SYSTEM SUMMARY

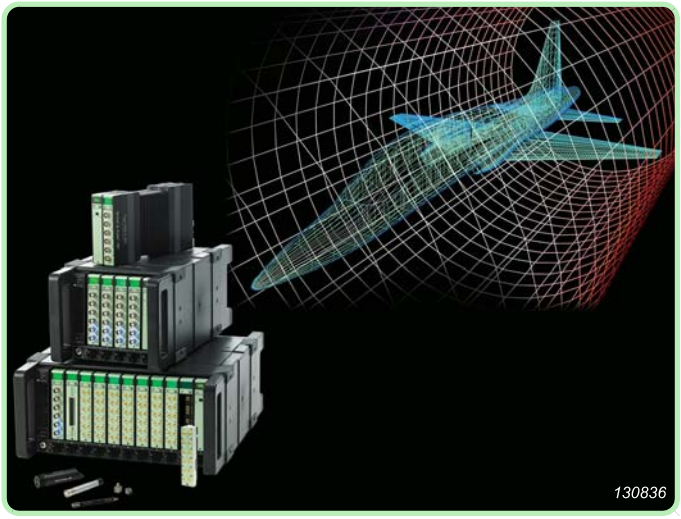
Wind Tunnel Acoustic Test System

Reduction of noise emissions is a critical technology for aircraft manufacturers, so various analytical, empirical and numerical tools exist to help in the design of quieter aircraft.

Given the complexity of the noise source mechanisms, aeroacoustic measurements in wind tunnels are used to provide vital contributions to the understanding and mitigation of these phenomena.

The Brüel & Kjær Wind Tunnel Acoustic Test System accurately performs all the tasks needed for aircraft acoustic scale model testing.

The system is based on Brüel & Kjær's standard, commercial-off-the-shelf (COTS) products that cover the entire measurement chain of transducer, data acquisition, analysis and reporting.



Noise Measurements and Measurement Challenges in Wind Tunnels

Noise pollution, fuel efficiency, and low carbon emissions are key drivers for 21st century aircraft designs. The combination of increasingly strict aircraft noise certification criteria, aircraft-noise-related landing fees, and interior-noise guarantees keeps the pressure on airframers, and engine, and nacelle manufacturers, to ensure that the development of noise-reduction technology remains centre stage.

Wind tunnels are traditionally used to develop and validate aerodynamic designs at much reduced cost when compared with full-scale flight testing. These facilities can also be used for aeroacoustic measurements of aircraft noise sources and their directivities; both for the validation of prediction methods and for the investigation of the acoustic impact of noise-reduction treatments.

Airframe noise research is generally focused on the components on an airframe that produce noise: flaps, landing gear, and high-lift leading- and trailing-edge devices, etc. Other areas of growing aeroacoustic interest include open rotors and cavity acoustics.

Open-circuit vs. Closed-circuit Wind Tunnels

Both open-circuit, anechoic wind tunnels, and closed-circuit wind tunnels are used for aerodynamic and aeroacoustic studies of various flow-induced noise phenomena. The choice of test facility is driven primarily by the type of application, the design speed, and the desired model scale. The preferred set up is also influenced by the priority for aerodynamic or noise measurements. Due to the issues around maintaining Reynolds number (the ratio of inertial to viscous forces), wind tunnels can also be pressurized and run at cryogenic temperatures. A further challenge is that it is often necessary to work at very high acoustic frequencies, particularly for small scale models. As the frequency of the noise created using a scale model is inversely proportional to the size of the model, this also challenges the capabilities of the acoustic data acquisition and analysis system.

