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SEPTEMBER 2013

AEROSPACE TESTING INTERNATIONAL

Smash & grab

NASA Langley's latest helicopter crash test examines seat safety and the performance of lightweight composites

VIRGIN GALACTIC

Virgin Galactic's chief pilot, David Mackay, on the program's first powered flight and further testing

DARPA TRANSFORMER

The latest ducted lift fan test efforts in the race to realize a compact vertical take-off and landing aircraft

SPACE UPDATE

Exclusive updates from the SNC Dream Chaser and Boeing CST-100 programs for NASA

EMC TESTING • EUROCOPTER X3 • PAUL BONHOMME • X-47B

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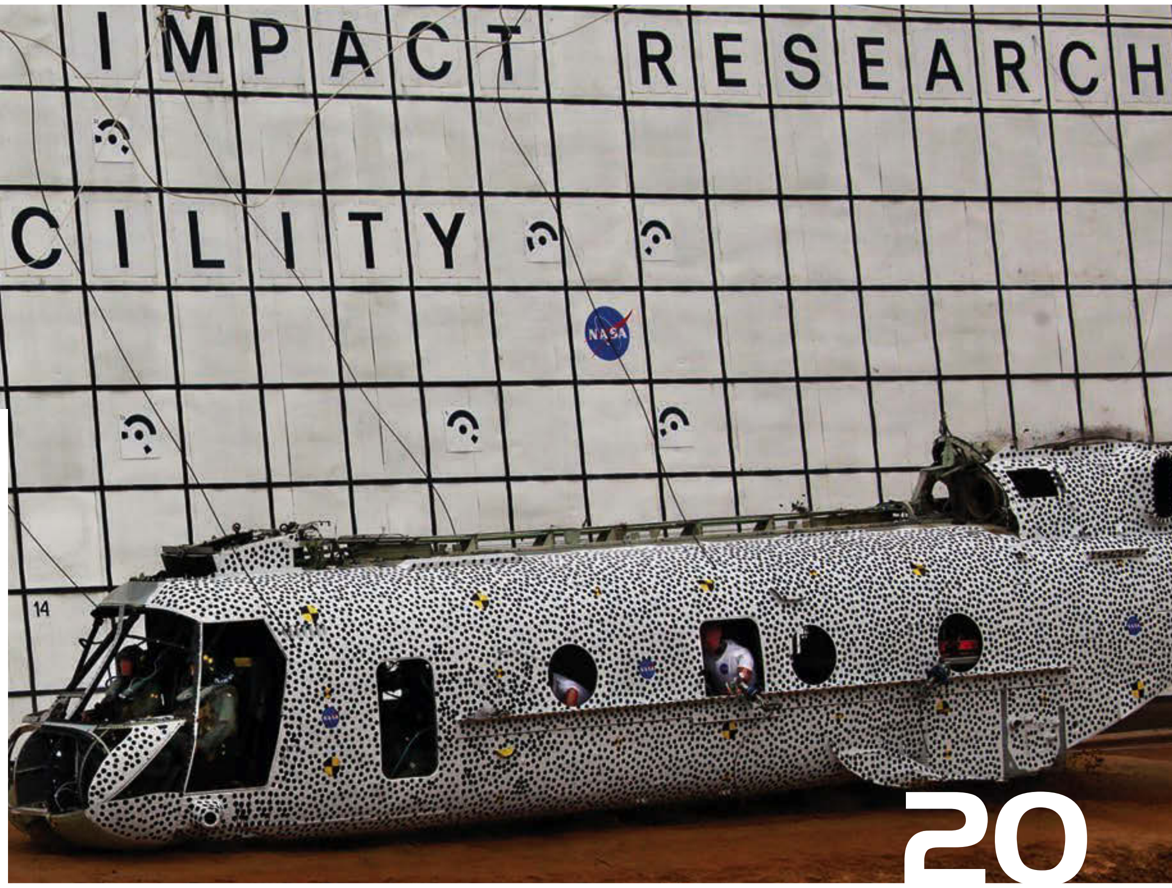
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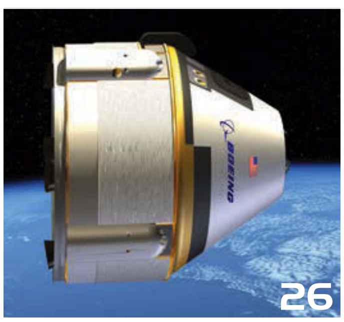
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Maya Angelou, the American poet and author (still going strong at 85), said, “If you don't like something, change it. If you can't change it, change your attitude.” I would replace the last word with ‘altitude’.

Sixty years ago, heading beyond the gravitational ties of the atmosphere was almost inconceivable. In 1969, man landed on the moon. And now we are looking at a new age of space travel: the commercial enterprise.

In 2001 Dennis Tito, a US engineer and multimillionaire, became famous for being the first space tourist. He was accepted by the Russian Federal Space Agency, but met criticism from NASA before the launch as NASA considered it inappropriate for a tourist to take a ride into space. Tito joined the 2001 Soyuz TM-32 mission to the ISS, spending nearly eight days in space and orbiting Earth 128 times. He performed several scientific experiments in orbit that he said would be useful for his business, and paid a reported US$20 million for the taxi ride.

In fact, space tourism began a little earlier than 2001. The Tokyo Broadcasting System (TBS) offered to pay for one of its reporters to fly on a mission, and in 1990, at a cost of US$28 million, Toyohiro Akiyama was flown to Mir and returned a week later, having broadcast throughout.

Why do I mention this? There is an interview on page 14 that I have been trying to secure for a long time. David Mackay, the chief pilot for Virgin Galactic, talks exclusively to *Aerospace Testing International* at a time when the airline is on the brink of taking commercial space travel to the (very wealthy) masses, having just passed the latest phase of high-altitude flight tests.

It was in 2004 that SpaceShipOne won the Ansari X Prize, which awarded US$10m to the first private company to fly three people to an altitude of 100km (62 miles) twice within two weeks. The altitude is beyond the Kármán Line, the arbitrarily defined boundary of space. The first flight was flown by Mike Melvill on June 21, 2004, making him the first commercial astronaut.

The interview with Mackay came about after I went to a recording of an amazing BBC comedy/science radio show called *The Infinite Monkey Cage*. The subject of the episode was space tourism. Later I was talking to the panelists in the ‘green room’, including presenter Professor Brian Cox; the very vocal actor Brian Blessed; BBC presenter, expert on space medicine, and co-director of UCL's Centre for Altitude Space and Extreme Environment Medicine, Dr Kevin Fong; and the commercial director of Virgin Galactic, Stephen Attenborough. The conversation was riveting. Fong was particularly eloquent, saying that since man went into space, commercial space travel is the greatest leap forward, far beyond a money-making enterprise. Why? Well, in his eyes the whole concept of space travel has been one long test. “We are naturally protective of our physiology; people need layers of protection. We have gone through the testing phase where pioneers lived, tested and, too often, died. Space tourism is taking space travel to a place where people survive and expect to, much the same as with normal aviation; everyone now gets in an aircraft.” It's true – until the late 1920s, the only people who got into an aircraft were pilots – and maybe machine gunners!

Blessed was even more forthcoming, comparing modern space travel to Antarctic exploration. In 1912 two expeditions (Norwegian and British) raced toward the South Pole. One was successful, the other team died in its entirety. No one went to the South Pole again until 1956, by which time technology had advanced. They arrived by aircraft, very safely!

Attenborough's take was that technology has advanced to a point of safety that makes space travel viable and sustainable. Economies of scale have come down, opening up the possibility for many thousands to travel into space. A fleet of vehicles is currently being built in the Mojave Desert.

A Virgin Galactic suborbital tourism flight costs US$200,000. To date, the company has accepted more than US$70 million in deposits from approximately 650 individuals, which is roughly 10% more than the total number of people who have ever gone to space.

In February 2013, Tito announced his intention to send a privately financed spaceflight to Mars by 2018. Elon Musk, a 42-year-old entrepreneur, has won contracts with his SpaceX foundation, and is getting ready to go to Mars in his lifetime.

What's next? Well, according to Attenborough it is hotels in space. However, Fong is convinced that humankind is on the brink of developing the technology to get to Mars, aided by enormous private enterprise and architecture, but it would be a very, very horrendous journey, and explorers would probably not come back. Book me in to the suborbital hotel!

Christopher Hounsfield, editor

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COVER IMAGE: Crash test: NASA Langley

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WORLD TEST UPDATE

1 A13 PROGRAM

The US Army and Raytheon have announced the successful interception and destruction of a low quadrant elevation (QE) 107mm rocket as part of the second series of guided test vehicle flight tests of the Accelerated Improved Intercept Initiative (AI3) program.

Yuma, Arizona, USA

2 US NAVY UNMANNED HELICOPTER

The US Navy plans to begin flight-testing a new version of its Fire Scout unmanned helicopter in October 2013. The new aircraft, called the MQ-8C, will undergo ground-testing at a Navy base in California before having its first flight, scheduled for the second week of October, says Captain Patrick Smith, the Navy's Fire Scout program manager. The Navy hopes to begin deploying the new variant in 2014.

California, USA

3 BOMBARDIER CS100

Bombardier's CS100 medium-range jetliner has taken to the skies on its maiden flight, marking the Canadian manufacturer's entry into airspace dominated by Airbus and Boeing. Bombardier, which has always focused on building regional jets and trains, spent C$3.5bn and 10 years developing the CS100 and its slightly larger sibling, the CS300, which seats 160 passengers and is expected to launch in early 2014.

Montreal, Canada

4 SCORPION PROTOTYPE

A versatile intelligence, surveillance and reconnaissance (ISR)/strike aircraft platform named the Scorpion has been unveiled by Textron. The aircraft was introduced at the Air Force Association Air & Space Conference and Technology Exposition in National Harbor, Maryland. The demonstration aircraft is now in test phase, with the first flight scheduled to occur before the end of this year.

Maryland, USA

5 F-35 SEABORNE LANDINGS

UK military pilots have taken part in the second round of vertical night landings at sea of the new F-35B Lightning II fighter aircraft. The pilots, along with UK ground crew, are testing three Lightning II jets, working alongside the US Marine Corps. The latest testing has been used to expand the operational envelope, with aircraft landing at day and night. The vertical night landings were the first to be conducted at sea.

Eglin AFB, Florida, USA

6 CSERIES FLIGHT TEST PERMIT

Bombardier has submitted an application for the CSeries flight test permit to Transport Canada, as it moves a step closer to the aircraft's imminent first flight. The Canadian regulator has confirmed that it has received the airframer's application and says that it is "reviewing the information and documentation".

Toronto, Canada

7 BOEING 787–9

The 787-9 Dreamliner has taken off for the first time, beginning a comprehensive flight-test program leading to certification and delivery in mid-2014. Powered by two Rolls-Royce Trent 1000 engines, the first 787-9 will be joined in flight test by two additional airplanes, one of which will feature General Electric GEnx engines. Over the coming months, the fleet will be subjected to a variety of tests to demonstrate the safety and reliability of the design.

Seattle, USA

8 V-22 REFUELING

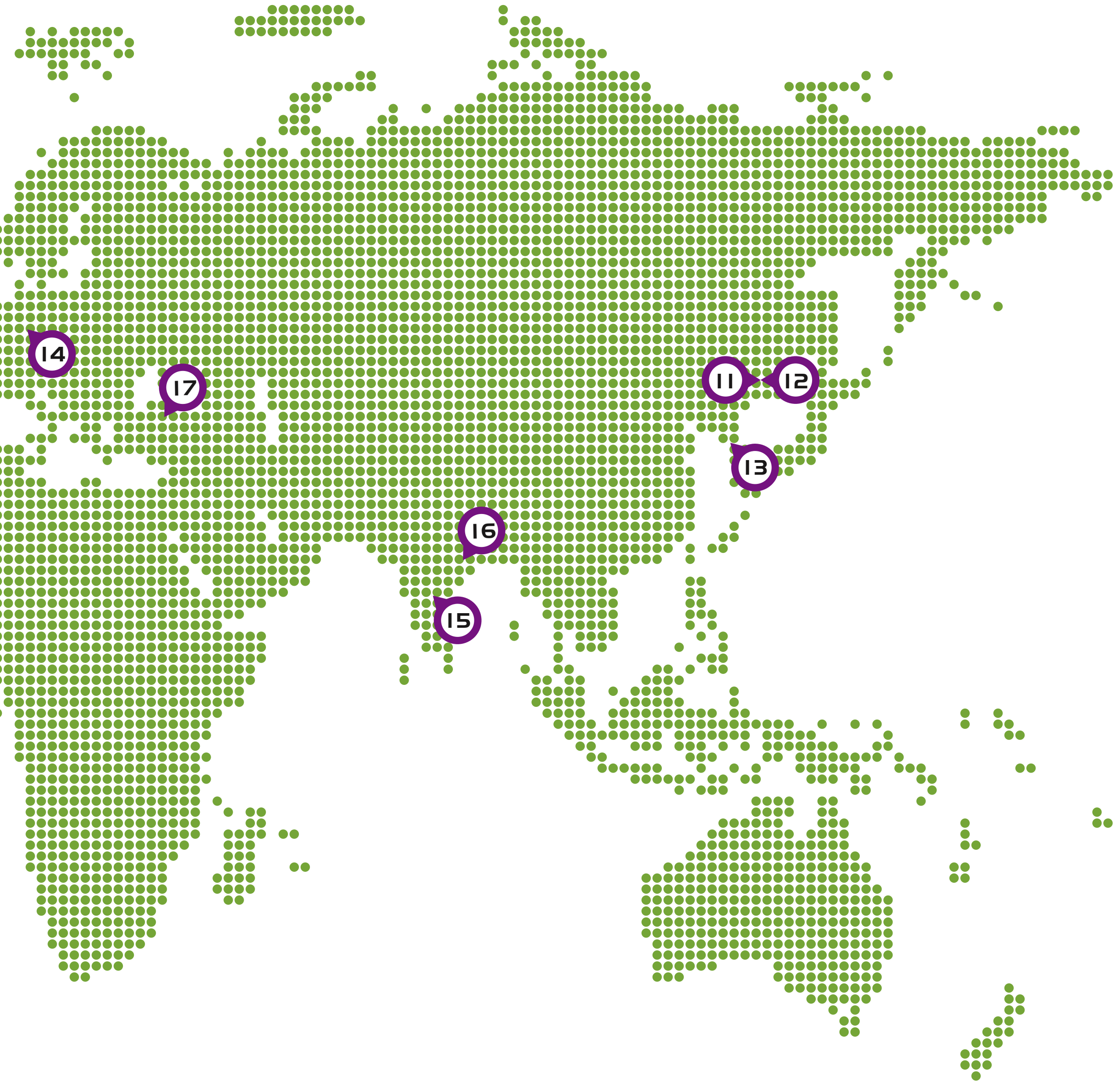
The Bell Boeing V-22 program has successfully completed an initial test of the V-22 Osprey performing as an aerial refueling tanker. Adding this capability to the tiltrotor aircraft would improve its versatility in operations. In the trail over Texas, a V-22 equipped with a prototype aerial refueling system safely deployed, held stable, and retracted the refueling drogue, as an F/A-18C and an F/A-18D Hornet flew just behind the aircraft.

Texas, USA

9 DROP TEST

Engineers at NASA's Langley Research Center in Hampton have dropped an old Marine CH-46E helicopter fuselage filled with 15 dummy occupants from a height of 30ft to test improved seats and seatbelts, and to gather data on the odds of surviving a helicopter crash. See full feature on page 20.

Virginia, USA



15 PILOTLESS AIRCRAFT

Hindustan Aeronautics Ltd (HAL) has delivered the first Lakshya-1 (pilotless target aircraft) to Bharat Dynamics, which is based in Hyderabad. "The aircraft has been delivered ahead of schedule in a record 15 months, against 24 months of normal manufacturing cycle time," said Dr Tyagi, chairman of HAL. It will be used by the Indian Army.

Hyderabad, India

16 NUCLEAR MISSILE TEST

India has continued its series of missile tests as part of its ongoing nuclear missile test program. The Defence Research & Development Organisation has, for the second time, successfully test-fired the Agni V – the country's most potent nuclear-capable inter-continental ballistic missile.

Odisha, India

17 TURKEY SPACE PROGRAM

Turkey has announced an ambitious, three-part effort to make the nation a 'space power' by 2023. The government has said it will work to synchronize efforts to build an anti-missile system, develop a long-range offensive missile capability, and construct the country's first launch center to place satellites in orbit.

Ankara, Turkey

18 NIGERIAN UAV

Two indigenously developed unmanned aerial vehicles (UAVs) made their maiden flight at the Nigerian Air Force Base in Kaduna last month. The UAVs are designed to enhance the aerial surveillance capabilities of the Nigerian Air Force, but serial production of the system still seems far away.

Kaduna, Nigeria

10 A400M RUNWAY

Airbus Military has completed an important set of trials of the A400M new-generation airlifter, demonstrating the aircraft's performance on gravel runways. In tests lasting more than a week at Ablitas in northern Spain, development aircraft MSN2 performed 25 landings during six flights on the same runway. The trials confirmed that despite the harsh conditions, damage to the aircraft exterior from stones and dust was minimal.

Ablitas, Spain

11 CHINA MAIDEN FLIGHT

Embraer's joint venture with Aviation Industry Corporation of China has announced that the first Legacy 650 large executive jet assembled in China has successfully completed its maiden flight. Delivery of the first Legacy 650 is scheduled for the end of 2013. The test pilots flew the aircraft for more than two hours, assessing its handling. The aircraft's systems were evaluated, including flight control, communication and navigation.

Harbin, China

12 A350XWB COMPOSITE ELEVATORS

Harbin Hafei Airbus Composite Manufacturing Centre (HMC), a joint venture between Airbus and its Chinese partners, has started to deliver elevators for the Airbus A350 XWB program. The elevators manufactured at HMC are delivered to Spain-based Aernnova Aerospace, which will deliver them to the Airbus plant in Getafe, Spain, where they will be integrated into the A350 XWB's horizontal tail plane.

Harbin, China

13 SILENT PROCUREMENT

The Boeing F-15SE Silent Eagle now stands alone as the remaining candidate for South Korea's US$7.4bn F-X Phase 3 fighter aircraft procurement. South Korea's Defense Acquisition Program Administration announced that one of the two finalists for the 60-aircraft procurement has been eliminated from the competition. The agency cited unspecified "flaws found in the bidding documents" as a reason for the elimination.

Seoul, South Korea

14 SATELLITE SYSTEMS

A copy of ESA's Gaia satellite in Toulouse was linked to the mission control system at ESOC in Germany recently, enabling flight controllers to send commands and receive data just as they will once the actual satellite is in orbit. The system validation test was the final one in a series of nine live link-ups over the past four years. Some were performed using the actual flight model, while some involved engineering models of the satellite's subsystems.

Darmstadt, Germany

X-47B CARRIER LANDING SUCCESS

DESIGN CHALLENGE

The US Navy has been awarded four development contracts to develop designs to compete for the Unmanned Carrier Launched Airborne Surveillance and Strike air vehicle. The contracts, each for an alleged US$15m, went to Boeing, General Atomics Aeronautical Systems, Lockheed Martin and Northrop Grumman.

In July 2013, the US Navy achieved a major advance in the development of unmanned aerial vehicles when Northrop Grumman's X-47B demonstrator successfully landed on board the nuclear-powered aircraft carrier USS George H W Bush in the North Atlantic.

The two successful 'trappings' of the X-47B unmanned combat air system (UCAS) on the Bush's arrestor wires came as the conclusion of more than eight months of shipboard trials and testing by personnel of an integrated test team made up of US Naval Air Systems Command personnel and supporting contractors.

The Navy UCAS program successfully completed carrier deck operations aboard USS Harry S Truman in December 2012 and aboard Bush in May. During the May underway period, the X-47B completed its first-ever catapult launch from the deck of an underway carrier.

Since May, the integrated test team conducted a number of shore-based arrestor wire systems at Naval Air Station Patuxent River in Maryland in preparation for the demonstration aboard the ship.

"We have been using the same [carrier] landing technology for more than 50 years now and the idea that we can take a large UAV and operate in that environment is fascinating," said Captain Jaime Engdahl, the US Navy's UCAS program manager.

"When I think about all of the hours and all of the work-ups the development team has invested into executing this event, I had no doubt the air vehicle was going to do exactly what it was supposed to do," continues Engdahl.

"We have learned a lot from our flight deck operations, our shore-based flight test, and extensive modeling and simulation. Our team has executed all major program objectives and developed the concept of operations and demonstrated technologies for a future unmanned carrier-based aircraft capability. We have proven we can seamlessly integrate unmanned systems into the carrier environment."

While the first two attempts to trap on the Bush were successful, a third landing had to be aborted when the aircraft's systems detected a problem with an onboard computer. Following its programming, the aircraft then flew to a 'divert' field on Wallops Island, Virginia.

The second X-47B was launched on July 15 to make more traps, but it developed technical issues while in flight from Patuxent River to the ship, and officials decided to abort the attempt before the X-47B reached the vicinity of the carrier.

The UCAS project is part of an effort by the US Navy to field an Unmanned Carrier Launched Surveillance and Strike capability by 2019.

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USAF SETS UP TEST UNIT FOR KC-46 TANKER

The first staff of an integrated test force (ITF) to bring the Boeing KC-46 tanker into US Air Force service set up shop in Seattle, Washington, in July 2013, ahead of delivery of the first aircraft in three years' time.

The establishment of the ITF by the USAF follows Boeing's successful move through a critical design review and the beginning of assembly of the first KC-46 wing spar. "The detachment will provide a permanent presence for the 412th Test Wing as the responsible test organization for developmental test on the KC-46," said Lieutenant Colonel James Quashnock, 418th FLTS, Det. 1 commander.

The detachment will report through the 412th TW to the Air Force Test Center at Edwards Air Force Base in California, but will be based out of King County International Airport, in Seattle – better known as 'Boeing Field'.

"When Boeing won the bid for the KC-46, the contract allowed it the flexibility to choose its test site. Boeing elected to test the aircraft out of Boeing Field, where it conducts most of its commercial aircraft testing," Quashnock continued. "Since the KC-46 is a derivative of the 767 design, and will leverage much of the airworthiness testing from the commercial aspect of the 767, it was a logical location for Boeing."

The KC-46A is intended to replace the USAF's aging fleet of KC-135 Stratotankers and provides a vital air refueling capability. Although the detachment currently has three people at the location, Quashnock said by next summer the detachment will increase to approximately 40 people in preparation for the first flight in Seattle.

"We will have pilots, boom operators, flight test engineers, logisticians and disciplined engineers – all working together with their Boeing counterparts just like any integrated test force at Edwards. Many of the personnel are coming from Edwards and are already working on the program from their current positions and locations," Quashnock said. "In addition to those 40 assigned to Det. 1, we will have a significant number of people working on the program from Edwards and from the test integrated product team at the program office in Wright-Patterson Air Force Base, Ohio.

"We have an aggressive test schedule, which has us wrapping up developmental test and transitioning to dedicated operational test in the summer of 2016," said Quashnock. "The test program will actually stretch over the whole country, but testing will primarily be accomplished out of Washington and some short duration testing will also be done at Edwards; Eglin Air Force Base, Florida; and Naval Air Station Patuxent River, Maryland. Detailed test plans are still being worked on, but those three additional locations are very likely."

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TARANIS MOVES TO AUSTRALIA

BAE Systems' new unmanned aerial combat vehicle concept demonstrator has been flown to Australia ahead of its expected first test flight in September.

The move of the only Taranis air vehicle to the remote Woomera test center in South Australia is a major milestone for the project, which is jointly funded by the UK Ministry of Defence and a consortium of British defence and aerospace companies.

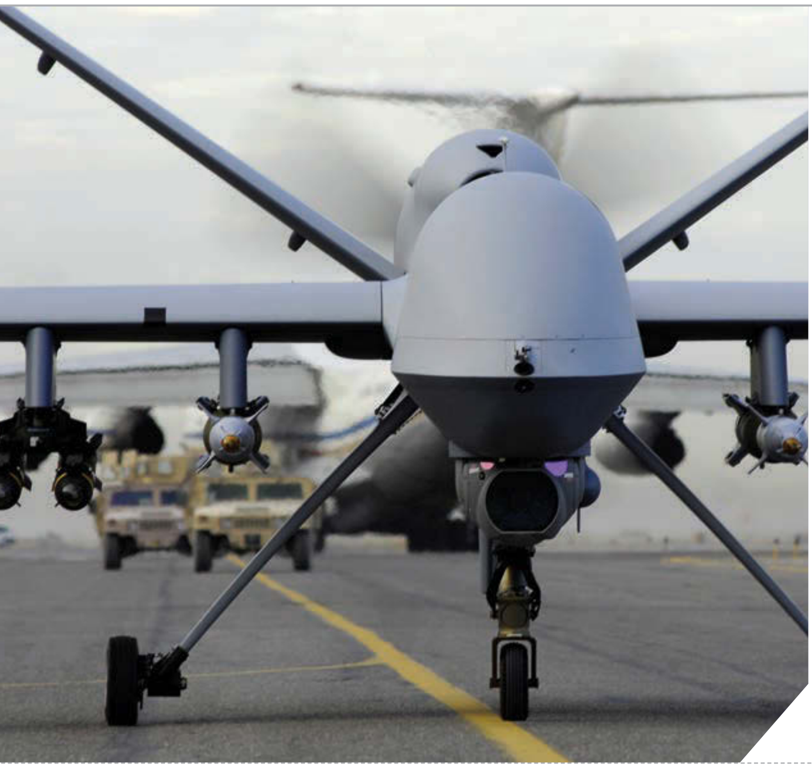
Airspace restrictions and security concerns have prompted BAE Systems test experts to use the Australian site rather than a location in the UK. There had been suggestions that a remote location in Scotland or Wales, such as QinetiQ's Benbecula or Aberporth sites, might be used, but they were not deemed suitable. Woomera has been used extensively by BAE Systems for unmanned aerial vehicle test flights, including the first flight of its Mantis medium altitude, long-endurance demonstrator.

