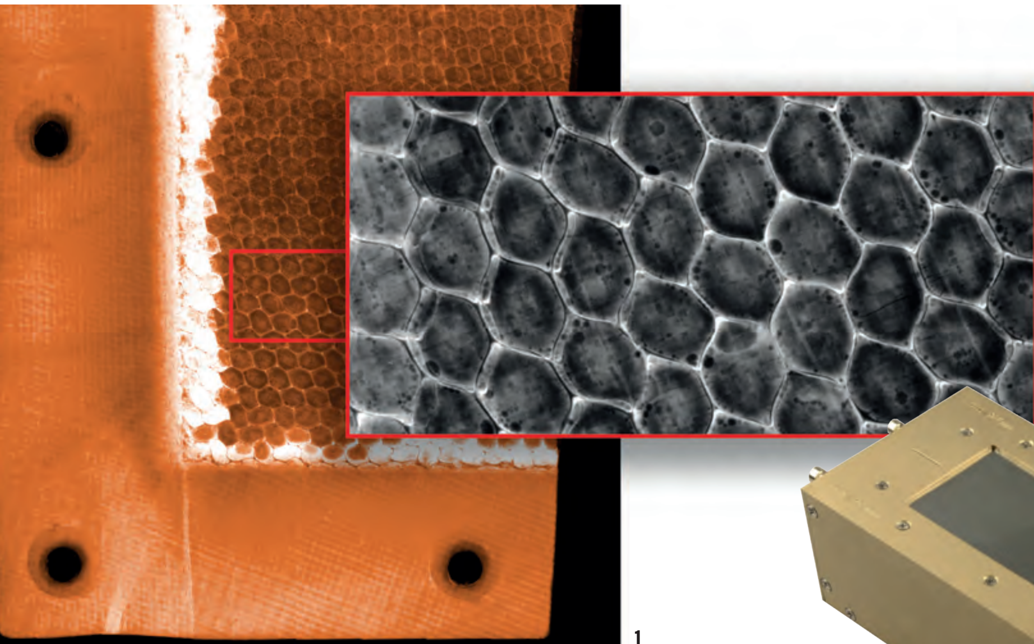
Both pneumatic and electrically controlled bleed and trim air platforms are supported. The interchange among the broad range of compatible components is fast and friendly. The designers of the PP250 engineered ways to quickly cool off the units under test (UUT) and capture the heat to reduce downtime and increase energy efficiency. They also found unique ways to improve the connection clamps to reduce risk of injury due to captured heat.

This is all evidence that operator interests and user experience have been at the forefront of this design.

The initial operation and customer acceptance test took place at Test-Fuchs' headquarters north of Vienna. This gave the advantage of fast fine-tuning by qualified technicians and resulted in acceptance within two days and a consequently short delivery period.

The aerospace industry has few limits on ambitions to push the envelope and Test-Fuchs is one of a few premium-level suppliers that has shown it provides superior aerospace test capability all over the world. Test-Fuchs has nine additional service offices in Europe and Asia and in 2017 started a second production line in Cleveland, Ohio. \\

Israel Richmond is head of sales region Americas at Test-Fuchs



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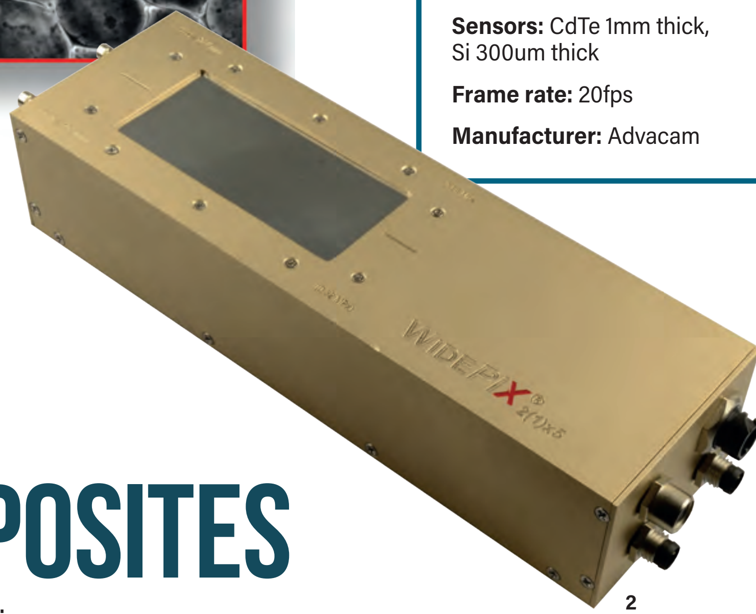


2

WIDEPIX 2X5 PHOTON COUNTING DETECTOR

Pixel array: 512x1280

Pixel pitch: 55µm

Sensors: CdTe 1mm thick, Si 300um thick

Frame rate: 20fps

Manufacturer: Advacam

CUTTING-EDGE X-RAYS FOR COMPOSITES

Inspection of CFRP is improved using x-ray imaging detectors with 'clever pixels' that are capable of processing every photon detected

// JOSEF UHER

Tough, light and reliable materials are of great importance to the aerospace industry. The new generation of x-ray imaging technology pushes the limits of detectable defects way beyond common non-destructive testing methods.

