# CASE STUDY

## BAE Systems
## Advanced Noise and Vibration Testing Facilities at Warton and Brough

United Kingdom

Aerospace and Defence

PULSE™, Transducers

*BAE Systems designs, manufactures, and supports military aircraft, surface ships, submarines, space systems, radar, avionics, electronic systems, guided weapons and a range of other defence products. With global markets and partners, BAE Systems has annual sales of some £12 billion. BAE Systems' prime contracting capability combines key in-depth skills enabling it to manage the most complex high-level systems tasks and provide total solutions.*

*Located in the United Kingdom, BAE Systems' facilities at Warton and Brough use highly advanced acoustic and vibration measurement and analysis solutions to provide testing capabilities to its customers, both within BAE Systems, and for external companies. BAE Systems' relationship with Brüel & Kjær began in the 1950s. Today, PULSE™ data acquisition and analysis systems are used, together with a wide range of microphones, accelerometers and calibrators supplied by Brüel & Kjær.*




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Brüel & Kjær

## Advanced Defence and Aerospace Systems

BAE Systems is an international company engaged in the development, delivery and support of advanced defence and aerospace systems in the air, on land, at sea and in space. The company designs, manufactures and supports military aircraft, surface ships, submarines, fighting vehicles, radar, avionics, communications, electronics and guided weapon systems. It is a pioneer in technology with a long heritage.

BAE Systems has major operations across five continents and customers in some 130 countries. Employing more than 90 000 people worldwide, the company has a major presence particularly in Europe and the United States as well as in the Middle East, Asia Pacific and Australia. The company has a full in-service support and logistics organisation so that it can work with customers both in specifying solutions to their needs, and offering the management and operation of their facilities, as well as training, repair and overhaul of products and the provision of professional logistic support.

Key skills include systems integration, complex software and hardware development and advanced manufacturing while its research and development projects cover the spectrum of technologies, materials and synthetic environments, that constantly extend the frontiers of performance

## Aviation

***Fig. 1***
*The BAE Systems Harrier has given proven and reliable short take-off and vertical landing capabilities worldwide for decades*

In aviation, BAE Systems takes a leading role in joint programmes for military and civil aircraft such as Eurofighter Typhoon, F-35 Joint Strike Fighter and Airbus, in partnership with the world's other leading aircraft companies. The BAE Systems Hawk, built at Brough and assembled at Warton, is the world's most successful jet trainer while its Tornado multi-role aircraft has been the backbone for UK air defence and operations for years. The innovative Harrier has given proven and reliable short takeoff and vertical landing capabilities worldwide for decades.

The company also develops, integrates, and produces test equipment for advanced electronic systems including space launch, satellites, and provides avionics systems for the Atlas and Titan launch vehicles.

BAE Systems is globally accredited to ISO 9000 and ISO 9002.

## Centre of Excellence

BAE Systems has facilities in more than twenty English counties. Just two locations are Warton and Brough.

The Structural and Dynamic Test Department is the Centre of Excellence for testing military aircraft for BAE Systems. The department undertakes to provide empirical qualification evidence, through the representative application of mechanical loading to aircraft structures. The work within the department is categorised into five business streams; static testing, fatigue testing, acoustic testing, vibration and impact testing and aircraft calibration. These test activities are primarily carried out at Brough, which is the managerial centre.

### Warton

Located about 35 miles northwest of Manchester, construction of three runways began at Warton in 1940. The airfield was used by the United States 8th Army Air Force during world war two.

Warton now provides the final assembly facilities for BAE Systems' Eurofighter Typhoon and Harrier aircraft. It also carries out mid-life updates on the Nimrod, Hawk and Harrier.

### Brough

The Brough site near Hull on the River Humber, dates back to 1916 when Blackburn Aircraft Ltd. built a new factory. Today, BAE Systems' Hawk trainer is assembled and flight-tested at Brough. In addition, the facility manufactures a wide range of components and systems for both BAE Systems and external partners.

