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

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MARCH 2010

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Lockheed Martin F-35

The second Lockheed Martin F-35 has now been delivered to the BAE Systems test facility in Yorkshire, UK for structural and fatigue tests

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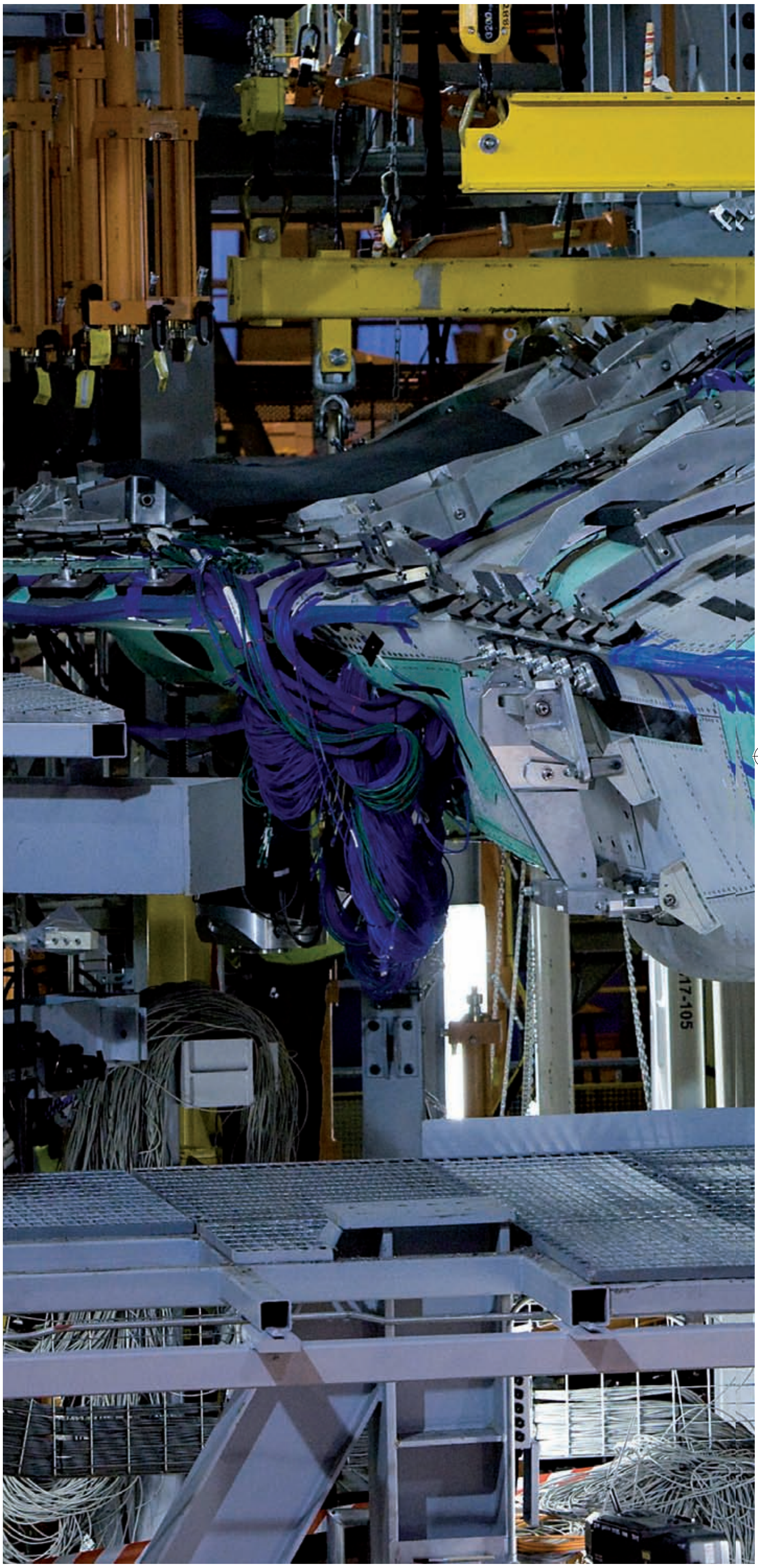

Superiority complex

A STRUCTURAL TEST FACILITY IN THE NORTH OF ENGLAND TOOK RECEIPT OF A SECOND F-35 AIRFRAME. IT IS NOW EMBARKING ON ONE OF THE MOST COMPLEX FATIGUE TEST PROGRAMS UNDERTAKEN BY ANY FACILITY IN THE WORLD

BY ALAN GEORGE

The second Lockheed Martin F-35 has now been delivered to the BAE Systems test facility in Yorkshire, UK for a series of detailed and intricate structural and fatigue tests. It follows a month-long sea voyage across the Atlantic from Fort Worth Texas.