Identification of defects, impurities or cracks is essential in material non-destructive testing (NDT). X-ray imaging is a well-established tool for this purpose. However, most of the standard non-destructive testing (NDT) x-ray imaging systems are tuned for steel parts. Moreover, the common x-ray imaging technologies such as film, imaging plates or flat-panel detectors do not provide sufficient sensitivity, contrast and/or resolution. Combination of both of these leads, in many cases, to a poor image quality for light materials. Therefore, the traditional x-ray imaging systems fail in the case of NDT of modern materials such as composites, resulting in a need for novel inspection technologies. Luckily, the next generation of x-ray imaging photon-counting detectors that are ideal for this purpose is here.

CLEVER PIXELS

These detectors have 'clever' pixels that contain electronics capable of processing every x-ray photon detected. This has major advantages for imaging, since the photon-counting detectors do not suffer from the same electronic noise that deteriorates the image quality in commonly available devices. Moreover, the pixel electronics can be combined with very sensitive CdTe (or CdZnTe - CZT) sensors with thickness of 1-2mm, while still maintaining high resolution (the pixel pitch is 55µm). Moreover, the pixels can also measure the wavelength of x-ray photons, opening new possibilities for the recognition of different types of material in inspected samples.

IDEAL FOR COMPOSITE NDT

The novel photon-counting x-ray imaging detectors are produced by Advacam, a

1 // X-ray of a honeycomb structure clearly showing bubbles in the glue attaching to the substrate

2 // Advacam's WidePIX 2x5 photon counting detector

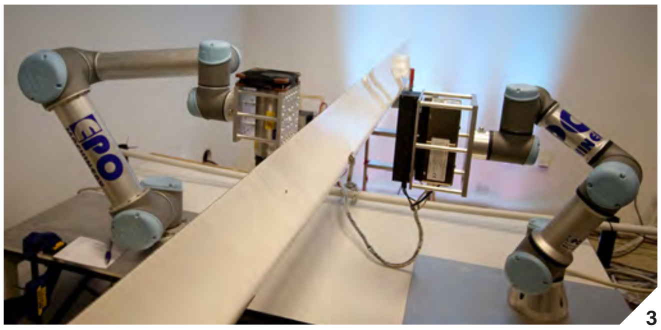
3 // Robotic system inspecting a glider aileron. The robot on the left holds a compact x-ray tube. The x-ray imaging detector is mounted on the robotic arm on the right

4 // The final x-ray image reveals voids and impurities in the internal structure

Prague-based company that was founded in 2013. A high-tech spin-off of an academic institution, it is commercializing Medipix/Timepix technology that is under development at the European Organization for Nuclear Research – known as CERN – in Switzerland.

Advacam brings to the market a whole range of x-ray imaging devices. The detectors are optimized for a variety of applications, the most important being the inspection of composites such as carbon fiber reinforced polymers (CFRP).

Composite NDT takes advantage of the detector sensitivity to lower x-ray energies, which provide the best contrast in composites and carry the most information about the internal structure. Therefore, light materials such as carbon fibers and epoxies are easily revealed in greater detail. Defects such as porosity, foreign objects and micro-cracks are easy to detect, with resolutions of 55µm or better. Even challenging defects such as deep laminate wrinkles, kissing bonds and delamination



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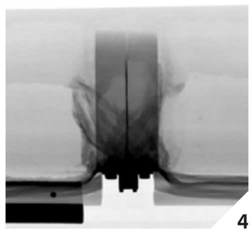
can be found thanks to the excellent sensitivity of these novel devices. Combining sensitivity to low x-ray energy photons with the very high dynamic range of photon-counting detectors creates a powerful tool for NDT. Advacam has confirmed that spectral imaging in the x-ray region means measurements such as the ratio of fiber to resin can be accurately achieved.



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ROBOTIC SCANNERS

The power of novel imaging detectors is further expanded by robotized scanners that are being developed by Advacam's partner company, Radalytica.

"DEFECTS SUCH AS POROSITY, FOREIGN OBJECTS AND MICRO-CRACKS ARE EASY TO DETECT, WITH RESOLUTIONS OF 55µM OR BETTER"

In classical x-ray imaging systems, both the x-ray tube and the detector are fixed, or move only in a limited range of directions (left, right, up, down).

Computed tomography systems also include only a single-rotation axis. It is not easy, or possible, to inspect some areas of larger structures, especially when they have complex shapes.