The £180m (US$285m) Taranis project was launched in a bid to position BAE Systems and its UK partners in the global unmanned systems market and potentially provide a launch pad for the fielding of a UCAV by the Royal Air Force.

UK Ministry of Defence sources suggest that Taranis could take to the skies over Woomera during September, where the craft is already located, but a ministry spokesman was not able to provide any sort of prediction.

The Mantis program spent several months in Australia ahead of its first flight in November 2009 as designers, engineers and test experts fine-tuned the air vehicle ahead of its trials program,

UK TO TEST BRIMSTONE MISSILE ON REAPER



The first trials of a foreign-designed weapon on the General Atomics MQ-9 Reaper will begin later this year, according to UK defence equipment, support and technology minister, Philip Dunne.

He first revealed the trials of MBDA's Dual-Mode Brimstone (DMB) air-to-surface missile in May this year and in July gave more details of the trials, which are to be held in the USA in cooperation with the US Air Force's Big Safari Group, which specializes in the rapid testing of new weapon systems to meet urgent front-line user requirements.

Experts from the UK Ministry of Defence and MBDA will begin feasibility and integration trials in the fourth quarter of 2013. It is believed that the trials will take place on the Nellis test range complex in Nevada, where previous weapons trials on the Reaper have taken place.

Dunne did not provide a timetable for the Brimstone integration trials, nor did he say when either the UK or USA would look to field such a capability. He also did not give any rationale for the project, but RAF sources suggest that it is linked to moves to keep the Reaper in UK service after the ending of operations in Afghanistan in 2015.

The RAF purchased its first Reapers in 2007 with urgent operational requirement funding, and to speed its entry to service it purchased US weapons – Lockheed Martin AGM-114 Hellfire missiles and Raytheon 500 lb Paveway laser-guided bombs – which had already been cleared for use on the air vehicle.

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suggesting that BAE Systems is very cautious about when to move to flight trials.

"There is only one Taranis air vehicle, so we have to get it right and can't afford to take any risks with the flight test program," said a BAE Systems source.

The first flight follows a three-year delay and more than £55m (US$87m) in additional costs caused by technical issues, an increase in requirements, and extended risk mitigation work.

A Ministry of Defence spokesman said the additional risk mitigation work was behind an increase in program costs to "around £180m". The original budget when the program was launched in 2005 was £124m (US$197m). By 2011, the delays and requirement changes had driven up the Taranis costs to £142m (US$225m).

The spokesman declined to confirm either the site of the maiden flight test or the date: "The location of the flight trials is confidential information. Progress continues with Taranis and its initial trials program, and we expect the first flight trials to take place in 2013."

Named after a Celtic god of thunder, the 8 ton Taranis is about the size of a Hawk jet trainer, and will demonstrate autonomous controls, stealth and other technologies for possible inclusion in an operational aircraft. The demonstrator is powered by an Adour jet engine.

Government and an industry team comprising BAE Systems, GE Aviation Systems, QinetiQ and Rolls-Royce launched the effort to design and fly Britain's largest unmanned air vehicle in December 2005, with the intention of having the aircraft airborne during 2010.

By integrating a UK-sourced weapon, the RAF hopes to get enhanced weapon employment profiles. Although the Brimstone is a derivative of the Hellfire, it is of a more modern design and incorporates a millimeter wave seeker, as well as laser-guidance equipment. This would give the UK a bad weather weapon employment option for its Reaper.

Industry sources also suggest that the trials are aimed at providing MBDA with an entry into the ongoing Pentagon efforts to procure a replacement for the 1970s vintage Hellfire. So far this procurement process has stalled on two occasions over the past decade and the Brimstone would offer the US military an off-the-shelf alternative, potentially opening a market for several thousand rounds.

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GARNET RIDGWAY

ZERO PERSONALITY

Like them or loathe them, unmanned aerial vehicles are here to stay. But are they as challenging to test as their manned counterparts? Aerospace engineers Garnet Ridgway and Sophie Robinson investigate

SOPHIE ROBINSON

By far the most complex and interesting component of any aircraft is its pilot. Human pilots give an otherwise inert machine the ability to aviate, navigate and communicate, and have an unparalleled capability to make split-second decisions.

The fact remains, however, that flying is not a normal activity for the human body. The effects of altitude, temperature and g-forces are constantly conspiring to endanger pilots, and our attempts to alleviate them tend to be compensatory rather than comprehensive solutions. Despite wearing g-suits, the pilots of fast jets are still exposed to massive forces, and even the most powerful environmental control system can't protect helicopter pilots from extremes of temperature. The result is that pilots of manned aircraft are personally invested in the safety of the aircraft through an often inexorable physical link. If this safety concern were to be negated through the removal of the human element, aircraft testing would be far less challenging.

Garnet Ridgway has a PhD from the University of Liverpool. He has designed cockpit instruments for Airbus and currently works for a leading UK-based aircraft test and evaluation organization

From an engineering perspective, the human brain can be considered as a high-order dynamic system with relatively few inputs (sight, vestibular, aural, etc) and outputs (limb movements, speech, etc). However, these inputs and outputs are so strongly interlinked, or 'coupled', that the relationships between them are not always easily predictable. Humans can be proficient at performing two different tasks in isolation, but attempting them simultaneously can result in a substantial drop in performance. For example, it has been found that intermittently switching to a near-field visual task results in severe degradation in far-field visual acuity. In a search-and-rescue scenario this could literally be a matter of life and death. Designing a test program that encompasses such subtleties is a major challenge.

Finally, the assessment of flight handling qualities and workload relies on an element of subjectivity and pilot opinion. Different pilots can react to the same test point in different ways, and so defining and declaring compliance with pass criteria can be very difficult indeed. It could be argued that this is the true art of aircraft testing – quantifying the subtleties of the pilot-aircraft relationship. Although to a limited extent this is applicable to remotely operated vehicles with human pilots, the future is undeniably autonomous. Two questions therefore arise: how are these skills to be retained, and do they really need to be?

Unmanned aerial vehicles are swiftly becoming an important feature on both the military and civilian aviation landscapes. This rapid acceleration in use presents many challenges in testing compared with piloted vehicles.

Testing of manned vehicles has around 100 years of thinking, standardization and process refinement behind it. UAVs have entered the marketplace in the past 15 years and the associated process and infrastructure have been racing to catch up.

Manned aircraft often have strongly defined roles – for example most, if not all, military rotorcraft can be placed into one (or more) of four roles: attack, scout, utility and cargo. The method of testing aircraft in each of these roles has been honed and perfected, and these roles and methods, unsurprisingly, aren't directly transferable to UAVs. Engineers have to be careful not to try to force a square peg into a round hole.

The testing requirements for manned aircraft are also well known. Performance requirements and safety standards are predefined and applicable across a wide range of aircraft. This isn't necessarily the case for UAVs. While specifications do exist, they lack maturity and often can't be applied across a variety of platforms. Cost, size and capability make it impossible to standardize the testing methodologies used. The differences in requirements between a hand-launched Raven UAV with a 4ft wingspan and those of a 131ft wingspan Global Hawk illustrate the broad spectrum of UAV operations – no single specification could assess both aircraft successfully.

Integration of UAVs into conventional airspace operations also proves problematic – often

Sophie Robinson is currently finishing her PhD as part of the Flight Science and Technology Research Group within the Centre for Engineering Dynamics at Liverpool University. In the course of her research, Sophie regularly works with test pilots

UAVs just aren't designed to fit in. It can be difficult to obtain Certificates of Airworthiness and permits to fly, because until recently there were no airworthiness standards to comply with! Some UAVs also lack a lot of the standard equipment required to operate in normal airspace, such as transponders and traffic collision avoidance systems.

Despite all these challenges, UAVs represent a potentially revolutionary capability, with the ability to save money and lives, and both the military and civilian realms want to make use of this capability to its full potential as quickly as possible. This makes UAV testing one of the most exciting and fastest-moving fields in test and evaluation – and we engineers do love a challenge!


Virgin
EVE
DAVE MACKAY

Spacecraft or aircraft?

He became the first Scotsman in space when piloting SpaceShipOne in 2004. Now David Mackay is the chief pilot of Virgin Galactic, and as the spacecraft enters the next phase of testing, *Aerospace Testing International* gets an exclusive insight into the progress made so far

BY CHRISTOPHER HOUNSFIELD

It takes considerable skill to handle and fly the oldest, original flying aircraft (and engine) in existence on the planet. It dates back more than 100 years and is the 1909 Bleriot. It was made from ash wood, in a 'tractor' box configuration, with wire bracings and steel tubes, and 'pulled' through the air by a tiny 50hp engine.

What makes the expert pilot who flies this craft all the more different is that over and above having the flying skills to display the Bleriot XI around the world, test pilot Dave Mackay is also the chief pilot for Virgin Galactic, arguably the most advanced and unique air/spacecraft of modern times. His aim? To be the first commercial astronaut/pilot in the world. In 2004, he became the first Scot in space, when he piloted SpaceShipOne on October 4.

LOOKING BACK DOWN

It was back in 2004 that the 'Ansari X Prize' called for private sector innovation that would look into the field of manned space exploration. Participants were asked to design and manufacture a privately funded vehicle that could deliver the weight of three people (including one real person) to suborbital space (100km above Earth). The vehicle had to be 80% reusable and fly twice within a two-week period. Indeed, to cut a long story short, Mojave Aerospace Ventures and Burt Rutan's Scaled Composites pursued the X Prize with Rutan's SpaceShipOne, sponsored by Virgin, with an air-launched, all-composite rocket ship.

Virgin Galactic was born and development was put in place for two vehicles, the carrier, and then the actual spaceplane. Mackay has been involved in the development of both these craft.

SpaceShipTwo (SS2) is a reusable spaceplane designed to carry six passengers and two pilots into space. It uses much of the same technology, construction techniques, and basic design of the earlier SpaceShipOne, but is twice the size. It was unveiled in December 2009, and test flights began in March 2010. The first rocket-powered supersonic flight of SS2 took place on April 29, 2013.

WhiteKnightTwo (WK2) is the carrier aircraft for both SpaceShipTwo and LauncherOne. It is the largest 100% carbon composite carrier craft ever built. It made its first flight in December 2008.

Mackay says, "I have flown both – WhiteKnight, a lot, and SpaceShip, a little. Although outwardly the vehicles are very different, there are many similarities internally. Also, WhiteKnightTwo has the ability to act as an inflight trainer for SpaceShipTwo; with its gear down and its powerful speedbrakes deployed, it can replicate SpaceShipTwo's approach path angle."

LATEST DEVELOPMENT

On September 5, 2013, SS2 successfully completed the second rocket-powered, supersonic flight. In addition to achieving the highest altitude and greatest speed to date, the test flight demonstrated the vehicle's technical mission profile in a single flight for the first time, including a high-altitude deployment of the unique wing 'feathering' re-entry mechanism.

Chief pilot Dave Mackay was at the WK2 controls. SS2 pilots Mark Stucky and Clint Nichols, both of Scaled, ignited the rocket motor for the 20-second burn, propelling the spaceship vertically to 69,000ft. During this time, SS2 achieved a maximum speed of Mach 1.43. According to Virgin Galactic, the flight was flawless.

Mackay has flown many types of aircraft, from the oldest to the latest, and cut his teeth in the Royal Air Force flying Harriers, and later as a test pilot on exchange with the French test pilot school, EPNER (École du personnel navigant d'essais et de réception), through an exchange with the RAF's Empire Test Pilots' School. He became Commanding Officer of the RAF's Fast Jet Test Flight in 1992 at RAF Boscombe Down. Life's a bit different now! And it was in 1995 that it all changed.

ABOVE: SS2 flies supersonic for the first time – piloted by Scaled's test pilots Mark Stucky and Mile Alsbury

INSET: Sir Richard Branson and Mark Stucky congratulate each other after the first rocket-powered flight of SS2 in April

RIGHT: Boom camera shot of SpaceShipTwo breaking the sound barrier

"THERE IS NO FLY-BY-WIRE SYSTEM – THE FLIGHT CONTROLS ARE SIMPLE CABLES, AND PUSH-RODS; THERE IS NO AUTOPILOT OR AUTOTHRUST"

Talking exclusively to *Aerospace Testing* just a few days before the latest flight, Mackay describes the lead-up to the trial, and explains that although both vehicles have such different roles, there is still a conformity of design that is incredible.

"Both vehicles [SS2 & WK2] were deliberately designed to be as simple as possible," he says. "The rationale is that a simple system is less likely to fail and therefore is inherently safer. Because of this, there are very few pilot aids that are common in the majority of modern aircraft. There is no fly-by-wire system – the flight controls are simple cables, and push-rods; there is no autopilot, autothrust or artificial feel system. In other words, the pilots really do have to fly the vehicles and, of course, that's what pilots enjoy doing most of all! As a result, the crew feels the real vehicle directly, not through some artificial feedback system."

The result, says Mackay, is that WK2 feels like you might expect a large aircraft to feel: "It's a little slow and heavy in roll and it has quite a lot of inertia," he says, "Other than that, it flies surprisingly well given its very unusual configuration. Its most unusual aspect is probably the twin fuselage, which is flown from the right-hand-side. On the ground, pilots have to be careful when positioning it, especially on narrow taxiways. But in the air, it feels just like any other aircraft and it's easy to forget there is another fuselage out there on the left-hand side."

Mackay says WK2's performance is very impressive, capable as it is of carrying a large and very heavy external payload up to 50,000ft in around 45 minutes. But what of SS2?

"SS2 follows the same simple design philosophy," he responds. "For a vehicle designed for very high Mach numbers and for the critical re-entry from space, you might perhaps expect its low speed handling characteristics to be poor. In fact, it flies really nicely on the approach and landing. It has a very good field of view and is quite agile; if a rapid maneuver is required, it is capable of responding quickly. The feather configuration is highly stable and the beauty of it is that no matter what angle the vehicle meets the atmosphere at on re-entry, it will automatically orientate itself in the optimum position, requiring no pilot input. In the feather, the crew is able to point the vehicle in whichever direction they desire – as there is a small forward velocity in feather, this is a useful capability," says Mackay.

DOUBLE TROUBLE

It is sometimes easy to forget that Scaled Composites has built and developed the two vehicles in parallel – a big undertaking, especially since both are unusual designs and have demanding roles. To help it better understand their projected performance, Scaled performed a great deal of CFD analysis prior to beginning flight testing.

Clearly, coupling one air vehicle to another can drastically impact handling. This was certainly the case back in the 1970s when a Boeing 747 was used to give piggy-back rides to the Space Shuttle. The 747 had to be stripped out completely to make it lighter, but the combined weight and dynamics made drag and vibration a huge factor. When you consider it took the entire craft to somewhat less than 1% below absolute maximum take-off weight, it was amazing it ever got off the ground.

However, when you provide bespoke vehicles, the situation changes, as Mackay is keen to point out: "When attached to WK2, riding in SS2 is a very comfortable experience. If there is any turbulence in the air, it tends to have a greater effect on the extremities of a wing, so as SS2 is mounted in the center of WK2's wing, it is remote from, and well isolated from, the greatest movements."

Surprisingly, Mackay says having SS2 attached to WK2 does not make a great deal of difference to the way WhiteKnight handles. "However a fully-laden SS2 is a significant part of the all-up vehicle weight and so it's performance is not quite as sparkling as when it's on its own," he admits.

Another benefit of Scaled's bespoke approach is evident in the cockpits of both vehicles: "The displays in the vehicles were designed and built by Scaled," he says. "In principal, they are very similar to those found in the majority of modern aircraft. Both vehicles have three multifunction displays – one in front of each pilot, normally set up as a primary flight display, and one in the center of the instrument panel.

"The primary flight displays are quite conventional flight instruments and navigation information. In WK2, the center display normally shows the engine parameters and top-level systems information. In SS2, the center display shows vehicle energy, which is very useful for the approach and landing. Most pilots would quickly be able to identify all the normal parameters they require to fly the vehicles. However, the advantage of having the avionics system designed and built in-house is that, particularly in SS2, there are many bespoke features that make it much easier to fly the vehicle in the atmosphere and in space.

650	The number of individuals so far who have signed up to become a Virgin Galactic astronaut – Katy Perry, Ashton Kutcher, Justin Bieber and Leonardo DiCaprio are just a few of the stars on board
70 secs	How long SS2's rocket engine fires for to boost it to its maximum altitude of 361,000ft (110km)
US$250,000	The current cost to sign up as a Virgin Galactic astronaut!
90in	SS2 cabin diameter, which is similar in size to a Falcon 900 executive jet – but without the floor, to allow passengers to experience floating in zero gravity

SIMULATION AND MODELS

A flight simulator has been developed in parallel for both vehicles and has now reached the stage where it is a prime test device. According to Mackay, it accurately simulates vehicle performance, the influences of various atmospheric conditions, and almost any system failure. It also feeds information to Scaled's telemetry system in its mission control, enabling effective training for the entire test team. Mackay adds, "It was initially designed to be an SS2 simulator, but as the cabins of both vehicles are built from the same molds, and the flight controls and the avionics are very similar, it can also be used with a WK2 aero model as an effective simulator for that vehicle too. It is hard to imagine carrying out a flight test program on a vehicle such as SS2 without such a capable simulator."

ENGINE TESTING

The September 5, flight tests opened up the flight envelope following the second successful rocket-powered test over Mojave. The vehicle's Sierra Nevada RM2 solid rocket motor was tested for a longer duration than previous tests at more than 20 seconds, ignited just four seconds after release, which pulled it straight into a vertical climb.

As Mackay states, "The rocket testing is a huge part of the development program and there have been a very large number of test firings, to optimize the fuel, as well as the general performance of the motor

RECENT TESTING MILESTONES

Second rocket-powered flight of SpaceShipTwo
Date: September 5, 2013
WhiteKnightTwo took off carrying SS2 to an altitude of 46,000ft. Virgin Galactic chief pilot Dave Mackay was at the WK2 controls, assisted by Scaled Composites' co-pilot Mike Alsbury and flight test engineer Scott Glaser. Upon release from WK2, SS2 pilots Mark Stucky and Clint Nichols, both of Scaled, ignited the rocket motor for the planned 20-second burn, propelling the spaceship to 69,000ft. During this time, SS2 achieved a maximum speed of Mach 1.43. SS2 landed in Mojave at 9:25am.

First rocket-powered flight of SpaceShipTwo
Date: April 29, 2013
The test began at 7:02am local time when SpaceShipTwo took off from Mojave Air and Space Port mated to WhiteKnightTwo. In control of SpaceShipTwo were Mark Stucky, pilot, and Mike Alsbury, co-pilot. At the WK2 controls were Virgin Galactic's chief pilot Dave Mackay, assisted by Clint Nichols and Brian Maisler, co-pilot and flight test engineer, respectively, for Scaled. Upon reaching 47,000ft altitude and approximately 45 minutes into the flight, SS2 was released from WK2. After cross-checking data and verifying stable control, the pilots triggered ignition of the rocket motor, causing the main oxidizer valve to open and igniters to fire within the fuel case. At this point, SS2 was propelled forward and upward to a maximum altitude of 55,000ft. The entire engine burn lasted 16 seconds, as planned. During this time, SS2 went supersonic, achieving Mach 1.2.

The rocket-powered flight test lasted just over 10 minutes, culminating in a smooth landing for SS2 in Mojave at approximately 8:00am local time.

"The rocket motor ignition went as planned, with the expected burn duration, good engine performance and solid vehicle handling qualities throughout," said Virgin Galactic president and CEO George Whitesides. "The successful outcome of this test marks a pivotal point for our program. We will now embark on a handful of similar powered flight tests, and then make our first test flight to space."

SS2's control and handling was very positive during its first supersonic, rocket-powered flight. The motor operated as designed, and provided a strong, yet surprisingly smooth, acceleration through the sound barrier. The boost was terminated at the intended shutdown duration of 16 seconds. Trajectory was nominal, with Mike and Mark topping out at 1.3 Mach and 56,200ft. Post shutdown glide was nominal. The vehicle and the team performed excellently according to the company.

SpaceShipTwo 'Cold Flow' test
Date: April 4, 2013
Preparing for SpaceShipTwo's first powered flight, test teams from Scaled Composites and Virgin Galactic completed the profile of the upcoming milestone flight – apart from actually igniting the rocket. Importantly, and for the first time in the air, oxidizer was flowed through the propulsion system and out through the nozzle at the rear of the vehicle – thus successfully accomplishing the 'Cold Flow' procedure.

As well as providing further qualifying evidence that the rocket system is flight-ready, the test also provided a stunning spectacle due to the oxidizer contrail, and, for the first time, gave a taste of what SpaceShipTwo will look like as it powers to space.

Feather flight and nitrous vent test
Date: April 9, 2013
On a beautiful calm Mojave morning, SS2 completed her 24th glide flight and the sixth inflight test of her patented feathered re-entry system. The flight test team also successfully verified SS2's nitrous loading and venting system, another key milestone on the way to its first powered flight. Galactic's chief pilot David Mackay was at the controls of WhiteKnightTwo, and Scaled's pilot Mark Stucky was in command of the spaceship.

First glide in powered flight configuration
Date: December 19, 2012
SpaceShipTwo undertook its 23rd glide flight in the pre-powered portion of its incremental test flight program. This was a significant flight as it was the first with rocket motor components installed, including tanks. It was also the first flight with thermal protection applied to the spaceship's leading edges. It followed an equally successful test flight the week before that saw SS2 fly in this configuration, but remain mated to WhiteKnightTwo. All objectives of both flights were successfully met.

ABOVE: **A view of a SpaceShipTwo hybrid rocket engine test firing by SpaceShipTwo builder Scaled Composites**

itself. Most of the ground tests have been conducted by SNC at its Powey facility. But several have also been carried out at Mojave. Motor testing continues in parallel with flight testing.

"With a rocket motor, which accelerates the vehicle very rapidly, the challenge becomes much more difficult. So the first powered flight expanded the flight envelope significantly and very quickly, also passing through the transonic region [there have been flutter and oscillation concerns that Virgin explained were entirely predicted and expected]. This was one reason we were so pleased with the highly successful outcome.

"The path forward now is to incrementally increase the rocket motor burn-duration to expand the flight envelope and eventually achieve our goal of space flight. We will then start flight testing the customer equipment, to optimize the experience for all those hundreds of people patiently waiting for their ride into space," says Mackay.

So what has been the experience that has stood out the most? Mackay shows his sense of humour: "For me personally, it was my first feather flight in SS2. I was so impressed by the fact that you could fold this vehicle in half and yet it still flew really well. I also recall us all talking after my first flight experience in SS2 in June 2011. As a UK citizen I am classified, under the TSA rules, as an alien, so the Scaled test pilots were delighted to be able to honestly say they had seen an alien fly a spaceship."

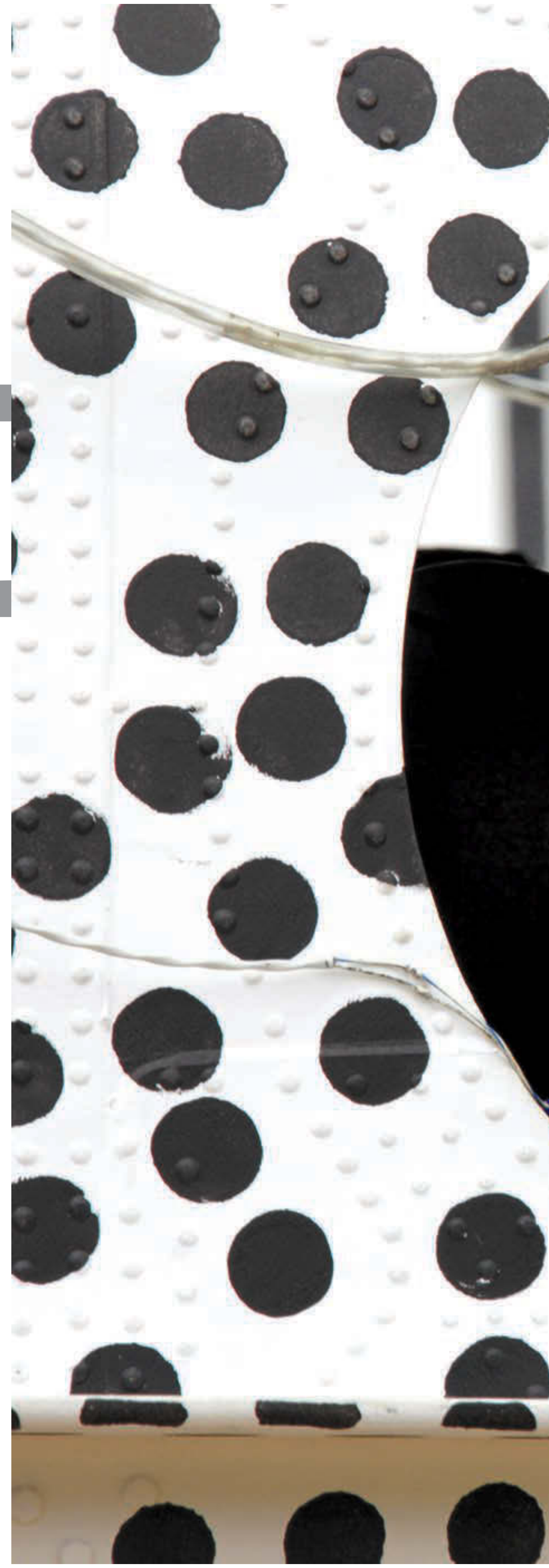
WHAT NEXT?