## Acoustic Fatigue Test Facility – Warton

***Fig. 2***
*The specially designed and built Acoustic Fatigue Test facility was commissioned at Warton in 1999*

The Acoustic Fatigue Facility at Warton in 1999 is one of only a few such facilities worldwide and has been developed in line with identified future test requirements relating to a new generation of vertical take off and landing aircraft which must operate under extremes of noise and heat, and possible research and development testing to support the design of future advanced airframe structures.

Andrew T. Olsson (Andy) is BAE Systems' Acoustic Fatigue Test Specialist. He explains, "This £3 million facility has been designed to provide capabilities for extreme levels of noise in conjunction with thermal and in-plane loading capabilities. A modular approach has been used so that various test specimen sizes and shapes can be tested. Test specimen sizes and configurations can be tested with differing acoustic fields and loading conditions".

***Fig. 3***
*Left: Colin Ayers is Team Leader Noise and Vibration at BAE Systems' Warton facility*
*Right: Andrew Olsson is BAE Systems' Acoustic Test Specialist. He was extensively involved in the design of the test facility*

Aircraft panels or assemblies of up to $1.2 \times 2.5$ m can be tested with noise level in excess of 175 dB, thermal loading of 800°C and applied static loads of up to 70 tonnes.

Andy continues, "We have been at the forefront of acoustic fatigue research since the development of the Harrier Jump Jet. This work will continue in support of our programmes including the new Joint Strike Fighter".

"The new facility is expected to play a vital role in the development and final flight clearance of the JSF whilst putting innovative test methods in place as test requirements. Noise is converted to heat and/or mechanical vibration. Our tests focus on the effect of noise on the test object rather than on the noise path".

## Specification

***Fig. 4***
*The noise generator can produce the equivalent of 200 000 watts of acoustic energy – it' test flexibility is unique*

The facility has been designed to withstand noise levels of 155 dB within the 1440 $m^3$ test cell. The progressive wave tube runs the full length of the 20 m long test cell and comprises a noise generator connected via a horn to the working section and an exhaust chamber at the end. The system can generate some 200,000 watts of acoustic energy.

Andy continues, "The test specimen is placed in the working area so that as the sound waves travel down the working section, the specimen is also exposed. This produces a noise environment similar to that seen on an aircraft during flight. The specimen is held on a moveable loading frame and is usually built up so that the specimen forms the closing wall to the working section. The cross-section area can be reduced by inserting sleeves within the duct to required depths".

***Fig. 5***
*Another view of the test cell. A jig to hold the test specimen is shown adjacent to the aperture*

"Tests represent the in-service life plus an additional factor. In the case of mechanical components, this might be several times the total service life. Actual test times can range from minutes to many hours. Andy comments, "Test methodologies must be configured to the test requirements and we work closely with our customers to ensure that the best test approach is used to achieve their requirements".

## Noise Generation

The facility can generate very high levels of noise at low frequencies down to 30 Hz and some test requirements have been fulfilled with narrow band noise levels of 170 dB RMS at 40 Hz – a unique capability for this facility. The noise generator, essentially a reciprocating poppet valve, can produce controlled noise in the frequency range between 30 Hz and 500 Hz. at levels of up to 175 dB – louder than the near-field noise levels of the jet efflux of a Eurofighter Typhoon on full reheat.

***Fig. 6***
*Close up of the noise generator, essentially a pneumatic/hydraulic driven reciprocating poppet valve*

Thermal loading can also be applied to a specimen using an in-house designed heating system consisting of forty 8 kW heater elements. Recent tests required the development of a testing methodology, which generates thermal cycles with rise rates of 20°C to 400°C in 10 seconds and 20°C to 700°C in 30 seconds. Cooling rates of 700°C to ambient in 30 seconds were also achieved. In-plane loading, if required, is achieved by applying a static load through the test frame holding the test specimen. Up to 70 tonnes can be applied and held in conjunction with acoustic loading.

