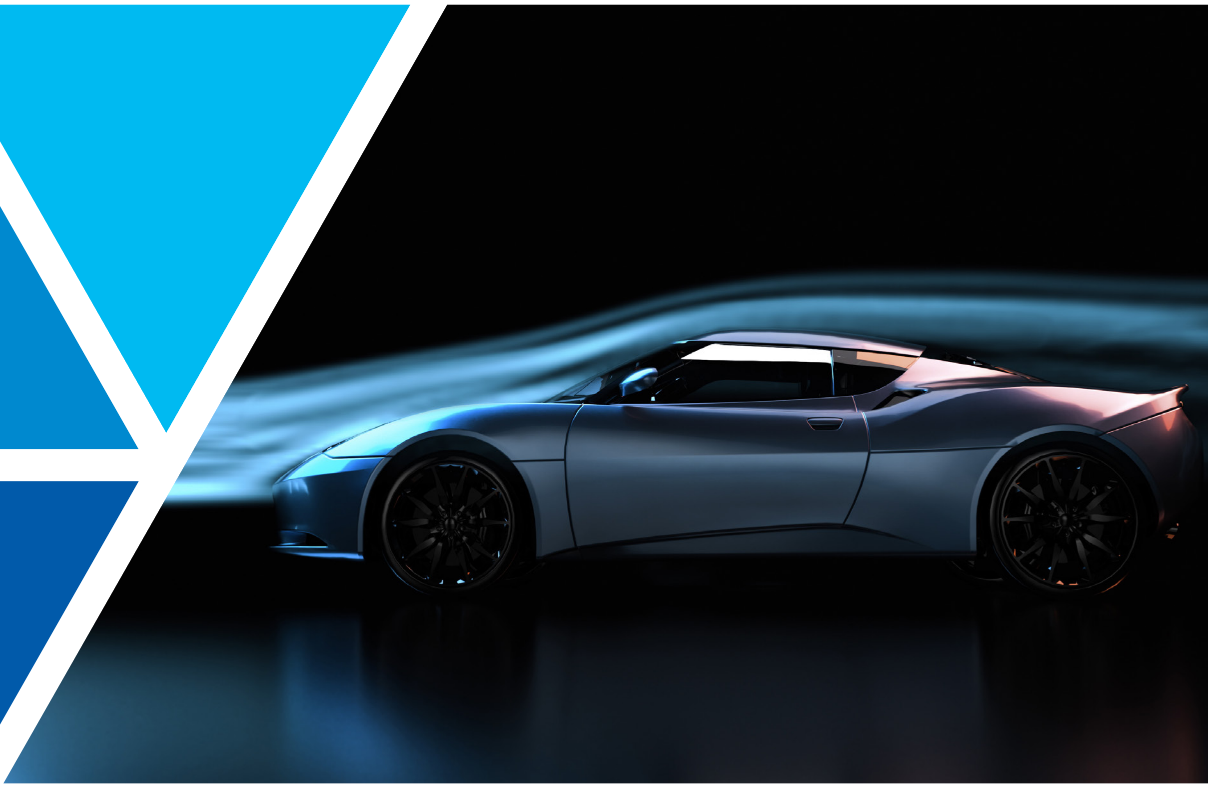
APPLICATION NOTE

MASTERING WIND TUNNEL MEASUREMENTS

HOW TO OVERCOME 5 CRITICAL CHALLENGES IN SENSOR INTEGRATION, SYNCHRONIZATION, SCALABILITY, AUTOMATION & DATA ANALYSIS



DEWETRON

ABSTRACT

Accurate, reliable, and synchronized measurement data is essential for successful wind tunnel testing. This paper examines key measurement challenges from integrating diverse sensor technologies and scaling measurement systems to synchronization, test environment integration, and data analysis. It also outlines practical approaches for building efficient, flexible, and scalable measurement solutions.

INTRODUCTION

Wind tunnel testing is crucial to the development and validation of aircraft, vehicles, motorsports applications, civil engineering structures, and many other aerodynamic designs. Whether optimizing aerodynamic performance, validating simulation models, or complying with regulatory requirements, engineers depend on accurate, reliable, and repeatable measurement data to make informed design decisions.

As wind tunnel testing continues to evolve, so do the demands placed on integrated measurement systems. Engineers must integrate a wide variety of sensor technologies, acquire hundreds or even thousands of measurement channels, synchronize distributed measurement systems, and efficiently process large volumes of data. At the same time, the data acquisition system must integrate seamlessly into automated test environments while remaining flexible enough to accommodate changing test requirements. Meeting these demands requires more than high-performance data acquisition hardware, it requires an integrated measurement solution that simplifies the complete workflow, from sensor acquisition and synchronization to data analysis and post-processing.