The test article designated AJ-1 was shipped from the USA directly into Hull docks in the UK and then transferred to a barge to continue its journey up the Humber to the river bank bordering the Brough, East Yorkshire site.

Using a specialized mobile crane with a reach of 90m, it was lifted off the barge and into the site itself. Internal transfer from the crane location to the test hall was via a four-axel extremely maneuverable Mammoet powered trailer. The trailer was used to maneuver the test article into the test hall, at times leaving only millimeters clearance around the wing tips. This required all of the Mammoet trailers maneuverability and the skill of the operator to negotiate other test rigs and a rotation through 90º to be brought to rest in front of the test fixture. The whole logistical exercise was only made possible with the co-operation of Lockheed Martin in Texas, CEVA the logistics team, Mammoet the crane provider, and the Brough team including skills from site facilities, and structural tests.


S.W.L. 6.4 Tonne
W.L.L. 14144 lbs
REMOVE BEFORE FLIGHT

It was an international effort to bring the F-35 airframe to Brough, showing the importance of the Structural Test Centre, which now houses some of the most advanced major airframe fatigue tests in the world.

The test article, a Conventional Take-Off and Landing (CTOL) variant of the F-35 Lightning II, is destined for the fatigue test program due to commence this year. The test will be carried out by BAE Systems as part of the work share agreement between itself and Lockheed Martin, and will be one of the most complex fatigue tests undertaken by BAE Systems and by any test facility in the world. Hydraulic actuators will apply the service loads to the airframe using state-of-the-art control system technology to ensure safety of the specimen and operators is maintained at all times.

Service life analyses

The structural fatigue test on the F-35 CTOL airframe forms part of the structural certification in support of the service life analyses, and the demonstration of airframe fatigue compliance. This airframe designated AJ-1 is an instrumented fully production-representative version, which will be subjected to two lifetimes of cyclic spectrum fatigue loading. Minor modifications have been made to the airframe to allow for load introduction fittings and various exit locations for instrumentation wiring. Loads will be applied to the airframe using an optimized loading arrangement. The sequence is flight-by-flight, contained in repeated 1,000-hour blocks. Each flight contains randomized cycle-by-cycle loadings in correctly ordered flight segments (taxi, take-off, etc). Upon completion of all testing activities, the test article will be returned to Lockheed Martin Aeronautics in Fort Worth.

The purpose of the fatigue test is to demonstrate that the economic life of the CTOL variant is equal to or greater than the design service life when subjected to the design service loads spectrum. It will also provide strain gauge data for structural health monitoring of the airframe in service, providing a basis for establishing special in-service inspection and modification requirements. Some modifications to the airframe structure have been introduced to allow loads to be applied to the airframe through 'dummy' structures (horizontal tail, engine, etc). Strain gauges identified for the durability test article have been installed during the build sequence.

Aerodynamic and inertia loads will be applied to the test article using hydraulic actuators connected to the airframe via dummy components and loading linkages. These linkages have been designed to distribute the load accurately to achieve the required shear, bending moment and torsion distributions, without adding structural stiffness to the fatigue test article. Linkages are in general, tension/compression stable. The linkages are attached to the airframe via neoprene rubber pads bonded to aluminum backing plates and bolted fittings. To remove the mass effects of the horizontal hydraulic actuators and loading linkage, mechanical counterbalances have been provided. The masses of vertical loading systems are counteracted via tare loads from the relevant hydraulic actuator when the test is powered up.