## Environmental Test Laboratory

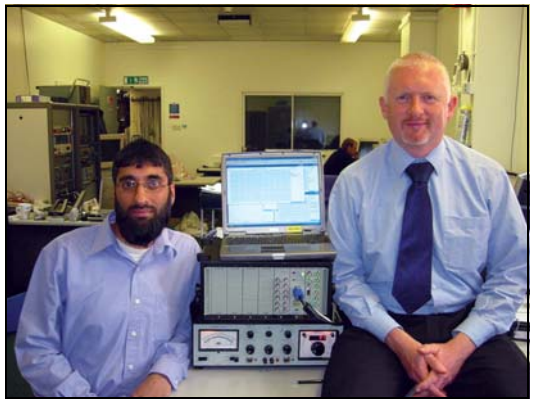

***Fig. 7***
*Senior Test Engineers Azhar Pathan (left) and Richard Wylie (right) with the17-channel PULSE system*

Azhar Pathan and Richard Wylie are Senior Test Engineers. Richard says, "Within the Environmental Test Laboratory, we carry out a wide range of noise and vibration-related testing, frequently using our PULSE data acquisition and analysis systems".

Examples of testing include:

- Vibration qualification testing of electrical and mechanical system – equipment is generally qualified for 6000 flying hours

Richard explains, "Examples of tests performed are on the Eurofighter Typhoon In-flight Refuelling Probe, Airbus 'Y' Duct and the Eurofighter Typhoon Throttle Box. Shakers are available with random thrust ratings from 550 lb. to 16 000 lb.

- In-flight noise surveys for aircrew on Eurofighter Typhoon, Hawk, Tornado and Nimrod aircraft

Azhar comments, "This test generally involves mounting miniature microphones on the flying helmet and in the ear cups of the aircrew for recording noise to a DAT recorder. The data is analysed to allow evaluation of the noise exposure and articulation index (clarity of communications). If unwanted noises are present, noise/vibration measurements can be taken on test rigs to investigate noise sources and, if necessary, noise reduction".

Generally rig testing of aircraft systems is performed during the development phase to allow early identification and reduction of unwanted noise sources. The Pulse system is widely used on these tasks.

- Noise contour surveys around all the military aircraft manufactured by BAE Systems – this data can be used to predict noise exposure for ground crew and the environmental noise impact of operating aircraft at various locations. PULSE is widely used for these tasks.
- R&D noise/vibration testing of materials and manufacturing processes. PULSE is also frequently used on these tasks.

Richard concludes, "Other testing performed by the Environmental Test Laboratory comprises of acceleration (centrifuge), shock, temperature/humidity, salt/fog and contamination testing".

## Instrumentation

The accurate measurement and analysis of test data is essential, and instrumentation such as low mass accelerometers, microphones, strain gauges, thermocouples, etc., is used to enable a comprehensive picture of the dynamic response of a specimen to be obtained. This information can also be used alongside a geometric model of the specimen so that the model can be animated and mode shapes, mode frequencies and other dynamic parameters identified.

The relationship between Brüel & Kjær and the antecedents of BAE Systems dates back to the 1950s.

Andy says, “Nearly all our accelerometers are from Brüel & Kjær and we use their microphones exclusively – they are the only supplier I can choose for our noise testing applications”.

Type 4941 1/4-inch Microphones connected to NEXUS™ Range of Conditioning Amplifiers are used to measure the very high levels of noise in our acoustic fatigue test cell. Using a Type 4229 Hydrophone Calibration (this type of calibrator can calibrate microphones at much higher sound pressure levels than conventional calibrators or pistonphone), the microphones are calibrated at a sound pressure level of 160 dB before and after every test. The calibration is checked against a Condenser Microphone Cartridge Type 4180 which is regularly sent to the National Physical Laboratory near London (NPL is the UK’s national measurement laboratory).

Also used are Type 4191 and 4192 ½-inch Microphones together with a range of Brüel & Kjær supplied accelerometers including Types 2226 C, 2248, 2510, 7290 and 7258 triaxial accelerometers (specially developed for the Eurofighter Typhoon), and Type 8530 and 8515 Pressure Sensors.