Further flights will continue to expand the supersonic aerodynamic flight envelope, launch weight and structural loads. Testing is expected to end with a maximum apogee demonstration flight to 361,000ft (110km), after which SS2 developer Scaled Composites will turn the vehicle over to Virgin Galactic.

The company says it is adamant the first commercial sub-orbital flights will commence next year from New Mexico, with more tests this year.

As Mackay reflects, "Some of this may sound rather far-fetched, but if you look back at the way technology has evolved over the past 100 years, it would be a brave man that would say this cannot happen." Indeed, as Mackay next climbs into the Belriot XI, the original French aviator Louis Belriot could not have dreamed of the revolution he was pioneering as he crossed the English Channel a little over a 100 years ago. ∎

Hit the dust



A recent helicopter crash test conducted by NASA, the US Navy, the US Army and the FAA hopes to shed new light on seat safety and lightweight composites, while also exploring the value of new testing methods

BY ANTHONY JAMES

Have you ever wondered what would happen if you took an old CH-46E helicopter fuselage and dropped it from a height of about 30ft? Engineers at NASA Langley's Landing and Impact Research Facility (LandIR), in Hampton, Virginia, certainly have – in fact their curiosity, fueled by a desire to improve the crashworthiness of seats and seatbelts, as well as to gather data on the odds of surviving a helicopter crash, led them to do exactly that at the end of August.

The US Navy provided the CH-46E Sea Knight helicopter fuselage, complete with seats, which was then fitted out with 15 occupants – 13 instrumented crash test dummies and two uninstrumented manikins.

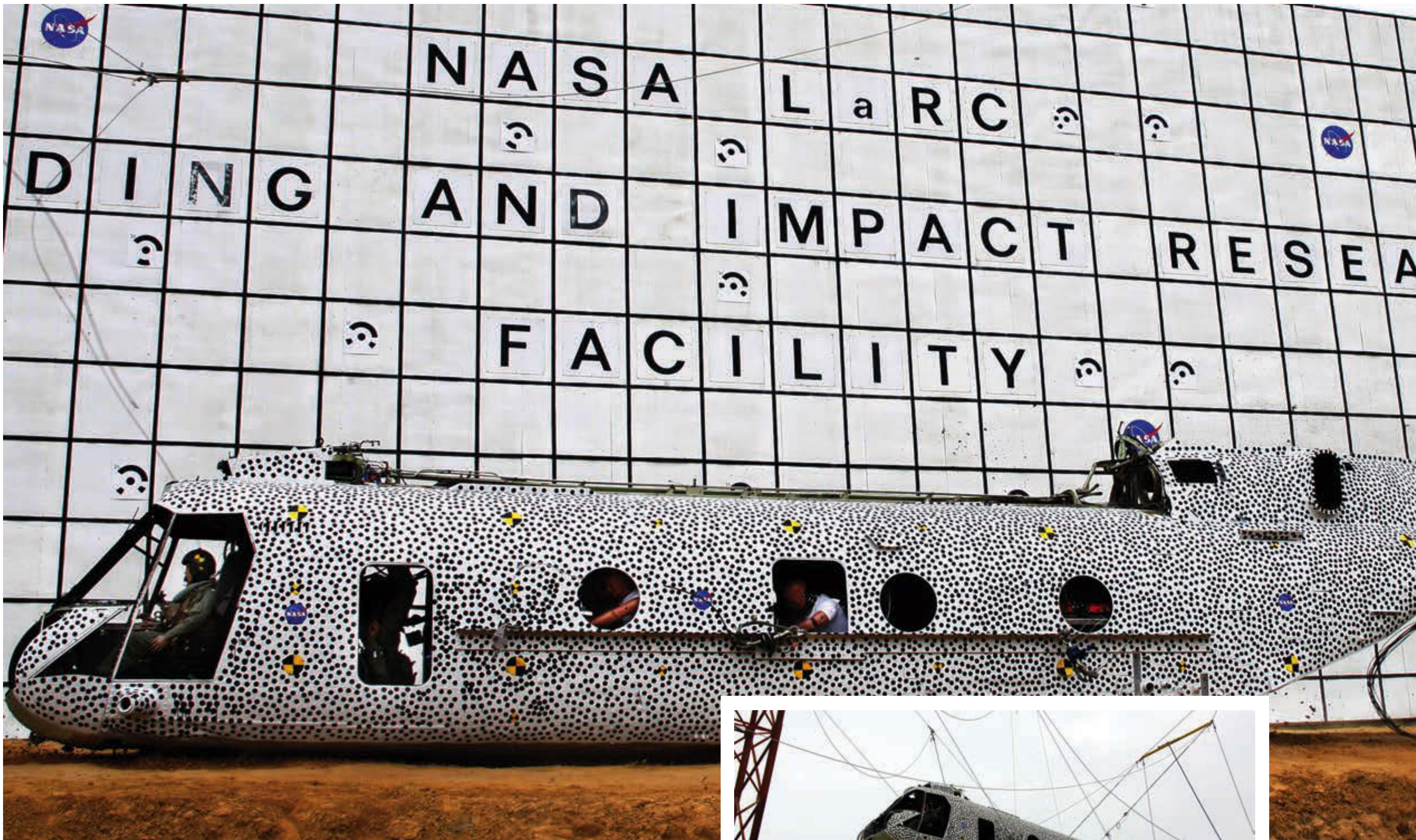
The Navy also contributed five of the crash test dummies, one manikin and other equipment, while the US Army provided a manikin and a crash test dummy that was placed in a position representative of a patient in a medical evacuation litter.

The FAA provided a side-facing specialized crash test dummy and part of the data acquisition system; and NASA Langley added six of its own dummies, as well as lead technical expertise and the use of its own specialized facility, known as 'the Gantry' (see sidebar, overleaf).

Engineers then used cables to hoist the helicopter fuselage into the air and swing it above the ground like a pendulum. It was traveling at 30mph when pyrotechnic devices separated the cables, sending the fuselage smashing into the soil below.

"Four swing cables and two pullback cables were attached to the test article," explains lead test engineer Martin Annett. "The pullback cables are pyrotechnically severed, and the swing cables guide the test article to the ground with a controllable horizontal and vertical impact velocity," he continues. "We chose a soil impact surface, because the majority of mishaps occur on non-prepared surfaces. The velocity conditions are a trade-off between civilian and military requirements for what is considered severe but survivable."

The test article was fitted out with 350 sensors to capture data on airframe accelerations and crash test dummy loads. Over 40 high-speed and



high-definition cameras recorded onboard and external movements.

JOINING THE DOTS

Researchers also made use of a new photographic method available to them to help analyze the data collected from the crash test. Called 'full field photogrammetry', it saw the helicopter fuselage stripped of its usual coat of naval grey paint in favor of an altogether more eye-catching – or rather camera-catching – scheme. "We painted more than 8,000 dots on the side of the test article to measure global and local deformation on the fuselage skin," explains Annett.

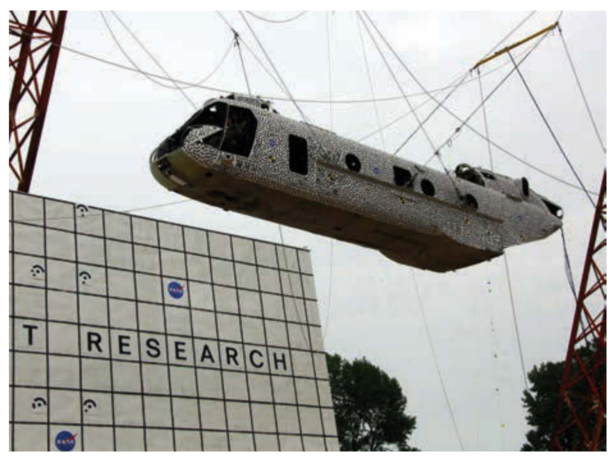
High-speed cameras filming at 500 images per second were used to track each dot, ensuring researchers were able to plot and 'see' exactly how the fuselage behaved under crash loads.

"Two cameras were positioned and calibrated against the large backboard to provide 6DOF motion for those points," continues Annett. "The dots were over one inch in diameter to accommodate the necessary field of view and resolution, so localized strains were not computed. Relative deformations and the overall spatial and temporal response could be tracked."

Another testing technique adopted for the first time involved researchers making use of some rather familiar 'off-the-shelf' technology – taken from a video game sensor: "We also tested a markerless tracking technique using an Xbox Kinect sensor," continues Annett. "The sensor was aimed at one of the standing dummies and identified 19 joint locations to track."

Preliminary observations from the test indicate good data collection, which the team at Langley will now take months to fully analyze, as well as informing their simulation models.

"We designed this test to simulate a severe but survivable crash under both civilian and military requirements," says Annett. "It was amazingly complicated with all the dummies, cameras, instrumentation and collaborators, but it went well. The deceleration response of various locations on the airframe is now being correlated directly to the simulation models, and the models will be calibrated based on those results."



ABOVE: **The US Navy CH-46E Sea Knight helicopter fuselage used during the test was painted with over 8,000 dots as part of a high-speed photographic technique**

ABOVE INSET: **The fuselage was hoisted to a height of 30ft before hitting the ground at 30mph**

This was the first of two planned tests using US Navy-provided CH-46E Sea Knight fuselages. A similar helicopter equipped with additional technology, including high-performance, lightweight composite airframe retrofits, will be used in a crash test next summer. Both are part of the Rotary Wing Project (RWP) in NASA's Aeronautics Research Mission Directorate. "The overarching goal of the RWP is to develop and validate tools, technologies and concepts to overcome key barriers for rotary wing vehicles," explains Susan Gorton, who heads up the RWP for NASA.

The project is one of four in the Fundamental Aeronautics Program (FAP) and contributes to the FAP goals

> **"WE DESIGNED THIS TEST TO SIMULATE A SEVERE BUT SURVIVABLE CRASH UNDER BOTH CIVILIAN AND MILITARY REQUIREMENTS"**

PROUD HISTORY

LandIR, NASA's 240ft high, 400ft long gantry, has an almost 50-year history. It started out as the Lunar Landing Research Facility (LLRF), built in 1965 at a cost of US$3.5m, and used by Neil Armstrong and other astronauts in preparation for landing on the moon. It simulated lunar gravity via an overhead partial-suspension system that counteracted all but one-sixth of the Earth's gravitational force, allowing the Apollo Lunar Module to fly unobstructed within a relatively large area. The LLRF was also used as a lunar-walking simulator, with subjects walking on inclined planes while suspended by a system of slings and cables.

It was converted into a full-scale aircraft crash test facility and used to conduct important research on aircraft and other vehicles between 1974 and 2003, when it was known as the Impact Dynamics Research Facility (IDRF). More recently it added a big pool where NASA is testing Orion space capsule mock-ups in anticipation of water landings. The 'hydro-impact basin' is 115ft long, 90ft wide and 20ft deep, and was completed in January 2011.

of advancing vehicle technology capabilities for improved efficiency and increased mobility within the air transportation system. "To achieve the objectives, the project is organized around research themes that articulate the longer-term, important areas of research necessary to advance the state-of-the-art," continues Gorton.

RWP has three research theme areas: advanced efficient propulsion; advanced concepts and configurations; and rotorcraft integration into NextGen. These three themes provide a framework to deliver research that addresses the main barriers for expanded use of rotary wing vehicles: efficiency, performance and public acceptance, including noise and safety. But where does the recent crash test fit into all of this?

"The recent full-scale crash test is part of the larger effort in rotorcraft crashworthiness research in the RWP," responds Gorton. "RWP invests in fundamental crashworthiness investigations to improve the safety of rotary wing vehicles."

Researchers want to increase industry knowledge and create more complete computer models that can be used to design better and safer helicopters. NASA says the ultimate goal of its rotary wing research efforts is to help helicopters and other vertical take-off and landing vehicles carry more passengers and cargo more quickly, quietly, safely and with less harm to the environment, ultimately leading to their wider use in the airspace system.

MIND THE GAP

However, Gorton admits the test was also focused on examining how lightweight composites withstand impact testing: "As composites become more widely used as primary structure in helicopters and advanced rotary wing vehicles, it becomes apparent that there is much that is still unknown about their characteristics in a crash environment, and the ability to design for specific crashworthiness criteria with composite structures is still an active research area," she says.

Hence the decision to fit a composite component inside the fuselage to be used in the second test to be carried out next summer: "We will test another CH-46E airframe and will seek our partners' input on the experiments they would like to include this time," says Annett. "We intend to remove the cabin subfloor and replace it with composite concepts that can provide equal or better crashworthy capability compared with the metallic counterpart. We would crash with the same impact conditions and overall weight for comparison with the first test."

LEFT: Researchers installed 40 cameras, 350 sensors and 15 crash test dummies

30mph	The speed at which the helicopter hit the ground during the helicopter crash test
240ft	The height of the 400ft-wide LandIR gantry used to conduct the test
500fps	The frame rate (images per second) of the high-speed cameras used during the test
10,300 lb	The weight of the US Navy CH-46E Sea Knight helicopter fuselage

REPEAT PERFORMANCE

The goal of the drop recently carried out at NASA Langley's Landing and Impact Research Facility was to test improved seatbelts and seats, collect crashworthiness data, and check out some new test methods. But it was also to serve as a baseline for another test scheduled for 2014. A full-scale crash test of a similar helicopter airframe equipped with additional technology, including composite airframe retrofits, is planned for next summer. Both are part of NASA's Rotary Wing Project. The cost of the recent full-scale crash test was about US$900,000 in FY13. It was about US$400,000 in FY12 and is expected to be an additional US$850,000 for the next phase in the summer of 2014. These costs include the facility fees, the researcher and contractor costs for testing, simulation and analysis, the test article and the associated hardware.

BELOW: The fuselage appeared to survive better than some of the occupants, with initial observations indicating many of the dummies suffered what would have been severe human injuries

But Annett isn't waiting around until next year's second test to begin making use of all the data collected so far – or the valuable testing observations already noted: "Many of the lessons learned from the test relate to test preparation and performing adequate checkout of the data acquisition system and the crash test dummies," he says.

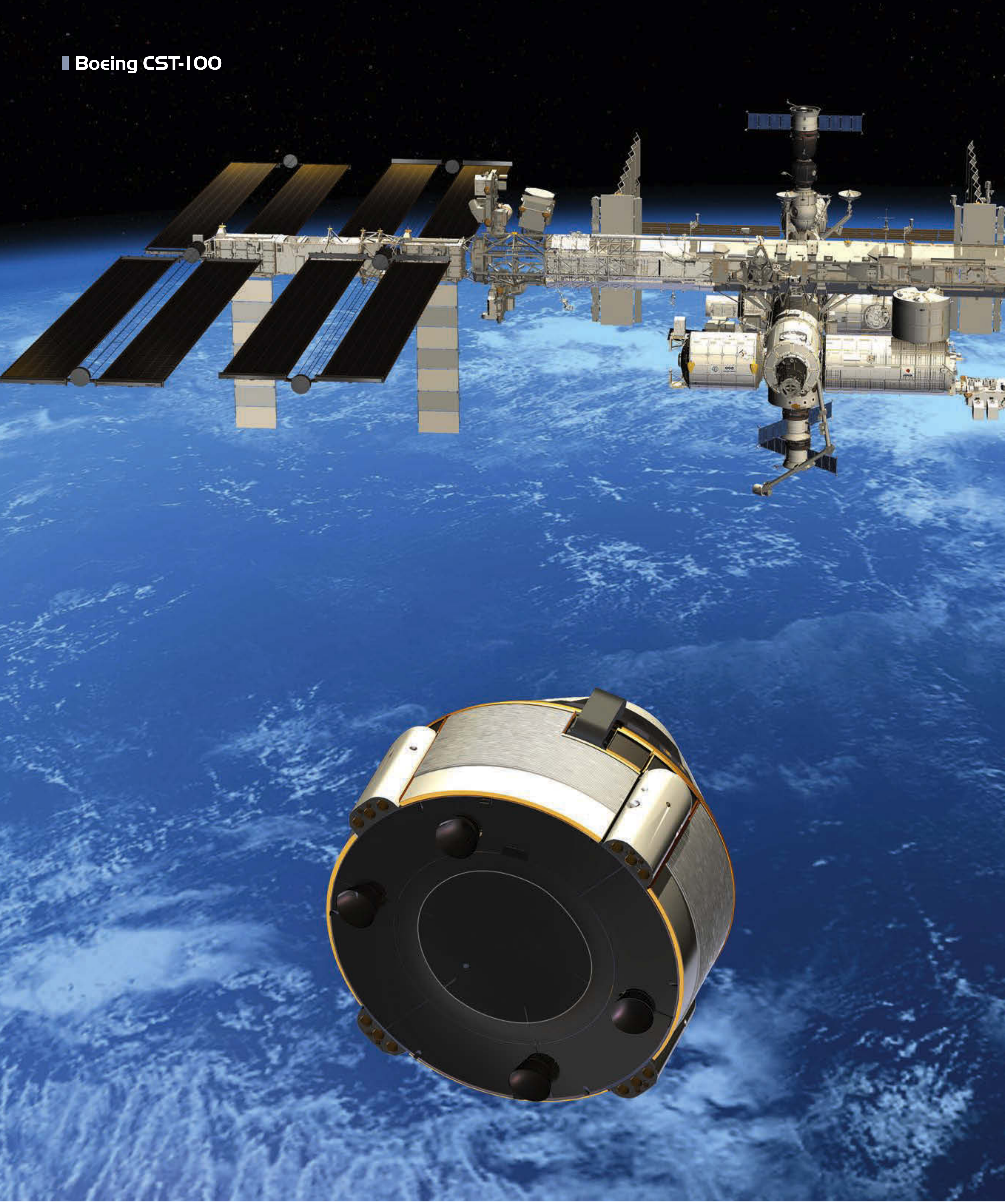
One particular problem identified involves instrument clutter: "Once the airframe is fully populated with instruments and dummies, it becomes difficult logistically to debug and diagnose. Also, having a full dry run was very beneficial as all the systems, with the exception of the pyrotechnics, could be tested out under normal procedural conditions."

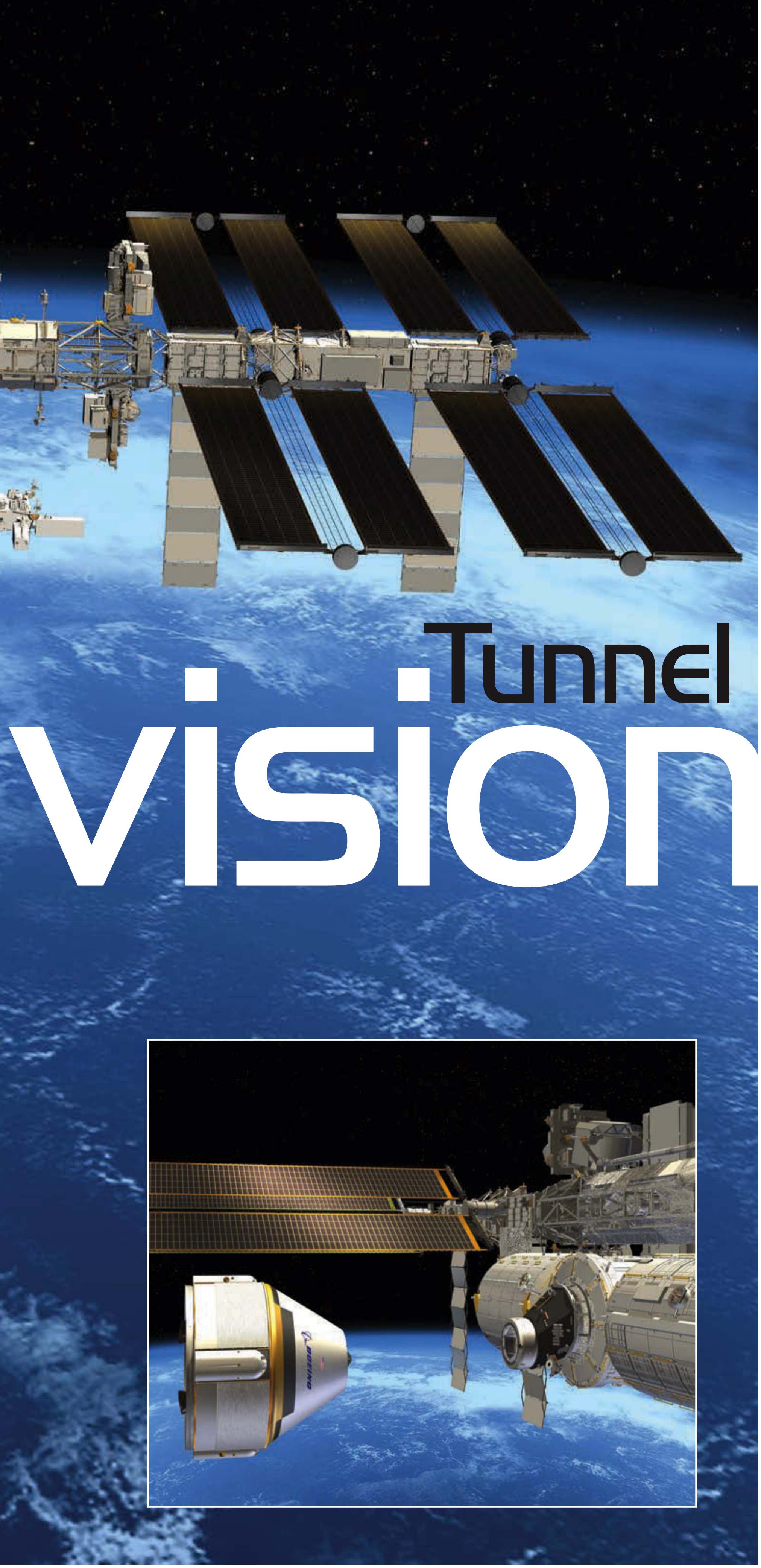
Asked how the test might be improved, Annett underlines the challenges of checking onboard equipment immediately prior to crash testing: "The biggest challenge is ensuring that our sensors, cameras and data acquisition systems are operating properly prior to the final swing and crash," he says. "Also, experiments must be designed to allow the proper crash performance without affecting experiments nearby."

As for the anthropomorphic test devices (ATDs) used, Annett says work continues on improving their performance with regard to side impacts: "The ATDs have been designed to handle the typical vertical and forward load experienced in aerospace crashes," he says. "There is ongoing work to evaluate side-facing ATDs."

Finally Annett confirms the 'test, test, and test again' mantra of all test engineers when asked how testing could be further improved: "Frequent testing is always recommended, as there are always lessons to be learned with every crash test," he says.

Helicopter passengers and pilots of the future couldn't agree more!





Tunnel vision

Since NASA contracted Boeing to develop the CST-100 module, James Johnson, lead test and evaluation manager of the program, has seen the team progress – but also face development challenges along the way

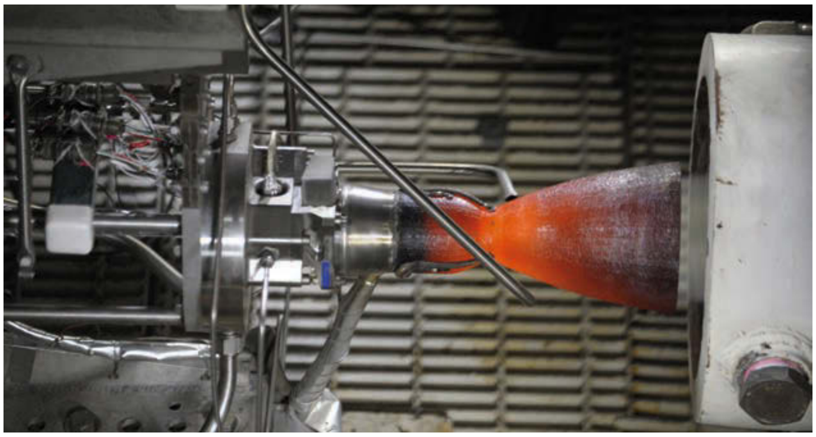
BY JOHN CHALLEN

The development of NASA's next generation of spacecraft is proving to be a combined effort, with Boeing involved in many of the agency's projects. One program is the CST-100 (Crew Space Transportation) capsule – a device designed to carry up to seven passengers and compatible with a number of launch vehicles, initially the Atlas V but also the Delta IV and Falcon 9. As part of NASA's Commercial Crew Development program, Boeing, in collaboration with Bigelow Aerospace, has been tasked with bringing the CST-100 – the primary function of which is to carry crew to the International Space Station – to the next level of design maturity.

Overall responsibility for development of the CST-100 lies with James Johnson, test and evaluation manager, at Boeing's Commercial Crew division. Having undertaken two development phases since 2009, Johnson is currently looking to move the program into Commercial Crew Transportation Capability, a phase planned for December 2014.