Vertical landing

As February 2010 drew to a close and the historic snowfalls on the East Coast of the USA began giving way to fairer weather, the first F-35B short takeoff/vertical landing (STOVL) test aircraft began the final handful of flights leading to a vertical landing. Planned missions included progressively slower (down to 60kts), semi-jet-borne flights around the airfield pattern at Naval Air Station Patuxent River, Maryland, 100kt short takeoffs and 70kt slow landings. BF-1, as the first F-35B is known internally, ferried to Pax River in November from its assembly point at Lockheed Martin's Fort Worth, Texas, plant. It was joined in November by BF-2, and by BF-3 in February.

Two more STOVL F-35Bs will ferry to Pax River this year, but BF-1 is the aircraft most intensely focused on validating STOVL flight performance. As of February 19, it had completed 36 flights, six of those with the STOVL propulsion system engaged. On January 7, F-35 Lead STOVL Pilot Graham Tomlinson of BAE Systems engaged the STOVL propulsion system in flight for the first time, and on February 17 he conducted the first slow landing (130kts), with the lift-fan operating and the 3-bearing swivel nozzle deflected.

The first vertical landing appeared to be imminent as the last week in February ticked by, and crucial STOVL-mode flights were completed. The first vertical-landing flight most likely will include a short takeoff, followed by low-speed jet-borne flight to confirm performance. Tomlinson will then accelerate to about 150kts then reduce speed to the point of hovering over the airfield. From that point, about 150ft above the ground, he will command the F-35 to descend to the runway vertically. It will be the first of many vertical landings for BF-1, which will validate the F-35B's ability to operate from ships and from confined, austere land bases.

BF-2, which so far has completed 20 flights, is poised to begin envelope-expansion missions at Patuxent River, while BF-3 (six flights to date) will be used mainly to evaluate vehicle systems and expand the aircraft's structural-loads envelope. BF-3 also will focus on weapons testing, and will carry and release most of the ordnance the F-35B will use in combat. BF-4, planned for an early-spring arrival at Pax, will be the first avionics-equipped F-35 and will perform the initial on-board flight testing of the F-35's mission systems, which are essentially 100% common across the three variants. Extensive mission systems testing, including sensor fusion and SAR mapping, already has occurred on the Cooperative Avionics Test Bed, a converted 737, and on surrogate airborne laboratories and in ground-based labs. The final F-35B test aircraft, BF-5, will ferry to PAX later in the year, along with the F-35C carrier variants, CF-1, CF-2 and CF-3.

AJ-1 specimen lifted from the installation trolley ready for the transition into the test frame

The airframe, loading systems and control/data acquisition hardware will be located within a self-reacting test frame. The frame will provide the restraint of the test specimen and the connection of the test loading systems. This loading arrangement distributes the load across the airframe, duplicating the aerodynamic and inertia load experienced by the structure and system hardware in flight and ground-operating modes.

Total control

Control of the hydraulically applied test loading is by a digital, closed loop, multi-channel servo control system supplied by Moog. This is a standardized system employed across all BAE Systems' major fatigue tests. The test controller is integrated with the data acquisition system so that specific data logging actions can be carried out automatically. The design of the system accommodates the test being run 'unattended' for 24 hours, seven-days a week, in between inspection/maintenance stand-down periods, providing significant cost savings.

Loads in each of the test article supports and reaction locations will be monitored via dual bridge load cells and compared to those provided in the test spectrum. Fuselage and fuel tank pressures will be controlled and monitored by dual-pressure transducers. The control system will be linked to the hydraulic and pneumatic power supply facilities to provide the test operator with remote start and stop and status data. A comprehensive safety system is embodied as part of the controller so that in the event of any system malfunction the load is removed under full system control without risk to the specimen. The data acquisition system (DAS) utilises HBM data logging equipment. The DAS is linked with the test control system such that specific data logging actions may be undertaken manually or automatically during the test programme. This link also permits the DAS to undertake 'watchdog' duties.

With a capacity of 2,000 channels, the DAS is configured to log strain gauges, displacements, and loads. The Control-DAS link will also be used to record the applied loads, reaction channels, fuel tank pressures and spectrum position. The system is also able to log all parameters either statically for any selected balanced load case, or dynamically during fatigue cycling. The system can log all channels at a rate high enough to capture peaks with the test running at its maximum anticipated speed.