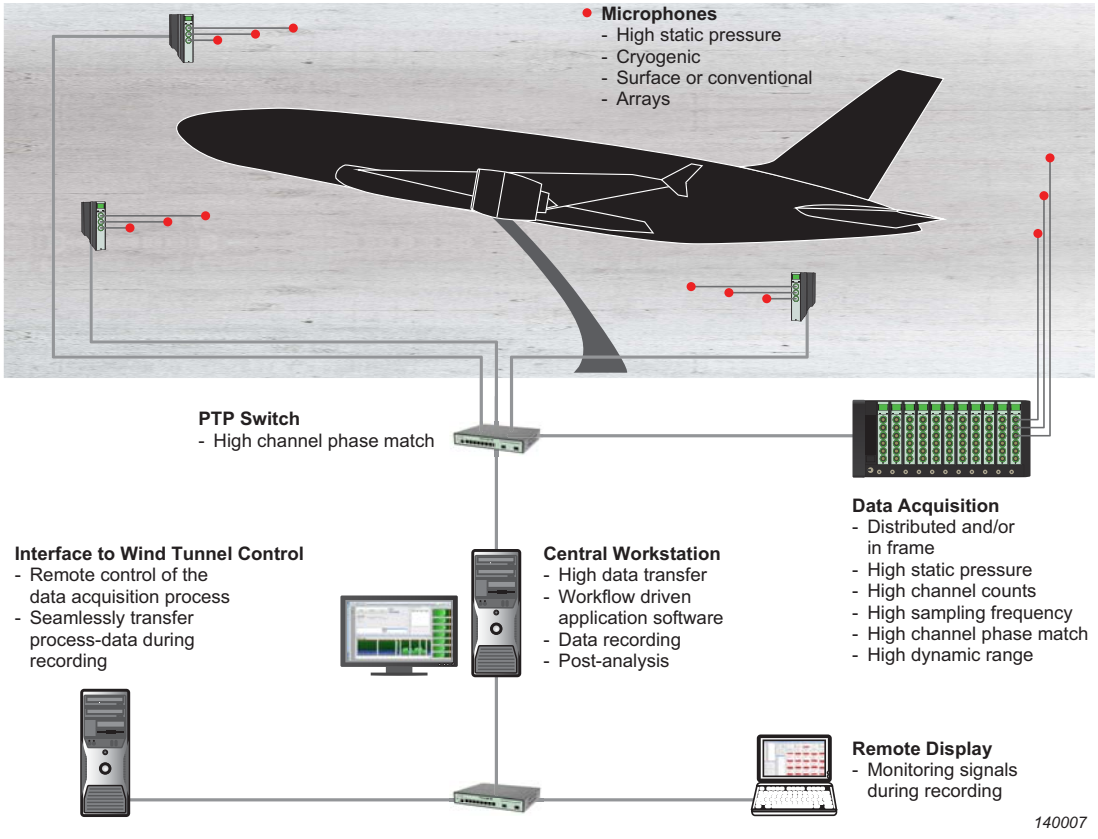
Brüel & Kjær can supply the instrumentation to suit all aeroacoustic testing requirements. We can also pass on years of experience with multiple microphone measurements and optimised microphone installations, which can help you to choose the most effective, and cost-efficient, test solution.

Wind Tunnel Acoustic Test system

The Brüel & Kjær Wind Tunnel Acoustic Test System is a dedicated solution, integrating and optimising the different inherent features of Brüel & Kjær COTS products. These products encompass the whole measurement chain, and they are optimised for the specific issues faced with wind tunnel test applications. Furthermore, dedicated streamlined workflow software ensures that all required tasks and operations for setup, calibration, recording, analysis and reporting are performed with maximum reliability and efficiency.

A schematic is provided in Fig. 1

Fig. 1
Wind tunnel acoustic test system architecture



System Components

The system typically consists of:

- The necessary number of microphones, preamplifiers, and cables to support the desired noise measurements. Examples are:
  - 1/4″ Pressure-field microphones with a flat frequency response up to 6 atm., and useable down to – 40° C
  - Surface microphones and high SPL microphones
  - Preamplifiers with a short body design for mounting in confined spaces
  - TEDS, CIC and VIC capabilities
  - Beamforming phased-array microphones
  - Cables at desired lengths
- LAN-XI Data Acquisition Modules. Mounted in racks, or distributed individually:
  - Sampling frequencies up to 524 kHz
  - Tight phase matching between channels
  - Changeable front panels with signal conditioning to suit different inputs, for example, classical/CCLD microphones, CCLD/charge accelerometers, Kulite® pressure sensors
  - Can safely operate under high/low static pressures at relatively high temperatures – from 0.4 bar (30°C) to 6 bar (50°C)
- An Acquisition Workstation installed with:
  - Data Recorder software
  - Software for real-time FFT, CPB (1/n-octave) and Overall Analysis
  - Software for post-processing of recorded data
  - Workflow-oriented application software, to guide you through the data acquisition and analysis operations.