Contrary to the classical x-ray imaging setups, the robotic system gives nearly absolute flexibility of viewing angle. Robots allow full examination of parts using x-rays from different perspectives to better identify and localize defects. 3D imaging techniques such as computed tomography or tomosynthesis when combined with robots overcome the limits of using these techniques on large complicated shapes. Robotic systems could be used in quality control or built into production lines. \\

Josef Uher is the CTO at Advacam

2

ELECTRICAL TESTING: ELIMINATING BOTTLENECKS

3

The latest testing technology enables real-time validation of harnesses and connections as they are constructed in the aircraft, enabling OEMs to redefine the production process and achieve notable time savings

// JASON EVANS

Manufacturing teams are commonly seeking ways to reduce the amount of testing and asking if they really need to test. The reality is not a desire to eliminate testing, but to stop the test phase bottlenecks. The question is, "How can I test more effectively, more efficiently, in order to reduce the impact on production?"

What testing is effective and necessary and how can data be used to eliminate or reduce it? Working with MK Test Systems, time-consuming delays can be eliminated or reduced by integrating testing into the build process.

Aircraft OEMs have always tested their installed electrical systems. The extent of this varies according to the OEM and program, but typically includes tests for continuity, low voltage isolation, high voltage insulation, electrical bonds, and a degree of function testing of components such as switches, breakers and relays.

Unfortunately, in many instances the test report has been limited to a simple pass/fail. In MK's systems, all data is collated as a measured value and made available in a database that can be interrogated using a range of custom analysis tools, including the company's latest report analyzer.

This data provides an in-depth understanding of the kinds and regularity of specific types of failure and an opportunity to design out the causes of faults. The effect of moving specific tests to other production stages can also be accessed. A harness fully tested in the shop may not need all tests repeated at the installation stage.

A test system that tests the harness and active components in a single pass (MK's Multi-Bus Technology), may have the potential to carry out all testing without waiting for the aircraft power-up test.

1 // MK RTS systems are typically used in aircraft wiring harnesses for initial manufacturing testing and for final assembly tests

2 // Measurement Signal Routers (MSR) are installed where black boxes or avionics units will be fitted

3 // Remote Signal Return (RSR) modules are installed at the ends of wiring harnesses

The MK Results Database and Report Analyzer toolset uses statistics and data to quickly and visually identify common faults and changing trends. This can highlight material batch issues, changes in supply chain quality, and specific training needs.

The tool also identifies tests that never fail, enabling decisions on whether the test is stringent enough, relevant, or required at that stage.

A customer recently found that by increasing the stringency of high-voltage (HV) testing at the harness shop, there was no need to test HV insulation resistance during equipment installation and he implemented a smaller number of final HV checks on the final assembly line – resulting in a massive time saving, at a pressured stage of aircraft production.

The MK Database and Report Analyzer toolset has been developed to support

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industry's move to digitization and big data through paperless test processes and use of this information to improve processes.

In-production testing can be integrated, avoiding a test stage bottleneck, by using MK's RTS real-time scanning solution (RTS), which is a step change in testing technology and methodology.

This system's small modules fit directly onto the harnesses connectors. Remote signal return (RSR) modules are fitted to the ends of harnesses prior to installation – typically during manufacture.

Measurement signal routers (MSR) are installed where black boxes or avionics units will be fitted. A number of main control modules (MCM) are located around the fuselage or vehicle, and connected to the input ends of the harnesses.

These MCMs generate current, measure volt drop, and control access switching into the harnesses. As harnesses are fitted into the aircraft and connected to form complete wiring network legs, the MCM 'sees' the RSR via the MSR and measures the resistance of each connection made.

The result is compared to the netlist (in real time) and reported as a 'completed leg' and a continuity resistance pass, or it will show as a failed (unmade) connection. The MCM scans at up to 5,000 measurements/second – thus providing real-time scanning.

Multiple MCM modules can work in parallel, feeding into and measuring the wiring network, scanning many thousands of connections per second.

The beauty of the MK RTS system is that integrating testing with installation eliminates the testing bottleneck. \\