The next stage is to ensure the test rig and fuselage support structure hardware are ready to accept the test article, and that the test article is assembled with loading linkage and wiring prepared in loomed bundles, then the test article can be lifted into the test frame. The lift into the test frame will take place over the next few weeks. Full test rig configuration and commissioning will lead into strain surveys and the start of the fatigue spectrum cycling early in 2010. ∎

Alan George is the project manager on the F35 CTOL full scale fatigue test in the UK

The fully padded airframe AJ-1 ready to be lifted into the test fixture

Take the strain

F-35 Lightning II Conventional Take Off and Landing AG-1 and AJ-1 full airframes are sitting comfortably inside the structural test facility in Brough, UK. BAE Systems' Structural Test Facility is a very busy place, having taken in two F-35 Lightning II airframes in 2009.

The centre of excellence at the facility houses some of the most advanced airframe fatigue tests in the world, providing evidence that airframes meet the design requirements for structural strength and durability.

The test airframes arrived after a month-long sea voyage across the Atlantic from Fort Worth, Texas to Hull docks and then a journey up the River Humber, arriving at Brough site to be safely lifted off the barge using a 90m mobile crane.

The F-35 Lightning II AG-1 airframe has commenced its latest testing having completed three of the five phases of tests it will undergo during its 15-month stay in the facility. The airframe is connected to a highly complex test rig in which 165 hydraulic actuators are replicating the loads the aircraft will see in flight, certifying the strength of the airframe and its components. The data from the testing is being captured from the 4,000 sensors that are bonded to the airframe, 53 miles of wiring spread connected to the systems and sensors, with the rig itself weighing 365 tons.

AJ-1 airframe will commence its fatigue tests early this year, being subjected to two lifetimes of cyclic testing during its stay. Loads will be applied to the airframe using an optimised arrangement of sequence through flight by flight 1,000-hour blocks. Each flight segment load will try to reproduce a taxi run, take-off and flight in sequence.

The purpose of the durability tests is to demonstrate that the economic life of the F-35 Lightning II CTOL variant is equal to or greater than the design service life when its is subjected to such rigorous load testing. The durability tests also provide data for the structural health monitoring of the airframe in service, providing a basis for establishing special in-service inspection and modification requirements.

On completion of the tests, both airframes will be shipped back to the USA.

Blade runner

THE LATEST MOOG AEROSPACE TEST SYSTEM IS A GREAT PARTNER FOR THE AGUSTAWESTLAND ROTOR BLADE FATIGUE TEST APPLICATION

BY MARIE LAURE GELIN

Advanced aerospace test systems are required to create and measure force to simulate and test real-time durability and resistance of helicopter components, especially fatigue tests on the rotor, hub, and blades. Recent developments from Moog include the development of a system supplied to AgustaWestland to perform a wide range of structural and fatigue tests for helicopter rotor blades.

An important part of helicopter development is the fatigue testing of the rotor blades. During operation, helicopter rotor blades are subject to substantial flap (vertical), lag (horizontal), torsion, and centrifugal (CF) loads. Flap and lag occurs as bending of the blade, as well as shear loading. Moog's aerospace test system, in conjunction with the HBM data acquisition system, has been designed to accommodate these elements and to ensure the required relationship between the flap, lag, and torsion moments on the blade at all times.

At AgustaWestland, all test conditions are defined in terms of CF load, flap, lag, and torsion moments to be applied at a particular blade station (span-wise location). Moments and torsions are measured by strain gauges installed along the blade. As it is possible for strain gauges to be damaged during fatigue testing, these must not be used to close the control loop. The controller must control the loading actuators in force mode using six load cells to provide the individual loop feedback.

To meet these specifications, Moog supplied its aerospace test controller with six servo control channels, incorporating the latest quad core IPC processor and a real-time Ethernet platform to enable playback of the complex loading spectrum on the helicopter blade.

The system's real-time Ethernet platform increases the functionality of servo controllers and boosts the performance of aerospace testing, providing faster graphics, accurate synchronization of up to 500 control channels, reduced latency time, and complete management of many safety procedures to eliminate risk on the test specimen. It provides the test system with a high bandwidth and an unprecedented level of safety, and is particularly suited for high performance aircraft, helicopter, and spacecraft testing.