Colin Ayers, Team Leader Noise and Vibration says, “The Acoustic Fatigue Facility has now been testing since 1999. It is operated on a commercial basis for customers both within BAE Systems and externally, currently on a 50/50 ratio. It is available to test military and commercial structures that are subject to extremes of noise, heat and static loads – either individually or combined. These may include jet engine linings, panels close to jet efflux and under body panels on vertical take off and landing type aircraft. Other areas that benefit from our unique testing capabilities are found in the space, nuclear or transport industries”.

## PULSE

BAE Systems at Warton has two PULSE data acquisition and analysis systems – one has 5 channels and the other 17 channels.

The five channel front-end is used for making general noise measurements, to measure the noise footprint of a parked/taxiing aircraft with its engines running, and to make noise measurements in connection with health and safety. The larger 17-channel system is mostly used as a portable data acquisition platform for a wide range of noise and vibration measurements. Examples of test applications include measuring vibration of components used for in-flight refuelling or vibration in a throttle box. The test component is excited by a shaker with either the prerecorded sound, white or pink noise, or a sine wave. It has been used in a BAE Systems Nimrod maritime reconnaissance aircraft during flight testing.

Andy comments, “Brüel & Kjær is the leading developer and supplier of noise and vibration solutions. They set the standard. PULSE does everything we need – it’s portable, rugged, compact and has the required functionality. And it can be expanded easily to give more channel capability (BAE Systems intend to increase the capability of the system to 34 channels). Its intuitive and easy to use, and suits our group’s needs. The service and support is excellent”.

### Contacts

For enquiries contact Andy Olsson or Colin Ayers on +44 (0)1772 855014,
e-mail: andy.olsson@baesystems.com.

## Testing at Brough – Examples

As with the acoustic test facility at Warton, the static testing, fatigue testing and vibration testing facilities at Brough are operated on a commercial basis, for customers both within BAE Systems and externally, and are available to test military and commercial structures.

## Ground Resonance Testing


***Fig. 8***
*left to right:*
*Ian Carr, Technical Specialist Ground Resonance Testing*
*Steve Denniston, Technical Specialist Vibration and Buffet Testing*
*Andy Russell, Technical Specialist Thermo-Acoustic Testing*

Ian Carr has worked at BAE Systems for 17 years and is Technical Specialist Ground Resonance Testing.

Ian explains, “The purpose of ground resonance testing is to determine the natural frequencies of the complete aircraft and to validate the finite element model. The frequencies are below 150 Hz. As the aircraft engines are not running, its hydraulic and electrical systems are powered by external generators, and are used to move the control surfaces during the test. The turbine fans of the engines are rotated using electric motors.”

It is surprising how little excitation is needed to determine an aircraft’s natural frequencies. For example, the BAE Systems Nimrod ground resonance test used a shaker of only 250 N. The aircraft is fully instrumented, and, in the case of the Nimrod, some 270 Brüel & Kjær supplied accelerometers were used. Data was acquired from three groups of 90 transducers using multiplexing techniques.

Ian adds, “We can view the test results in real-time. Following the test, we post-process the data using a variety of tools, validate it and forward it to the customer with a fully documented report”.

## Vibration and Buffet Testing

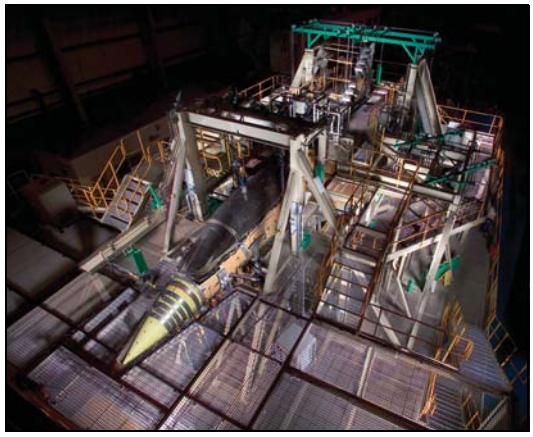

***Fig. 9***
*Fatigue testing the airframe of a Eurofighter Typhoon aircraft*

Steve Denniston is Technical Specialist Vibration and Buffet Testing. Steve has worked in the field of testing at BAE Systems for over 25 years.