Jason Evans is sales director at MK Test Systems

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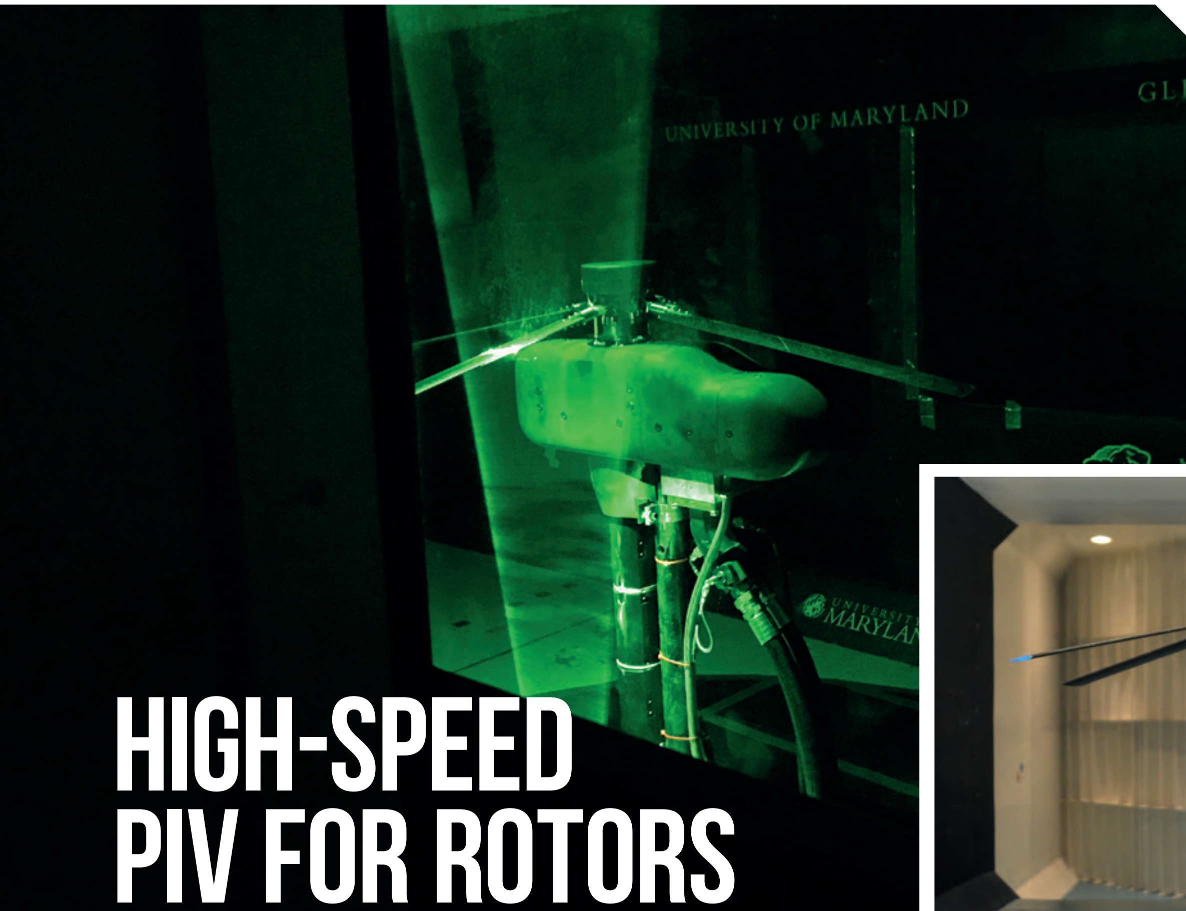

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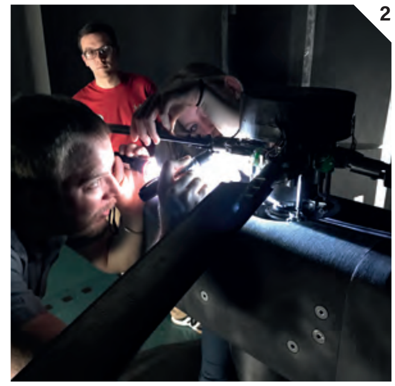
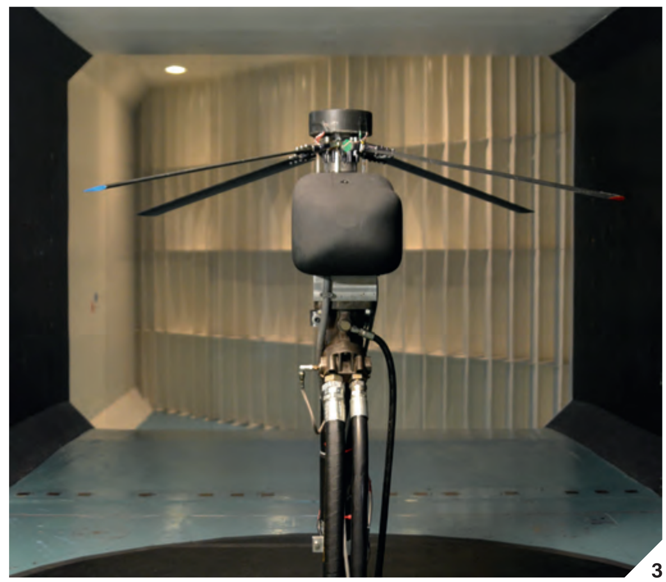


HIGH-SPEED PIV FOR ROTORS



3

The Glenn L Martin Wind Tunnel illuminates the complex aerodynamics of high-speed rotors

// **ANDREW H LIND AND JEWEL B BARLOW**

The Glenn L Martin Wind Tunnel (GLMWT) has been fixture at the University of Maryland (UMD), College Park, since 1949, offering research and development testing services on a wide range of land, air and water vehicles as well as antenna, signage and the US Olympic speed skating and bobsled teams. Additionally, the GLMWT has a long history of collaboration with the Alfred Gessow Rotorcraft Center (AGRC) at UMD to test Mach-scaled helicopter rotors in various flight conditions. The AGRC 6ft (1.8m)-diameter rotor is frequently tested in the GLMWT 11 x 7.75ft (3.4 x 2.4m) test section. Rotor tests have been performed at windspeeds over 160mph (258km/h).

