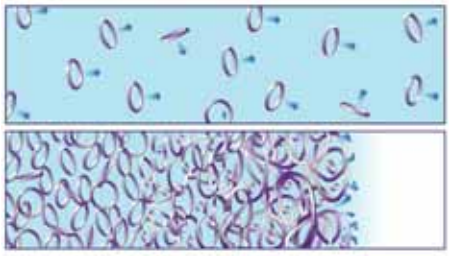
Technology update

Cool research into turbulence

From the earliest days of flight, wake vortices and the turbulence they cause have created problematic aerodynamic effects for aircraft and aerospace designers. Research continues into turbulence, its effect, and how to avoid or mitigate it. In fact, turbulence remains "the last great unsolved problem of classical physics," believes George Pickett, Professor of Low Temperature Physics at the UK's **Lancaster University**. To try and find that solution, he and his team, who are world leaders in the field of ultra-cold physics, are now using superfluids—generally regarded as nothing more than a curiosity—as a central part of research into a greater understanding of turbulence.

Superfluids make up a class of materials that exist only at temperatures close to absolute zero. Pickett describes them as the "simplest and most ordered" of all accessible materials. All their particles are in the same quantum mechanical state. Instead of each atom acting independently, they act in unison and endow the fluid with unique properties.



Research into turbulence at Lancaster University using superfluids has demonstrated interesting phenomena. The upper half of this illustration shows a low-density, fast-moving gas of independent vortex rings; below the rings coalesce into a sluggish, turbulent configuration at high ring densities.

Many of the properties of "conventional materials" are also seen in the conceptually simpler superfluids, making them ideal "laboratories" for studying what in other forms are very complex problems. "Amazingly, a superfluid cannot be rotated; it just sits there absolutely still whether or not its container rotates," said Pickett. "Its motion is irrotational."

However, when an attempt is made to rotate a superfluid, it can mimic rotation by developing an array of eddies—or vortices. "If you puncture a superfluid by vortices, then threads of rotation penetrate it along the vortex cores (where the superfluidity has broken down) but leaving the liquid outside the core still not rotating," he said.

Pickett believes that understanding the extraordinary properties of superfluids could help explain the phenomenon of turbulence that occurs from the subatomic to the cosmological, affecting, amongst other things, aircraft safety.

In ordinary turbulence there can be vortices on all scales, but the quantum nature of the superfluid means that they are all the same, or "quantized." Pickett and his team were amongst the first to observe quantum turbulence in a helium-3 superfluid and developed a technique to directly observe it by the simple method of moving a thin wire loop back and forth in the fluid.

Resistance was offered to the motion of the loop by the few atoms that had not condensed into the superfluid state. When turbulence was introduced, it shielded the wire and the resistance fell. The vortices threw shadows on the wire that could be photographed with a one-pixel camera.

Subsequently, the Lancaster team evolved a more efficient technique using wire mesh vibrated in the superfluid to cause agitation and generate turbulence with simple wire loops close to it. "What we found to our surprise was that gently moving the grid through the superfluid initially generated showers of micro-meter-sized vortex rings," said Pickett.

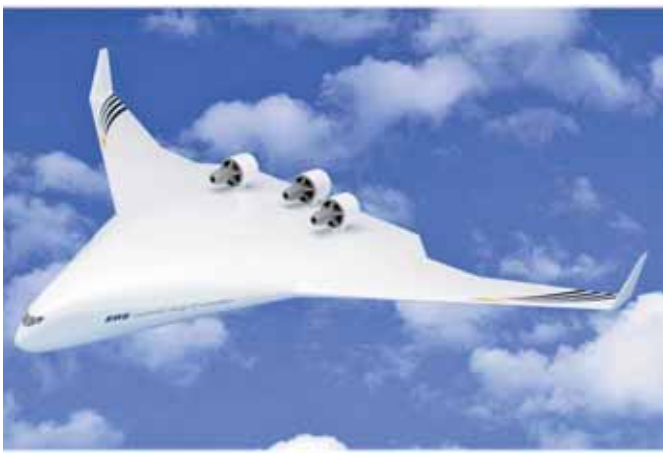
When the motion of the grid is halted, the vortex rings disappear almost instantaneously as each ring flies off from the grid without colliding with others. But if the grid is moved more rapidly, the turbulence disappears much more slowly—over about 10 s. The faster the grid moves, the more rings are produced. Eventually, so many are generated that they become entangled and coalesce to form random turbulence. "This coalescence is not unreasonable seen with hindsight but nevertheless was completely unexpected," he said.