ACOUSTIC TEST

NASA recently revealed details of wind tunnel tests using a model of the CST-



RIGHT: Test of CST-100 orbital maneuvering attitude control engine

100 spacecraft and integrated Atlas-V rocket, but Johnson says those evaluations only scratch the surface. "The main objective of the wind tunnel work is to address our aero capabilities during ascent, and to ensure we can align our forces of moment so that when we reach the speed we need to travel at, we don't experience too much acoustic influence. We also need to confirm that the rocket can handle the amount of buffeting experienced," he explains, revealing that the list of tests completed outside the tunnel is a long one. "We have parachute drop tests, engine firing tests in the desert, in-vacuum tests and structural tests. We are also working on a thermal protection testing system, and we have built an avionics systems integration lab specifically for this program."

"AMES ALLOWS US TO MAKE MANUAL CHANGES TO THE MODEL VERY QUICKLY, WHILE AEDC OFFERS A MORE AUTOMATED APPROACH"

TESTING IN THE TUNNEL

For the aforementioned wind tunnel tests, Johnson and his team visited Arnold Engineering Development Center (AEDC) in Tennessee, Langley Research Center in Virginia, and NASA's own Ames Research Center in California. "We have to build unique models and use our own sensors, but where we can, we are trying to leverage what technology is already out there," explains Johnson.

The reason for going outside Boeing's own development sites was primarily for the testing opportunities they offer for spacecraft. "AEDC and Ames both have specific capabilities, and the one model that we used for abort testing was tested at both sites," says Johnson, adding that work at Langley was predominantly concerned with engine calibration. "We could probably do it at one site, but they both have different strengths when it comes to testing," he says. "Ames allows us to make manual changes to the model very quickly, while AEDC offers a more automated approach, which helps with our abort wind tunnel tests [of the Atlas V-mounted CST-100]. Here, we have one model that moves forward while the other moves backward, and we keep flying them in and out, allowing the two pieces to come apart and together again. When we need to calibrate the model, Langley's wind tunnel can measure the engines in the tunnel and the thrust on the nozzles – so all three sites offer something different."

MODEL DATA

Boeing used Ames's Mach 1.24 transonic tunnel, as well as the smaller supersonic tunnel, which can test up to Mach 2. "The first model we had was used for abort testing, and we used both tunnels," recalls Johnson. "The data for that correlated really well with our CFD and modeling predictions, which means our models were in good shape. We used a 7% model, which had a 12-14in diameter, and the follow-on is the same size, but with an updated design, and has thousands of data points."

Another model – built to 2% scale (5in diameter) but measuring the full length of the rocket (about 8ft) – was also tested at Ames. "Here we investigated force and moment by specifying the angle and a Mach number, and we went super- and transonic to prove the performance.

"The ultimate goal of all our test work is to correlate and validate our models," says Johnson. "Everyday vehicles you can fly in all situations, but with these vehicles we can't hit or fly every data point. When you've identified that your wind tunnel tests can overlay directly onto your model, then you can verify the design to fly what you are asking it to fly. Once you verify it, you go into test flights, and then take that data to help execute the missions."

The size of the models was in part determined by the need to have, in some cases, up to 350 acoustic sensors (plus wires) installed within them. This presented a packaging challenge for Johnson and his team, but it was

DROP IN THE OCEAN

In June 2013 the European Space Agency's (ESA) experimental re-entry vehicle passed its descent and landing test (pictured below) at the Poligono Interforze Salto di Quirra off the east coast of Sardinia in Italy.

The full-scale Intermediate eXperimental Vehicle (IXV) prototype was released at an altitude of 3,000m from a helicopter, falling to gain speed to mimic a space mission before parachute deployment. The parachute slowed IXV for a safe splashdown in the sea at a speed below 7m/sec.

The IXV project is developing and flight-testing the technologies and systems for Europe's future autonomous atmospheric re-entry vehicles.

It will be launched into a suborbital path by ESA in 2014 on Vega, Europe's new small launcher. It will reenter the atmosphere as if from a low-orbit mission, testing new European reentry technologies during its hypersonic and supersonic flight phases.

Previous campaigns included several water impact tests at CNR–INSEAN, a marine-engineering research institute in Rome. An instrumented subscale prototype was released at various angles and speeds to assess the best configuration for minimum impact loads.

2016	The year for which Boeing is planning its first CST-100 flight test
6-8 hours	How long it will take for the capsule to reach the International Space Station
12 x 14in	The size of the aluminum CST-100 model undergoing tunnel testing at NASA's Ames Research Center
7.5 tons	Weight of the CST-100, which can accommodate up to seven passengers or a mix of crew and cargo

essential in order to get the data needed for the development. "For simple force and moment tests, you can make smaller models, because fewer sensors are used. We are able to size it by changing parameters of the pressure and air density in the tunnel, and then you scale that up to what the full-size vehicle would see."

In addition, two other major wind tunnel tests were conducted by United Launch Alliance (ULA). "One was the integrated buffet test, which used our model with the first half of the Atlas rocket," says Johnson. "It measured the forces and the buffets on the rocket, the crew and service modules, the dual-engine Centaur and the first section of the booster of the Atlas. The other test we did was primarily gathering acoustic and buffet information, to check for vibrating parts on the model."

Evaluation of the vehicle's emergency detection system is also being conducted at ULA, according to Johnson. This unit alerts the crew if there is an issue with the rocket, such as problems with pressure, in-flight, or any other element.

Away from the wind tunnel, engine test work has been completed in the Mojave Desert, says Johnson. "Polaris built a bespoke test stand that would hold our launch/abort engine when they fire the engine. A lot of the facilities we use could quickly pull things together, but we were keen to use our existing data infrastructure facilities. For GPS testing, we used chambers that already existed," says the Boeing man.

CST-100 CHALLENGES

As with all test programs, not everything has run smoothly for Johnson and his team on CST-100. "We had a challenge with the parachute drop test because when we were preparing to start testing, we were told we had a stability problem," he recalls. "We looked at the mass and the drop in the vehicle and its aerodynamics, and decided that instead of doing a static drop from the helicopter, if we did a drop when the helicopter was moving, it would increase the stability.

"It didn't matter if the drop article was static or moving; for us to get the data required, we just needed it the right way up," he continues. "When we came up with the right parameters to drop it, we did two separate drops. The first was just the main unit, and then we deployed the drones together

BELOW: Wind tunnel testing of the CST-100 and Atlas V rocket at NASA's Ames Research Center in Moffett Field, California

INSET: NASA astronaut Randy Bresnik prepares to enter the capsule as part of a fit check with the main unit. Both times it worked perfectly."

Success on that occasion, then, but another, more recent, challenge Johnson recalls, was borne out of the team trying to develop the CST-100 at the same time as they were learning about its design characteristics. "We were told that more points were needed for the wind tunnel test matrix, so the thousands of runs we were doing at AEDC had to be fully prepared in advance. We couldn't just turn up and run a test. When we give them one run they are used to putting in 100 data points, but for this new information we had to give them 5,000 runs. So when we made the changes we had to correlate them accordingly in our model to make sure they were right, before sending AEDC the correct data we needed to get to them. It all took a lot of extra hours," admits Johnson.

Exercises such as the one detailed above create a huge amount of data to be processed – for one buffet testing session, it totaled 10TB. "For data collection we rely on each particular location, using specific tools to mine the data as it is generated from the test team. They can then send it to our team in real time, so by the time we get to the next run we can see what we need to achieve and if we need to make any changes ahead of the test.

The vehicle's data points are dependent on the phases of flight – a combination of pitch and yaw that puts given forces onto the vehicle. "After establishing the data points we need to figure out how many sensors there are on the vehicle collecting information at each point," explains Johnson.

ABOVE: Testing of CST-100 forward heat shield jettison system

INSET: Air bag drop test – six air bags inflate with a mixture of air and nitrogen to cushion impact

FUTURE PROGRAM DETAILS

More wind tunnel work is expected, as well as further development of the overall system – beyond just the rocket and the spacecraft. "We need to work on the ground system, the mission control system, and the launch control center – all need to be tested," says Johnson. "We are conducting further hardware tests, such as airbag drop tests, to ensure that if we don't land in the water correctly we can right the vehicle. We had a water recovery test where the crew were climbing around on a model under water to make sure that they could get out onto the rafter." The team has also dropped the model from a big rig, to analyze how the airbags deflate.

There will then be the 'runs for record' stage, where the units will start their qualification and acceptance testing in accordance with the required standards: "The general directive standard is SMC-S-016 and we are testing to that, but the first person that tested to that standard said it was terrible because it doesn't allow you to shape it to your event. As a result, we created our own quality standard that we design and test all our hardware to, and that is how the runs for record for the unit and the major assembly will be executed." The CST-100 is set for a 2016 launch – with one manned and one unmanned test vehicle planned.

John Challen is a freelance aviation and automotive journalist

FUTURE EVALUATION GOALS

Going into the design certification phase, there are five key milestones for qualifying the performance advances of the integrated spacecraft, as James Johnson reveals:

- **Quality test vehicle – a full flight article with flight testing, EMC, acoustic and thermal vacuum evaluation;**
- **Structural test article – looking at shock, stress strain, separation of all the major elements. "There will also be a pressure test, where we will fire all the parachute motors and separate all the fairings;"**
- **Hot fire test. "This will take place at the White Sands test facility, where we will evaluate the surface module of the propulsion system from front to back. We're going to take the surface module, mount it on a stand 45ft up off the ground, fuel it, fire the engine and conduct a cold flow test, checking out the pressurization control system;"**
- **Landing tests, assessing airbag performance on the ground and in the water;**
- **Parachute drop tests – dropping the CST-100 from balloons or helicopters.**

Lift fan labs

DARPA has sponsored two ducted lift fan test efforts aimed at compact vertical take-off and landing aircraft that can fly safely in close quarters

BY FRANK COLUCCI

The Transformer (TX) program of the US Defense Advanced Research Projects Agency (DARPA) has morphed from a flying car into a modular unmanned air vehicle (UAV) that uses ducted lift fans to operate in constrained areas without rotor strike hazards. Lockheed Martin Aeronautics Skunk Works and Piasecki Aircraft are building their subscale powered TX model for wind tunnel tests this autumn. A full-sized, turboshaft-driven demonstrator should fly in 2015. Separate from the Transformer effort, a rejected TX proposal from Aurora Flight Sciences turned into a successful electrically driven ducted-fan demonstration aimed at other vertical take-off and landing (VTOL) platforms. Aurora delivered its lift fan final report to DARPA in late July. Although the company's government-sponsored fan work is done, "Aurora will be using this technology in the future," says program manager and principal investigator Dan Cottrell. "There will be follow-on work; this will have future application."

The DARPA Tactical Technology Office solicits high-risk, high-payoff battlefield technologies through Broad Agency Announcements (BAAs) and transitions successful technologies to military users and industry suppliers. In 2009 a BAA described an ambitious drive-or-fly vehicle that could carry 1,000 lb of cargo or four troops over ambushes and IEDs and travel 250 nautical miles without refueling.

Transformer Phase 1 concept study and Phase 2 preliminary design contracts teamed Lockheed Martin with Piasecki, and AAI Corp. with Carter Aviation Technologies, to design off-road vehicles that could unfold and fly. Protected fans promised vehicles small enough to travel on narrow roads and safe enough to take-off and land vertically near ground personnel and terrain. Lockheed Martin and Piasecki proposed tilting lift fans in a fixed wing to achieve VTOL and cruising flight. The AAI-Carter Slowed Rotor Concept was an autogiro with a jump-started lift rotor, fixed cruising wing and ducted thrust fan.

Lockheed Martin and Piasecki were selected last December to continue Phase 3 prototype development on what is now an Unmanned Aircraft System (UAS) with a lift fan flight module designed to carry cargo, sensors and other interchangeable payloads. Within the TX team, Lockheed Martin Skunk Works is prime contractor and responsible for overall vehicle design, aerodynamics, flight controls and flight testing. Subcontractor Piasecki Aircraft in Essington, Pennsylvania, builds the Flight Module, including the drivetrain, gearboxes and subsystems.

In the 1950s and 1960s, Piasecki's Airgeep transitioned from vertical to forward flight with manual flight controls (see sidebar, overleaf). Today, fly-by-wire flight controls derived from those in the F-35 Joint Strike Fighter (JSF) promise to make a lift fan vehicle

The DARPA Transformer has evolved from a flying off-road vehicle to a modular UAS to carry cargo, vehicles and other payloads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PIASECKI VZ-80 (AIRGEEP)

Piasecki Aircraft Corp (PiAC) began development of the VZ-8P Airgeep for the US Army under a 1957 Transportation Research Command contract. The first VZ-8P, delivered to the Army in 1958, had two ducted three-bladed fans driven by twin 180hp Lycoming piston engines through a common gearbox. It was subsequently powered by a single Turbomeca Artouste IIB turboshaft. The follow-on VZ-8P(B) Airgeep II flew in 1959 with two 400shp Artouste IIC turboshafts and incorporated an angle rear duct, ejection seats and power-driven landing gear for ground speeds to 35mph.

The Airgeep II, test flown in 1962, had 8ft 2in diameter ducted fans and could hover out of ground effect at 3,670 lb gross weight and fly at speeds to 65kts. Independent fan pitch commanded attitude, and cyclic pitch and steerable vanes on the ducted rotors provided yaw and roll control. Flight tests near the ground revealed that fan downwash gave the pilot good visibility without blinding debris recirculated by open helicopter rotors. The ducted rotor platform was stable and could fly safely under trees and between buildings. Testing concluded in the 1960s.

The Piasecki ducted fan Airgeep was tested by the US Army in the late 1950s and early 1960s

both flyable and flexible. Lockheed Martin Transformer program manager Kevin Renshaw explains, "The ability to use the same flight module with a variety of modular payloads requires the flight control system to be adaptable to differing weights and aerodynamics."

Three F-35 versions each use an onboard model tailored to predict the response from control deflections based on current aircraft state. Common control laws maintain consistent handling qualities across the different aircraft and reduce development costs for the JSF variants. Lockheed Martin plans to implement a similar architecture in an existing flight control computer to control changing Transformer configurations. Following F-35 practice, control and handling qualities simulations will clear software releases for hardware-in-the-loop tests and subsequent flight tests. Skunk Works is testing the first versions of Transformer control software in its flight controls lab.

An operational Transformer will have to be a highly autonomous UAS to work with non-aviator ground troops. The Skunk Works will consequently draw on the work that Lockheed Martin Mission Systems and Training has done on the K-MAX Cargo Resupply UAS deployed to Afghanistan. (See '*Warhorse*', November-December 2011, p28-32.)

The current TX also builds on a patent-pending Piasecki design and concept of operations. Piasecki received US Army study contracts in 2006 and 2008, one for a UAV – Combat Medic Collaboration for Resupply and Evacuation, the other for an Unmanned Ground and Air System for Contaminated Personnel Recovery. The vehicle concepts included a modular ducted fan design with separating flight and ground modules for air and ground mobility. The Modular Air/Road System (MARS-TX) carried over to the unmanned Transformer.

Though TX prototype gross weights and dimensions are still to be revealed, the variable-pitch fans of the Lockheed Martin-Piasecki Transformer should be about the size of those on the manned VZ-8 Airgeep. Small lift fan models have already been tested in Lockheed Martin wind tunnels, and Piasecki is building a one-third scale flight module with drivetrain, fans and tilt mechanism to characterise various thrust, duct angle and control combinations. The model will be anchored to a calibrated reaction frame to measure lift, drag and control moments through the flight regime.

Data from the model will in turn refine the flight control software for the

> **"TX ENGINEERS WILL ALSO EVALUATE FAILURE MODES AND EMERGENCY PROCEDURES WITH FLIGHT HARDWARE AND SOFTWARE ON THE GROUND TEST STAND"**

full-size Transformer prototype. The TX team will assemble and test their full-scale propulsion system drivetrain next year. Duct structure, flight controls and electronics will be added, and tests of the complete system on a ground test stand will measure thrust and control responses. TX engineers will also evaluate failure modes and emergency procedures with flight hardware and software on the ground test stand, then move on to flight test including hover and transition to cruising flight.

ELECTRIC FAN

The Lockheed Martin-Piasecki Transformer will drive its fans with a familiar turboshaft to cut prototyping costs. DARPA early-on acknowledged hybrid electric propulsion as a means to extend the range of a land-air vehicle. A brushless ring motor driving a fan in a duct could also eliminate heavy gears and linkages and scale up or down for different sized vehicles.

Aurora Flight Sciences in Manassas, Virginia, received a Phase I hybrid ducted lift fan contract in August 2010. Under a Phase II option contract from DARPA, late last year Aurora successfully demonstrated an integrated hybrid lift fan system including electric motor, high switching frequency power controller, and 32in diameter fixed-pitch fan. "The technology was interesting to DARPA for several concepts," explains Dan Cottrell. "Aurora has an aircraft called Excalibur. The full-scale version of that would have employed fans of this size."

The turbine-electric hybrid Excalibur with three lift fans flew in 2009. Aurora also drew on earlier fan experience from its GoldenEye-80 UAV. (See *Aerospace Testing International*, March 2007.) The main goal of the DARPA program was to produce a 70kW motor able to generate over 400 lb peak thrust with a 32in diameter ducted fan. Continuous thrust at 40kW was to be about 300 lb. Required performance called for a thin, five-bladed rotor more efficient than that used in the Excalibur. "It boils down to rotor area, the efficiency of system, and total thrust – it's a figure of merit," notes Cottrell.

The lift fan system included the fan and duct and a 4 x 4ft section of a wing to fit within a notional aircraft profile. Program lead and system integrator Aurora was responsible for the lift fan structures and aerodynamics. "We fleshed out the design of the ducted fan," says Cottrell. "We validated our internal tools with standard CFD [computational fluid dynamics] packages." Aurora recruited motor expert ThinGap in Ventura, California, and controller specialist Trust Automation in San Luis Obispo, California, to build the powerful new fan system.

Phase I tests of a re-amped 20kW motor revealed serious limitations with conventional motor designs. "It was limited thermally and in the dielectric strength of the material used in the motor. It couldn't quite get up to the power they needed," recalls Cottrell. Early performance characterization also uncovered the challenges of a motor with low inductance and high commutation rates. "It boiled down to needing its own controller."

Phase II of the hybrid lift fan development bench-tested purpose-built motors with innovative control technologies. Electric car motors of comparable power have liquid cooling. "That's great for a car application; it doesn't make as much sense for electric propulsion for aircraft," says ThinGap principal investigator Evan Frank. The lightweight, air-cooled brushless

URBANAERO AIRMULE

In Israel, Urban Aeronautics has modernized and refined what it calls the fancraft concept with fly-by-wire flight controls and composite structures. The unmanned AirMule demonstrator is currently powered by a 640shp Turbomeca Arriel 1 turboshaft and has been upgraded from four-bladed to six-bladed fans with 20% more lift. A vane control system on the top inlet and bottom outlet of each lift fan duct deflects thrust either in parallel or differentially to generate either pure lateral force or pure rolling moment. The front and back ducts can also deflect air differentially to generate yaw.

The AirMule has ducted fans at the rear for forward thrust. Drag reduction louvers at the front of the forward duct and rear of the aft duct open in forward flight for speeds up to 120kts. The AirMule fuselage functions as an airfoil and generates sufficient lift at high speeds to off-load 50% of the needed lift from the rotors. Since 2011 the AirMule has logged 120 tethered hover and low-speed flights, each lasting 10 to 15 minutes. The aircraft will transition to untethered cruising flight at the end of 2014.

The AirMule fancraft uses fly-by-wire controls and aerodynamic refinements to advance the ducted lift fan concept

The Aurora Excalibur UAS used turbine-electric fan power to take off and land vertically and transition to cruising flight

ABOVE: Under DARPA contracts, Aurora Flight Sciences conducted a successful high-power test of an electrically powered ducted lift fan applicable to VTOL aircraft

permanent magnet lift fan motor incorporated an ironless stator to improve the power-to-weight ratio and achieve the required power density. "Essentially the stator design is composite with electromagnetic conductors embedded in it," summarizes Frank.

MOTOR CONTROL CHALLENGES

ThinGap, Trust and Aurora engineers connected their motor and controller to a DC bus to simulate battery power. They measured motor currents on oscilloscopes to compare power-in and power-out, and ran the motor on a computer-controlled dynamometer to monitor temperatures to assess overall motor health. The fan motor control varies fan speed to modulate lifting power. "Rather than controlling the thrust with blade pitch, the motor speed is what drives the thrust output," explains Frank. "The torque – power is torque times speed – is proportional to whatever speed you're operating at. With the push to higher power-to-weight ratios in higher power machines, inductance is getting lower. That makes motor control more challenging."

Lift fan control developer Trust Automation drew on previous experience with a traction drive for an electric vehicle to provide the control for the new motor. "One of the things is to maximize efficiency. You want to have a controller – hardware and software – that's mated to the motor," says Trust vice president of business development Craig von Ilten. "The greatest challenge that needed to be overcome was the low inductance of the motor winding. When you have a very low inductance motor the current in the phase winding collapses very quickly." Compared with the optimized lift fan controller, a non-flying commercial controller working with the same power might be 15% less efficient and potentially three times heavier. "There was a tremendous amount of development and test as the system came together," says Von Ilten.

> **"RATHER THAN CONTROLLING THE THRUST WITH BLADE PITCH, THE MOTOR SPEED IS WHAT DRIVES THE THRUST OUTPUT"**

Aurora ran the integrated controller, motor and fan system on a seesaw test rig with load cells at one end. "Through the geometry of that system we would read thrust through the moment arms into the load cells," says Cottrell. "Aurora and ThinGap worked to balance the motor magnetically and structurally. There are some large loads there, not to mention that the rotor itself is attached to this." Strain gages measured stresses for system safety, and high-definition video cameras recorded the tests.

Test engineers used National Instruments' LabVIEW software to collect their data. "The key data we were looking at was thrust and then power-in and power-out, so we could get efficiency," says Cottrell. In December 2012 the system generated 440 lb hover thrust at 70kW for short bursts and 320 lb continuous thrust at 40kW.

The demonstrated ducted lift fan is not flight-rated hardware or optimized for weight. Cottrell notes, "Aurora has an extensive history of lightweight composite aircraft structures and components, so we know that when this technology is integrated into an aircraft we can address those concerns." ∎

Frank Colucci specialises in writing about rotorcraft design, civil and military operations, test programs, materials and avionics integration

Same difference

Dream Chaser vs Space Shuttle: how does Dream Chaser's flight test program compare with that of its bigger brother?

BY SAUL WORDSWORTH

Dream Chaser has successfully completed a series of ground tow tests

In 2010 the Sierra Nevada Corporation (SNC) was one of three organizations to be awarded 'seed money' under NASA's Commercial Crew Development (CCDev) program to build a crew-transportation system capable of traveling to the International Space Station (ISS). Since then SNC has been hard at work developing its Dream Chaser 'space taxi' as a potential replacement for the retired Space Shuttle.

That same year SNC announced it had achieved three successful firings of a single hybrid rocket motor in one day – a critical milestone for the CCDev program. Fast-forward to June 2013 and the second phase of the hybrid rocket motor qualification testing took place. A motor firing and ignition test was completed to validate SNC's motor test stand in preparation for further tests and development under the Commercial Crew Integrated Capability (CCiCap) award.

"We have been making measured and steady progress with the hybrid rocket motor testing and are pleased with the results," says John Olson, vice president of space systems at SNC and former assistant director of space and aeronautics at the White House. "They have been meeting or exceeding our expectations."

RUNWAY MANEUVERS

The Dream Chaser rolled out of its hangar in the Mojave Desert at dawn on August 2, 2013, as teams prepared to pull the flight vehicle through a series of 60mph ground tow tests. The tests formed the fourth set of incremental range and taxi tow tests that the Sierra Nevada Corporation (SNC) has performed to prove the spacecraft's braking and landing systems could handle upcoming captive-carry and approach-and-landing tests to be carried out at NASA's Dryden Flight Research Center. The test followed two months of sequential low- and high-speed ground tow tests, using a pickup truck to pull the flight vehicle across concrete runways at 10, 20, 40 and 60mph to verify the integrity of spacecraft's performance under landing and rollout conditions. The Dream Chaser flight vehicle verifications included flight computer and flight software, instrumentation, guidance, navigation and control, braking and steering performance, flight control surface actuation, mission control and remote commanding capability, and landing gear dynamics.

Through a reimbursable Space Act Agreement with the center, SNC is using Dryden's unique testing facilities and experienced flight-test personnel to prove the system is safe: "Dryden has a rich history of testing advances in aerospace technology from the early lifting body aircraft, through the shuttle program and now the next generation of manned spacecraft," says NASA Dryden Center director David McBride.

CARRY THE CAN

The Dream Chaser has completed a full-scale captive-carry test. Conducted at NASA's Dryden Flight Research Center on August 22, 2013, the test saw Dream Chaser carried under an Erickson Air-Crane helicopter.

The test helped validate several of the Dream Chaser's systems and sub-systems prior to the upcoming free-flight test. The software tested included: flight computer; guidance, navigation and control; aero surfaces; and the landing gear and nose skid, which was deployed during flight. In May 2012 SNC performed a similar, but less extensive, captive-carry test in Broomfield, Colorado.