In February 2017, staff at the GLMWT teamed up with AGRC principal investigators Dr Inderjit Chopra and Dr Anya Jones to collect velocity field measurements over a rotor using time-resolved particle image velocimetry (TR-PIV). Recent research in the rotorcraft community has focused on developing improved understanding of the performance, dynamics, and aerodynamics of a rotor operating at a high advance ratio (the ratio of the freestream relative to the rotor tip speed). The goal of the research is to inform the development of a new generation of high-speed helicopters that can cruise in excess of 300mph (480km/h). The test entry described here aimed to simultaneously gather measurements of forces and moments at the rotor hub, blade pitch angles, vibrations, and flow fields. UMD graduate student Lauren Trollinger led the rotor performance aspects of the test, while Dr Andrew Lind led the design and execution of the PIV effort.

PIV

The rotor test entry marked the first successful PIV campaign at the GLMWT. The technique of time-resolved PIV uses a high-power, high-speed laser to illuminate micron-scale droplets of vaporized mineral oil. Since the GLMWT was not initially designed to accommodate PIV equipment, modification of the test section floor was needed to provide a path for the laser beam. A lens was placed below a slit in the floor to diverge the beam into a thin triangular sheet (Figure 1). During data collection, the laser fired thousands of pairs of short-duration pulses, with each pair separated by a few microseconds. A high-speed camera was synchronized to the laser to capture the image pairs. A correlation algorithm was then used to determine the displacement of patterns of these particles, thereby producing a time history of the velocity field in a non-intrusive manner.

1 // The laser sheet illuminating the retreating side of the rotor during a wind-off run

2 // Trollinger and Lind work to darken the aluminum pieces of the rotor hub with the assistance of GLMWT co-op Noah Robinson

3 // The model rotor and fuselage installed in the test section, looking upstream toward the turning vanes

REVERSE FLOW

The objective of the PIV effort was to investigate the reverse flow region of a rotor operating at high advance ratios, between 0.6 and 0.9. Conventional helicopters typically operate at a maximum advance ratio below 0.4. At high advance ratios, the freestream flow exceeds the rotational velocity of the inboard portion of the retreating rotor blade. As a result, the flow locally travels backward over the blade from the sharp trailing edge toward the blunt leading edge. This is called reverse flow and is problematic because it causes downward-acting lift, increased drag due to flow separation, and strong torsion due to the rapidly changing center of pressure and the creation of unsteady flow structures. If we can better understand the aerodynamic

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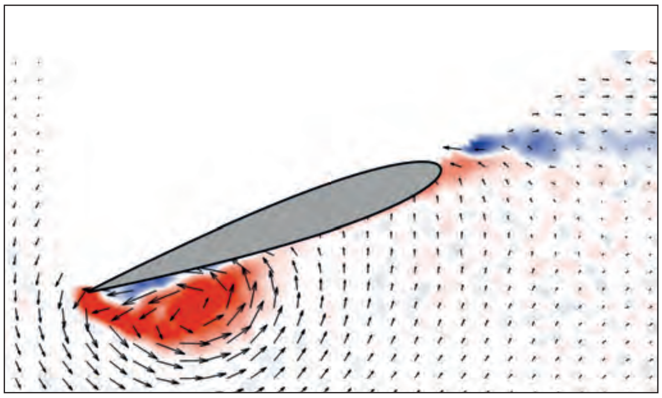


environment of the reverse flow region, we can target passive or active means to mitigate these unfavorable effects.

For this test, the laser sheet was positioned on the retreating side of the rotor disk to investigate the lower surface of the rotor blade – which serves as the suction side in reverse flow – as it passed through the field-of-view of the high-speed camera. The time-resolved nature of the setup enabled data acquisition rates in excess of 700Hz, perfect for highly unsteady flows such as those around rotor blades. This enabled new insight to be gained on the evolution of the four flow features in the reverse flow region. These start with the reverse flow starting vortex, which forms as a retreating blade first enters the reverse flow region; wake sheet forms due to bluff body separation. The reverse flow dynamic stall vortex then grows in size as it rolls up beneath the sharp trailing edge of the blade (Figure 4).

4 // One of the four flow structures that were identified during the test campaign is the reverse flow dynamic stall vortex

The results of the test were documented in a recent paper presented at the 43rd Annual European Rotorcraft Forum in Milan, Italy. The paper focused on the evolution of the reverse flow dynamic stall vortex, since it has the greatest influence on the unsteady blade surface pressure distribution. Those fluctuations manifest as vibrations and torsion loads that can fatigue the blades or pitch links – undesirable effects that need to be mitigated during the development of high-speed helicopters.