Quantum turbulence is being studied in the U.S. and Japan as well as Europe. The big question yet to be answered is how quantum turbulence decays close to a temperature of absolute zero where there is no longer any friction and the decay must arise from purely quantum effects.

"While this work, close to absolute zero, is at present a long way from aircraft turbulence, the fact remains that there is no satisfactory fundamental theory of classical turbulence; to find a solution is quoted as one of the seven outstanding Millenium mathematical problems," said Pickett. "This work in a simpler material will hopefully provide another step on the way to a full theory."

Once that is established, focus could be placed on the type of turbulence experienced by aircraft, with possible significant contributions to enhanced safety, he believes.

Stuart Birch



A deep understanding of turbulence and its effects on aircraft aerodynamics remains a challenge for aerospace engineers. Complex research work is under way across the world and may lead to knowledge breakthroughs for next-generation aircraft, such as this blended wing body concept by Cranfield University.

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Getting fuel cells to fly

Fuel cells used to be the catch-all when it came to possibilities for power systems that would in the future essentially emit only water. But as observers began to notice that their viability in day-to-day mobility applications perpetually seemed to be 10 or more years away, hybrids began to grab most of that attention. This change in focus could be attributed to the fact that while fuel cells were mainly seen in print (*i.e.*, magazine and newspaper articles) or on a rocket headed to space, a hybrid could be in front of you in stop-and-go morning traffic or even parked in your own driveway.

Not that work on fuel cells stopped while hybrids were being driven in real time. **Delphi** in particular has never given up on the technology. "We were working with PEM [proton-exchange membrane] fuel cells when we were part of **General Motors**," said Bruce Moor, Business Development Manager, Fuel Cells & Reformers, at Delphi Energy & Chassis. "When we were spun off of GM [in 1999], GM continued with its PEM activity."

But Delphi changed strategy to take better advantage of its internal resources, and ended up focusing on solid oxide fuel cells (SOFC).

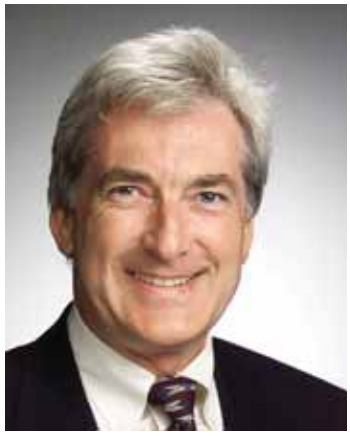
"In the near term we're looking at anti-idle applications for heavy-duty trucks in which the [SOFC auxiliary power unit] would negate the need to run the diesel engine for things such as the air conditioner, heater, radio, *etc.*, but the applications are endless," he said. "We have been contacted by [people in] the aerospace industry who want to put these things on airplanes. Pretty much anywhere you need electrical power, these can be used, with a payback in two to three years just in fuel savings alone."

Moor added that Delphi's process is about 35% efficient, whereas diesel gensets, for example, are about 15 to 17% efficient.

"The cell uses the same fuel as the vehicle and is itself made up of three main elements: the anode, cathode, and the electrolyte," said Moor. "When we say 'solid oxide,' we're really referring to the electrolyte, which is a ceramic material. You could just as easily call this a ceramic fuel cell."

The ceramic material allows oxygen ions to pass through it. Air is blown through the cathode to provide the oxygen. A fuel reformer inside the SOFC vaporizes the system fuel and a catalyst breaks the fuel into hydrogen and carbon monoxide. That gaseous mix is then fed through the porous anode, where it comes into contact with the electrolyte. The carbon monoxide combines with the oxygen ions to form carbon dioxide and the hydrogen combines with the oxygen to form water, and those are expelled out of the anode. Electrons are produced in the process, creating a voltage across the cell. Cells are stacked, generating an output of about 40 V that can be converted to another voltage, including 28 or 12 V, or even ac, for use as an auxiliary power unit.

Delphi is currently contracted with the **Department of Energy** (DOE) in a partnership with **Volvo Truck North America** and **PACCAR** to determine how to integrate the device into a heavy-duty on-highway truck for anti-idle applications, but "in the longer term, we'd like to have this [SOFC] take over all the electrical power for the vehicle," said Moor. "That step would mean we would off-load all the mechanically driven devices on the engine, such as pumps, fans, *etc.*, and run those electrically so you'd only use the engine for propulsion." The DOE has shown that an 8% improvement in fuel economy can be achieved if all the mechanical accessories are unloaded from the engine.



