

The benefits of replacing the traditional dimensional calibration system with the Laser Measurement Technology in the CSIR Wind Tunnel Facilities

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Abstract

Calibrations in any aerodynamic metrology field require patience as it is time-consuming. The Council for Scientific and Industrial Research has wind tunnel facilities with a wind tunnel model support system of 6 degrees of freedom. These degrees of freedom are three translations and rotations, which must be calibrated per project-specific requirements and the facilities maintenance management schedule. This paper addresses the impact of introducing advanced laser measurement technology instead of traditional dimensional instrumentation calibration systems at the CSIR Wind Tunnel Facilities. Conventional calibration methods typically entail extensive manual processes and significant downtime, resulting in higher operational costs and slower instrumentation calibration and wind tunnel testing cycles.

The advantage of implementing the laser tracker system is that it enhances the calibration accuracy in the CSIR Wind Tunnel facilities. Therefore, the laser tracker system addresses these challenges and offers an efficient alternative. By enhancing precision and speed, the new technology improves the wind tunnel facilities' dimensional instrumentation maintenance processes and aerodynamic testing while delivering substantial cost and time savings. Manual and time-intensive traditional methods incur higher costs, slower calibration processes, and limited precision and human errors. Laser measurement technology simplifies these tasks, producing faster and more precise calibrations. Through several calibration activities and data collection, it is evident that this replacement enhances instrumentation calibration efficiency and decreases operational expenses, representing a valuable improvement for future aerospace research and development.

1. Introduction

Precision calibration is crucial to ensuring accurate and reliable data in aerodynamic metrology. The CSIR Wind tunnel facilities equipped with a sophisticated wind tunnel model support system offering six degrees of freedom have traditionally relied on labor-intensive and time-consuming manual calibration processes. Operational costs and extended downtime have been caused by conventional methods. This paper describes the successful implementation of advanced laser measurement technology at the CSIR Wind Tunnel

Facilities. We've boosted calibration precision, efficiency, and value by swapping conventional dimensional instrumentation calibration systems for laser tracker systems. This technological advancement results in a substantial improvement in the upkeep of dimensional instrumentation and the entire aerodynamic testing procedure, resulting in substantial time and financial savings.

2. Traditional Dimensional Calibration Method

Tracking the attitude of the Wind Tunnel Test Model such as aircraft models, which is usually done via an encoder or sensors or potentiometer in the wind tunnel model support system, is one of the most critical requirements for Wind Tunnel Test campaigns. These sensors are crucial for determining the model's location during wind tunnel testing in the CSIR wind tunnel facilities. Sensor calibration is required to provide reliable feedback. Traditionally, this calibration involved manual alignment of the defined calibration body and mechanical measurement tools such as Vernier, inclinometers, micrometers, etc., a process that is time-consuming, inaccurate, and vulnerable to human error [1].

The traditional calibration method for each of the 6 axes requires the calibration body to be installed on the model support system and aligned as part of the reference system. For rotational calibration, additional measuring tools are mounted on the calibration body. Translational calibration involves setting up various equipment to ensure proper calibration and positioning of the model support system in the wind tunnel test section and aligning it with the calibration tools.

During translational calibration, tools like the stick micrometer location stand and other calibration bodies are used. The calibration body is manually aligned using a Vernier, and the axis location stand is positioned horizontally in the tunnel test section. The stick micrometer, a mechanical measurement tool, requires frequent adjustments by the technician to measure the model support system's movement accurately. This process is labor-intensive and prone to errors, often necessitating recalibration.

Rotational calibration also suffers from similar drawbacks. It involves installing a roll position angle adapter and aligning the model support system and calibration body. The clinometer is used as the reference standard, but its accuracy depends on the technician's familiarity with the tool, leading to potential human errors. If one of the movement sensors fails during the wind tunnel testing, it requires the full removal of the sensor, leading to all testing model dimensions and installation checks. This is time-consuming and leads to long downtime during production.

Once the process is complete for each axis, the metrologist analyses the result and compiles the report.

3. Implementation of Laser Measurement Technology

3.1 Overview of the laser measurement technology.

With the use of advanced laser measuring technology, exact physical measurements may be obtained without making direct contact with the item [2]. Using the different characteristics of laser light, the technique achieves a high degree of precision and resolution, frequently

reaching the micrometre or nanoscale range. Because of their efficiency and speed, laser measuring devices are well-suited for taking quick measurements in quality assurance and production[3]. Because of their versatility, they are employed in many different sectors, such as electronics, automotive, and aerospace, for jobs including surface analysis, dimensional inspection, and alignment.