As this article was being written, additional time-resolved PIV tests were underway at the GLMWT to develop best practices in gathering large amounts of unsteady flow field data. Multiple sheet and camera positions will permit three-component measurement of larger flow volumes. GLMWT staff are also working toward synchronizing time-resolved PIV data with both time-resolved Vicon tracking and unsteady surface pressure measurements. Collectively these techniques will provide our clients with rich data sets that can be used to quickly pinpoint unsteady flow phenomena and their effects on unsteady loading and the resulting aeroelastic response. \\

Dr Andrew H Lind is an assistant research engineer and Dr Jewel B Barlow is director of the Glenn L Martin Wind Tunnel

PORTABLE, POWERFUL, UV LED INSPECTION LAMPS

A high-end rechargeable Li-ion battery pack with up to a 12-hour life is now available for all Secu-Chek handlamps

// **MARC BREIT**

Secu-Chek now offers a groundbreaking, lightweight, rechargeable Li-ion battery pack, the 'BION one', for all the handlamps in its H1 and H2 series. The battery pack powers the H1-09 lamp (3 UV LEDs) for 12 hours of uninterrupted UV inspection light operation. With a weight of less than 1.1kg (2.4 lb), it offers more than double the life of comparable NiMH battery packs. This high-end rechargeable Li-ion battery pack, with up to 12-hour life, is now available for all Secu-Chek handlamps.

The external battery pack is easy to handle. It offers various carrying and mounting options, due to the spring clip that is integrated in the robust aluminum housing and its shoulder strap option.

Because 'failure is not an option' for Secu-Chek's UV LED lamps, all qualified handlamps automatically switch off before performance and intensity is lost due to a low battery.

Secu-Chek's UVN and UVE handlamps, whether AC and/or powered with the BION one battery pack, fulfil all required specifications and full qualifications such as Airbus AITM 6-1001 Issue 11, ASTM E-3022, NADCAP, Rolls-Royce RRES 90061, Pratt & Whitney FPM-Master and many more.

The four-hour recharging time is shorter than the normal operating time of the UVE365 H2A24 FL (eight UV LEDs) handlamp, which offers an extremely large and uniform beam with soft radiation drop at the edges.

Secu-Chek UV LED Flood Lamps (FL Series) have extreme uniform irradiation areas with soft drop to the edges. In combination with their very short minimum working distances, these UV LED lamps allow much easier, faster and more reliable detection of fluorescent indications and their inspection, by enabling the full detection capabilities of the human eye. Further it gives the inspector an orientation on the working surface to ensure correct and complete inspection of the full area.

Several integrated features enhance the inspection process and make it more secure. Automatic white light dimming allows an uninterrupted observation of the indication. White light is slowly dimmed in and out – or crossfaded between the UV. This groundbreaking feature allows enhanced interpretation by the inspector without any stress to their eyes or the flash blinding caused by abrupt changes of the white light illumination levels.

An additional feature is an adjustable white light level where the illumination output at the end of the dimming cycle can be adjusted by the user and stored for the next usage. The automatic adaption time signal blinks for one, two or five minutes at every switch-on of the lamp. This feature makes an external timer redundant and prevents audit findings, because the usage of t he timer will never be overlooked.

The beam of the H2A24 FL offers a large central area (more than 1,200µW/cm^2) of 490cm^2 (75in^2) and a peripheral area (more than 100µW/cm^2) of 3,900cm^2 (600in^2).

Compared with the average mercury vapor lamp, the central area is more than five times larger and the peripheral area is nearly three times larger (measured at a distance of 38cm (15in)).

The battery pack and charger are manufactured in Europe. \\

Marc Breit is the managing director of Secu-Chek

1 // The UVE-H1-18 WFL has an extremely uniform beam with very short minimum working distance and soft drop-off at the edges of its illumination

2 // The BION one battery pack weighs less than 1.1kg (2.4lb) and offers double the performance of comparable NiMH packs

1

MODULARITY BENEFITS

Small, hot-pluggable modules provide flexible electrical testing to evolve with aircraft configuration changes

// ERIC BOISLEVE

2

An aircraft's electronics change throughout its life. Electrical systems often face obsolescence, either of the onboard equipment or because of the method of testing itself. The design cycles of electrical testing methods can be very short, and a tailored and powerful testing system is required.

This creates the need for testing solutions that are flexible and evolve to adapt to aircraft configuration changes over time. Such solutions need to adjust across the aerospace product's whole life – research and development, production, in-service operation and maintenance.

AEROSPACE ELECTRONIC MODULES

Based on smart electronic modules, T-Cell technology is capable of acquiring, generating and switching all types of aircraft electrical signals. This technology benefits from 30 years of ECA Group's experience in aerospace testing tools design, manufacturing and maintenance, including full hardware and software obsolescence management. Complex and oversized test benches are outdated in favor of compact and agile testing.

T-Cell modules are much smaller than traditional testing boards and achieve the same accuracy as larger standalone testers. In less than five minutes, hot-pluggable modules can be arranged to perform avionics bus and analog testing in and around the aircraft. Other benefits are easy maintainability and full obsolescence management over software and hardware.

The modular, streamlined architecture offers unlimited tooling form factors, ranging from hand-held testers with fewer than 10 test points to a distributed functional testing system handling more than 2,000.

For example, 50 T-Cells can be grouped in ECA Group's TB500 functional tester, reaching up to 500 testing points. With the hot-swap capabilities, operators are using it in aerospace assembly lines with an availability rate over 98%, reconfiguring modules depending on workflows.

A major benefit of compactness is test benches can be distributed in and around the aircraft rather than in a centralized system needing long test harnesses. By placing each testing bench closer to the aircraft, test harnesses get shorter, increasing system reliability.