While Delphi has targeted from the start transportation applications for its SOFC, "The goal is to get to high volume, so we're designing in commonalities for both stationary and mobile applications," said Bruce Moor, Business Development Manager, Energy & Chassis, Delphi. "If you had one of these in your home, you could run it on natural gas to supply electricity to your house."

The third-generation Delphi SOFC now in development is about the size of an airline-authorized piece of carry-on luggage and capable of about 3 kW. But that will change. "In the future, the power will need to grow; we don't know yet to where," said Moor. "Maybe 10 kW will be suitable."

Moor uses refrigeration trucks as an example. Running the compressors electrically could make the system more fuel efficient by a power of about two. "Today's truck refrigeration units run at about 10 kW," he said. "We're not quite sure yet whether we need all that power because those are thermostatically controlled, kind of like your refrigerator at home. It comes on for a while, then it turns off. This fuel cell runs continuously, so in the future we might be better off powering the system down a little bit."

Besides heavy-duty trucks, Moor also cites uses for the 80-kg (176-lb) SOFC in recreational vehicles, construction and agricultural equipment, boats, military and utility vehicles, and aircraft. "The biggest adaptation problem for the different industries is the fuel itself," he said. "We have to change the reformer formulation of the catalyst for the different fuels, which include gasoline, natural gas, diesel, and JP8 for the military."

Jean L. Broge

Delphi was able to take advantage of in-house talent during the design of its solid oxide fuel cell for both stationary and mobile applications. The heat exchangers are from Delphi's Thermal & Interior division, the fuel injectors used for the reformer come out of Delphi Diesel Systems, and the electronics are courtesy of Delphi Electrical, Electronics, & Safety.

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Cool-running electric UAV motors

The Inventus E electric UAV is a robust flying wing platform developed by **Lew Aerospace** for detailed low-altitude reconnaissance. Its capabilities include autonomous takeoff and landing, catapult or air launch from a minimal clear area, manual parachute recovery system, and live downlink video cameras. Using an electric motor to power the UAV required system component optimization, including motor efficiency, battery power, and weight and thermal loading.

When the company first started using electric drives, motor failures were a problem, with the best mean time between operational mission failure (MTBOMF) of the motors being 15 hours, or about every 15 to 20 flights. Most of the flights achieved a much lower MTBOMF of 3 or 4 hours. Because it was unable to reach reliability targets with geared brushless dc motors, the company began testing direct drive motors from **ThinGap**.

The Inventus E features a cruise speed of 44 mph (battery life 120 min), maximum speed of 85 mph (battery life 20 min), range of 90 mi, and altitude of up to 10,000 ft.

Conventional motors can fail at high ambient temperatures, but the ThinGap motors seem to be immune to their effects. Lew Aerospace designs and manufactures in Las Vegas, where ambient air temperatures in July often reach 120°F. The temperature of an Inventus E waiting on the runway can exceed 160°F. When the motor stator runs at full power, such as for takeoff, the combination of ambient temperature and motor-generated thermal loads can cause magnets to demagnetize and windings to burn, leading to premature motor failure.

High altitude limits motor heat dissipation because the cooling properties of the air are much less effective due to its lower density. More often, a motor overheats because of misapplication. The leading cause of motor failure from overheating is a result of running at higher loads than the motor ratings, for example, using an undersized motor. This issue has become more commonplace as concern for energy efficiency and vehicle weight puts the emphasis on eliminating oversized motors.

The Inventus is a state-of-the-art reconnaissance system packaged in an efficient, highly stable flying wing constructed from composite materials. Able to fly manually or autonomously, the Inventus E offers a line-of-sight real-time video and flight link.

The inside and outside surfaces of the ThinGap coil used in the Inventus E are exposed to moving air inherently pumped into the gap by the rotor, allowing the use of more current without overheating the motor. There are no laminations or iron core in the ThinGap motor.

Most electric motors reach peak efficiency at 80% load. When the load is higher, such as climbing, the motor becomes less efficient and can use more energy than the correct or larger size motor. In effect, undersizing a motor uses more energy.