3.2 Steps involved in the calibration process using laser systems.

The process begins with setting up and warming up the laser tracker, which typically takes about 45 minutes to reach thermal equilibrium. During this time, the device is positioned in a stable location within the wind tunnel test section, and the leveling bubble is centered to ensure proper alignment. Once the laser tracker is ready, the initial alignment phase begins. This involves establishing a fixed reference point within the test section and attaching reflective targets or retroreflectors to the model support system at key measurement points. The laser tracker then measures the position of each target, with the integrated software capturing and displaying the data in real time for immediate assessment and adjustments [2]. The calibration procedure involves sequentially calibrating each of the six degrees of freedom (three translational and three rotational axes). The software automatically assesses whether the measurements fall within the set tolerances. After collecting the data, it is reviewed to identify any deviations or anomalies, and necessary adjustments are made to the model support system.

Verification is a crucial step where re-measurements are conducted to ensure the calibration is accurate and within the desired tolerances. A final check is performed to confirm all measurements are consistent and reliable. The entire process takes just over two hours and is documented, with calibration data saved within the software for future reference and analysis, and a detailed calibration report generated

4. Discussions

4.1 Calibration Duration and Efficiency: Traditionally, calibrating the wind tunnel model support systems could take up to three weeks. In contrast, laser systems, despite requiring up to 45 minutes to warm up, significantly reduce this time. Once the laser system reaches equilibrium, the user must ensure the leveling bubble is centered. This new method has reduced the calibration process from three weeks to just one day, resulting in substantial savings in human labor costs.

4.2 Comparison of Calibration Methods: The CSIR wind tunnel model support system, which has six degrees of freedom, underwent calibration using both traditional and laser methods. Traditionally, calibrating each axis takes about two days, resulting in a total of approximately three weeks for the entire system. In contrast, the laser system completes the calibration of all six axes in just two hours. The comparison of data underscored the laser system's superior efficiency and accuracy.

However, despite its significant time-saving advantages, the laser system does come with certain drawbacks. These include high costs and the necessity for specialized user training. Additionally, traditional calibration reference standards are considerably cheaper, even when accounting for the cost of annual recalibration.

4.3 Gained benefits of Laser Systems in the CSIR dimensional calibrations

Real-Time Data Monitoring: One significant advantage of using laser systems is their integration with software for real-time data monitoring. Users can input nominal values and tolerances directly into the software. The system then displays results, such as yaw calibration ranging from -20° to 20° , and automatically assesses whether the results pass or fail based on the set tolerances. This capability significantly enhances the reliability and efficiency of the calibration process.

Control	Nom	Meas	Tol	Dev	Test	Out Tol
X/Y Angle	-19.989	-20.116	$\pm 0,050$	-0.126	Fail	-0.076
X/Y Angle	-15.021	-15.171	$\pm 0,050$	-0.150	Fail	-0.100
X/Y Angle	-10.024	-10.095	$\pm 0,050$	-0.071	Fail	-0.021
X/Y Angle	-4.977	-5.039	$\pm 0,050$	-0.062	Fail	-0.012
X/Y Angle	4.998	4.906	$\pm 0,050$	-0.092	Fail	-0.042
X/Y Angle	9.960	9.745	$\pm 0,050$	-0.215	Fail	-0.165
X/Y Angle	15.014	14.588	$\pm 0,050$	-0.426	Fail	-0.376
X/Y Angle	20.086	19.225	$\pm 0,050$	-0.861	Fail	-0.811

Figure 1: laser system data monitoring

Precision and Accuracy: Laser systems offer unparalleled precision and accuracy compared to traditional methods. This high level of accuracy ensures that the calibration is more reliable, reducing the likelihood of errors and the need for re-calibration.

Time Efficiency: The laser system drastically reduces the time required for calibration. While traditional methods may take up to two days per axis, the laser system can complete the calibration of all six axes in just two hours, saving valuable time and resources and wind tunnel test downtime.

Reduced Human Error: The automation and precision of laser systems minimize the potential for human error. This leads to more consistent and repeatable results, enhancing the overall quality of the calibration process.

Data Storage and Analysis: The software associated with laser systems often includes features for data storage and analysis. This allows for easy tracking of calibration history, trend analysis, and quick access to past calibration data, which can be invaluable for ongoing maintenance and troubleshooting.