This modular concept also enables the modification of testing hardware and software to handle aircraft design evolution, throughout the life of an aircraft program that typically lasts over 20 years with numerous upgrades. If modules become obsolete, they can be swapped for new ones with the same form and function without needing to redesign the entire testing system – which typically happens in complex electrical testing systems.

In a maintenance environment, the TC200 universal E-GSE (ground support equipment) allows the grouping of up to 200 testing points in a cabin luggage-sized tool, bringing complex and versatile testing

1 // The TB500 functional Tester uses 50 T-Cells to enable it to handle 500 testing points

2 // T-Cells are small, hot-pluggable modules providing flexible electrical testing that can evolve with changes to an aircraft's configuration

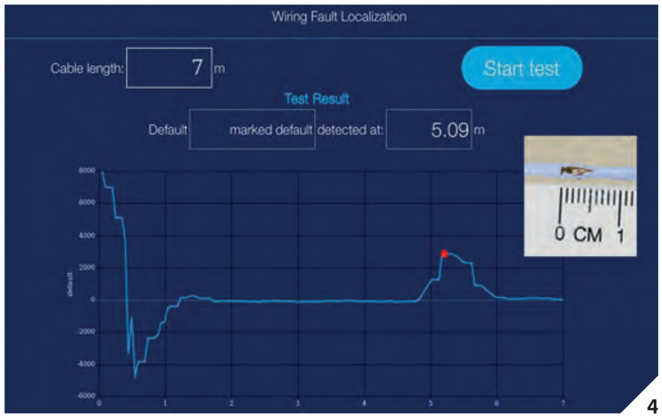
3 // In a maintenance environment, the TC200 universal E-GSE (ground support equipment) provides up to 200 testing points in a cabin luggage-sized tool

3

capabilities to the aircraft. Operators can conduct lower cost on wing tests with the precision of advanced automated equipment. It avoids the need to remove equipment or a computer for workshop testing while ruling out no fault found (NFF), and replaces multiple tools with one smart box that can interface with a maintenance database.

MODERN SOFTWARE INTEGRATION

T-Cell technology includes an embedded web server in one of the modules called T-Brain, which ensures communication with the outside world. This architecture is web-based and not PC dependent. Outside results are displayed as ergonomic web pages. It can be connected with other ground test systems, to receive automatic test sequences and broadcast results to databases. This data can later be examined in big data analyses.



4 // With the new orthogonal multitone time domain reflectometry (OMTDR) method, SmartCo-based modules can accurately detect wiring faults as scratches with millimeter precision

Based on the same architecture, ECA Group also formed a partnership with Nicomatic for the development of a solution to precisely locate wiring faults in any type of aircraft. As aircraft include more electrical functions, wiring harnesses play an increasingly important role in onboard systems. Testing these complex harnesses is a major challenge for aircraft manufacturing and maintenance.

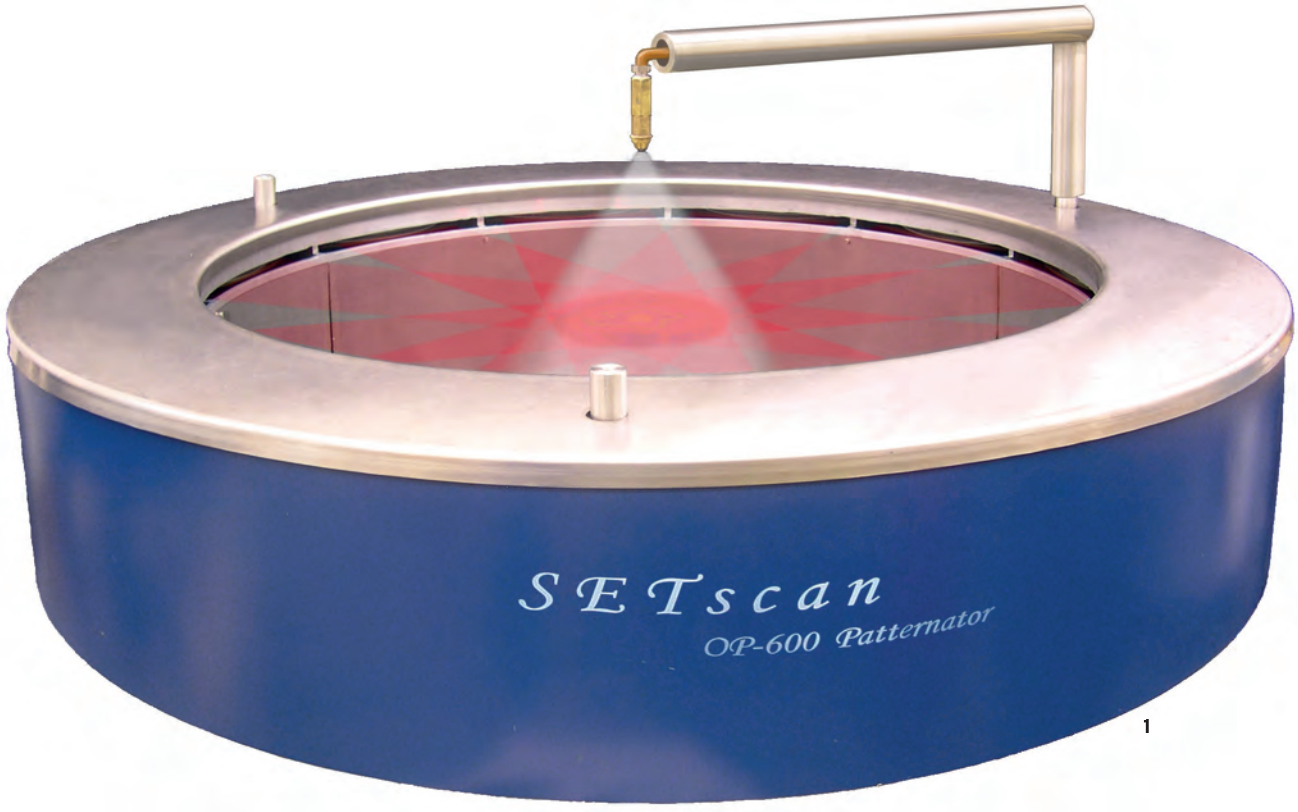
SmartCo uses reflectometry, a diagnostics method based on the principle used by radar. The innovation combines reflectometry with communication using the new orthogonal multitone time-domain reflectometry (OMTDR) method. This performs preventive maintenance function and detects faults in complex wired networks faster and more accurately than standard time-domain reflectometry.