This whitepaper explores five key measurement challenges in wind tunnel testing and demonstrates how an integrated measurement solution helps engineers improve efficiency, ensure data integrity, and maximize the value of every test campaign.

Fig. 1: Wind tunnel testing scenario

CHALLENGE 1: INTEGRATING DIVERSE SENSOR TECHNOLOGIES

A comprehensive wind tunnel test may capture numerous physical parameters simultaneously, including voltage, current, temperature, speed, torque, stress, and strain. Collecting this information requires many different sensor technologies to operate together within a single measurement system.

A typical test setup may combine strain gauges, pressure sensors, thermocouples, RTDs, IEPE accelerometers, force balances, displacement sensors, digital I/O, and environmental sensors. Each technology introduces specific requirements for signal conditioning, sensor excitation, sampling rate, connectivity, etc.

The challenge is therefore not simply connecting these sensors - it is integrating them into one synchronized, scalable, and easy-to-manage measurement system.

DEWETRON addresses these requirements with its TRION3-18xx-MULTI measurement modules. The modules support a broad range of sensor and signal types within a single hardware platform, including:

- Strain gauge sensors (quarter-, half-, and full-bridge)
- Force and torque transducers
- Pressure transducers
- Thermocouples and RTDs
- IEPE/ICP® accelerometers and microphones
- Voltage and current signals
- Digital inputs and outputs

Each input channel can be configured independently via their OXYGEN measurement software, allowing you to optimize the measurement for each connected sensor. You can individually adjust the input mode, sampling rate, measurement range, filtering, excitation, and scaling without replacing or reconfiguring the measurement hardware. This approach creates a compact and flexible system that can adapt to different test requirements.

Key features of the TRION3-18xx-MULTI measurement board include:

- High measurement accuracy and dynamic range: The modules provide accurate signal acquisition from DC to an industry-leading bandwidth of 100 kHz while providing a dynamic range of up to 140 dB SFDR. This allows the precise detection of small signal components, which is especially important when testing scaled models and transferring results to the full-scale DUT.
- Hardware-based filtering: An analog anti-aliasing filter and programmable digital Bessel or Butterworth filters (up to the 10th order) provide real-time signal conditioning directly on the FPGA.
- Phase-synchronous channels: The channel-to-channel phase offset remains below 10 ns. This precise channel alignment allows accurate phase, correlation, vibration, and dynamic-response analyses across the module's channels.
- Freely programmable sensor excitation: Each channel can supply up to 24 V or 60 mA, with a maximum of 1 W per channel, to support a wide range of sensor technologies. Integrated sense lines compensate for voltage drops across long cables and help maintain accurate excitation, particularly for bridge-based sensors.
- Comprehensive strain gauge support: The modules support quarter-bridge configurations with three- or four-wire connections, as well as half-bridge and full-bridge configurations. Automatic shunt calibration simplifies setup verification.
- Integrated self-test and calibration functions: A precise internal calibration source verifies module functionality before and after a test. Auto-Zero measures and compensates for internal amplifier offsets, while Gain Cal uses an ultra-stable internal reference to identify and correct gain errors.

- Dedicated reference input: A separate reference input allows you to route a known, calibrated signal to all analog inputs at once, without disconnecting the attached sensors.
- Optional isolated analog outputs: Eight programmable channels provide voltage outputs of ±10 V or current outputs of ±30 mA. High-speed mode offers latency below 5 µs, while high-resolution mode provides 32-bit DAC resolution.