- PTP (Precision Time Protocol) Enabled LAN
  - PTP LAN switches to maintain a high phase match on all channels even in LAN networks with multiple switching layers
- One or more Remote Monitoring Stations
  - At remote monitoring stations you can select some or all of the channels to monitor in real-time during data recording

Data Recording and System Performance

The prime objective of the wind tunnel application is to get quality data recorded without any test complications. Ease-of-use and up-time are essential system parameters.

Spreadsheet Setup

The system uses a spreadsheet file to set up the entire test. This gives very fast load and re-load of the test system. It also allows the test engineer to configure multiple tests in the office before the test, without having access to the test system.

Workflow-oriented Operation

The application is organised with a sequence of tabs providing workflow guidance through the various stages of setup, calibration, recording, analysis, data management and reporting.

Data Recording

The system user-interface provides no-nonsense access to vital test system information and recorder control, see Fig. 2.

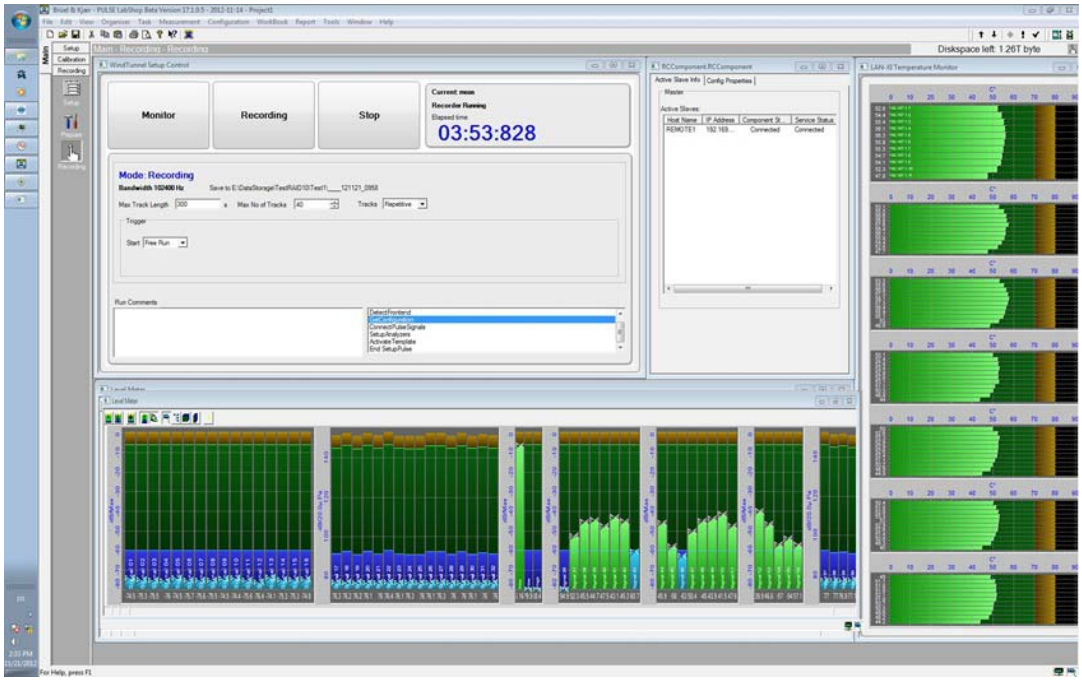


Fig. 2
The Wind Tunnel Acoustic Test System user-interface.
Top-left, the recorder control.
Right, LAN-XI module status (temperature).
Bottom, the overall level from each of the measurement channels. (Note that this UI can be customised to suit your specific application needs)