The ThinGap coil is mounted directly to an aluminum structure that provides a conductive heat path to the mounting surface. This, and because both sides of the coil are exposed to air and have dual radiation surfaces, provides improved cooling capability for the motor, which coupled with high efficiency reduces the amount of heat generated, allowing the motor to run cooler.

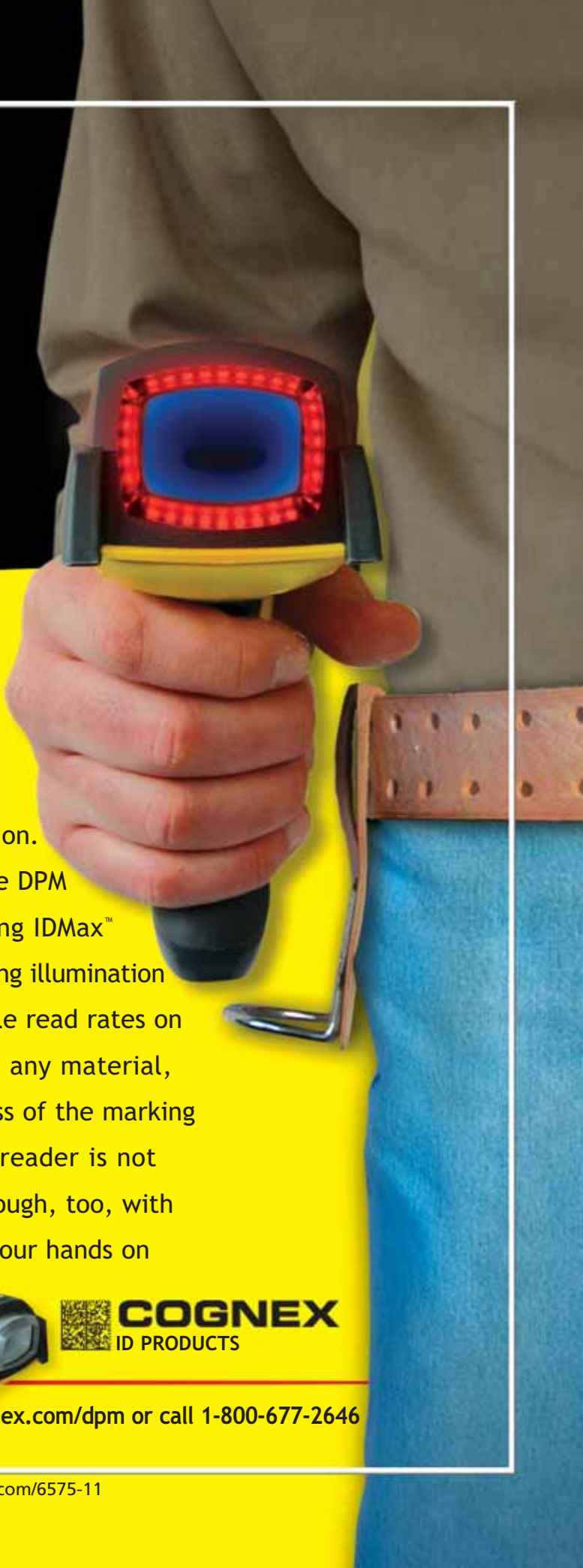
The inside and outside surfaces of the coil are exposed to moving air inherently pumped into the gap by the rotor. This air movement effectively dissipates more heat, allowing the use of more current without overheating the motor. There are no laminations or iron core in the ThinGap motor. By eliminating the iron core, eddy current and hysteresis losses are eliminated and efficiency is improved. The ThinGap motor has all the magnetic circuit rotating together. The rotor has more inertia because of this construction. This higher inertia reduces vibration and without the gearbox produces power with very little noise. These characteristics, combined with very low harmonics, enable the motor to deliver smooth velocity with quiet and cool operation.

Low heat gain, a secondary benefit of the low-loss design, allows intermittent (such as battery powered) performance at a high-energy conversion level and high power input. The efficiency of the motor remains high over a wide performance range.

Lew Aerospace uses TG 2300 ThinGap motors to power the props of the Inventus E at close to 10,000 rpm. The company was able to get some other motors to run under the same operating conditions, but they performed poorly and failed prematurely. The ThinGap motor operated the same whether the ambient temperature was 60 or 120°F without any failures. Additionally, it has flown its electric UAV in heavy rainstorms and found the motor is unaffected by water.