Steve explains, “The customer, whether from within our group, or external, gives a requirement specification for the test. We then work out the testing methods to be used and define a test programme. The object of buffet tests is to drive the natural resonant frequencies of aircraft components up to levels seen in flight. Our largest buffet test uses an 11 kN TIRA shaker to excites the structure at frequencies of specific interest”.

Steve adds, “We can make buffet tests on airframe sub-assemblies or components, for example, the aircraft's fin and rudder. In this example, the rudder is locked in the neutral position and is used to give the correct resonance frequency of the tail assembly and is locked in the neutral position. If required, two shakers can be used, driven in the appropriate phase to produce a push-pull system”.

“We also have facilities for full fatigue testing of a complete airframe. This uses hydraulic and pneumatic jacks to excite the relevant points on the airframe. We use shakers to buffet the control surfaces and the airframe is fully instrumented to allow us to determine the load transfer paths.”

Airframe fatigue testing is usually specified to replicate 18000 flying hours, equivalent to three times the expected service life of the aircraft. In the case of the BAE Systems Harrier and Hawk airframes, full fatigue testing was specified to five times the aircraft’s expected

service life. Upon completion of the test, the post-processed data is validated before being sent to the customer together with a fully document full test report.

## Thermo-Acoustic Facility – Joint Strike Fighter

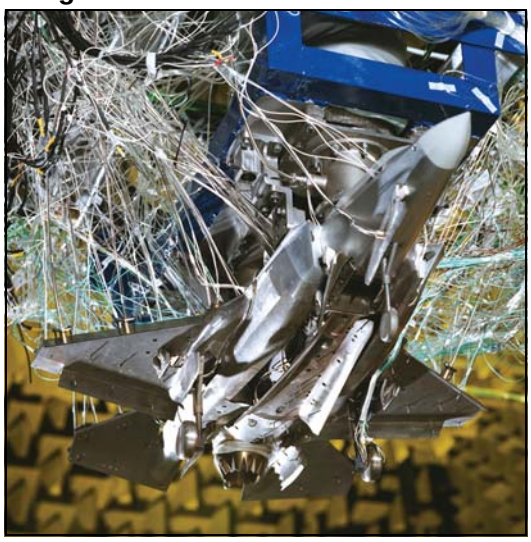

***Fig. 10***
*1/15th scale model of the JSF STOVL variant*

The Thermo-Acoustic Facility (TAF) at Brough is currently being used to simulate the ground environment on and around the short-take off/vertical landing (STOVL) and carrier variants (CV) of the Joint Strike Fighter F35 using a 1/l5th scale model. This is the only facility in the world designed specifically to measure the thermal and acoustic environment around vertical take off aircraft at model scale.

Andy Russell (*another Andy*) is Technical Specialist Thermo-Acoustic Testing and responsible for the TAF facility. Andy explains, "When a STOVL aircraft is hovering above the ground, the weight of the aircraft is supported solely by columns of gas generated by the aircraft's engine(s). These columns of gas spread out in all directions when they hit the ground - jet outwash. A further effect is where a fountain of gas comes back up from the ground hitting the underside of the aircraft. The TAF measures the airflow, temperatures and noise on and around the aircraft, both from the jet outwash on the ground and the upwash onto the aircraft underside".

The facility operates by burning a mixture of air and hydrogen in gas turbine combustion chambers, piping the gasses into accurately modelled jet nozzles which recreate the actual engine exhaust gas temperatures and pressures, which are essential in recreating the acoustic environment. The model fuselage and wing are manufactured from high-temperature steel which has been profiled using CNC machining centres. The jet nozzles have been produced using investment casting direct from the computer model.