The captive-carry test is just one in a series of tests completed at Dryden. To date, the Dream Chaser team has completed ground taxi- and tow-tests, evaluated the performance of the main landing gear and completed a flight test readiness review. All systems have been verified and the Dream Chaser flight vehicle will undergo final preparations for the upcoming approach-and-landing test (ALT) scheduled for the autumn.

Comparisons between Dream Chaser and Space Shuttle rocket testing methodologies are difficult because of their markedly different operating systems – the Shuttle used a liquid oxygen and hydrogen propulsion system, the Dream Chaser hybrid engines burn nitrous oxide and industrial rubber. Flight testing of these similar-looking vehicles, on the other hand, garners some fascinating comparisons and interesting parallels.

TOW TESTING

In May 2013 the Dream Chaser engineering test article (ETA) spacecraft – nicknamed Eagle – was transported in a shrink-wrapped state to NASA's Dryden Flight Research Center on California's Edwards Air Force Base, the same place the Space Shuttle was first flight tested in 1977. Dream Chaser was reassembled in July before undertaking its first tow test.

"Once we had validated that all the systems were working we went through a series of ground tests, starting at 10mph before progressing to 20, 40 then 60mph," says Olson. "We are trying to be innovative and thrifty with our flight test program, but thorough in driving through an incremental test build-up approach. Our overall philosophy is 'build a little, test a little' to establish technical credibility. We're walking, crawling, jogging, then working up to a run and building our endurance too."

The ground tow testing was done using a Ford F-450 pickup truck on Dryden's concrete runway. Multiple NASA and Edwards Air Force Base telemetry systems were used to capture the data along with onboard data acquisition and recording systems. As part of the test team's systematic integrated vehicle check procedures, SNC carried out extensive systems validation, ensuring that the polarity, integrated flight test components, subsystems, transponders, radar altimeters, various sensors, brakes,

"OUR OVERALL PHILOSOPHY IS 'BUILD A LITTLE, TEST A LITTLE' TO ESTABLISH TECHNICAL CREDIBILITY"

ABOVE: The captive-carry test was undertaken at NASA's Dryden Flight Research Center

> **"WITH THE SHUTTLE WE ALSO HAD ONBOARD RECORDERS BUT THE DIFFERENCE WAS THE AMOUNT OF DATA THAT COULD BE STORED"**

landing gear, flight software, nose sensors and special flight test nose boom elements were working.

"There has been a substantial amount of integrated subsystem and system-level testing leading up to each of the ground tow test speed milestones," says Olson. "It's not just towing an inert vehicle but rather a fully live and operating vehicle system. We get it to the desired speed then release and assess the vehicle's autonomous runway alignment. As it maintains the runway heading we measure and assess the performance and responses of the various systems, including differential braking to assess the steering, as well as the performance of the nose strut and main landing gear."

Cheryl McPhillips of NASA is partner manager for SNC as part of NASA's Commercial Crew program. She was at NASA through most of the Shuttle years and is well placed to observe the differences in the development and testing approaches.

"As the Shuttle was so much bigger than Dream Chaser, NASA had to engage the use of elaborate tire and gear testing equipment as well as larger aircraft tugs," she says. "The Dream Chaser tow-testing data is captured using telemetry datalinks and onboard recorders. With the Shuttle we also had onboard recorders but the difference was the amount of data that could be stored. Initially we were only able to keep approximately 56KB of memory aboard the Shuttle. A typical SIM card today holds 8-12GB."

CAPTIVE CARRY

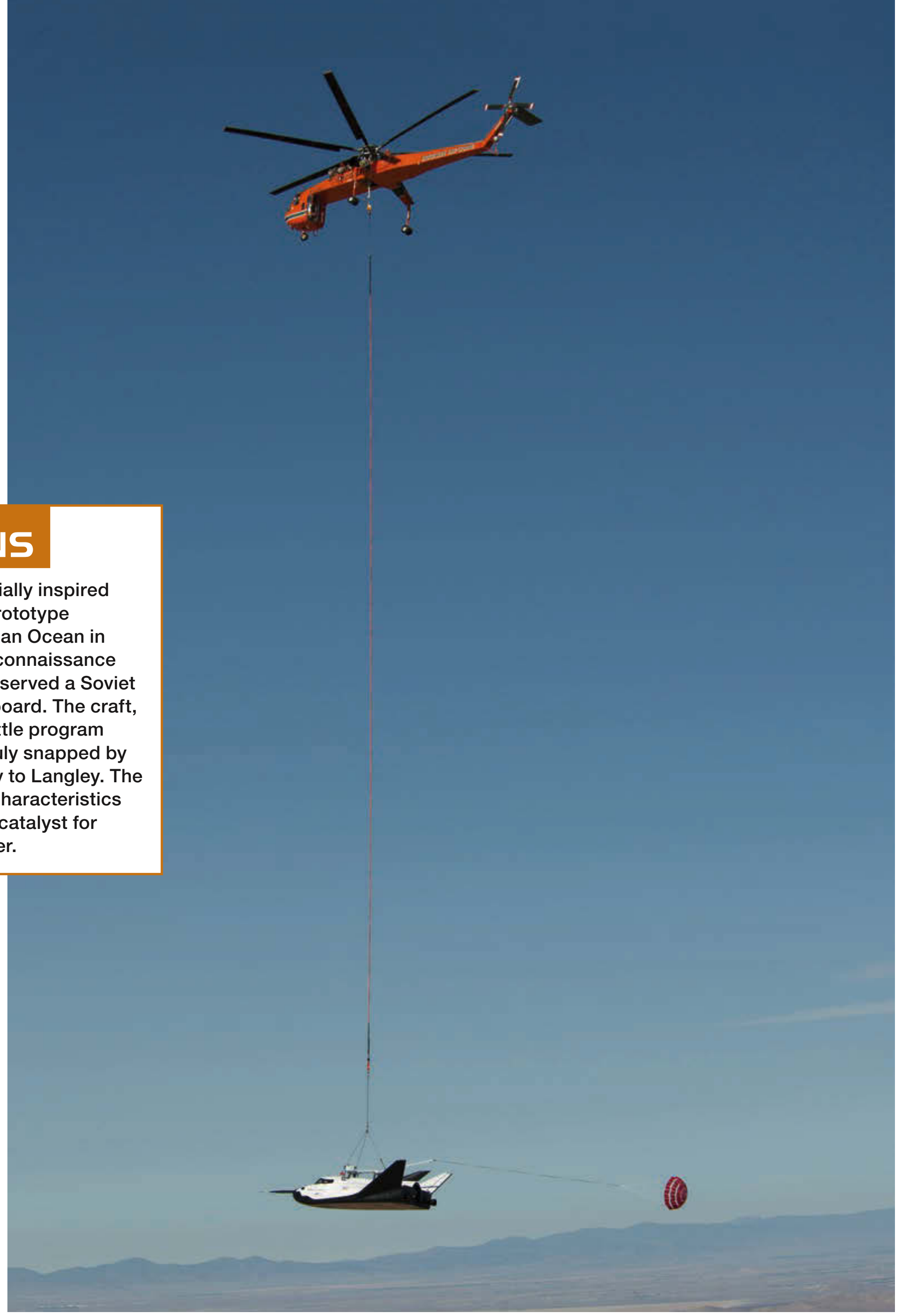
The captive carry test saw the unmanned spacecraft connected by a long Kevlar cable to an Erickson Air-Crane Helicopter and hauled more than 10,000ft above ground before being released. During this successful test SNC systematically verified that all its systems functioned in an airborne environment and examined the loads the vehicle will encounter during flight, as well as the system performance and aerodynamic handling the vehicle may experience upon release from the helicopter.

"We achieved the airspeed and altitude parameters planned for the approach and landing free flight test and tested all the essential subsystems and components necessary to safely land autonomously on the runway," says Olson. "We assessed everything from the air data systems to the flight computers and software, the radar altimeters and other sensors throughout the planned approach and landing flight profile. This included validation of our data acquisition systems both onboard and on the ground, including tracking, telemetry, and command-and-control integrated systems. Following the successful completion of this series of ground tests and our captive carry test, we'll assess all the data and make sure we're ready to go before progressing to the free flight test."

One similarity between Dream Chaser and Shuttle flight testing is that both vehicles were initially flown unpiloted to identify any issues before introducing a pilot. A notable difference, however, is the way of getting the spacecraft airborne. The Space Shuttle Enterprise used a Boeing 747 as its carrier vehicle while SNC is using a heavy-lift helicopter, the Erickson Air-Crane S-64F, also known

ABOVE: Dream Chaser hybrid rocket motor firing

BELOW: Tow testing has seen the test vehicle pulled at 10, 20, 40 and then 60mph



COLD WAR ORIGINS

The design for Dream Chaser was initially inspired by the BOR-4, an unmanned Soviet prototype spacecraft that came down in the Indian Ocean in 1982. A Royal Australian P-3 Orion reconnaissance airplane was patrolling nearby and observed a Soviet ship attempting to drag the vehicle aboard. The craft, which was part of a Soviet space shuttle program that never saw the light of day, was duly snapped by the P-3. These images made their way to Langley. The center of gravity and apparent entry characteristics exemplified by the design proved the catalyst for what eventually became Dream Chaser.

as the Sikorsky Sky Crane. This is possible principally because Dream Chaser is slightly less than one-third the size of the Shuttle and only one-fifth of the weight. The helicopter used by SNC will be rented, whereas the 747 NASA used was purchased specifically for the Shuttle program. This is all part of what SNC calls its "affordable, innovative and credible" flight test program.

"During flight testing SNC uses a lot of GoPro cameras," says McPhillips. "These tiny, inexpensive cameras are often used in extreme sports events, scuba diving and so on. They are able to record hours of data in HD. During any airborne testing, cameras will be pointing out of the windscreen to provide a pilot's view of what it's like to be flying Dream Chaser. We certainly didn't have access to such technology for the Shuttle, instead relying on high-bandwidth television signals."

FREE FLIGHT TESTING

The free flight testing will be an emulation of the captive carry test. The protocol will be the same so that it will be familiar to the helicopter pilot, mission control team and test director. The craft will still be autonomous and the profiles flown will be identical. The difference is that Dream Chaser will be released at an altitude of 12,500ft mean sea level. With Dream Chaser's likeness to the Shuttle it promises to generate great media interest.

"The release altitude and airspeed will be driven by the maximum performance characteristics of the helicopter, which is determined by the temperature and density altitude," says Olson. "Because we are operating over a high mountain desert we will execute this test in the very early morning to take advantage of the cooler temperatures and generally calmer wind conditions. We want to ensure that we can hit the precise parameters of the release box necessary for a successful setup of the approach and landing free flight test. Cool, calm and clear weather is essential. By then this will be a well-choreographed activity and we expect that this methodical preparation will lead to success. We won't release until we are ready, but when we do, it will be a beautiful sight for the entire team."

ABOVE: **NASA and SNC saved money by only renting the helicopter used for tow testing**

WHAT CHALLENGES?

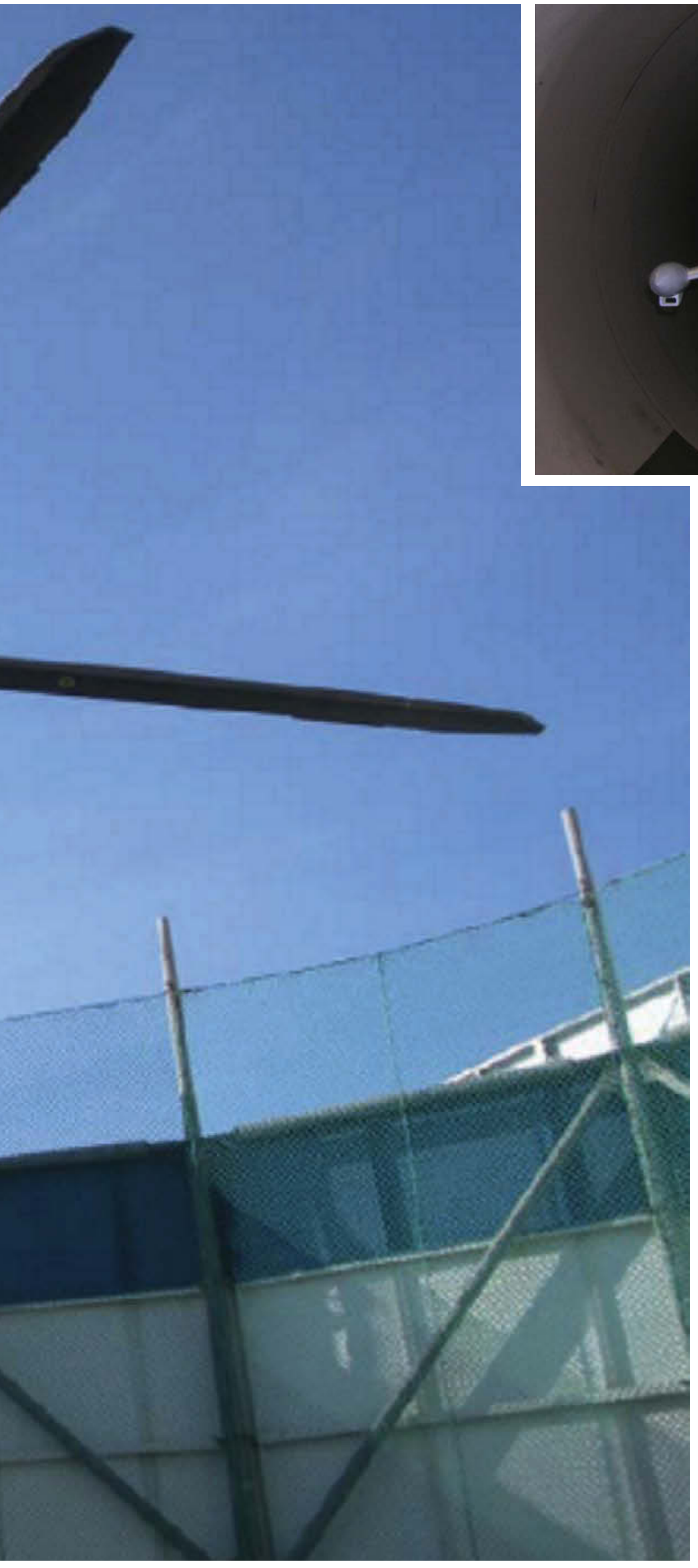
Olson says the team has achieved tremendous progress with the spacecraft in the last 90 days during its time at NASA Dryden. He refers to the litany of challenges the team has faced as a 'whack-a-mole': "All these pesky problems crop up and you have to address and fix them systematically in a timely, accurate and regular fashion. The team, under the leadership of former astronaut Steve Lindsey, is thriving at the pinnacle of what could be termed 'professional fun'."

Saul Wordsworth is a freelance aerospace journalist for Aerospace Testing International

X factor

Eurocopter pushed existing rotor technology with its X3 demonstrator. Flight test engineer Dominique Fournier explains the company's step-by-step approach to testing and proving the helicopter over its 156-hour test program

BY PAUL E EDEN



MAIN: **Rotor and propeller full-scale test bench used to measure propeller performance with and without main rotor wake interference**

LEFT: **Reduced scale model used during wind tunnel testing to measure drag and stability of the X3 airframe, and to design tail parts**

Eurocopter revealed its X3 technology demonstrator on September 27, 2010, just days after its first flight. The aircraft was designed to test high-performance helicopter technologies and achieved a string of notable milestones in flight test. But while flying was the most obvious and dramatic component of the X3 project, Eurocopter also developed an exhaustive test program for the machine, including wind tunnel tests, bench tests and simulator work, which continues to inform its work.

The company initially made extensive use of the wind tunnel at its Marignane headquarters, aiming to identify and quantify global drag, and then to define the optimal sizing of the tailplane and fins for sufficient dynamic stability for the X3 to be flown throughout its flight envelope without recourse to autopilot.

Marignane was also the site of a multipurpose rotor bench used to optimise the propeller design. The bench was significantly modified with the addition of a stub wing and transmission, the latter complete with gearbox and propeller. The X3's propellers were required to deliver optimal performance under the contrary demands of high-speed forward flight and the hovering regime. The bench proved very effective in the assessment of interactions between main rotor downwash and the propellers in the hover.

SIMULATION

Eurocopter's fixed-base research simulator also had an extensive role to play in the pre-flight test phase. X3 flight test engineer Dominique Fournier explains, "The simulator was used to examine flying and handling qualities, and modifications were made to both the software and hardware to incorporate specific models – including those for the wing and propellers – and specific X3 controls, such as the propeller thrust and yaw controls. Simulation was used to define propeller control and power management data, as well as limitations specific to the X3. We also studied the aircraft's behavior should any of its unique systems fail, so emergency procedures were checked and validated prior to first flight."

The X3's transmission systems were exposed to extensive endurance and fatigue testing, especially the main and propeller gearboxes, on dedicated benches. The transmission test schedule was actually phased through several steps throughout the X3 program. The main gearbox was an EC175 unit modified by the addition of two lateral outputs.

Although the X3 was designed to reach 220kts, it was decided to perform the initial transmission tests at the lower power settings required to achieve 180kts, in order to reduce development lead time and risk. Gearbox endurance and fatigue bench testing continued to clear components for full power in parallel with the early, limited-power test flights.

It quickly became apparent that the X3 was capable of exceeding performance estimations by a considerable margin. At just 80% power, the aircraft exceeded 232kts in level flight in May 2011, and after full power became available, it achieved an impressive 255kts in June 2013.

Critical flight control components for the main rotor and propellers were

DLR'S AIR-BLOWING ROTOR

Early in 2013, researchers at the German Aerospace Center (DLR) revealed details of their work on an air-blowing rotor blade designed to improve helicopter maneuverability. "Helicopters have a particular problem with dynamic stall at high rotor loads during maneuvering flight," explains Tony Gardner, from the DLR's Institute of Aerodynamics and Flow Technology. "Systems to reduce dynamic stall allow helicopters to fly into stall without damage and thus increase maneuverability," he continues. "With the air-blowing rotor, the increase in maneuverability is proportional to compressed air use, so a system of this type is most suitable for short bursts of 10-20 seconds maximum, rather than constant use."

DLR constructed the experimental rotor blade section (pictured) using two carbon fiber half shells around an aluminum spar. Dry compressed air was supplied under high pressure and fed through the aluminum spar to the jets aft of the blade's leading edge. Each jet had an individual fast-acting valve that could be turned on or off, or pulsed at up to 500Hz.

Gardner reports that the rotor section model was tested in the 1 x 1m adaptive-wall test section of the Transonic Wind Tunnel Göttingen (DNW-TWG), which has a Mach number range of 0.3-0.95. The pitching aerofoil was installed between two hydraulic motors and pitched up and down with a frequency between 3Hz and 6Hz. It was instrumented with pressure, temperature and acceleration sensors, and mounted on a force balance. A wake-rake measured drag data, and additional points with pressure-sensitive paint measured the full dynamic surface pressure field.

The wind tunnel model and attachments to the DLR air system were specially prepared for the project and the model was given a dynamic pitching motion using a hydraulic pitching rig to investigate the aerodynamics of flutter, buzz and dynamic stall.

The pressure in the wind tunnel can also be varied, between 0.3 and 1.4 bar, allowing investigation of Reynolds number effects over a limited range.

Initial measurements with the air-blowing rotor showed a small (1-10%) increase in drag due to the exit portholes of the jets, while turning the jets on enabled a 20% increase in static maximum lift and a 40% increase in lift for stalled flow.

However, Gardner explains that these were not the key results: "The most important test conditions were those with the rotor section performing forced pitching motion," he says. "Here we tested cases without stall, with light dynamic stall and with deep dynamic stall between Mach 0.3 and 0.5. The test conditions were similar to those on a small to medium helicopter at high altitude performing highly loaded maneuvers. Particularly deep dynamic stall is difficult to control and we were pleased that at least a 60-80% reduction in the dynamic loads could be achieved for deep stall. Full suppression of stall was achieved for many light-stall test cases."

submitted to endurance and fatigue tests, either by Eurocopter or its suppliers, but the rotor itself was subject to very little testing outside assessing its interaction with the propellers, since it was a standard EC155 unit. Fournier explains, "One of the primary objectives of the X3 project was to show that a standard helicopter rotor can fly at a speed that would never be possible on a standard helicopter. The 'hybrid' helicopter concept allowed us to push the boundaries for a standard rotor and we demonstrated this by safely using an EC155 rotor at 255kts, while the maximum dash speed of the EC155 is around 150kts!"

The avionics and autopilot, and the engine's FADEC software, were also validated on dedicated benches. The Rolls-Royce/Turbomeca RTM322 turboshafts and their FADEC system underwent endurance testing with Turbomeca.

FLIGHT TESTING

Eurocopter fits its prototypes with a flight test installation (FTI) and the X3 was no exception, featuring an enhanced FTI in keeping with its technology demonstrator role. A large number of sensors were distributed around the aircraft and data from these, plus other items of equipment, were sent to acquisition units and recorders. Information across more than 600 parameters was acquired, of which 500 were broadcast through the X3's telemetry system.

Eurocopter kept the X3 project secret for more than two years while it designed the aircraft, parts were manufactured and, ultimately, the machine was assembled at Marignane. Maintaining secrecy during test flights from Marignane International Airport would have been impossible however, and it had been decided very early on that flying operations would require a remote, secure location.

255kts	The speed achieved by X3 in level flight on June 7, 2013
263kts	The speed achieved by X3 during descent, a few days earlier
2,541shp	The maximum power output of the X3's two RTM322 (01/9a variant) engines
156	Number of hours aloft the X3 demonstrator has accumulated since making its maiden take-off in September 2010

The French Air Force base at Istres was chosen, Eurocopter renting a hangar at the facility's Direction générale de l'armement (DGA, the French armament procurement agency) flight test center. The X3 team moved from Marignane to Istres with the aircraft on July 31, 2010. A dedicated

X3 telemetry room was installed in the DGA hangar, as although the majority of Eurocopter prototypes are monitored via telemetry on their first flight, it is less common to use telemetry thereafter. However, as a technology demonstrator the vast majority of the X3's flights were telemetered.

The X3 was built with only two seats – for a test pilot and flight test engineer – but with the aircraft's unique configuration in mind, it was decided to depart from standard Eurocopter practice and a second flight test engineer always assisted from the telemetry room. In mid-2012 a third seat was nevertheless installed.

The flight test program began on August 16, 2010, with the initial ground run. "The ground runs were used to study the behavior of different systems – transmissions and gearboxes, engines, propellers, controls and so on – and for final validation of the FTI and telemetry," explains Fournier. The first flight came on September 6, 2010.

Fournier says that flight envelope expansion was conducted through a safety-first, step-by-step approach. "This was not a novelty; it is the basis of Eurocopter flight tests on all projects, but perhaps we were more aware that unexpected problems could occur due to the unusual concept. This was why the presence of a second flight test engineer in the telemetry room was so important. An experienced crew member, the engineer could 'feel' what was going on in the aircraft, while having access to a huge amount of information. He was then able to report only his essential observations to the flight crew."

The X3 actually worked exceptionally well from the outset; on flight number 12, the 180kts objective of the first phase was achieved with a significant power margin remaining. On the 17th flight, 232kts was achieved in level flight using 80% of the available power, although the aircraft had been designed to achieve 220kts only at full power.

"THIS WAS WHY THE PRESENCE OF A SECOND FLIGHT TEST ENGINEER IN THE TELEMETRY ROOM WAS SO IMPORTANT… THE ENGINEER COULD 'FEEL' WHAT WAS GOING ON IN THE AIRCRAFT"

ABOVE: Flight testing was carried out at the French Air Force base at Istres, to ensure secrecy

LEFT: The X3 achieved a speed milestone of 255kts in level flight on June 7

PLANNING AND PREDICTION

With its unusual design concept, it would seem reasonable that Eurocopter should develop specific flight test techniques for the X3. On the contrary, Fournier says, "Standard techniques were used but, because of the small size of the team, dissemination of information and the decision-making process were faster than for a standard project."

He also emphasizes the importance of modeling, even as the flight test campaign was underway. "Dedicated performance prediction models were developed using flight test data, using our understanding that on the X3 many more parameters could be used to optimize performance than on a standard helicopter. The lift ratio between the wing and rotor is a

primary example, but there were many others," he says.

"These models were very useful when we came to plan the attempt for maximum speed in level flight. For this kind of flying, where you are trying to reach performance limits, you first need to be sure that you're simultaneously using maximum available engine power and the maximum power authorized for the transmissions. This means that the engines must be operating at their limits and the transmissions at their torque limits," says Fournier. "For these parameters to be achieved, ambient temperatures have to be optimal. That's why the 255kts flight was performed on June 7; spring was cold in the south of France this year and we'd been waiting for warmer weather since the end of April, checking the internet every day for atmospheric conditions and predictions," he continues.

With conditions favorable, the X3 team had to address the other essential parameters for the maximum speed attempt. These included the need to fly at the correct altitude for the best lift/drag ratio, but also where the engine power and transmission torque limits were reached. And the ideal lift ratio between the rotor and wings also had to be achieved, while the best compromise on rotor speed, between the optimum advancing blade tip Mach number (in order to reduce compressibility effects, and achieved by reducing rotor speed) and the need to control advance ratio values to reduce retreating blade stall effects (which calls for a minimal reduction in rotor speed) also had to be reached.

The predictive models developed during flight testing were vital in achieving the level 255kts. In fact, such was the significance of these models that their data was confirmed by an earlier flight, during which 260kts was achieved in a dive.