This article was written for *Aerospace Engineering* by **Paul Lew**, President, Lew Aerospace.

TOP GUN



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Are you sitting comfortably, firmly, safely?

Materials for aircraft interiors that offer new approaches to compliance with regulations on flame, smoke, and toxicity, including environmental mandates for flame retardants that eliminate the use of brominated additives, have been developed by **GE Plastics** in Europe. "These regulations have become increasingly strict following the 1998 crash of **Swissair** Flight 111, which was attributed to a cabin fire caused by faulty wiring," said a company statement from GE's Bergen op Zoom facility in The Netherlands. The company's Ultem resin has been developed to support regulatory compliance by providing inherent flame retardance without the need for additives.

Ultem resin is claimed by the company to protect aircraft cabin fabrics and carpet better than traditional textiles and non-woven types that are surface-treated with flame retardants and can, it states, "wash off over time."

GE's statement added that another application for fibers using Ultem resin is in composite panels used to attach seating to the cabin floor. The panels can be treated by mixing fibers made from Ultem resin with glass fibers. The hybrid yarn is woven into fabric by UK specialist **Carr Reinforcements**, and then heated and molded. It is said to offer enhanced design flexibility, reduced system costs through reduction of the number of components, ease of assembly—and flame retardance.

"A rule of thumb in high-tech industries is that the more advanced a component, the smaller it will be," said Bob Love, Technical Manager at **THK**, a linear motion guide producer. "But in the aerospace industry, it is also weight saving that is crucial and it is secondary systems that often offer particular scope for those savings. Reliability and maintainability are also crucial."

Slide packs used in aircraft for seat runners and for drop-down trays, drawers, and storage lockers may vary in quality, said Love, but fit-and-forget linear motion (LM) guides offer an alternative. THK works with industry partners to provide fully integrated systems comprising integrated LM guides, motors, power supplies, HMI, and cabling.

The design of a LM guide is based around a rail and carriage, incorporating balls and end caps, plus relevant seals, lubrication, and mounting mechanisms for the specific application. "Its function is typically to transport a piece of equipment the length of the guide rail smoothly and efficiently via ball bearing raceways that are mounted within the carriage, recirculating in a profile groove of circular arc geometry to give smooth motion with high levels of precision, repeatability, reliability, and control, particularly important in applications such as use in conjunction with ejection seat rails in military aircraft," said Love.

THK has also developed the Micro LM Guide (Type RSR 1 and RSR 2) with rail

Airline seats incorporating GE Plastics' Ultem resin are claimed to protect aircraft cabin fabrics and carpet better than traditional textiles and non-woven types.

Pilot/co-pilot and flight observer seats from Ipeco, designed for the Boeing 787.

Cutaway of a THK caged ball linear guide.

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widths down to 1 mm, making them the smallest LM guides available anywhere in the world, according to the company.

Flight deck and specialist crew seat supplier for commercial aircraft, **Ipeco**, has introduced an extra 15 software systems of their PLM (Product Lifecycle Management) solutions CATIA V5, ENOVIA, and SmarTeam to manage current products, **IBM** and **Dassault Systèmes** have announced, bringing the total PLM software systems count to 25. Ipeco plans to widen the exposure of SmarTeam across the company to increase collaboration between departments.

The solutions will help strengthen supplier/OEM links. Ipeco's crew seating incorporates adjustable vertical and horizontal lumbar support, specially contoured cushions, and angled seat backs, and needs to meet comfort and performance criteria for a wide range (weight and height) of users. Because of this, it is necessary to handle high volumes of anthropometric and ergonomic data during design and manufacture to ensure that each seat meets comfort criteria and is easy to operate.

Ipeco, a group of specialized engineering businesses, uses CATIA, ENOVIA, and SmarTeam to manage data for more than 20 current projects. CATIA V5 enables users to simulate the entire range of industrial design processes, while ENOVIA and SmarTeam allow manufacturers to manage their documentation and share and exchange product information. Ipeco's seats will equip the **Boeing** 787 Dreamliner.

Stuart Birch

Zephyr breezes in from QinetiQ

UK research and defense organization **QinetiQ** has an extensive unmanned aerial vehicle (UAV) program. In March, it completed the first flight trials of its solar-electric-powered Zephyr, a HALE (high-altitude, long-endurance) UAV that has a mass of only 27 kg but a 12-m wingspan. Two examples were flown from the White Sands Missile Range in New Mexico. The longest flight was for six hours, and maximum attitude reached was 27,000 ft.