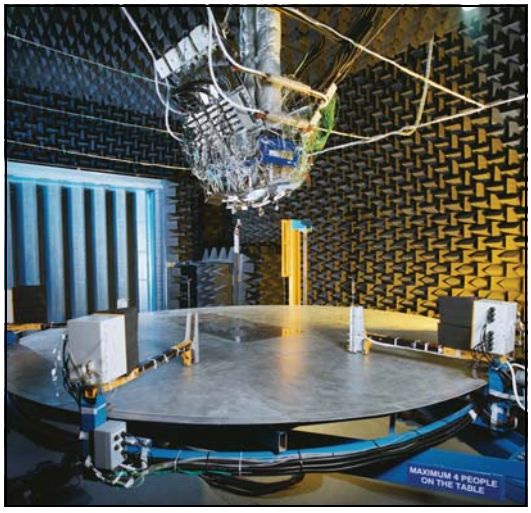


***Fig. 11***
*The Thermo-acoustic test facility at BAE Systems' Brough site. A computer controlled table is used to simulate the ground, and can be moved to various heights away from the aircraft.*
*The facility has recently been enhanced to allow it to take simulated aircraft carrier deck measurements for the JSF carrier variant*

Andy continues, "The model is mounted in the centre of the semi anechoic facility which is lined with sound deadening foam wedges above a computer controlled table. This simulates the ground and is moved to various heights away from the aircraft. Probes around the edge of the table sweep around during the test to measure the outwash air speed, temperature and sound levels".

The underside of the aircraft model is instrumented with 48 miniature pressure transducers, each with custom-made water cooling jackets necessary for the transducers to survive the environment, and 48 clusters of thermal instrumentation measuring air temperature, air pressure and the transfer of heat into the aircraft. Data is gathered 200 000 times per second for each of the pressure transducers and a 100 times per second for the thermal data.

For each pressure transducer, a Brüel & Kjær High Pressure Microphone Calibrator Type 4221 is used together with a custom made adapter to provide the traceability back to national standards by back-to-back calibration against a Type 4138 reference microphone.

Andy adds, “Following the test, the data is post-processed to determine the conditions underneath the real aircraft and to predict the contours around the aircraft where ground crew can safely work. The effect upon the aircraft structure resulting from exposure to these high noise levels and operating temperatures is evaluated in the Acoustic Fatigue Facility and provides structural qualification evidence”.

Ian concludes, “All the microphones, accelerometers, calibrators and signal conditioning used in our test facilities at Brough are supplied by Brüel & Kjær. We have used their products for many years and regard them as the reference standard”.

### Bird Strike Test Facility

An unusual but vitally important facility at Brough tests the effects of bird strikes on airframe components such as the cockpit canopy or radomes. A large bird striking an aircraft at subsonic speeds of up to 500 knots creates a huge shock and is potentially hazadous. To simulate this, a laser guided pneumatic ‘cannon’ has been developed which propels a dead chicken at a range of 5 to 10 metres on to the test object. The structural effects of the impact (if any) are clearly visible. In additions accelerometers are used to measure the acceleration of the high speed collision.

### Contacts

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e-mail andy.russell@baesystems.com

## Transducers and Conditioning

***Fig. 12***
*BAE Systems at Brough has used Brüel & Kjær products for many years. The equipment shown here is not now in daily use but still in full working order*

Ian says, “All the microphones, accelerometers, calibrators and signal conditioning used in our test facilities at Brough are supplied by Brüel & Kjær. We have used their products for many years. used”.

Steve adds, “We regard Brüel & Kjær as the reference standard. We check the accuracy of each transducers before starting a test and have developed our own accelerometer calibration system based on a ‘back-to-back’ principle. We have a standard accelerometer that is sent to the National Physical Laboratory once a year”.

## Key Facts

- BAE Systems designs, manufactures, and supports military aircraft, surface ships, submarines, space systems, radar, avionics, electronic systems, guided weapons, etc.
- BAE Systems’ facilities at Warton and Brough use highly advanced acoustic and vibration measurement and analysis solutions to provide testing capabilities to its customers, both within BAE Systems, and for external companies.
- BAE Systems’ relationship with Brüel & Kjær began in the 1950s
- PULSE™ data acquisition and analysis systems are used, together with a wide range of microphones, accelerometers and calibrators supplied by Brüel & Kjær
- “Brüel & Kjær is the leading developer and supplier of noise and vibration solutions. They set the standard”

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