Moog has delivered a new aero test rig to the Korean Aerospace Research Institute (KARI) to perform a wide range of tests in a South Korean project to develop and build 245 utility helicopters

Multilevel blocks

Fatigue loads vary during different maneuvers, both for ground and inflight conditions, and the aerospace test software accommodates this using multilevel instruction blocks. A fatigue spectrum for rotor blades consists of up to 200 instruction blocks containing a total of 10 million fatigue cycles.

To apply the correct bending moments on the rotor blade, a cascaded closed-loop control is used, where an inner loop controls six servo-hydraulic loading actuators in force mode and an outer loop adjusts the actuators' command set points based on current bending moment errors.

The strain gauges are measured and converted into bending moments by the HBM data-acquisition system and then transmitted to the Moog controller via a bi-directional Ethernet communication interface. In the aerospace test software, these 'actual' bending moments are compared against 'desired' bending moments using a corrective PID loop in soft real time. The output of the PID loop is translated into force commands for the individual force loops using a 66 transfer matrix. This is set up using the aerospace test software's online calculation channels, called Shared Memory.

The corrections to the inner-force loop commands are made at intervals, rather than instantaneously. This is because it is necessary to verify that the bending moment information can be relied upon to guard against damage to the strain gauges before the system responds to the outer loop. The control system provides a means of bringing the test to a controlled stop in the event of errors being detected, or an emergency stop switch being thrown.

Moog's aerospace test system proved to be a perfect match for AgustaWestland's fatigue test application, offering all the functions needed in one software suite. ∎

Marie Laure Gelin, marketing manager, Territory (Europe), Moog

Korean helicopter program

Experience in helicopter testing and Korean technical support capabilities helped Moog win a project that included system development, configuration, and comprehensive training for the Korean Aerospace Research Institute (KARI).

The aerospace test system is being used by KARI to perform a wide range of structural and fatigue tests for helicopters. This system is part of a multibillion dollar procurement project by the South Korean Ministry of National Defense to develop and build 245 utility helicopters over a 16-year period.

Moog's previous experience with similar test-rig installations, knowledge of helicopter test techniques, and on-the-ground technical support from its Korean engineering team helped win and develop the project.

KARI's specifications for the customized test-rig installation included six cabinets with 16 control channels each and a 256-channel HBM data acquisition system. It incorporates new software functions that give real-time Ethernet-based data transfer between the command generator (real-time front end) and the localized control loops. A dedicated Ethernet interface is used for the transfer of the load cell, position and spectrum data from the Moog test controller to the CatMan data acquisition unit, and activation of commands (for example, taking a snapshot) from the test controller system to the Cat-Man system.

Installed in just three days in 2008, the test rig is now fully operational and running full-scale structural tests. The system has the potential to run up to 12 independent helicopter tests.

The requirements of the brief sent to Moog specified the need for a hydraulic system, actuator, and data acquisition system to carry-out static structural and fatigue tests for the helicopter rotor system. The hydraulic system was installed in the rotary wing aircraft laboratory to supply the flow used in the hydraulic actuator for repetitive loading during the fatigue test.

The KARI test rig needed to create and measure forces to simulate and test real-time durability and life of helicopter components, especially fatigue tests on the rotor, hub, and blades. It also needed to integrate seamlessly with KARI's existing data acquisition systems and hydraulic control equipment in the test labs.

"The KARI project was specific in its requirements and presented us with an exciting technical challenge. Our engineering team, and our depth of experience in aero test rigs and helicopter testing, were crucial to the success of this program and we are delighted with the end result," says business development director for test systems Tom Pierce.

"The new aero test system gives KARI a multitude of benefits including cost-efficient operation, almost unlimited flexibility, and total access to local Moog expertise and ongoing system support."

The KARI load-control system can perform 12 different tests independently with up to eight-channel control stations or one full-scale test. In both cases, up to 96 channels can be used. The load-control system has been set up to communicate seamlessly with two different data acquisition external systems (such as HBM and VTI), giving KARI the flexibility it requires to handle a wide range of tests.

The system also delivers fast and efficient analysis and comparison of tests. Because the two systems are connected via Ethernet, KARI can directly cross-check data from the load control system and data acquisition system through time stamps. This means all data can be stored and archived on a hard disk for post-test analyses. KARI's test program currently runs eight distinct and independent component tests simultaneously.

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