The first flight trials of QinetiQ's solar-electric-powered Zephyr UAV were made this spring.

With solar panels on its upper wing surfaces linked to rechargeable batteries, and with a carbon-fiber airframe, the Zephyr has been designed to achieve a ceiling of 50,000 ft, keeping it clear of regular commercial aircraft flight levels and above most weather systems. In service, it is expected to demonstrate duration of several weeks and could stay airborne for months.

The Zephyr program has gone from concept to validated flight demonstrator in about two and a half years. It has been designed to meet civil, defense, and security applications including remote sensing and communications. It has been selected as the platform for the Belgian Verhaert Mercator HALE UAV system, a remote-sensing demonstrator to be used for mapping.

QinetiQ has also flight-trialed a lightweight, high-performance, robust experimental antenna that has enabled a helicopter to receive images at what is described by the company as "operationally useful" ranges, directly from a **Boeing** ScanEagle UAV. The antenna combines high gain and wide beamwidth, features normally deemed mutually exclusive although both are needed to satisfactorily receive weak signals from low-visibility transmitters.

For the trials, the antenna was mounted externally on the helicopter to demonstrate all-weather capability and ability to cope with intense vibration. It was developed from novel designs by QinetiQ for a smart commercial antenna.

The company's further UAV plans involve a demonstrator project based at ParcAberporth in Wales. The site, managed by the **Welsh Development Agency**, is being established as a UK center of excellence for testing and developing unmanned systems, with a particular focus on civil applications. The project aims are to raise awareness of potential civil UAV applications, identify possible users, and carry out preliminary work on civil certification for a number of UAVs.

"UAVs enjoy a long history of military use, but the additional benefits of the technology are only now being understood and appreciated," said Andrew Chadwick, Manager of QinetiQ's UAV Test and Evaluation Programs.

Stuart Birch

Morphing into next-generation aircraft

Athena Technologies, which has applied flight controls in UAVs that range from tactical to ducted fan UAVS, from target drones to missiles, is working with **Lockheed Martin Aeronautics** to implement the flight controls for Lockheed Martin's Morphing UAV. The Morphing UAV is part of **DARPA**'s Morphing Aircraft Structures (MAS) program, to which Lockheed Martin Skunk Works is a contractor. Morphing aircraft are also often referred to as variable geometry or polymorphous aircraft.

Athena's GuideStar UAV flight-control system uses solid-state sensors, including accelerometers, rate gyros, magnetometer, air data pressure, AoA, and sideslip sensors, as well as a differential-ready, WAAS-enabled GPS receiver for a full INS/GPS navigation solution.

The MAS program is tasked to develop ground-breaking technologies to radically change the shape of an aircraft's wings in flight to rapidly accommodate a new mission. For example, by expanding and contracting wing structures in flight, a single aircraft can perform both loitering surveillance and reconnaissance missions and high-speed attack missions.