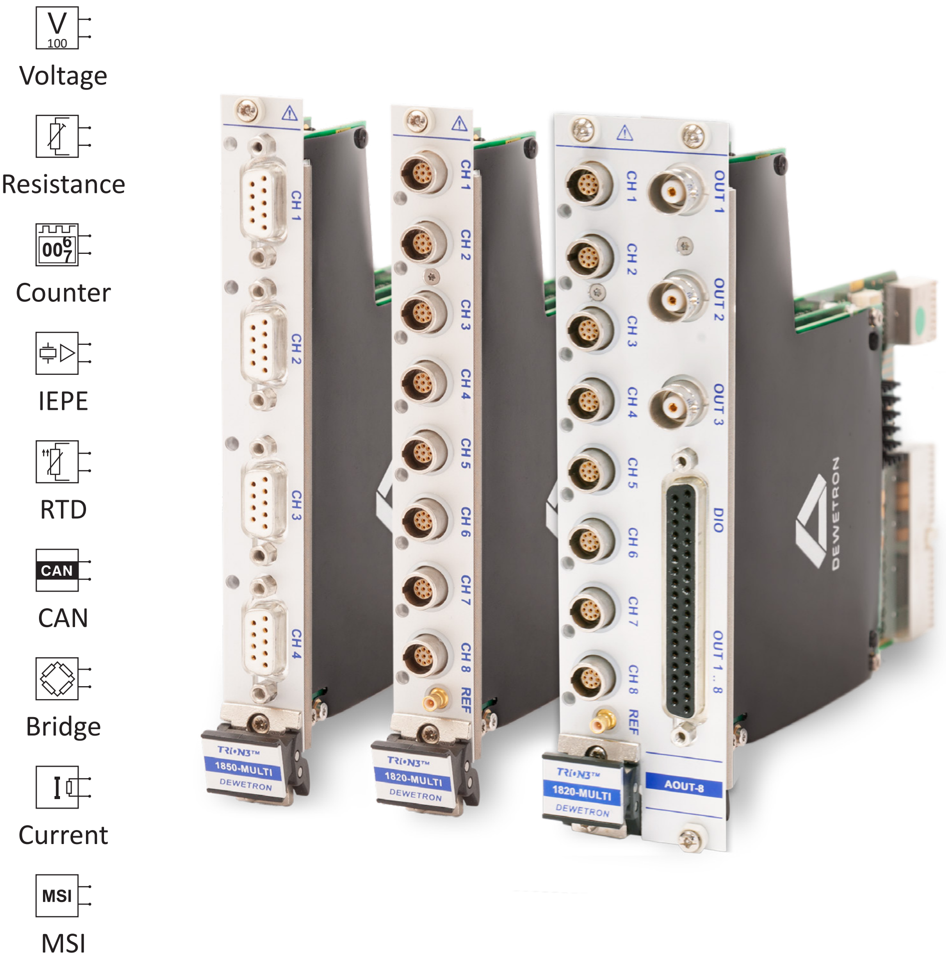


Fig. 2: TRION3-18xx-MULTI modules

CHALLENGE 2: SCALING WIND TUNNEL MEASUREMENTS

Channel count adds another layer of complexity to wind tunnel measurement. Test campaigns may require hundreds or thousands of channels distributed across the test object, tunnel infrastructure, and auxiliary systems. In these situations, routing every sensor signal to a single central acquisition system may be impractical.

Simply adding more instruments can also increase configuration effort, complicate system operation, and fragment the measurement workflow. A scalable architecture must expand with changing test requirements while maintaining acquisition performance and straightforward operation.

DEWETRON's OXYGEN-NET enables multiple independent DEWETRON instruments to operate as one distributed measurement system. Although the acquisition hardware remains physically distributed, you can configure, control, and monitor the complete setup from one central device. This architecture allows your test teams to scale from a few measurement channels to several thousand while continuing to work within a single measurement application.

Key features of OXYGEN-NET include:

- Unifies distributed instruments: OXYGEN-NET combines multiple DEWETRON data acquisition systems over standard LAN infrastructure and operates them as one synchronized measurement system.
- Supports scalability: The architecture scales from a few channels to several thousand while maintaining high sampling rates and measurement performance.
- Centralizes system operation: A single master unit manages configuration, control, monitoring, and recording across the distributed setup.
- Accelerates commissioning: Prepare-and-Claim technology allows engineers to configure instruments independently before combining them into the complete measurement system. Prepare different parts of the setup in parallel and reduce overall commissioning time.