Remote Monitoring During Recording

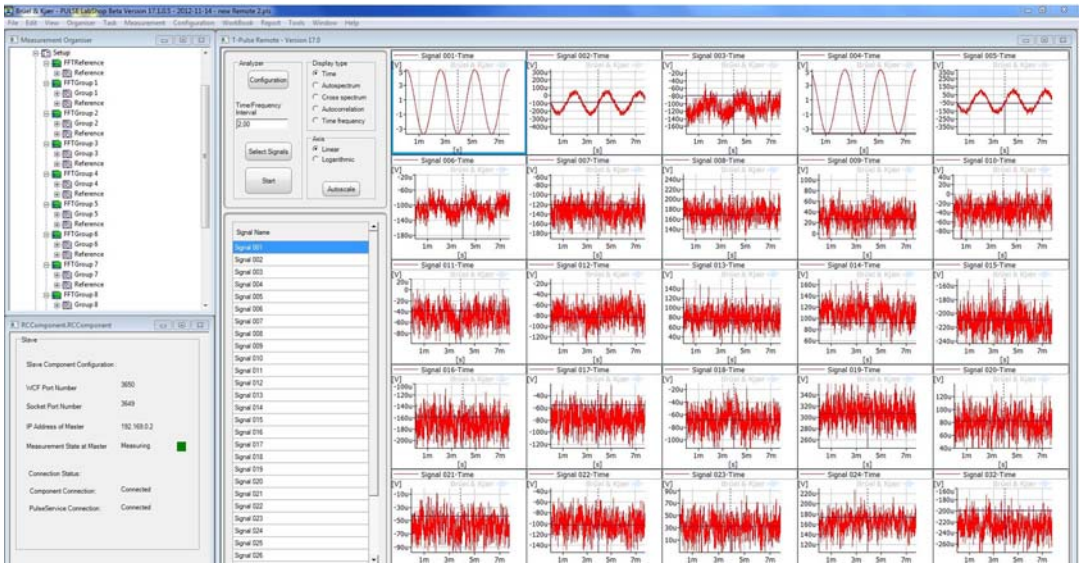
During the wind tunnel test, acoustic data is recorded to disk for downstream analysis. During the actual recording, it can be a benefit to monitor certain individual acquisition channels, supplying instant feedback on test quality and on the validity of data.

Test data can be analysed in real-time via a remote monitoring station providing real-time level, time, FFT and/or octave analysis. Process data from the wind tunnel control system can also be displayed, and a set of acoustic channels listened to via headphones, see Fig. 3.

Self-test

A data acquisition digital/analogue self-test function gives you a powerful tool to make on-site verification and/or calibration. This means that it is not necessary to ship equipment to an external calibration facility, with the ensuing down time of the test facility.

Fig. 3
Users on LAN-connected PCs can monitor data recording while it takes place. At Remote Monitoring stations you can select some or all of the channels to monitor in real-time as Histogram Level, Time, FFT or 1/3-octave displays during recording



Handling of Dynamic System Faults

Even if hardware is tested and calibrated prior to a test, failures such as network breaks can still happen, and here it is important that measurements continue with remaining working channels. In many multi-channel measurements, it is often more important to complete the measurement and use what is got, than to interrupt the test and spend time troubleshooting the test system.

The dynamic fault-handling capabilities of PULSE™ will ensure that in the event of a failure, defective channels are acknowledged and data ignored, and that recording will continue with the remaining channels.

Workstations Sized for the Application

Wind tunnel test systems are characterized by their high channel count and high sampling frequencies. A typical wind tunnel test system can therefore generate large amounts of data over a short time, requiring considerable computer processing power, and a high hard-disk performance. As an example, a ten second noise acquisition test, with a 100 kHz data bandwidth using an array of 200 microphones will result in about 2 GB of data. The Brüel & Kjær Wind Tunnel Acoustic Test System uses the latest in workstation technology, providing solutions that are preconfigured to handle these large data rates.