Some of the X3's rotor blades were instrumented with strain gauges along their whole span, but otherwise there were no modifications to the blades or rotor hub. Late on in the flight test program, the hub was streamlined with a fairing, primarily to facilitate study of its benefits, especially in terms of drag reduction compared with potential industrial and maintainability drawbacks.

X3 MOTIVATION

Going fast just to go fast was not the objective of the X3 project, nor is it the objective of the H3 (high-speed, long-range, hybrid helicopter) concept for which the X3 was a technology demonstrator. "The objective," says Fournier, "is to go fast at an affordable cost – manufacturing and maintenance costs are of the utmost importance. The X3 has provided a tremendous amount of data that is now part of Eurocopter's competence and intellectual property. It will be used if we decide to exploit it in a serial application, although some of it could already be used on standard helicopter projects."

ABOVE: Eurocopter achieved the historic 255kts speed milestone with the X3 flying at an altitude of around 10,000ft during a 40-minute test flight

ABOVE INSET: Having proved capable of offering the speed of a turboprop-powered aircraft and the full-flight capabilities of a helicopter, the X3 was retired in July 2013

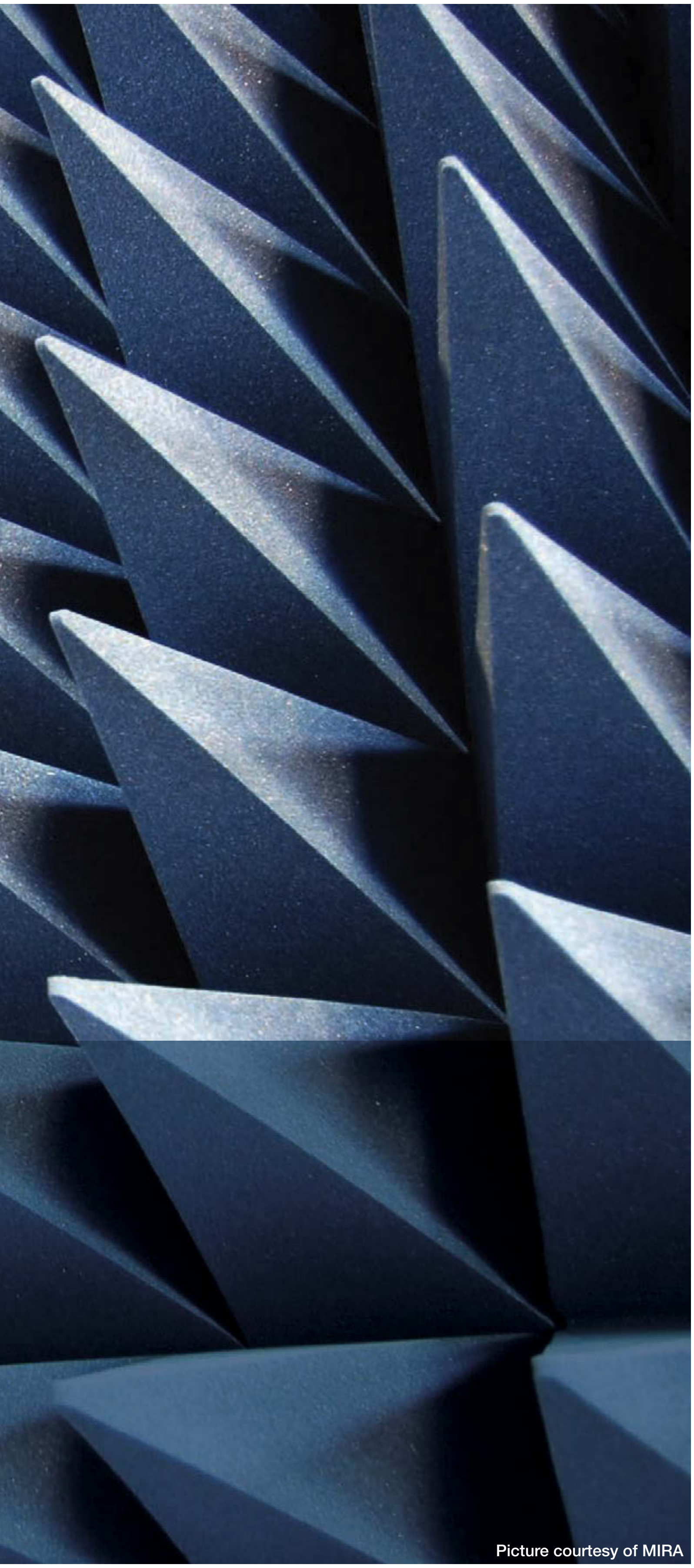
The X3 was retired on July 23, 2013, after 156 hours and 10 minutes airborne in 199 flights. More than 50% of these were for communication or marketing. "The X3's achievements lived up to Eurocopter's 'thinking without limits' slogan. Its technical and reputational success are down to the full engagement of the people involved, from upper management down to the front line," concludes Fournier. ∎

Paul E Eden is a UK-based freelance writer and editor in the aviation industry

Current affairs

As the amount of electronics on board aircraft continues to grow, so does the importance and sophistication of EMC testing

BY TIM RIPLEY



Picture courtesy of MIRA

In the 1980s the US Army's UH-60 Blackhawk helicopter fleet was plagued by a spate of crashes that left 22 soldiers dead. Subsequent investigations determined that the helicopter's electronically controlled flight control systems, as well as much of its avionics, were susceptible to radio frequency interference (RFI) from radar antennas, radio or microwave towers and illegal CB radio transmissions. Eventually, the US Army followed the lead of the US Navy and started retrofitting shielding to key components on its UH-60 helicopters.

This incident made headlines 25 years ago and put the issue well and truly on the aerospace safety agenda. Fast-forward to the second decade of the 21st century and media reports have suggested that an increasing number of aviation safety incidents have been attributed to electromagnetic interference from cell phones and other consumer electronic devices used by passengers.

"There is no doubt that electromagnetism continues to be a growth area," says Ian MacDiarmid, the head of electromagnetics in BAE Systems Military Air & Information business unit. "It is such a fundamental part of modern life with our increasing dependence on communications and sensors. Like gravity, the fundamental nature of electromagnetic fields is still a subject of considerable debate, but we do have some fundamental laws of physics, which, combined with a rapid growth in affordable, high-performance computing, enable us to predict behavior reliably and work with these fields very effectively."

REGULATORY ENVIRONMENT

Underpinning all testing for electromagnetic compatibility (EMC) are the regulations put in place by national and international aviation safety organizations. The US Federal Aviation Authority (FAA) and the European Aviation Safety Agency (EASA) have worked closely on this issue to put in place and regularly update EMC safety rules.

According to David Walen, the FAA's chief scientific and technical advisor for electromagnetic interference, it has established aircraft certification and airworthiness standards to be followed during the design and building of aircraft, and then airmen, airspace, general operating rules and air carrier operating rules for the safe operation of aircraft. He said the main airworthiness regulations address lightning protection, high-intensity radiated radio frequency protection and EMC.

"During certification, the EMC compliance is assessed initially on individual components, taking into account the environment in which they are installed, for example the shielding available from transmitters," Jeremie Teahan of EASA told *Aerospace Testing International*. "System functions are verified on the whole aircraft and some tests are performed on the aircraft level on ground and in-flight to verify system performance."

EARLY TESTING

According to Dr Nigel Carter, the former technical manager of the EMC Group at the UK technology company, QinetiQ, the earliest reported whole aircraft EMC test was an EMC type acceptance trial in 1932 on a Vickers Vildebeest Mark I, which took place at the Aeroplane and Armament Experimental Establishment at Boscombe Down in Wiltshire, UK. "Testing in these early days was concerned with the effect of engine

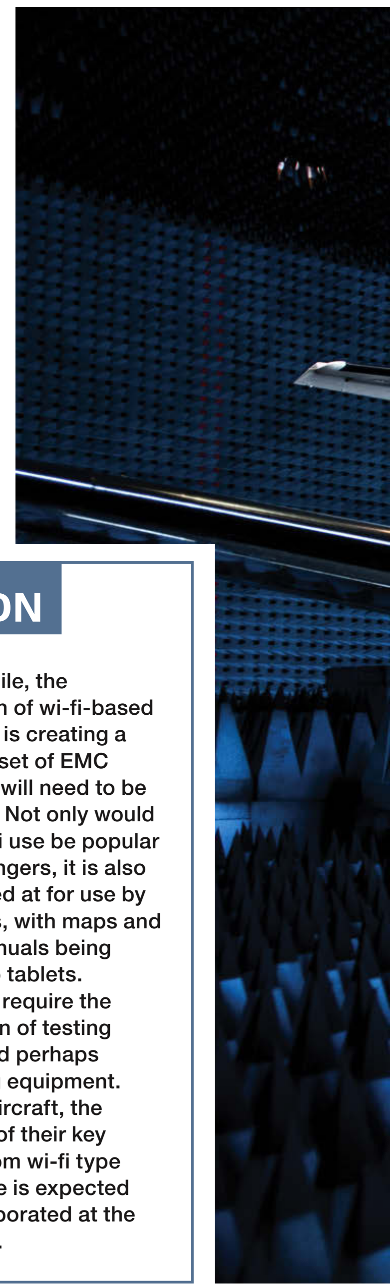
interference on communication and later navigation systems," he says. "Immunity testing of complete aircraft really developed in the military in the 1960s. Aircraft testing is already very expensive and time consuming, and greater emphasis is going to have to be placed on equipment and system rig testing to enable aircraft to be certified to an adequate level and frequency coverage. Irradiating aircraft using antennas in an open area site to achieve the levels will be impractical."

This has led to modern EMC testing moving into new areas, with greater emphasis being placed on testing of subsystems and components, as well as computer modeling of the performance of the whole aircraft's electrical systems.

While lightning protection testing has long been a major part of the design and testing of aircraft, according to Nicholas Wright, international sales manager, at Swiss company EMC Partner, the type and amount of electrical and electronic systems used in aircraft has increased dramatically, requiring new types of testing to be introduced. "Some of the latest systems rely on variable frequency power and electrical systems for everything from the galley coffee machine to replacing traditional hydraulic control of the flying surfaces," he says.

"Latest-generation aircraft require tests to the avionics equipment for which no previous experience existed," he says. "The responsibility is very much on the aircraft manufacturer to ensure that appropriate testing is performed. This situation requires a further test process and much more time. As these test types can already run for many days or even weeks, a further extension is undesirable."

LEFT: Lockheed Martin GPS III Prototype being tested to ensure multiple high-powered signals generated from the satellite's navigation downlink transmissions, or transmitted from the hosted nuclear detection system payload on the satellite, do not interfere with each other or themselves



VOLTAGE SPIKES

A key element of EMC testing in aircraft is the mitigation of 'voltage spikes' that might be transmitted around cabling bundles or wiring looms, with the fear being that they could activate or prevent the activation of flight critical systems at key moments, with catastrophic results.

"In modern times, the increasing complexity of electronic systems and the advent of full computer control of platforms has meant that voltage spikes need to be addressed at a whole different level to the past," says Wright. "Aircraft contain many sources that can generate voltage spikes. The most likely source of voltage spikes is

CONSUMER ELECTRONICS REVOLUTION

How best to deal with the growing issue of integrating consumer portable electronic devices or PEDs – cell phones, laptop computers, tablets, games consoles and video players – into commercial airliners?

"Data strongly suggests that passenger PED use has contributed to aircraft incidents and accidents," responds Douglas Hughes, retired aerospace accident investigator. "Flight-deck crew members are often expert at recognizing electromagnetic interference (EMI) events and having cabin crews search for passenger PED use and correlation. The data is extensive. The crew of an older Classic Boeing 737 recognized an EMI event and commented about the differences in these events experienced in the older versus the newer 'glass cockpit' aircraft."

Cell phone use during flight and airport taxiing has long been banned by most aviation authorities and the use of other devices is prohibited during landing and take-off. Claims persist that cell phone use has been implicated in several aviation safety incidents, although it has not yet been definitively identified as the main cause of any air crashes involving fatalities.

Meanwhile, the proliferation of wi-fi-based technology is creating a whole new set of EMC issues that will need to be addressed. Not only would inflight wi-fi use be popular with passengers, it is also being looked at for use by flight crews, with maps and aircraft manuals being migrated to tablets.

This will require the modification of testing regimes and perhaps new testing equipment. On future aircraft, the protection of their key systems from wi-fi type interference is expected to be incorporated at the build stage.

electric motors. All motors are inductors fitted in the power line. Energy is stored in the inductor's magnetic field and when power is removed, it is released as a spike with amplitude proportional to the inductor and therefore the motor size. In modern platforms, there is a tendency to add more and more motors to automate certain functions. Aircraft have huge motors for flap and landing gear actuation. Because of the motor size, spikes can attain many times the nominal voltage level.

The phenomenon is fairly well known and many standards already exist, however, with the increasing technological challenges, existing ideas need to be challenged and revised where necessary. In particular, the use of 'fly-by-wire' technology requires a new level of immunity to voltage spikes to ensure aircraft safety."

The preferred application method to replicate voltage spikes in aircraft cabling is known as serial injection. This involves inducing an electronic impulse into cabling using an inductive coupling clamp. It is the most widely used due to the non-intrusive nature of the coupling.

"A common thread running through the various standards is the need to superimpose the impulse on all lines simultaneously," says Wright. "This is logical as voltage spikes circulating in a system will impinge on all power interfaces simultaneously."

The testing of aircraft cabling and wiring for EMC is now a sophisticated exercise, with computer controlled systems that generate impulses through test rigs and then the wiring looms of actual aircraft. These allow multiple events and combinations of events to be tested, and the results recorded for analysis.

EMC testing is often run in radio frequency (RF) anechoic chambers to protect the local environment and test personnel from the damaging effects of persistent electromagnetic energy. The interior surfaces of the RF anechoic chamber are covered

BELOW: A C-12 Huron undergoing EMC testing in the anechoic chamber at Eglin Air Force Base, Florida, USA

with radiation absorbent material (RAM) to isolate the environment. The RF anechoic chamber is typically used to house the equipment for performing measurements of antenna radiation patterns, EMC and radar cross-section measurements.

In the past, RF anechoic chambers were used to test the effect of electromagnetic pulses generated by nuclear explosions on military aircraft, but the latest versions are being used to test the susceptibility of civilian aircraft to external electromagnetic influences.

REVERB CHAMBER

Another testing environment is an electromagnetic reverberation chamber, which is also known as a reverb chamber (RVC) or mode-stirred chamber.

An RVC is a screened room with a minimum of absorption of electromagnetic energy. Due to the low absorption, very high field strength can be achieved with moderate input power. A tuner is then employed with large metallic reflectors that can be moved to different orientations in order to achieve different conditions. RVCs are used principally to test the susceptibility of aircraft and components to external RF interference.

Testing in anechoic chambers and RVCs can be conducted on full-scale objects, including aircraft, or on scale models where the wavelength of the measuring radiation is scaled in direct proportion to the target size. For civilian airliners, this presents a major challenge because the size of the aircraft makes it impossible for them to be fitted into chambers. While open-air test sites cannot be used for the intense periods required to complete comprehensive testing, this has led to the growth of computer modeling of EMC. But on older aircraft, the build standard of airframes and their wiring was often not consistent, leading to inaccuracies in modeling-based testing. As new-generation aircraft come on line with more consistent build standards, then it has become possible to move to modeling-based testing.

There is now a very mature global EMC testing industry, which provides both the equipment to enable companies to carry out their own testing, and a large service sector that conducts testing on behalf of clients. Many aircraft prime contractors also offer their facilities for use by third parties to help offset their large capital costs involved in setting them up.

"AS NEW-GENERATION AIRCRAFT COME ON LINE IT HAS BECOME POSSIBLE TO MOVE TO MODELING-BASED TESTING"

FUTURE DEVELOPMENTS

"The safety of airliners and the traveling public is paramount," says EMC Partner's Wright. "To maintain the current high standard as technology evolves, there is a need to rethink test requirements."

Regulatory agencies are actively involved in pushing new testing requirements. "EMC test procedures is an area of constant development and this area is regularly updated by the industry/authority group working on the corresponding standard (RTCA DO160/EUROCAE ED-14 currently at revision G, dated May 2011 section 20 Radio Frequency Susceptibility)," says EASA's Teahan. "Further updates of that standard are under preparation. In 2007, RTCA DO 307 'Aircraft Design and Certification for Portable Electronic Device Tolerance' was developed and

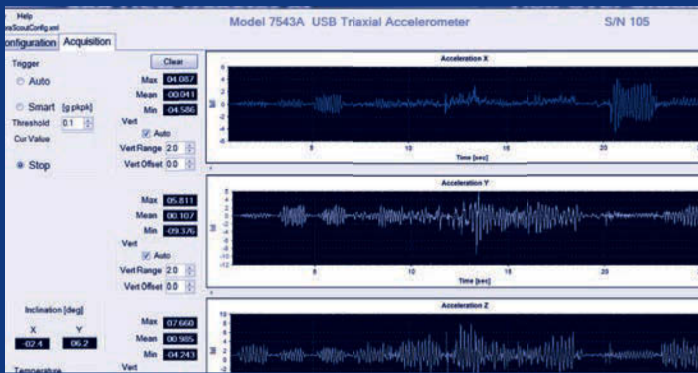
ABOVE: Tristar under EMC test at Boscombe Down, Wiltshire, UK

is used currently on new aircraft certification projects for air transport category aircraft on a case-by-case basis. Currently in the USA, an Advisory and Rulemaking Committee is finalizing its recommendation to the FAA in respect to allowing the use of personal electronic devices (PEDs) in a more general way during flight. Once published, EASA will review those recommendations and decide on appropriate actions in that area."

Many experts think that moving to modeling-based testing offers many opportunities to keep up with the rapid advances in aircraft designs.

"The main challenge facing EMC engineers for the future is to develop test procedures capable of handling the complexity of modern avionics in an ever increasing electromagnetic environment without incurring prohibitive cost and time penalties," says Dr Carter. "Less reliance may have to be placed on whole aircraft testing for this reason. In parallel, the development of reliable mathematical modeling codes to supplement and reduce the amount of testing required will increase in importance."

Tim Ripley is an international aviation journalist and freelance writer



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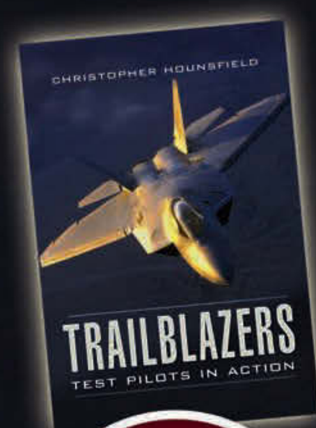

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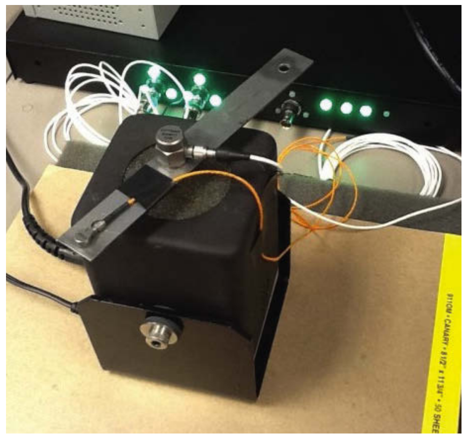
ADVANCED SRTD CONTROL

Vibration Research has developed Advanced SRTD Phase-Tracking Control, software that will help engineers conduct accurate tests and ensure quality

Traditionally, when test engineers have performed sine resonance track and dwell tests, they have controlled the frequency of the resonance with little concern for the phase of the resonance. There is good reason for this. Since resonance occurs when a material's vibrations are reinforced (constructive interference) by the 'reflected' waves in the material, it can be assumed that the ideal phase value for a resonance is 90°. Therefore, controllers would often set the default phase setting for a resonance to 90°.

However, in reality this theoretical phase value of 90° could be different. The phase value may be affected by the location of the accelerometer or due to a lag in the reading of instrumentation. When these real-life factors are considered, the test engineer should be concerned about the phase value of the resonance.

Since the resonance frequency may change slightly as the product fatigues, and the phase value does not change during the fatigue process, it is beneficial to control the phase value at the resonance rather than the frequency value. Vibration Research (VR) has developed a method that enables the test engineer to manually track the phase value in order to determine the maximum transmissibility value at a particular resonance (the value that gives the most damaging acceleration to the product). This method is 'advanced SRTD phase-tracking control'..



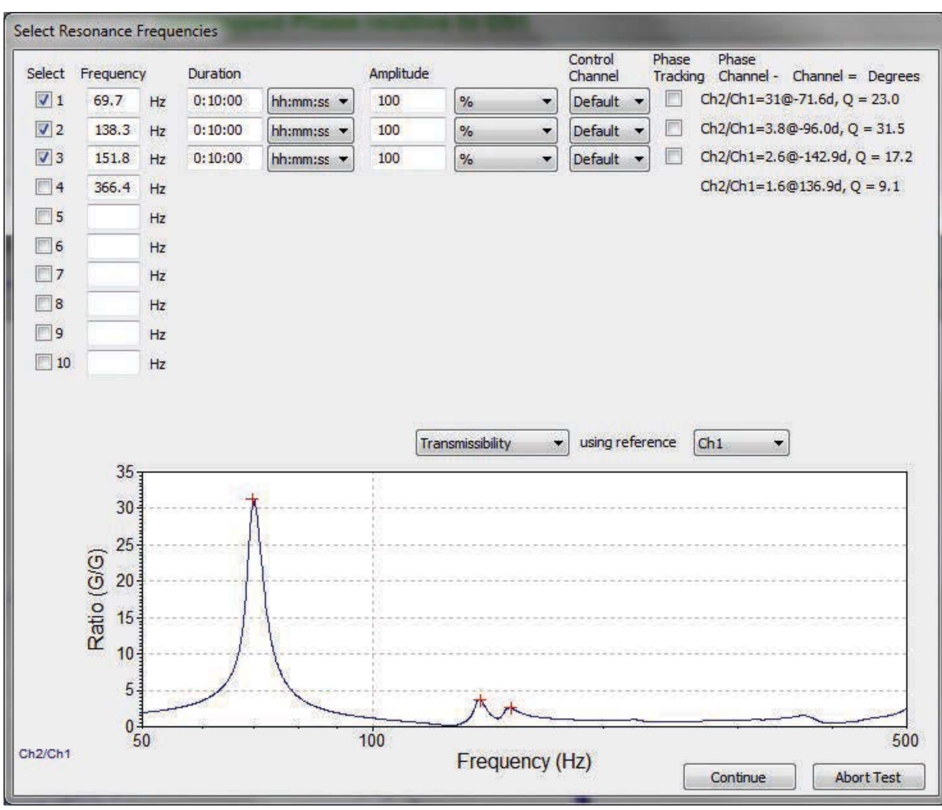
Consider a swept sine test that was conducted on a thin metal beam in which accelerations were measured on the end of the beam (Figure 1).

In this case, a resonance table was produced from the swept sine test that indicated that the fundamental mode of the long arm had a resonance at 69.7Hz, in which the measured transmissibility value was 31 G/G and the measured phase was -71.6° (Figure 2).

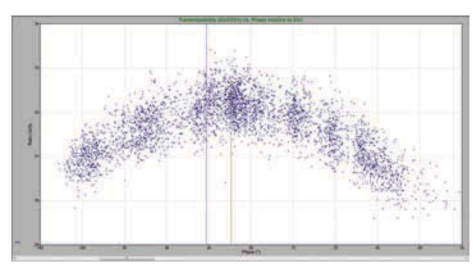
However, the actual phase of the test that produced the peak transmissibility was not the default value of -90° or the value predicted by the software of -71.6°. As can be seen in Figure 3, the peak transmissibility is not at the phase given by the controller (-71.6°) or the default value (-90°), but a completely different value of -82.5° (Figure 3).

These results indicate that the test engineer ought to manually control the phase, tweaking it as necessary in order to find the most accurate location for the highest transmissibility level for a resonance. This will serve as an improvement over simply tracking a constant phase value. A new add-on feature from VR in its VibrationVIEW software (version 11) is the advanced SRTD phase-tracking control that enables the test engineer to manually find the peak transmissibility at a particular resonant frequency by adjusting and controlling the phase value.

Test engineers would benefit from using VR's VibrationVIEW software with advanced SRTD phase-tracking control to conduct the most precise test – a test that maximizes the transmissibility value of the resonances, while maintaining high levels of quality control. ∎



Above: Figure 1 – Teardrop accelerometer attached to beam's 'short arm'
Left: Figure 2 – Resonance table for metal beam (long arm), showing fundamental resonance at 69.7Hz with a peak transmissibility of 31 G/G and a phase of -71.6°
Below: Figure 3 – A new feature, Advanced SRTD, allows the engineer to adjust the phase to -82.5° to obtain the true peak transmissibility (32.4 G/G)



FURTHER INFORMATION

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FLEXIBLE ARRAY TOOL

New developments in ultrasonic probe technology have provided a fast, more effective way to inspect corners and radii in composite components, says Dr Neil Hankinson, head of applied engineering at Phoenix Inspection Systems

Ultrasonic inspection is widely recognized as one of the most informative NDT techniques for testing CFRP components. Not only does it provide accurate information on defect sizes and positions, but it is also capable of measuring other material quality parameters such as porosity and fiber waviness.