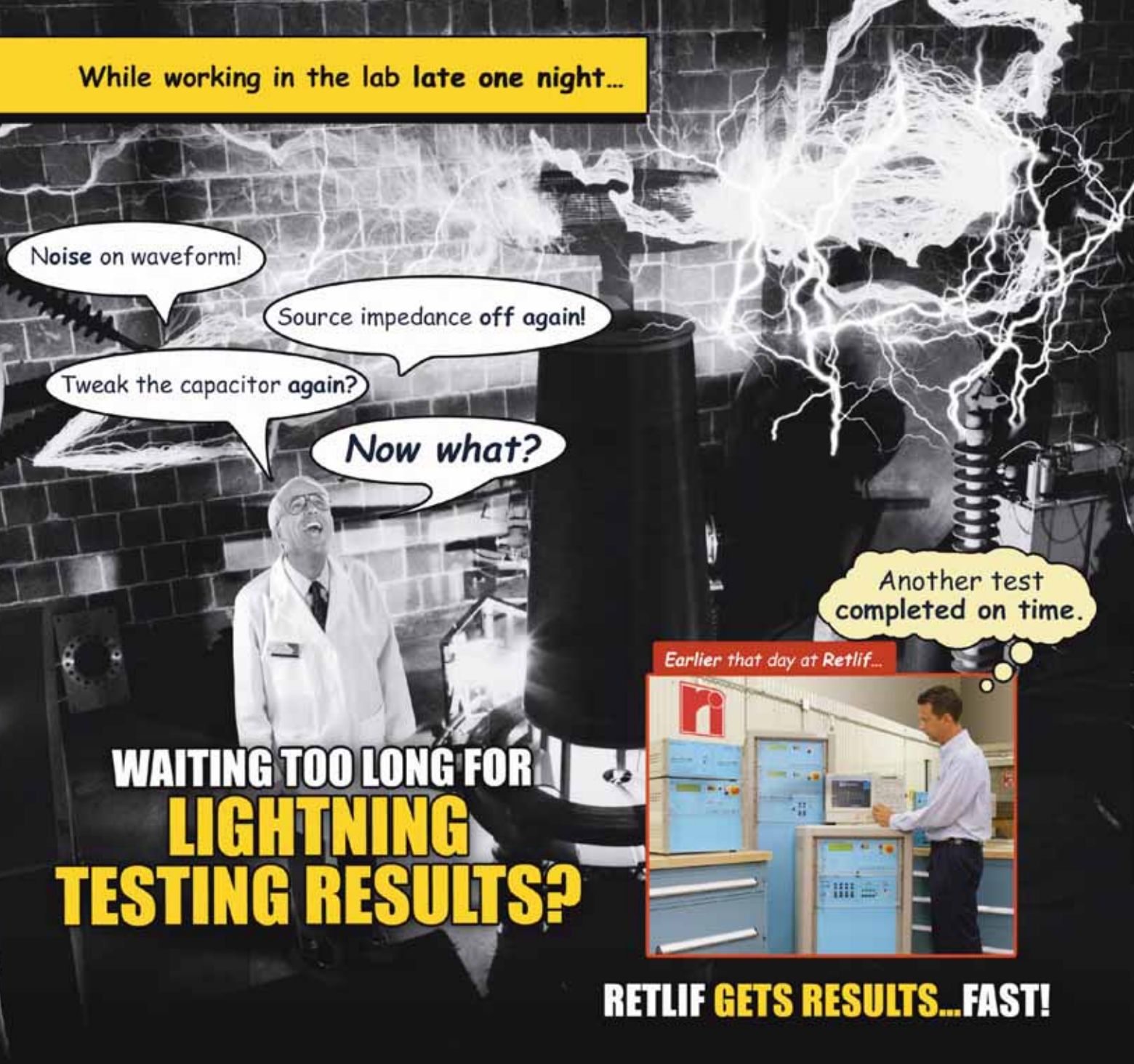
There are two primary technical goals of the MAS program:

- Develop active wing structures that change shape to provide a wide range of aerodynamic performance and flight control not possible with conventional wings, and
- Enable development of air vehicle systems with fleet operational effectiveness—including both **U.S. Navy** and **U.S Air Force** operations—not possible with conventional aircraft.

Athena is under contract to provide Lockheed Martin with its GuideStar navigation and flight-control system and integration. The GuideStar 111m is an advanced, miniaturized system specifically designed for small, high-performance UAV applications. It integrates navigation, control, and vehicle management in one unit and is described by the company as being "about the same size as a cigarette pack."

With a mass less than 0.5 lb, the GS-111m design is based on Athena's patented and proven flight controls technology, which it says has a "strong track record of reducing the overall life cycle cost of designing and developing multiple wide-ranging UAVs." The first flight of the Morphing UAV is scheduled for this summer.

Jean L. Broge



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Richard Reitz, Corporate Laboratory Manager
Retlif Testing Laboratories

Today's avionics equipment is required to comply with a wide range of electrical and environmental qualification test requirements. All major airframe manufacturers specify qualification requirements through their own standards or through variations of RTCA DO-160, "*Environmental Conditions and Test Procedures for Airborne Equipment*". Retlif Testing Laboratories, (locations in Ronkonkoma, NY, Goffstown NH and Harleysville, PA), is fully equipped to provide testing services for all Sections in RTCA DO-160. This includes environmental requirements such as Temperature/Humidity/Altitude, Vibration, Shock, Explosion, Sand & Dust, Fungus and Salt Spray and electromagnetic requirements such as Audio Frequency Conducted Susceptibility, Radiated & Conducted RF Emissions and Radiated & Conducted RF Susceptibility. Retlif is fully accredited for these methods in accordance with ISO 17025 by both NVLAP and A2LA to ensure the integrity and accuracy of our results. Of significant interest, and also within Retlif's scope of expertise and accreditation, is the ability of airborne equipment to withstand the effects of lightning induced electrical transients. The idealized waveforms and test procedures utilized to determine suitability of equipment are defined in Section 22 of RTCA DO-160.