Wind Tunnel Application Software

The Wind Tunnel application software provides an intuitive user-interface to step the user through the test processes.

Dedicated Data Acquisition and Handling Software Application

The Data Acquisition and Handling (DAQH) software provides workflow management of complex measurement, recording and analysis tasks.

Fig. 4
The DAQH software

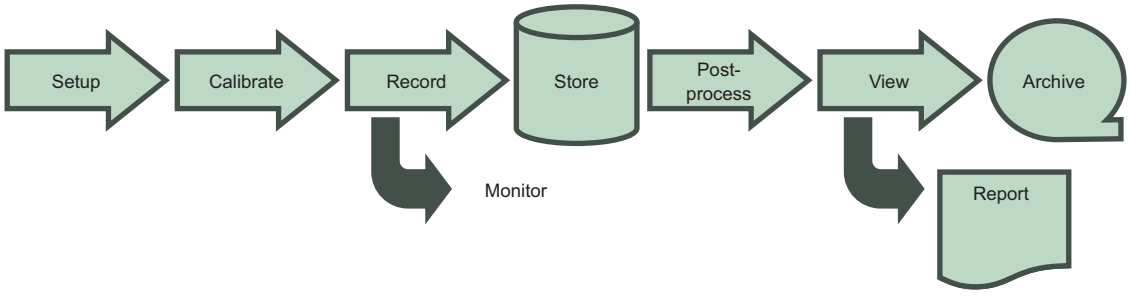
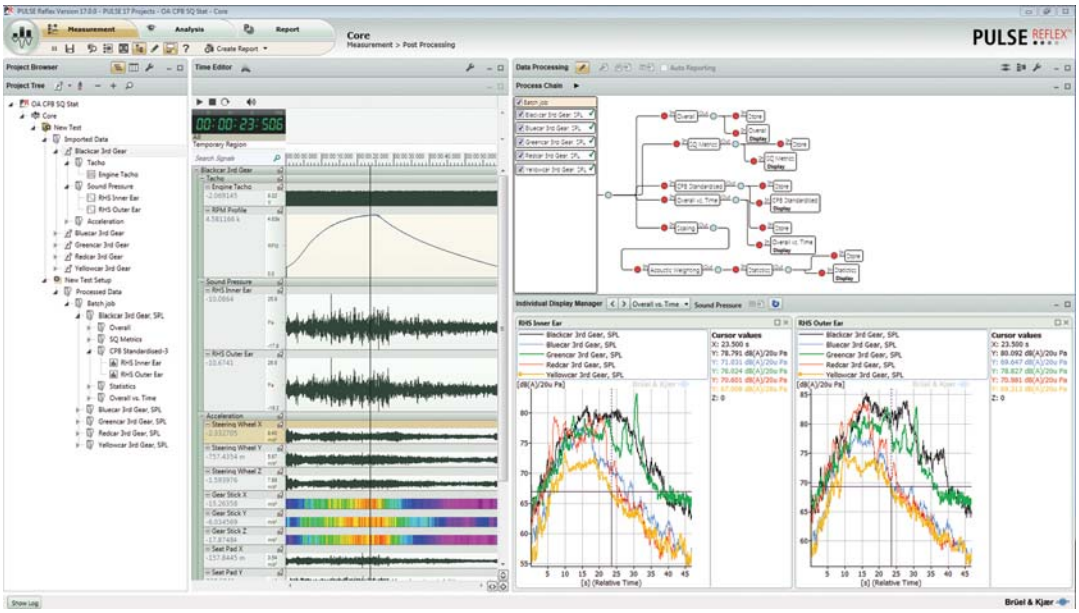


Fig. 4 shows the DAQH software workflow. The DAQH framework provides a dedicated customer user-interface to control PULSE software to manage all setup, calibration, measurement, analysis, data management and reporting. The user interface is designed with this workflow in mind, allowing you to easily step through the specific tasks of your testing.