One requirement when testing CFRP is that the probe be perpendicular to the component surface so that direct reflections are received. This is easily achieved over large, flat areas, but for sharper curves and corner regions it presents a real challenge. It is important for design and stress engineers to be sure that the corner region, and the transition area from flat laminate into the radius, is structurally sound. However the ultrasound inspection technologies typically employed for flat laminates are not easy to apply in radius areas.

Aerospace component designs frequently demonstrate variations in geometry along their length, including changes in the radius of curvature at corners. One example is the wing spar, which contains major changes in the geometry from root to tip. Coupled with this is the reality of manufacturing tolerances in composites; material wrapped into or around a tool surface can distort, producing local variations in geometry.

Inspection of corner regions has the potential to become an expensive production bottleneck. Multi-axis robotic systems can be programmed to follow a path along a changing radius, but the result is high-costs for still relatively slow inspection speeds. Semi-automated systems with rigid curved arrays can be used but these require constant adjustment and calibration by the inspector. Manual inspection is feasible, although it is prohibitively slow, dependent on the operator, and does not record auditable data for future review and evaluation.

Now a collaborative research program involving a major aerospace manufacturer, Wavelength NDT and Phoenix Inspection Systems has come up with a solution to these problems. The partners have developed a semi-automated device comprising a flexible phased-array ultrasonic transducer housed within a rubber structure that fits and conforms to the curvature it is pressed against.

The result is a scanning tool that adjusts itself to the corner profile and therefore remains perpendicular to the inspection surface for a wide range of radius profiles. The tool is pushed into the corner and then slid along the length of the component, quickly recording ultrasonic data from around the radius and adapting as it travels.

Dr Richard Freemantle from Wavelength NDT says that the radius corner problem has been a concern for NDT inspectors for some time and describes the new technology as 'an elegant solution'.

As the system self-adjusts to changing geometry, one tool fits a range of radius sizes. Another plus point is that the array and its novel housing is compatible with all types of phased-array instrumentation, making it easier to get the technology qualified and approved.

The flexible array tool means that, for the first time, the radius of composites can now be easily inspected in a way that is economical, versatile and fast enough for production volumes. ∎

Above left: Inspection of corner radius on a composite airframe component

Above right: Inspection of helicopter blade leading edge

Right: Flexible tool housings are preformed to a nominal radius

FURTHER INFORMATION

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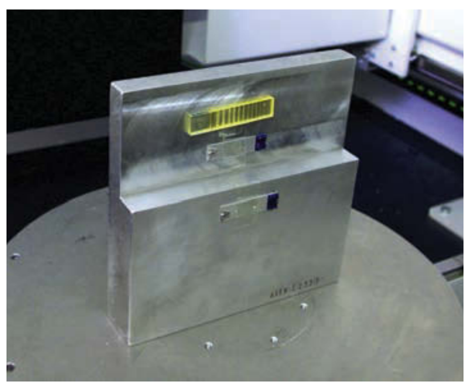
DIGITAL RADIOGRAPHIC TECHNOLOGY

Nadcap audit checklist AC 7114/6 opens the door for digital radiographic inspection in aviation and aerospace

Publication of Nadcap AC 7114/6 at the beginning of this year has finally made it possible for suppliers to the aviation and aerospace industry to switch over from film to digital radiographic technology during quality assurance, and also have themselves certified.

Unlike a great many other fields, companies involved in the aviation, aerospace and arms industries have long since agreed on a general binding standard for their suppliers: the National Aerospace and Defense Contractors Accreditation Program – Nadcap for short. As a result of the audit checklist AC 7114/6 ('Nadcap audit criteria for non-destructive testing facility digital radiography, digital detector array survey'), digital x-raying is now being taken into consideration and certification has been made possible. Alongside stipulation of the audit processes and documentation thereof, the checklist also contains detailed requirements to be met by the software in a digital radiographic inspection system.

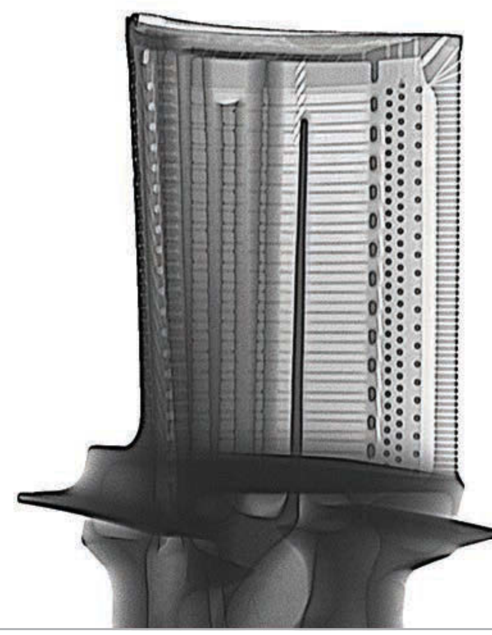
In many aspects, Nadcap AC 7114/6 is based on a variety of ASTM standards, as well as on the DIN EN 462 standard ('Non-destructive testing – image quality of radiographs'). Using enhanced Yxlon software, for example, simple and automated verification of the stable quality exhibited by the radiographic system, including flat-panel detector and imaging software, can be rendered in conformity with ASTM E2737-10 ('Standard practice for digital detector array performance evaluation and long-term stability'). Required system tests can be conducted without a great deal of effort and expense. The tests are subsequently summarized in a report that can equally be archived as a PDF file. This automatic system test makes use of measurement methods defined within the test, for instance the signal-to-noise ratio, as well as contrast sensitivity and spatial resolution to provide an objective assessment of image quality and, as a result, defect detectability. The integrated detector calibration detects defective pixels and correspondingly rectifies the findings mathematically so that they are ASTM-compliant. The integrated Diconde standard ensures documentation of the images and their traceability. The data format is based on the DICOM standard commonly used in medicine. It saves numerous parameters for the inspection system and inspection item within the image data.



In early 2013, Yxlon started equipping its universal Y.Multiplex x-ray inspection system with the new software on a standard basis. Now the 'standard' Y.MU2000-D X-ray system can also be equipped with the ASTM tools and geared for Nadcap certification.

The conversion from x-ray film technology to digital inspection systems eliminates cost-intensive film procurement and storage for producers. Over the past 10 years, the commodity price for silver has become six times as high. This has led to a massive increase in the cost of film. Digital inspection also dismisses the need for the suitably professional disposal of developers and associated chemicals, not least of all a benefit to the environment. Above and beyond these factors, a substantial amount of time is saved: with digital technology an image is ready and waiting in as little as a few seconds. Since the inspection data have already been digitized, data analysis and documentation are additionally simplified.

Thanks to the publication of the AC 7114/6 audit checklist, the aviation and aerospace industry can now also profit from these advantages and convert from film technology to digital radiographic inspection. ∎



With its large inspection envelope, the Y.Multiplex 5500 enables x-ray inspection to be used for a very broad spectrum of parts

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MEASURED APPROACH

Today's flight test engineers meet the challenge of making a wide range of measurements with less equipment, but with easier setup and better results in a shorter time

Every kind of analog sensor output, plus digital states, counters, multiple videos, GPS, IRIG, CANbus, ARINC 429 and MIL-STD-1553 need to be recorded. Furthermore power analyzers for 50-60Hz or even 400Hz and video feeds from onboard cameras in NTSC and PAL formats or high-speed cameras are required for dynamic testing. But it is most important that all these disparate measurands are recorded in sync with each other and referenced to external time from the very beginning to eliminate the need to laboriously time-align multiple files later.

All these vastly different parameters can be recorded using multiple dedicated instruments – or more simply by a single Dewetron system with Sync-Clock technology, such as the DEWE-2601.

Compared with multiple instruments, using a single integrated system has some obvious advantages such as smaller size, lower power consumption, lower cost, and dealing with only one user interface.

Furthermore, during testing, even simply trying to monitor values from several instruments at the same time is nearly impossible for a single person. But monitoring the DEWE-2601 is no trouble at all, even under challenging test conditions. But the real power of Sync-Clock is reflected in the analysis of the data. Since everything is already recorded in sync, analysis can be performed immediately – even online during the test.

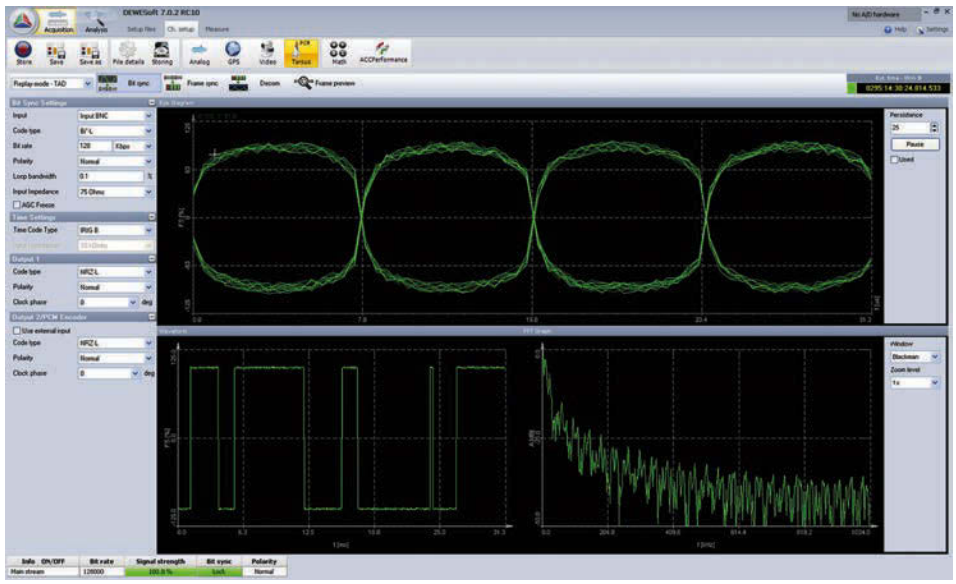
Dewetron systems use an innovative approach to keeping all these disparate data sources in sync with each other. They must also be referenced to external time from IRIG or GPS UTC. At the center of each system is an ORION card, which uses a high-resolution clock to time-stamp every sample from each connected device as it arrives. These can be frames from video cameras and sources, GPS sensors, inertial/gyro sensors, low-speed data from DC and temperature measurement signal conditioners and transmitters and, of course, the parameters from the ARINC 429 and MIL-STD-1553 interface cards.

All the analog sensor data is synchronized by nature, since it is sampled by the aforementioned ORION card, which uses a separate ADC chip for each dynamic input channel. Importantly, the clock on the ORION card itself can be hardware synchronized to an external time reference – either the highly precise PPS signal from GPS, or one of the popular IRIG time codes. In this way, the ORION card serves as the timing backbone of every Dewetron system, permitting synchronization to within 12.5ns based on its 80MHz clock.

Dewetron has developed a comprehensive interface to an FGPA-based bit-synchronizer interface card. It can be added to virtually any Dewetron instrument, from portable battery-powered units to large rack-mounted systems.

The bit sync and frame sync are handled in hardware in the graphical user interface within the software platform, common to all Dewetron acquisition systems, whereas the decommutator is implemented entirely in the software. This allows for maximum system flexibility, including the ability to handle one or more embedded asynchronous data streams.

The hardware can handle PCM data in numerous popular formats, and at rates up to 33Mbps. This hardware and software combination is heavily used by NASA's Kennedy Space Center and at the US Army's White Sands Missile Range. ∎



Above right: PCM setup screen. It can be graphically configured in minutes and data is easily displayed in a wide variety of formats during acquisition to disk

FURTHER INFORMATION

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NASA UPGRADES LAUNCH CAPABILITY

NASA continually strives to maintain, modernize and advance the infrastructure at its centers nationwide, not only to sustain its facilities, but also to enhance its technical capability to meet the ever-evolving demands of next-generation technology

Efforts are underway at Kennedy Space Center (KSC) to transition Launch Pad 39B for the next generation of launch vehicles. Modernization of Launch Pad 39B involves removing left-over equipment and launch structures required in the past decades of the Space Shuttle program, providing a clean pad capable of accommodating the Space Launch System and other proposed government and commercial launch vehicles.

Over the past five years, Jacobs has performed numerous engineering studies and final designs to support NASA KSC in this effort as it plans for the future of space transportation at Launch Pad 39B. Certain elements of the existing pad infrastructure continue to retain great benefit and usefulness for launches; NASA is taking advantage of these existing infrastructure elements, refurbishing the appropriate systems and structures in order to efficiently sustain the viability of the launch pad. To accommodate vehicle assembly and servicing needs, NASA is examining various flexibility options and requirements to promote ease-of-adaptation for next-generation launch vehicles as they are developed and deployed.

Upgrades to the infrastructure at Launch Pad 39B focus on providing new launch support systems to accommodate the next generation of launch vehicles. These systems range from basic utilities to critical, technically advanced systems required to fuel new vehicles. For example, to ensure that a reliable source of clean, dry air or GN_2 is available for purging and conditioning launch vehicles at Launch Pad 39B, Jacobs has developed concepts, performed engineering studies, and developed the final design for the replacement of the environmental control system.

Additionally, a ground-based liquid media cooling system is being designed to deliver cooling capability to launch vehicles while on the launch pad. This infrastructure will provide common support systems with the capability to enable the installation and preparation of next-generation launch vehicles.

While some systems are being replaced, others are being upgraded to provide enhanced technical capabilities and operational efficiencies. Approaches are being developed to greatly expand the liquid hydrogen fuel storage at Launch Pad 39B to enable a shorter turnaround in the event of a launch scrub. With this enhanced capability, launch scrubs can be overcome more quickly, resulting in reduced cost. Concepts have also been developed for the addition of hypergolic fuel services for new launch vehicles and payloads.

The various systems at Launch Pad 39B are not the only critical elements of the infrastructure to be upgraded or modified to accommodate next-generation launch vehicles. Like the systems, various structural components must also offer the flexibility to accommodate new vehicles. To meet the access needs of the geometries of new launch vehicles during assembly, Jacobs has developed concepts for latching mechanisms for new access platforms for the vehicle assembly building (VAB) that can be moved and fixed at various elevations. As part of this engineering study, Jacobs has worked closely with the NASA team to assess the current VAB/platform interfaces and to solidify the desired performance requirements prior to developing the required concepts.

Infrastructure enhancements at Launch Pad 39B will continue as NASA prepares for the future of space transportation using new launch vehicles. Jacobs will continue to assist the US space program in the preparation of Launch Pad 39B for future launches as NASA invests in the conceptualization, design and implementation of new systems and structural enhancements to sustain the viability of NASA's proven launch capability. ∎

Jacobs Technology will provide overall management and implementation of ground systems capabilities, flight hardware processing and launch operations at NASA's Kennedy Space Center in Florida

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VIRTUAL TESTING

Simulation and virtual testing is a vital method which can quickly evaluate multiple impact scenarios within the aerospace industry

Automotive companies benefit from a shorter time-to-market for their vehicles, but more importantly, it has led to safer vehicles. Simulation methods, once validated, can be exercised quickly to evaluate multiple impact scenarios so that the passengers are better protected in a wide variety of accident encounters.

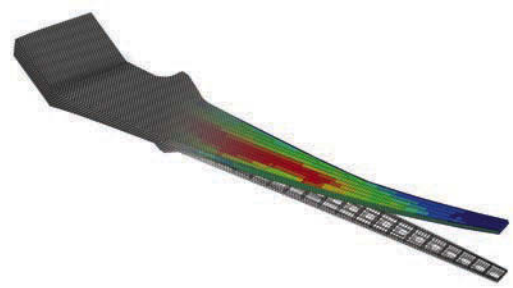
As we have recently seen with the Asiana Airlines accident in San Francisco, most passengers survived, but many have significant injuries that will permanently affect their lives. The impact scenario experienced by the passengers in the back of the airplane was different than the current FAA seat testing scenario. Given the costly nature of testing an airplane in a crash landing scenario, the greater reliance on simulation can lead to safer seating in a wider variety of hard landing situations.

The current airplane certification process relies heavily on physical tests and lightly on simulation. This has produced an air travel industry that has a stellar safety record. The downside here is that it is extremely costly to engineer a new airplane. In fact, for the general aviation industry, the cost and expense of designing and certifying a new airplane is getting to be prohibitive, which will result in a stagnant industry that ceases to innovate. The caution is that simulation can produce inaccurate results, so they have to be backed up with physical data. This is true, but the automotive industry has shown that if you validate your simulation modeling methods and consistently enforce these methods, you can achieve accurate and reliable simulations.

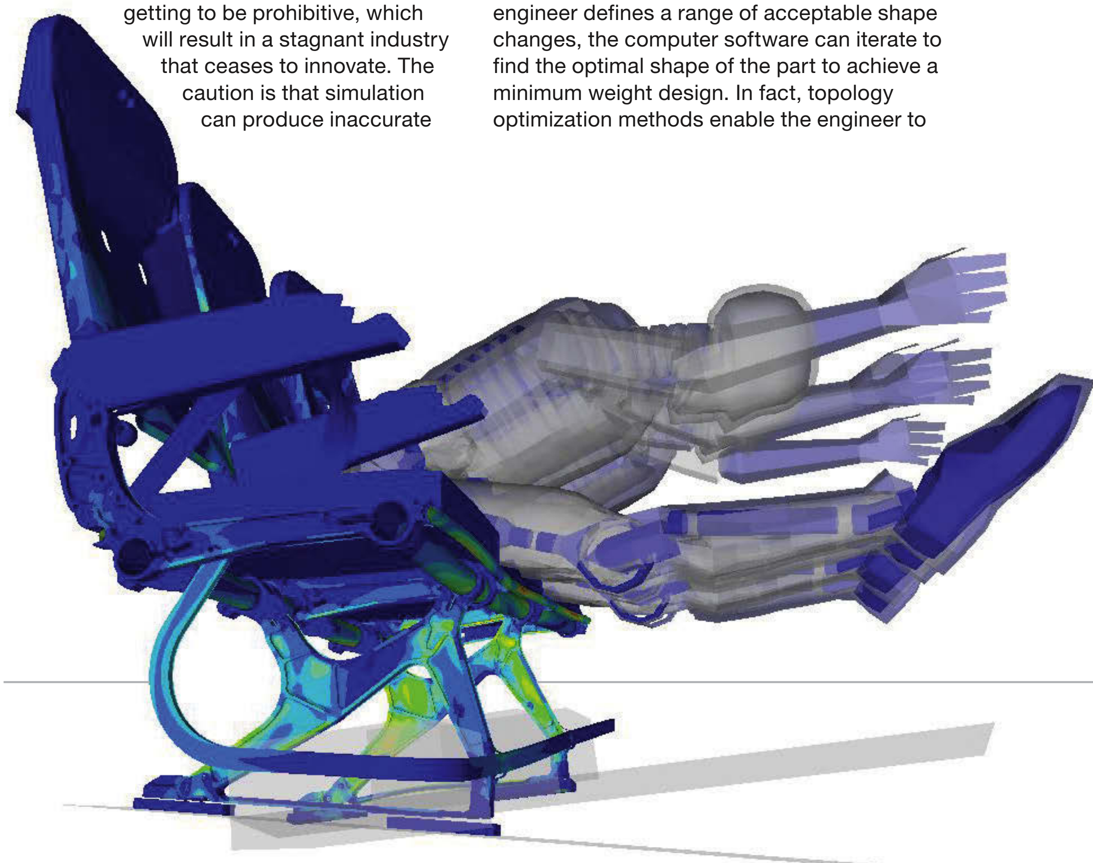
Simulation methods have led to safer automobiles, but they have also had a tremendous impact on improving the passenger and driver experience. Simulation is used to tune the ride and handling of the automobile, reduce the noise heard by the passengers, improve the aerodynamics and fuel economy, and better circulate the air in the vehicle. Cars have become quieter, smoother, more responsive and more fuel efficient – and simulation has had a large role to play in these improvements. Altair is working with a number of aerospace customers to better use simulation technologies to also improve the experience for the airline passenger.

An area of active use of simulation in the aerospace community is using design optimization methods to reduce the weight of the airplane. Mathematical optimization methods allow the engineer to let the computer change the variables in the simulation to achieve an optimum result. For example, if the engineer defines a range of acceptable shape changes, the computer software can iterate to find the optimal shape of the part to achieve a minimum weight design. In fact, topology optimization methods enable the engineer to simply specify the part envelope and the loads and boundary conditions, and the software determines the optimal shape. These methods have proved to be highly successful in reducing the weight of new airplanes, and this goes right to the bottom line of the airlines in fuel savings. The automotive industry, now faced with increasing fuel economy standards imposed by governments, is now increasingly using these weight-reduction methods for automobiles.

Many of the virtual testing methods of today originated in the aerospace industry. The automotive industry has taken advantage of these methods to accelerate product development, while improving safety, reliability and customer experience. The aerospace industry is now poised to take greater advantage of these technologies to engineer airplanes that are less expensive to develop, with the safety and reliability we have come to expect from this industry. ∎



Above: Detailed analysis and optimization of a composite wing using Altair HyperWorks



Left: Optimization early in the design process can reduce the weight of a typical leg-and-spreader unit by more than 30% (courtesy of

FURTHER INFORMATION

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TOUGH TREATMENT

Full-scale structural and fatigue testing of aircraft is performed to accelerate lifetime testing on airframes by varying the load, pressures and temperatures that the aircraft will experience during operations

Historically, multibridge load cells were used in the aerospace industry to provide a redundant output signal due to concerns over reliability. The load cells are used for active force feed back to hydraulic servo controllers that drive the aircraft structure during test in a 'closed loop.' The difference between the two bridge outputs can be monitored and if they exceed preset load limits the test is shut down to a neutral position in a controlled manner. The load cells are also used for measuring and recording the force level in a data-acquisition system.

Most structural and fatigue testing of aircraft occurs on a full-scale airframe, where the structure is cycled through taxi, pressurization, take off, climb out, flight maneuvering, descent, final approach, landing and depressurization. This is repeated multiple times and when run nonstop can simulate thousands of airframe hours and tens of years of aircraft life on the structure. Fatigue testing of aircraft is not limited to the entire airframe, but includes testing of subassemblies and components, such as landing gear, shear pins, flight control actuators, landing gear door connecting rods, propulsion system components, fan blades, shafts and fasteners, as well as 'iron bird' control simulation testing.

Load cells are also used for landing gear drop testing to simulate loading and performance of the landing gear. In this test, the landing gear is raised to a predetermined drop height and locked into position. Next, the wheel is rotated with a friction drum to a speed that simulates the forward motion experienced during touch down. Finally, the landing gear is dropped at a controlled rate similar to an actual aircraft landing and data is captured with load cells integrated into the test system. Additional measurements are often required in the test, such as shock absorber pressure and acceleration shock measurements.

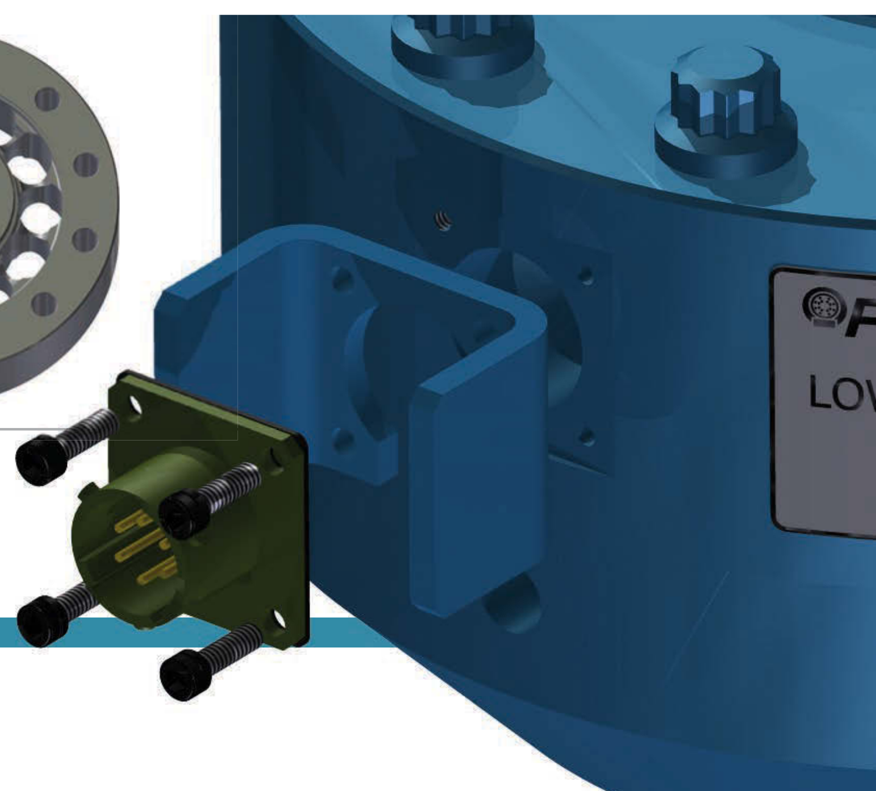
The load cell Series 1400-00ADB from PCB Piezotronics includes a dual output feature for structural and fatigue testing of aircraft. The dual-bridge output provides sensor redundancy and the ability to provide the necessary load feedback to hydraulic actuator servo controllers. The dual-bridge load cells are manufactured using a shear-web design and take the form of a cantilever beam. In order to minimize structural deflection, the load cell structure has been designed with a cross section optimized to the rated load to be carried. The state of stress on the beam's side is one of pure shear, acting in the vertical and horizontal direction. This makes for a stronger fatigue resistant design and has less error due to eccentric loading, creep and off-axis or side loading.