Versatility: Laser systems can be used for a wide range of calibration tasks beyond just wind tunnel model support systems. Their versatility makes them a valuable tool for various applications in different industries.

Enhanced Safety: By reducing the need for manual handling and alignment, laser systems can improve safety for technicians. The automated processes limit the physical strain and potential hazards associated with traditional calibration methods.

These advantages make laser systems a compelling choice for modern calibration needs, despite their higher initial costs and the requirement for specialized training.

5. Calibration and Results Analysis

5.1 Analysis of the yaw axis

The yaw axis of the model support system was calibrated using new laser calibration techniques and the results were compared to the traditional method of using the bubble inclinometer systems. The results of the two systems show no deviation between them. This laser measuring technology will not improve the accuracy of the system if it is not good. This can be seen in the two figures below showing the results of the laser systems on the left and the traditional method on the right. The behavior of the measuring potentiometer is the same with irrespective of the method used. However, the calibration of the laser was completed in 10 minutes and the results were auto-processed using the built-in software compared to the traditional method that required manual processing of the results.

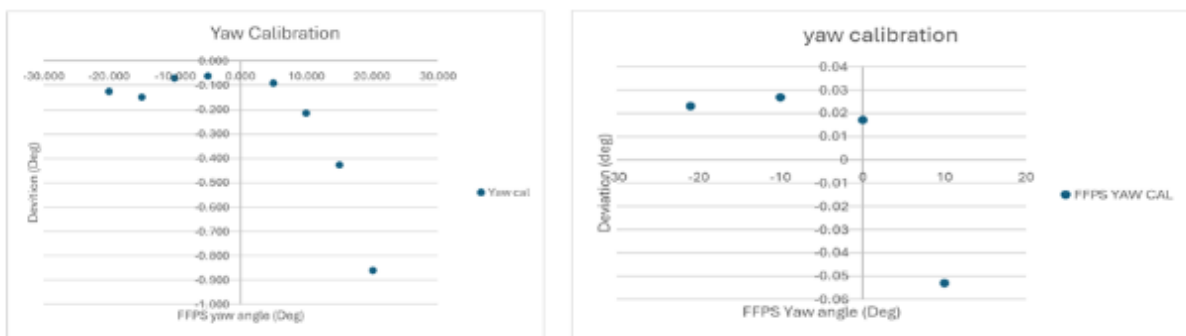


Figure 2: Laser system results(left), Traditional method results(Right)

5.2 Potential causes of anomalies in calibration data.

During the calibration of the model support systems using the new technology, there were some potential causes of anomalies that were found. The user must ensure that they have selected the right tool on the software that matches the correct hardware. If the software and the hardware do not match there will be a big deviation in the results. The other anomaly that has been found is the reference angle that needs to be selected after the measurements have been taken. The laser software systems produce multiple dimensions which the user must choose from which have got impact on the deviation of the results.

5.3 Impact of human errors and other factors.

The yaw axis calibration results plotted in Excel showed a linear behavior from -20° to 5° , followed by a downward trend, likely due to a faulty potentiometer used for measuring the yawing angle. This behavior can be attributed to several factors, including a faulty potentiometer, electrical noise, mechanical issues, temperature variations, software calibration errors, wear and tear, and power supply issues. Additionally, human errors such as incorrect setup, misreading data, calibration errors, data entry mistakes, and inconsistent measurement techniques can significantly contribute to these anomalies [4].

4 Conclusion

In conclusion, the adoption of laser measurement technology for calibrating wind tunnel model support systems at the CSIR Wind Tunnel Facilities presents a transformative opportunity. Although this technology does not change the behavior or improve the results of the unit under test (sensors) as shown in the two results of yaw calibration, it significantly reduces calibration time from approximately three weeks to just two hours for all six axes, offering substantial time and cost savings. The laser system's superior precision and accuracy, coupled with real-time data monitoring and automated assessment capabilities, enhance the reliability and efficiency of the calibration process. Despite the initial investment and need for specialized training, the long-term benefits of improved accuracy, reduced human error, and streamlined operations make laser measurement technology a highly advantageous upgrade over traditional methods.

The implementation of Laser Measurement Technology in the CSIR Wind Tunnel facilities offers significant advantages over these traditional methods. Laser trackers provide precise, efficient, and reliable calibration, reducing the time and effort required while minimizing human error. This technological advancement enhances the overall accuracy and efficiency of the Wind Tunnel Test sessions.

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