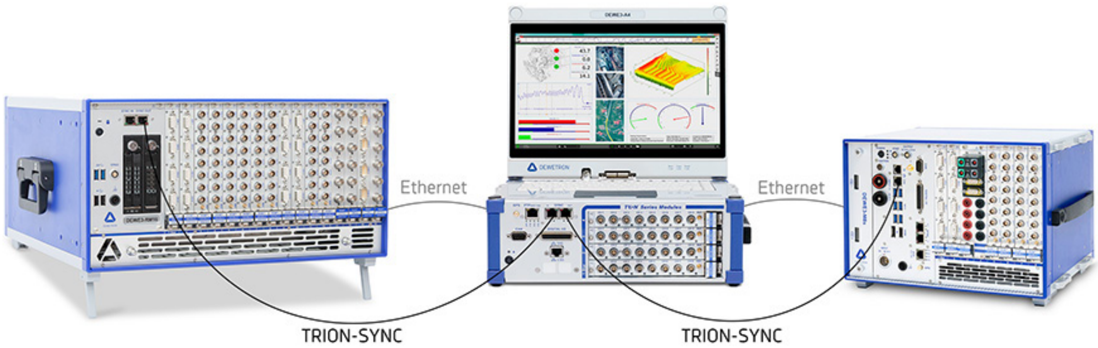


Fig. 3: Example configuration of an OXYGEN-NET

CHALLENGE 3: ENSURING SYNCHRONIZED MEASUREMENTS

Scalability only provides meaningful results when every measurement channel shares a common time reference. As measurement systems become distributed, the risk of timing differences between individual instruments increases. Without precise synchronization, small deviations between system clocks can accumulate and introduce phase shifts, inaccurate signal correlations, and unreliable analysis. These effects become particularly critical during dynamic measurements and tests that use high sampling rates.

DEWETRON uses a comprehensive synchronization architecture to keep measurement data aligned across standalone instruments, distributed data acquisition networks, and third-party systems. At the core of each DEWETRON system, the TRION-SYNC-BUS distributes a common time base and ensures synchronized sampling across every channel.

Key synchronization capabilities include:

- TRION SYNC I/O: Directly synchronizes multiple DEWETRON systems across distances of up to 100 m, making it suitable for distributed OXYGEN-NET installations.
- PTP, IRIG, and PPS: Industry-standard synchronization protocols connect DEWETRON systems with synchronized networks, wind tunnel control systems, and third-party test equipment.
- GNSS synchronization: Support for GPS, Galileo, GLONASS, and BeiDou provides an absolute time reference for geographically distributed systems and long-distance synchronization.

CHALLENGE 4: INTEGRATION INTO TEST ENVIRONMENT AND MANAGING DATA

A data acquisition system rarely operates in isolation. It must provide feedback to wind tunnel controls, and communicate with automation platforms, auxiliary equipment, and external data consumers throughout the test campaign.

Typical integration requirements include:

- Synchronizing the measurement system with the wind tunnel control system
- Configuring and controlling distributed instruments remotely
- Automating recordings according to external events or test sequences
- Transferring measurement data to other systems

At the same time, high channel counts and sampling rates can generate substantial data volumes. Test teams must store, organize, transfer, and process these data efficiently without interrupting the measurement workflow.

DEWETRON combines synchronization protocols, open communication interfaces, automation functions, and integrated data handling to connect measurement systems with existing test environments.

Relevant capabilities include:

- System-level synchronization: Protocols such as PTP and IRIG align the data acquisition system with the wind tunnel control system and other test equipment.
- Remote system control: You can configure the system, load measurement setups, start and stop recordings, and manage complete test campaigns without direct access to the acquisition hardware. SCPI commands provide remote access to a wide range of system functions.
- Event-driven automation: External events and test sequences can automatically start or stop recordings, activate digital outputs, capture snapshots, and trigger other predefined actions.
- Flexible data distribution: DataStream transfers binary measurement data at rates of up to several Gb/s. Additional interfaces, including CAN, Modbus, and Ethernet-based communication, support integration and monitoring across lower bandwidths.
- Integrated data handling: OXYGEN supports reliable data recording, structured file management, automated export, and efficient processing throughout the test campaign.

CHALLENGE 5: MONITORING, LIVE ANALYSIS, AND POST-PROCESSING

Every wind tunnel run consumes valuable time and resources. Engineers must therefore verify sensor operation, signal quality, and measurement results while the test is still running. Immediate visibility helps teams identify problems early, adjust test parameters, and avoid repeating an expensive test sequence.

In addition, analysis often continues after the measurement campaign. You may need to process large datasets, apply additional calculations, compare operating conditions, or transfer recorded data into specialized analysis environments and customer-specific workflows.

OXYGEN supports the complete measurement process by combining live visualization, online calculations, and flexible post-processing within one software environment.

Core capabilities include:

- Real-time visualization: OXYGEN displays signal trends in the time and frequency domains, statistical values, and calculated results through a wide range of display instruments and visualization widgets.
- Live processing and analysis: Apply customizable mathematical operations, statistical evaluations, advanced power calculations, multi-stage FIR filtering for phase-synchronous downsampling, and other online analysis functions while the test is running.
- Configurable measurement displays: Customize multiple measurement screens to present the parameters and analysis most relevant to a specific test.
- Flexible data export: OXYGEN supports numerous standard file formats for further evaluation in MATLAB®, Excel, DIAdem, and further customer-specific software tools.
- Comprehensive post-processing: Replay recorded measurements, add calculations and filters, and perform detailed offline analysis without repeating the test.