A field calibration element for the load cell is the shunt calibration resistor, which can be overlooked when making a last-minute load cell purchase. Shunt calibration simulates the mechanical input to a transducer by unbalancing the bridge with a fixed resistor placed across, or in parallel with, one leg of the load cell's Wheatstone bridge. Shunt calibration is a method of periodically checking the gain or span of a signal conditioner, which is used in conjunction with a strain gauge based transducer without exposing the transducer to known, traceable, physical input values. If required, adjustments can then be made to the signal conditioner to ensure accurate results.

The majority of load cell damage occurs at the electrical connection, so protecting the electrical connector on the side of the load cell from damage during installation is essential. Connector protectors are simple and effective devices that can save the load cell from the most common source of damage – a wrench that slips off during installation on the hydraulic actuator.

The final thing to consider is mounting the load cell to the hydraulic actuator. As the load cells will be cycled in compression and in tension during the entire duration of the airframe or component test, pre-tensioning studs should be used to eliminate any back-lash associated with loose joints. The studs typically thread into the load cell and lock the threads in position when connected to the end of the hydraulic actuator. Installation of the load cell starts with tension, preloading the cell to 120-150% of full scale capacity and lightly tightening a jam nut to lock in the preload on the cell and the base tension rods.

Fatigue-rated load cells are specifically designed for component durability and fatigue test machines where highly cyclical loading is present. All fatigue-rated load cells are guaranteed against fatigue failure for 100 million fully reversed cycles. Things to consider when installing such load cells are pretension studs or proper load cell performance, connector protection to avoid costly downtime, and shunt calibration resistors for periodic on-line calibration checks. Remembering these items is essential for minimizing errors and lost test time. ∎



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LAUNCH PAD

Environmental vibration and acoustic testing on spacecraft can play a major role in ensuring safe launches and deployment

Vibration and high-intensity acoustic pressure during launch can damage spacecraft structures. Therefore satellites are subjected to extensive analysis and testing to ensure survivability during launch and deployment. The typical satellite structure is not homogeneous, having several sub-structures such as antennas, solar panels and externally mounted cameras attached to it. Consequently, the launch experience of a satellite consists of vastly different motions at different points of time.

VIBRATION TESTING

Vibration qualification tests on satellites have to carefully reproduce this environment and must prevent excessive vibration at sensitive locations at all cost. Typically, a low-level test at about 25% of full level is done, and the results are used to verify analytical models that predict vibration levels at various locations. Every measurement point that is likely to exceed the required maximum vibration level at that point is designated a limit channel for the full level test. Limit channels act to notch the control spectrum (away from the normal reference level). For additional safety, sometimes the vibration reference profile itself is redefined to include the notching based on the predicted limiting.

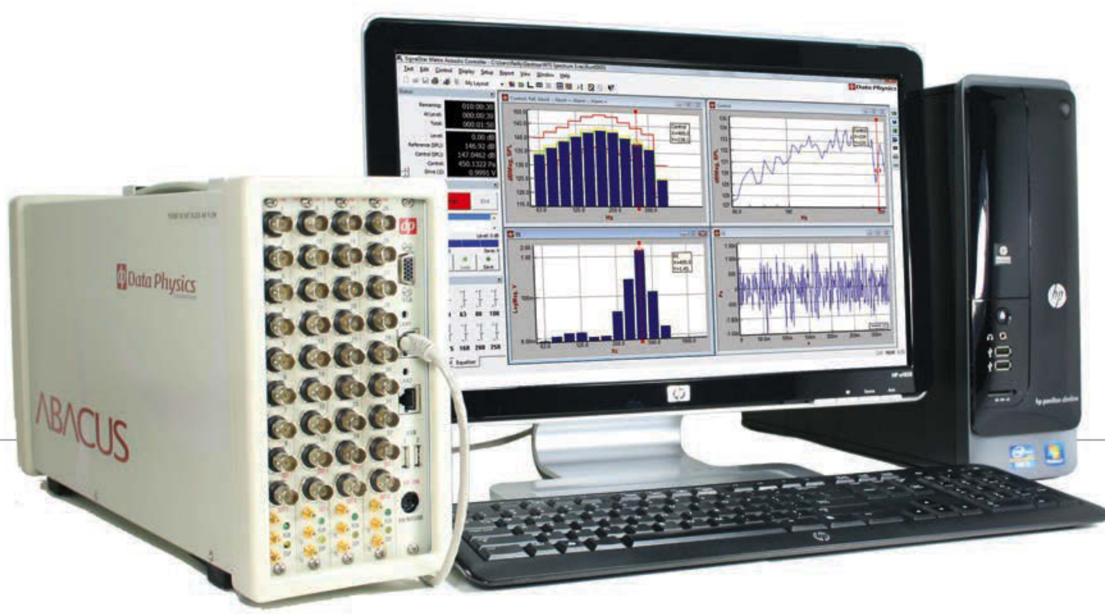
The Data Physics SignalStar vibration controllers provide these sophisticated capabilities to carry out effective and safe vibrations tests on spacecraft and related assemblies. Considering the extremely high value of some satellites, no amount of caution is too much. Users often add a SignalCalc sine data reduction analyzer to watch over such vibration tests. The sine data reduction system makes real-time measurements and acts to provide alarms on excessive vibration at sensitive measurement points. The monitoring system can even be used to abort a test if a limit channel is exceeded. SignalCalc dynamic signal analyzers, just like SignalStar vibration controllers, are capable of recording all the measurement channels to local disc in addition to their respective real-time analysis or control tasks, providing a full audit trail for sensitive tests.

Depending on the size of the satellite, a large number of channels – sometimes hundreds and occasionally as many as a thousand – may be required to monitor and analyze the data from a controlled vibration test. One useful feature of the SignalCalc analyzer is that during a sine vibration test, the analyzer can act to extend the number of measurements channels of the vibration controller by synchronizing to the sine sweep frequency using a COLA channel. A COLA channel is a constant level sine sweep output by a vibration controller. SignalCalc analyzers can work with any manufacturer's vibration controller to automatically sense the instantaneous frequency and provide synchronous sine measurements, effectively adding measurement channels to the vibration controller.

ACOUSTIC TESTING

To provide a realistic simulation of launch conditions, high-intensity acoustic testing is performed in reverberant acoustic test facilities (RATFs). These tests also require a large number of inputs for capturing a variety of dynamic measurements, including both acoustic and vibration levels. An RATF uses acoustic power generators, such as the Data Physics SignalSound APG-10K coupled to acoustic horns, to produce the high-intensity random acoustic field inside a closed chamber with the satellite mounted inside. Once again, to prevent damage to the satellite, the sound pressure level has to be closely controlled to a reference level defined in third octave frequency bands. The Data Physics SignalStar random acoustic control system is designed to control multiple sound generators simultaneously, using multiple drive signals. A large number of microphones would be used to measure acoustic levels and sometimes accelerometers would be added to measure vibration experienced by the satellite. The real-time third octave measurement capability of the SignalCalc analyzer comes in handy to provide the large number of measurements, while also recording the signals to disk in real time.

Data Physics Corporation manufactures high-performance test and measurement solutions for noise and vibration applications. Data Physics offers SignalCalc dynamic signal analyzers and SignalStar vibration controllers that provide best-of-class performance and results. ∎



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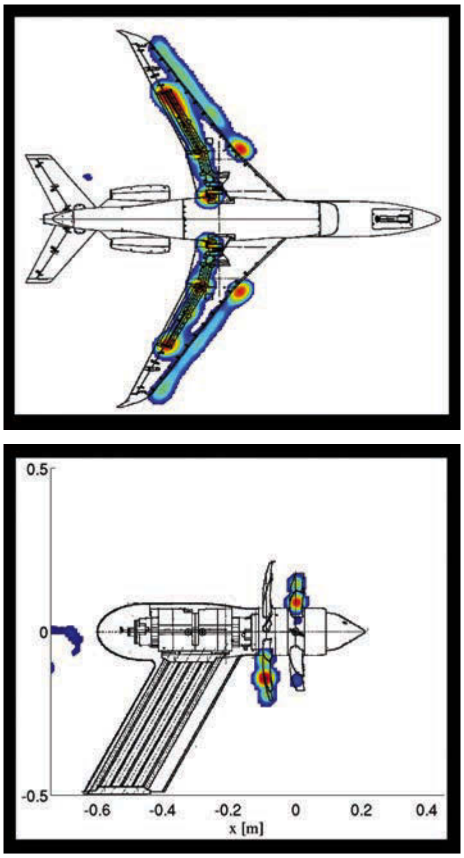
QUIET TIMES

Acoustic tests in RUAG Aviation's wind tunnel allow early airframe noise assessments

The ground and air transportation industries are under increasing pressure from regulators, customers and the general public to reduce the environmental impact of their fleets. This is clearly reflected in the current focus of the industries' research and development. Means to reduce the fuel burn per passenger mile are investigated, novel fuel-saving solutions conceived, and old ideas re-evaluated in light of newly available technology. The noise footprint of the aviation industry is also under close scrutiny.

These developments have produced an increased demand for the integration of acoustic measurements into standard aerodynamic wind tunnel tests, especially in the early stages of aircraft development. This capability enables acoustic problems to be discovered and rectified during the initial stages of a project, while design flexibility is still high and the ensuing costs low. It also provides initial validation for computational acoustic simulations that normally begin in this phase of the project.

The RUAG Aviation Large Wind Tunnel Emmen (LWTE) has been used for commercial aerodynamic development tests for many decades. Numerous improvements have been introduced over the years in response to the growing importance placed on accuracy and repeatability. The current demand for acoustic measurements was novel to RUAG Aviation, and it opened up a previously unexplored field for the LWTE.



ABOVE: Example of a noise-source mapping result from the demonstration test

Setup in the experimental wind tunnel at Emmen with RUAG Aviation-owned counter-rotating open-fan propulsor and microphone array

COLLABORATION

In collaboration with DLR Göttingen, the LWTE's acoustic potential was first assessed in an aero-acoustic demonstration test in June 2012. The acoustic signature of a business jet was evaluated with an array of 144 microphones, using a model supplied by Dassault Aviation. After only half a day's setup and one day of testing, approximately 60 aero-acoustic data points were collected. The control parameters used for this test were the model configuration, the angle of attack and the wind speed. The results obtained were consistent with the predictions, thus validating the entire setup and adding a promising new opportunity for further industrial applications to the LWTE's capabilities.

Wind tunnel tests of propeller and open fan-powered aircraft have traditionally been a focus of the LWTE's testing activities. Also of interest is propeller noise – particularly with regard to the new counter-rotating open rotor power concepts currently in development. For the measurements to be meaningful, the high-powered hydraulic motors powering the wind tunnel models must be sufficiently silent. This is to ensure that they do not mask the relevant aerodynamic sound sources. In order to evaluate the suitability of the motors used, a second test was conducted using the same equipment as in the LWTE , this time in the open-jet Experimental Wind Tunnel Emmen (EWTE).

END RESULTS

The outcome was positive: the motors – in this particular case driving a counter-rotating open rotor propulsor – did not disturb the aero-acoustic measurements whatsoever.

These two tests have proved that acoustic surveys of both powered and unpowered models are possible, and can be efficiently performed in RUAG Aviation's wind tunnels. This establishes the possibility of including acoustic investigations in regular aerodynamic tests, capitalizing on the overall synergies and providing valuable early information to the acoustic engineers. RUAG Aviation's customers have been quick to recognise this benefit, with the first commercial acoustic tests having since been performed in the LWTE. ∎

FURTHER INFORMATION

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SERVICE MAINTENANCE FROM SHAKER MAKER

The current record for an LDS vibration test system is 74,000 hours of operation and counting. Like all machines, that record-holding shaker needs regular maintenance to remain in top form and guarantee maximal uptime. Proper servicing with OEM parts maintains test accuracy and minimizes component wear – in turn prolonging lifetime. This is possible thanks to a Brüel & Kjær service agreement.

Brüel & Kjær believes that an investment on this scale should pay back with many years of faithful service. For long-term support, the company has significantly grown its world-spanning global service team with personnel expertly trained by the people who know the LDS range best – the people who build them. As well as reducing costly unexpected downtime, service agreements offer scheduled maintenance around which you can plan tests.

In addition to Brüel & Kjær's service agreements, third-party companies service LDS shakers. However, some have recently been found to use counterfeit spare parts, and since any system is only as strong as its weakest part, this can lead to serious problems.

To counter this, Brüel & Kjær has identified a Certified Partner network, so that customers who choose other suppliers can feel confident they will get a high level of service from organizations approved by the OEM. To ensure that suppliers use parts that are up to OEM standard, Brüel & Kjær has also created a 'genuine spare parts' badge that only approved suppliers are authorised to use.

FURTHER INFORMATION

Brüel & Kjær Sound & Vibration A/S
Tel: +45 77 41 20 00
Web: www.bksv.com/ServiceAgreements

or go to online enquiry card 111

OXYGEN AND NITROGEN TROLLEY FOR A400M

It is always a great honor to be involved in the development of a new aircraft. The Airbus A400M project provided Test-Fuchs with the opportunity to be involved in the prototype testing, followed by test equipment for the production, and later on with the design, manufacture and delivery of AGE for the first delivered Airbus A400M.

Test-Fuchs' most recent contribution to the A400M project is the oxygen and nitrogen trolley. This was designed specifically for military applications and will be formally certified by Airbus.

This special trolley has been designed and manufactured especially to meet the Airbus A400M's requirements, complying with the very special requirements for military use. The trolley pressurizes the aircraft's oxygen system for leakage and also performs pressure tests in accordance with ATA chapter 35. Its vacuum pump is nitrogen operated, making it independent of electrical or compressed air supplies – a feature that is extremely valuable for deployed operations.

Other benefits that are essential for military use include a wide temperature operating range and resistance to the severity of global winter weather.

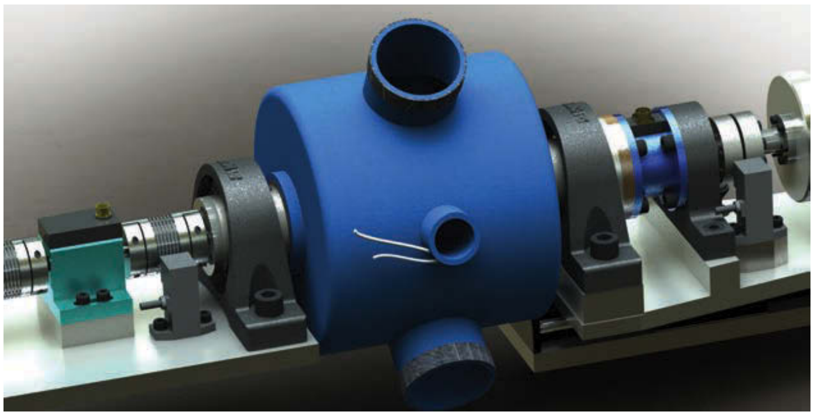
With more than 60 years of experience in designing and manufacturing test equipment for military aircraft, Test-Fuchs clearly had an advantage in this project, making the equipment safe, precise, operationally effective, and easy to operate.

The oxygen and nitrogen trolley has been codified with the NATO stock number 1740-41-000-6619 and has the Airbus number AJA35009207000 for use on aircraft.

FURTHER INFORMATION

Test-Fuchs
Web: www.test-fuchs.com

or go to online enquiry card 112



ENCLOSURES FOR ENVIRONMENTAL TESTING

Whenever high- and low-temperature testing of actuators, shafts, seal rings – or in fact any part of an aircraft – is being carried out, the problem arises of how best to encapsulate the part while still allowing free movement and the circulation of conditioned air around it.

K Value was approached by Comar Fluid Power from Wolverhampton, UK, a test rig builder with much experience in the aerospace industry, to address the recurrent problem of working with insulation materials around complex structures in a hot/cold, oily/wet environment. This had previously been done using Styrofoam, which had to be dismantled when not in use, and messily re-assembled when tests were to be carried out.

With a wealth of knowledge about insulation materials and fabrication techniques, K Value developed an enclosure that is flexible, durable (some have been in service for eight years), light and thin (15mm). The multiple layer construction and K Value's attention to detailed design ensure minimal loss of conditioned air.

The company has since completed a wide range of encapsulation procedures, from an actuator the size of a fist, to 4.5m-high A320 landing gear. Flex endurance of 50,000 cycles has been achieved, with no loss of integrity or functionality.

Feed and return ductwork is also provided, and K Value is working closely with Comar Fluid Power to supply custom-made RACS units to suit the customer's needs.

FURTHER INFORMATION

K Value
www.kvalueindustrial.com

or go to online enquiry card 113

HIGH-SPEED TRANSMISSION FOR MAXIMUM TEST STAND FLEXIBILITY

Cotta has developed a new high-speed transmission that provides maximum application flexibility for repair depot and multi-unit test stands. The new dual output SN2291 high-speed gearbox features a nominal power rating of 300hp, 25,000rpm output speed, and ratios up to 5 with the option to have different output ratios. The SN2291 has a horizontal shaft design, single-stage gearing, and comes with a lubrication system.

Cotta's high-speed transmissions are used extensively for R&D and production testing of components such as generators, constant-speed drives and pumps in the automotive and commercial/military aircraft industries.

Cotta also designs and manufactures precision-engineered transmissions for a wide range of specialized mobile and stationary applications. Models are available in a wide range of output speeds (up to 80,000rpm). Modified-standard and custom models are also available to meet specific requirements.

FURTHER INFORMATION

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or go to online enquiry card 114

NEW HARDWARE-IN-THE-LOOP TECHNOLOGY

Today, the usual case is specialization among the members of hardware-in-the-loop (HIL) teams – in other words, the division of tasks. There are tasks to design the electrical aspects of a simulator (HIL hardware, connecting real and substitute loads, cable harnesses), others to model the I/O and plant, and others to create and execute tests. Thus, today's HIL technology must enable different team members to work simultaneously on different tasks in the same project. For example, while one team member is setting up the I/O configuration of the HIL system, another is setting up the plant model.

Other key factors for today's HIL systems are the total cost of ownership, due to tight budgets and tough competition, and also flexibility and adaptability. Flexibility is necessary so that different control units or variants can be tested on a single system, either individually or in a network. This is particularly important when entire vehicle electronics are tested because HIL systems often have to be specified and set up at a stage when parts of the final ECU specifications might still be changed. Adaptability is needed because the HIL system must be able to handle executing any additional tests for new components added to an existing vehicle (airplane, satellite, etc). In addition, when one project has been successfully finished, it is becoming more and more common to reduce overall costs by completely converting the systems to test the next project. Finally, an HIL system is often used for network testing as well as for dedicated tests of single components: this occurs when a section of an HIL system has to be isolated to intensify troubleshooting for a single ECU, and when the component testers are interconnected after successful component tests so that network tests can be run.

The ability to use third-party hardware efficiently with an HIL system is crucial. This requirement can be fulfilled by using standard PC interfaces (Ethernet, PCI/PCIe, etc) to connect to the vast number of different hardware devices available on the market. The real-time capability of the HIL systems must obviously also be assured when using third-party hardware. In addition to these hardware-related requirements, the HIL technology must enable the efficient use of third-party hardware in its workflow.

The requirements mentioned above can be fulfilled with SCALEXIO from dSPACE, a new generation of hardware-in-the-loop technology that has been designed from the ground up. Its architecture provides full flexibility, adaptability and process efficiency to the embedded software development and testing process. With SCALEXIO's flexible component design, each system can be scaled precisely to any desired size, is completely software-configurable, and is versatile enough to be used in different test tasks. Component test systems and network systems are both built with the same hardware components. This lets users take subsystems from a network system and use them to run component tests.

Standard aerospace bus interfaces such as MIL-STD-1553 and ARINC 429 can be used with SCALEXIO via third-party PMC modules. PMC modules in general are well known in the aerospace industry. An indicator for their widespread use is their availability for all kinds of aerospace buses: every common aerospace bus type is available on PMC modules from a number of vendors. SCALEXIO technology enables the efficient integration and use of PMC modules due to its PCI/PCIe interfaces in the real-time PC. PMC modules mounted on carrier cards in the real-time PC enable the same optimal bandwidth between the I/O and the real-time processor as with IOCNET for the SCALEXIO I/O boards. The optimal real-time performance (e.g. for testing large numbers of bus channels) is ensured by PMC device drivers specifically developed for the SCALEXIO RTOS. Thus, the hardware-related requirements are fulfilled.

Third-party PMC modules are seamlessly integrated into the SCALEXIO workflow with the implementation and configuration tool ConfigurationDesk. This includes the ability to interface an external tool for the easy configuration of project-specific bus communication (e.g. based on an interface control definition).

FURTHER INFORMATION

dSPACE GmbH
Web: www.dspace.com

or go to online enquiry card 115

INDEX TO ADVERTISERS

Top of the class

Two-time Red Bull Air Race World Champion and commercial airliner pilot, Paul Bonhomme, says thinking is the key to safe flight

BY CHRISTOPHER HOUNSFIELD

Paul Bonhomme, who has flown more than 650 public displays and flies vintage fighters for The Old Flying Machine Company at Duxford, is seen above with a Hawker Hurricane

Successful English aerobatics and commercial airliner pilot, Paul Bonhomme, is a two-time World Champion of the Red Bull Air Race. The owner and race pilot of Team Bonhomme was born into a family of aviators, and at the age of 18 gained his pilot license and subsequently became a flight instructor. In 1985, he became an air taxi pilot, and joined Air Cymru.

The 48-year-old's aerobatics career started in 1986, flying an Ultimate Pitts. He then went on to fly the Yak-50, Extra 300 and the Sukhoi Su-26. Since 1994, he has been flying formation displays around the world with his colleague, former air race pilot and television commentator Steve Jones, as 'The Matadors'. They have won three gold medals and one silver medal in the FAI series. Bonhomme has competed in the Red Bull Air Race World Championship since its inception in 2003, achieving 30 podiums, including 11 race wins.

HOW MUCH OF YOUR FLYING TODAY IS AEROBATIC, VINTAGE AND COMMERCIAL?

I fly a variety of airplanes, from the Boeing 747 to aerobatic types such as the XtremeAir XA41, to vintage types like the Spitfire and Mustang. The 747 flying is obviously commercial and the other types are flown mainly for airshows.

TELL US ABOUT THE DISPLAYS YOU DO.

I fly in a two-ship formation in the Xtreme with Steve Jones as The Matadors and we display throughout the year at airshows and a variety of other events. We specialize in close formation and some slightly non-standard moves such as the lateral slide and tail-slide in formation. As for the vintage flying, I fly from Duxford mostly for The Old Flying Machine Company and we also fly solo and formation displays. The displays in the old airplanes are gentler than the Xtreme, but hopefully still spectacular and thought provoking.

HOW DOES TEAM BONHOMME WORK?

We work well together in both environments (aerobatic or vintage), and with the group of pilots we have, are able to mix in any way required depending on a mix of airplane types or differing weather conditions. It is vital to have such trust when you are flying in close proximity to each other.

WITH TRAVELING AIR DISPLAYS, HOW DOES THE MAINTENANCE CREW ENSURE THAT THERE ARE NO FAULTS?

Generally the airplanes are fit before we leave our home base and stay that way throughout the weekend (I'm touching wood now!). If we are doing a prolonged period of time away from base, we'll travel with the engineers and they will perform routine maintenance and any rectifications required along the way.

WHICH AIRCRAFT DO YOU FLY THE MOST AND WHICH IS YOUR FAVORITE?

I fly the Xtreme the most, and of the vintage types, have flown the Spitfire the most recently, with a busy period in a Hurricane at the start of the year. My favorite is the one I am in at the time!

HOW DO YOU TEST THESE AIRCRAFT TO ENSURE THERE WILL BE NO FAILURES?

There is very little 'testing' as such throughout the year as we are constantly on the lookout for any defects or abnormalities during normal flying operations. Some types require a permit renewal flight test at the start of each year, which is a fairly standard format and is normally flown after the winter maintenance.

WHAT TECHNOLOGY IS USED TO TEST VINTAGE AIRCRAFT?

The permit renewal test flights are flown using old technology, normally a kneeboard and a pencil record the data and the good old 'mark 1 eyeball' will be looking out for abnormalities, with 'hands and feet' feeling for any vibrations or unusual flight characteristics.

WHAT IS YOUR TOP TIP FOR A PILOT FACED WITH A PROBLEM WHILE FLYING?

Keep thinking is my top tip for system failures or problems. You can guarantee that whatever goes wrong will not be like you trained for; there will always be a twist or oddity that doesn't quite make sense. Planning for these and making allowances to keep the flight safe is always consuming and will almost certainly take your mind off something else, so keep thinking and don't stop thinking until the engines are shut down and the chocks are in!

YOU HAVE BEEN WORLD CHAMPION AIR RACER TWICE. DOES IT HAVE A FUTURE?

Watch this space! Something might happen soon regarding the Air Race. When we did race, it was busy and the key was to successfully manage the distractions so that you were always 100% focused on the race.

WHAT DO YOU SEE AS A FUTURE AEROSPACE INNOVATION?

We've got to get out of the treacle! We fly in the thick gooey sticky air near to the surface of the Earth; we've surely got to travel where there is no friction to save energy. But how do we get up there without using all of the energy we're trying to save? ∎


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