The test methods specified in DO-160 are designed to evaluate two aspects of the design: 1) the damage tolerance of the device (will it work after application of the disturbance?) and 2) the functional upset tolerance of the equipment (will it continue to function during the application of the disturbance?).

Assessing Damage Tolerance
The damage tolerance of equipment is evaluated through the use of a pin injection technique. DO-160 defines three different waveforms which are selected based upon the composition of the airframe that the device will be installed in. These waveforms are designated in DO-160 as Waveform 3, Waveform 4 and Waveform 5A.

In addition to the waveshape of the applied disturbance, DO-160 also provides guidance re: the appropriate test level (Voltage and Current) to be applied. Test levels are specified (1 through 5) and guidance on their selection is provided. Pin injection test levels are specified in terms of open circuit voltage (Voc) and short circuit current (Isc), the ratio of which (Voc/Isc) defines the required source impedance of the transient generator.

Prior to testing, the open circuit voltage and source impedance of the generator are verified. Once calibrated, the transient generator level is set to the level required to open circuit voltage. The output of the generator is connected directly between the selected connector pin under test and ground. 10 positive transients are applied to the pin under test, followed by the application of 10 negative transients. This procedure is repeated for each waveform on each connector pin specified. Upon completion of each waveform, compliance with the applicable equipment performance standards is required in order to consider the test sample in compliance with the applicable standards.

Assessing Upset Tolerance
The upset tolerance of equipment is evaluated through the use of either a Cable Bundle or Ground Injection techniques. Five different waveforms are defined which may be applied singularly (single stroke), repetitively (multiple stroke) or in groups of repetitive transients (multiple burst). Waveforms for upset tolerance are selected not only by the composition of the airframe that the device will be installed in, but also by the type of cables (shielded or unshielded) connected to the device under test. These waveforms are designated in DO-160 as Waveform 1, Waveform 2, Waveform 3, Waveform 4 and Waveform 5A.

Cable bundle test levels are specified in terms of a test level (voltage or current) and corresponding limit. Cable bundle test levels are specified by either a limit voltage and a test current (V_L / I_T) or by a test voltage and current limit (V_T / I_L).

Once the capabilities of the transient generator have been verified, the cable under test is installed in the coupling transformer. The transient generator output level is slowly increased while monitoring the voltage and current induced into the cable under test. The output of the generator is increased until either the test or limit level is achieved. For single stroke tests level 10 positive transients are applied, followed by the application of 10 negative transients. For multiple burst and multiple stroke tests, multiple transients are applied at random intervals. This procedure is repeated for each waveform on each cable specified. During the application of each waveform, compliance with the applicable equipment performance standards is required in order to consider the test sample in compliance with the applicable standards.

RTCA – DO-160, Section 22, Lightning Induced Transient Susceptibility Test Levels and Waveforms

Test Level	Electromagnetic Environment of Installation Location	Pin Waveforms			Cable Bundle Waveforms				
		3 1 MHz Damped Sine	4 6.4 by 69 uSec	5A 40 by 120 uSec	1 6.4 by 69 uSec	2 0.1 by 6.4 uSec	3 1 & 10 MHz Damped Sine	4 6.4 by 69 uSec	5A 40 by 120 uSec
		V_{OC} / I_{SC}	V_{OC} / I_{SC}	V_{OC} / I_{SC}	V_L / I_T	V_T / I_L	V_T / I_L	V_T / I_L	V_L / I_T
1	Well Protected	100 / 4	50 / 10	50 / 50	50 / 100	50 / 100	100 / 20	50 / 100	50 / 150
2	Partially Protected	250 / 10	125 / 25	125 / 125	125 / 250	125 / 250	250 / 50	125 / 250	125 / 400
3	Moderately Exposed	600 / 24	300 / 60	300 / 300	300 / 600	300 / 600	600 / 120	300 / 600	300 / 1000
4	Severe	1500 / 60	750 / 150	750 / 750	600 / 1200	750 / 1500	1500 / 300	750 / 1500	750 / 2000
5	Severe	3200 / 128	1600 / 320	1600 / 1600	1600 / 3200	1600 / 3200	3200 / 640	1600 / 3200	1600 / 5000