PROVEN RESULTS

Thanks to its compact, modular and revolutionary design, test methods based on T-Cell technology are very popular with aerospace customers – over 10,000 T-Cell modules are in service.

Availability of new features and extended functionality means technicians and engineers will be able to perform their wiring and avionics testing operations with a user-friendly tool into the future. \\

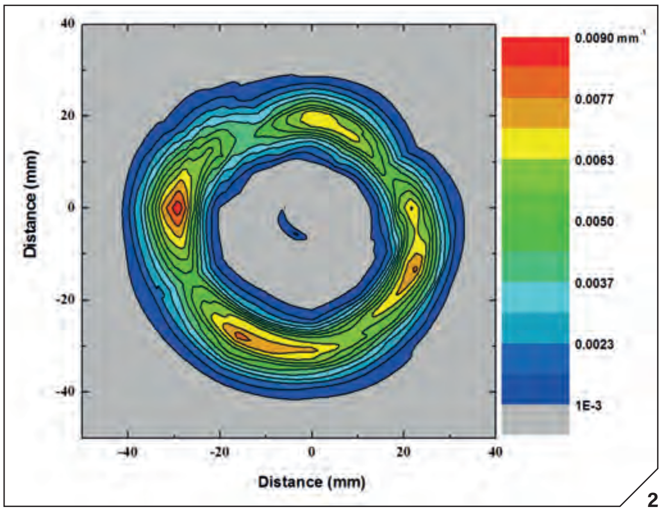
Eric Boisleve is sales and marketing director with ECA Group Aerospace Division



1

FUEL NOZZLE QUALITY AUDITS

Checking the quality of fuel nozzles during production is important. Recent advances in nozzle testing have also enabled testing of nozzles by MRO facilities



2

// **DR YUDAYA SIVATHANU**

Every nozzle that goes into an aircraft engine must have a rigorous quality audit. This test of the nozzle entails determination of the spray pattern, spray angles, steadiness of the spray, and comparative drop size. For many years, most advanced equipment for auditing the quality of aero-engine nozzles was owned by their manufacturers. Most MRO facilities only had mechanical devices for the quality audit of nozzles when the engine was undergoing an overhaul.

OPTICAL PATTERNATORS

Recently, optical patternators are being used for the quality audit of new fuel nozzles during production. There are several advantages to these optical systems, including greater repeatability, accuracy and reliability. The results from optical systems also provide the drop surface areas, a parameter that cannot be obtained with mechanical patternators. This information is important since the local combustion inside aircraft engines is directly proportional to the surface area of drops. Optical patternators provide much higher resolution and are easily operated by technicians. Furthermore, these units provide spray flutter and transient performance information that cannot be captured with mechanical systems.

"FUEL NOZZLES REMOVED FROM THE ENGINE DURING OVERHAUL CAN BE DIRECTLY EVALUATED AT THE MRO FACILITY"

1 // A typical optical patternator that is used for nozzle testing

2 // Surface areas of drops issuing from an aircraft engine nozzle

OPPORTUNITIES FOR MROS

One of the benefits of the optical patternator systems is that the fuel nozzles removed from the engine during overhaul can be directly evaluated at the MRO facility. The results can be compared digitally with pristine nozzles from the manufacturer. This eliminates any uncertainty in manually measuring spray parameters using handheld protractors and mechanical patternators. Only the nozzles that are found to significantly deviate from the original performance specs will need to be sent back to the manufacturer for reworking. \\

Dr Yudaya Sivathanu is technical director at En'Urga

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