Post-analysis Software

Recorded data can be analysed using the powerful suite of PULSE Reflex™ post-processing software. This software brings together a range of generic post-processing tools for offline analysis and processing of time data.

Fig. 5
PULSE Reflex post-processing software



The tools are built into a framework that provides for fully automated operation, including batch processing for sequenced or parallel analysis of multiple sets of imported data.

Data Acquisition

Fig. 6
LAN-XI data acquisition hardware

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LAN-XI Data Acquisition Modules

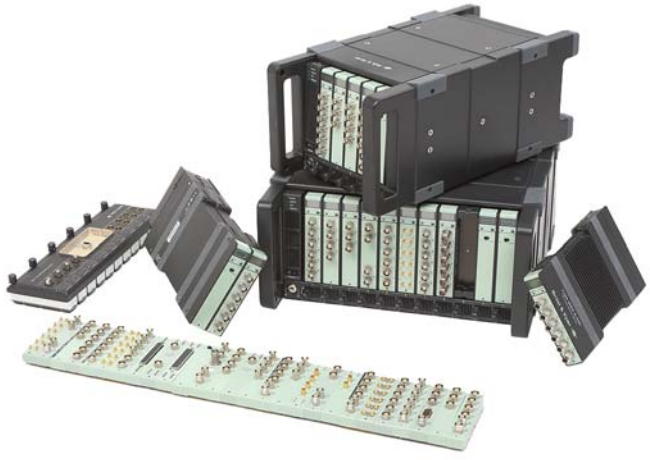
The Brüel & Kjær LAN-XI modular data acquisition system can be configured to easily handle the high number of channels typically found in wind tunnel systems. LAN-XI Data Acquisition Hardware is a versatile system of modular hardware that can be used as a stand-alone, single-module front-end, as part of a distributed module setup, or collected in 5- or 11-module frames, see Fig. 7.

Running on AC, DC, battery or Power over Ethernet (PoE), LAN-XI hardware provides an extremely flexible system: scalable from 2 to more than 1000 channels, with a frequency range up 204.8 kHz, and with a data transfer only limited by the workstation capacity.

Distributed Architecture

When used in a distributed architecture, the LAN-XI modules can be placed close to or in the wind tunnel itself.

Fig. 7
The LAN-XI family – a range of modules and front-panel conditioning units to suit a multitude of measurement needs



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In general, it is advantageous to place the data acquisition system as close as possible to the test object in order to shorten the amount of analogue microphone cabling required.

This provides significant cost savings on expensive high-quality transducer cables, fewer setup and measurement mistakes due to reduced cable 'infrastructure', and better signal quality as short cables minimise the risk of adding noise to the measurement data.

Under and Over-pressure Operation

The LAN-XI modules themselves can withstand static pressures up to 6 bar and down to 0.5 bar – meaning that they can be placed close to, or in the wind tunnel itself. For operation in under-pressures, Brüel & Kjær can supply purpose-built fan units to supply extra cooling.

Multi-sensor Conditioning

The LAN-XI modules' interchangeable front-panels provide sensor conditioning for a wide range of sensor types. Microphones (pre- and externally polarized), CCLD and charge accelerometers, Kulite pressure sensors and bridge sensors can easily be supported, without the need for bulky external conditioning units.

High Sampling Frequency

Test frequencies scale inversely with the model scale. As an example, a 5 kHz test requirement for a full scale test object equates to 50 kHz for a one-tenth scale model. Hence, the frequently encountered combinations of high model scale and high-frequency sources require a very high sampling rate. The Brüel & Kjær Type 3052 LAN-XI module system can sample at up 262 kHz, and for very special applications the LAN-XI Module Type 3161 is available that can sample up to 524 kHz.

Typical acoustic measurements are made using 1/3-octave filtering (CPB), which is internationally standardised for use in audio analysis. A 262 kHz sampling frequency will allow a measureable upper 1/3-octave frequency of 80 kHz, without cut-off of the upper filter flank, which would otherwise lead to a very asymmetric filter shape.