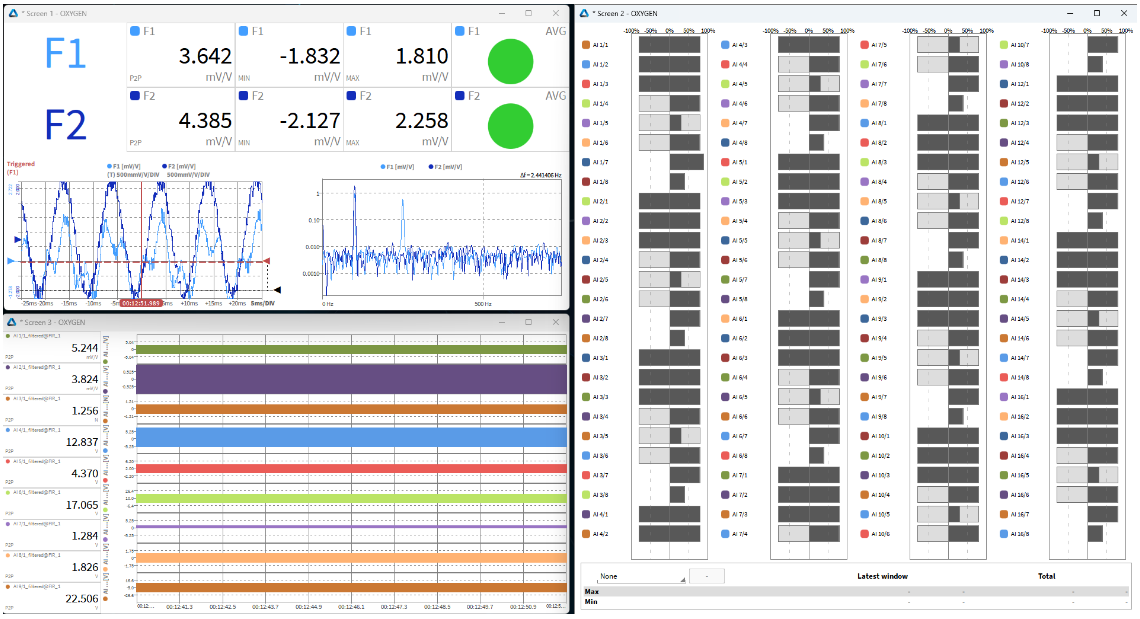


Fig. 4: Individually customizable measurement screens

SUMMARY

Reliable wind tunnel results depend on more than accurate sensors or high-performance data acquisition hardware. Your test teams must integrate diverse sensor technologies, scale to large channel counts, synchronize distributed measurements, connect with existing test infrastructure, and convert large datasets into useful engineering information.

A unified measurement platform simplifies these tasks throughout the complete test workflow. It reduces configuration effort, improves data consistency, and provides the flexibility required to adapt to different wind tunnel applications and changing test requirements.

By combining data acquisition hardware, synchronization, measurement software, automation, and data management within one ecosystem, DEWETRON enables you to spend less time managing measurement systems and more time interpreting results, validating models, and optimizing designs.

AUTHOR

Rafael Goldgruber

Rafael Goldgruber holds a Master‘s degree in Physics from the University of Graz, specializing in astrophysics and data analysis. Before joining DEWETRON, Rafael worked on various scienceresearch projects in Austria and Spain, gaining valuable experience in the field. Since 2022, he has been part of DEWETRON, where he serves as an Application Engineer. In this role, Rafael contributes his expertise to the development of advanced measurement systems, leveraging his background in physics and data analysis to support the company‘s projects and initiatives.

ABOUT DEWETRON

DEWETRON is a manufacturer of precision test and measurement systems and part of the globally operating Anritsu Group. Our reliable measurement data help customers worldwide make processes more predictable, efficient, and safer.

Our strength lies in customized measurement solutions: ready to use right away while remaining flexible to adapt to dynamic testing requirements in the energy, automotive, transportation, and aerospace industries.

More than 35 years of experience and innovation have made DEWETRON a trusted partner in the global test and measurement market.

More than 25,000 DEWETRON measurement systems and over 400,000 measurement channels are in continuous use at leading companies worldwide.

DEWETRON's quality is certified according to ISO 9001 and ISO 14001.
The high integrity of the measurement data is guaranteed by our own accredited calibration lab according to ISO 17025.

THE MEASURABLE DIFFERENCE.

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