PTP Synchronization

Source location measurements at 80 kHz require that microphone positions relative to one another be known with an accuracy of up to 0.003 inches (0.076 mm). This requires that the phase match between individual channels must be within a few degrees. The Brüel & Kjær system uses PTP Synchronization to maintain these tight phase specifications. LAN-XI Module Type 3052 has a channel-to-channel phase match of approximately 3° @ 100 kHz. The Brüel & Kjær 10-port Network Switch UL-0265 supports PTP, and can therefore be used to maintain these tight phase specifications across the entire network.

High Dynamic Range

Measurements in wind tunnels are often fraught with low-frequency, self-generated fan background noise. Use of the high dynamic range of the LAN-XI modules can remove this issue, as the low-level, low-frequency noise signals and the high-level, high-frequency signals of interest are all covered using a single input range. If required, microphone preamplifiers with high-pass filters are also available.

Microphones

Aeroacoustic testing in anechoic test chambers typically uses microphones positioned in the free field. Hard-walled wind tunnels typically employ phased arrays of microphones placed flush in the wall of the test section. However, microphones can also be installed on the noise-producing surface, or placed in the flow field.

Brüel & Kjær microphones are ideal for far-field measurements in open jet tunnels. Both the ¼″ Type 4938 (externally polarized) and Type 4944 (prepolarized) pressure-field microphones are available in versions for use in high static pressures and/or at cryogenic temperatures. The frequency response of these microphones is highly predictable at varying static pressure. The microphone can also be flush mounted in the wall of the chamber, and for this purpose 90° adaptors and short preamplifiers are available to reduce space needed.

The flat Surface Microphone Type 4948-B may be used on aerodynamic surfaces, and is also suited for use where space requirements restrict the mounting of conventional microphones. High acoustic pressure capable microphones may also be employed for measuring open-rotor, near-field measurements, while in-flow microphones can also benefit from a Brüel & Kjær Microphone Nose Cone that reduces noise.

A selection of Brüel & Kjær microphones and accessories used in wind tunnel testing is shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

TEDS (Transducer Electronic Data Sheet)

A TEDS microphone consists of a microphone cartridge and its preamplifier with a memory chip. TEDS IEEE 1451.4 transducers will greatly help to improve setup time. Even with just a few sensors, it can be a tedious and error-prone job to identify sensors and enter their specific data.

Fig. 8
Surface Microphone Type 4948-B

Fig. 9
High Static-pressure Optimised Microphone Type 4938-W-001 with short version of Preamplifier Type 2670-W-001

Fig. 10
Microphone Type 4944-W-006 with integral preamplifier and flush-mount adaptors WA-1760 (upper – adjustable) and DP-1059 (lower)

Fig. 11
High Static-pressure Optimised Microphone Type 4938-W-001 (without microphone grid) with short version of Preamplifier Type 2670-W-001

TEDS offers a number of benefits:
- Plug and play facilities
- Type, S/N, sensitivity and more read in directly from the transducer
- Significantly reduced setup time
- Practical elimination of cable routing errors

Classic Preamplifier vs. CCLD Preamplifier

A condenser microphone must be combined with a preamplifier to provide impedance conversion, some filtering, and the capability to drive long cables without signal degradation. Preamplifiers are designed in accordance with two principles: Classic preamplifier design (used with both external and pre-polarised microphones), and CCLD preamplifier design (only used for pre-polarised microphones). Classic preamplifiers have the advantage of a higher dynamic range, and they support CIC Calibration validation (see Calibration section). The CCLD preamplifier allows for simpler (and cheaper cabling), but does not support CIC. Both types support TEDS. (See Table1 for a selection of Brüel & Kjær microphones and accessories.)

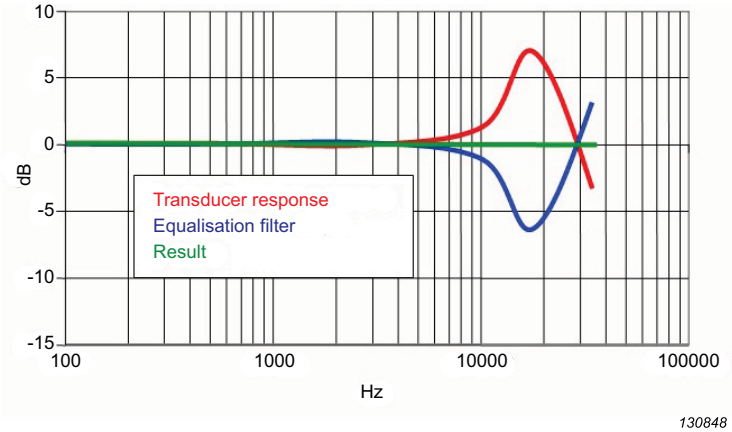
Table1 *Selection of Brüel & Kjær microphones and accessories used for wind tunnel testing*

Type No.	Size	Type	Suggested Preamp	Main Characteristics	TEDS Support	CIC Support
4948-B	Flat	CCLD	CCLD Built-in	Rugged Surface Microphone High Frequency	Yes	Yes
4948-W-005	Flat	CCLD	CCLD Built-in	Rugged Surface Microphone High SPL	Yes	No
4938-W-001	1/4″	Ext. polarized	Classic 2670-W-001	Optimised for high variations in static pressure	No*	Yes
4939-W-001	1/4″	Ext. polarized	Classic 2670-W-001	100 Hz HP filter	No*	No
4944-W-005	1/4″	Prepolarized	CCLD, Integral	For cryogenic temperatures	Yes†	No
4944-W-006	1/4″	Prepolarized	CCLD, Integral	Flush mounting (with Adaptor DP-1059)	Yes	No
4944-W-010	1/4″	Prepolarized	CCLD, Integral	Optimised for high variations in static pressure	Yes	No
Accessories:	EU-4000 90° adaptor; UA-0954 1/4″ extension for use with EU-4000 and others; DP-1059 and WA-1760 (adjustable) flush adaptors for Type 4944 and its variants					

* TEDS support with standard Preamplifier Type 2670 and 2670-W-012 (short version of preamplifier with the TEDS chip in the integral cable connector).
† Not at very low temperatures.

Frequency Response Equalisation

Fig. 12
REq-x technique



Frequency Response Equalization (REq-X) is a technique that allows you to flatten and stretch the frequency response of microphones, accelerometers and couplers in real-time, see Fig. 12. This extends the frequency range of transducers, improves the accuracy of the measurement and expands the uses of existing transducers. This means that you can use the same microphone for different sound fields – free field, pressure field and diffuse field – independent of the type of microphone. What's more, the microphone can be corrected for angle of incidence in steps of 30 degrees, that is, for 0°, 30°, 60°, 90°, 120°, 150° and 180° angles of incidence, thereby improving the measurement accuracy by a further 5 to 10 dB.

Microphone Calibration and CIC Validation

In line with the relevant industry standard, the Brüel & Kjær Wind Tunnel Acoustic Test System performs a full system calibration pre- and post-test, using an acoustic calibrator or pistonphone.

Acoustic calibration can be both time consuming and awkward. Due to mounting of the microphones (often flush mounted) and difficulties of access, it is not always possible to access the microphones for calibration. Brüel & Kjær's patented Charge Injection Check (CIC) function can therefore be performed regularly for rapid validation of the complete system. The CIC function provides a validation of the complete acoustic chain, including the microphone – carried out directly from the data acquisition workstation, without any need to access the microphones themselves.

Interfacing to the Wind Tunnel Control System

The Brüel & Kjær system can interface with the wind tunnel control system, to provide remote control of the data acquisition process, and to seamlessly transfer data to/from the Brüel & Kjær system. During data recording, processed data, for example, temperature, pressure and flow data, can be displayed simultaneously with real-time acoustic data in the form of time/frequency plots. Remote control functionality typically includes:

- Loading the test configuration file
- Setting up data recording
- Starting data recording
- Getting measurement results
- Starting post-processing of recorded data
- Sending process data for display together with acoustic data.

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