New Development of Flow Field Calibration in the 2.4 m Transonic Wind Tunnel

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Abstract. For the purpose of improving the flow fields of CARDC’s 2.4 m transonic wind tunnel in accuracy, two types of calibrations have been done in this tunnel. One was designing and manufacturing a new centerline pipe in high quality to calibrate the centreline flow, obtaining the accurate Mach number correction relationships and helped to build up new flow fields in accuracy. The other was applying a cone-cylinder model to measure the symmetries of the longitudinal flow fields to simulate the testing articles’ movement in pitching zone. It helped to investigate the detailed information of this flow fields. Based on these, the flow fields in higher accuracy were built up in the full-span model test section. This article presents the method, the process and the results of the calibrations herein.

Nomenclature
- $M$ = Mach number
- $|\Delta M|$ = absolute difference value of the Mach number’s fluctuation
- $L$ = length of the model region, meter
- $X$ = distance from the entrance of the test section, meter
- $X/D$ = ratio of the distance from the cone-cylinder model’s top to its outer diameter
- $\text{AOA}$ = Angle of Attack, degree
- $\text{ETW}$ = European Transonic Wind Tunnel
- $2.4$ m $\text{TWT}$ = 2.4 m Transonic Wind Tunnel

1. Introduction
Wind tunnel is a kind of artificial tubular construct which is built on the ground, and the principle is using the moving airflow to test the scaled aircraft models to obtain the needed aerodynamic performance characteristics. As the basic testing platform, it is very important in aircraft researching programs, and especially the flow quality plays a critical role in the procedure of getting accurate testing data [1]. In transonic velocities, either the real aircrafts or the scaled testing articles, both have a sensitive reflection with the aerodynamic performance characteristics when even a slight change happened in the transonic flow. So, it’s an important task to keep the flow fields in high quality, and because the high quality flow is the key factor of affecting the data. It’s necessary to carry out periodic flow fields calibration activities in transonic wind tunnels.

When going to calibrate the flow fields, some hardwares are needed. The common used hardwares are centerline pipe, cone-cylinder model and other rakes, etc. Each one has its special function in the
calibration activity, but the commonality is that they are used to get the pressure data of the flow fields, and then the data is used to calculate the Mach numbers, and through the Mach numbers, people can estimate the quality of the flow fields or optimize the flow fields easily. Thus, it’s necessary to get known about the flow fields in details so that the tunnel could be improved accurately for its flow fields. In this process, this goal must depend on the accuracy of the measurement and how much the details be known about. Under this background, some detailed improvements of the flow field calibration have been done in the CARDC’s 2.4 m TWT.

The improvements are made up of two parts, the first is updating the centerline pipe of the 2.4 m TWT. A new pipe in higher quality was manufactured and this new pipe was used in measuring the centerline flow. It helped to acquire accurate pressure data and obtain the Mach number correction relationships in accuracy. The second is inventing a new method of measuring the symmetries of the longitudinal flow fields by use of the cone-cylinder model, and this method helped to know the details of the flow fields.

2. Facility Description

The 2.4 m TWT is a conventional, half closed circuit, intermittent and pressurized wind tunnel with a Mach number capability of 0.3–1.43 and a stagnation pressure ranges from 1.1 to 1.5 atm under conventional operates, but its maximum capability is pressurized to 4.5 atm [2]. This tunnel has four test sections, a full-span model test section, a half-span model test section and another two sections. The most common used section is the full-span model test section and its dimension is 2.4 m by 2.4 m by 10.2 m.

The full-span model test section was installed during the calibrations. This test section consists of four porous walls, both of the right and left walls are fixed, and the floor and the ceiling walls are adjustable in a kind of expansion angles. The wall porosity is fixed at 4.3% in total and this value can be adjusted if changing the movable boards set outside of the floor and the ceiling. The test section is completely enclosed in a big plenum chamber and there is an evacuation system, removing part of the airflow out of the chamber in order to successfully build up the flow fields in supersonic velocities.

3. Update of the Centerline Pipe

3.1. Comparison of the New and the Old

The old centerline pipe consists of a cone-shaped head with 10 degrees and a cylindrical extension tube with the outer diameter is 86 mm, the total length of this pipe is 1256 mm. There are 194 pressure orifices with its diameter is 0.5 mm distributing on the upper and lower surfaces of the tube, 97 orifices on each in a straight line. The blockage ratio of the old pipe in the test section is 0.1%.

Due to the manufacturing level in the past and its long service time, the old pipe has suffered from corrosion and the drop of few bushings. These problems affected the measuring accuracy of the flow fields when using this pipe. Therefore, a new pipe in higher quality was designed and manufactured. The new pipe has the same parts and the same outer size with the old one but differentiating in technical requirements.

Some technical requirements are as follows:

Keeping the same arrangement and the same amounts of the pressure orifices with the old pipe, but adding 54 orifices arranged on the pipe’s left and right surfaces in row, 27 on each respectively. So that the new pipe totally has 249 orifices.

Manufacturing all bushings in stainless steel instead of copper material. Because the new pipe was manufactured in stainless steel so that the bushings and the pipe’s main parts have the same material, it’s good for owning the same thermal expansion and contraction performance. Then the pipe would not easily be damaged by temperature, and the pipe also couldn’t easily be rusted by wet weather because of its stainless steel material.

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The new pipe has a strict and a higher technical indexes in manufacture. The roughness of the new pipe on the outer surface is not more than 0.8 μm. The diameter error of the pipe’s cylindrical part is less than 0.05 mm. The straightness of the pipe’s cylindrical part is less than 0.25 mm.

Based on these, the new pipe owns a higher quality than the old one. The air can flow along the centerline pipe in a better linear line and the pressure data can be accurately acquired by use of this pipe. Figure 1 shows the photo of the new centerline pipe installed in the full-span model test section of the 2.4 m TWT.

Figure 1. The photo of the new pipe installed in the full-span model test section.

3.2. Comparison of the Centerline Flow Measured by Different Pipe
After the new pipe was manufactured, it was applied to calibrate the centerline flow of the full-span model test section in the 2.4 m TWT [1, 3, 4]. The calibrating Mach number ranged from 0.3 to 1.2, and the measuring data focused on the L=2.4 m model region are presented.

Figure 2 presents the centerline Mach distributions along all of the orifice rows of the new pipe. It can get known that the absolute difference of the Mach number’s fluctuation (|ΔM|) compared with each other is less than 0.004, the four curves are in good agreements with each other. Figure 3 presents the centerline Mach distributions along the orifice rows of the old pipe. It can be seen that the curve coincides not so well with the other if comparing with Figure 1, and the parameter |ΔM| is not more than 0.008, twice larger than that of the new pipe. Figure 4 shows the centerline Mach distributions along the upper or the lower orifice rows of the new and the old pipes respectively. It can get known that the old pipe has a larger fluctuation amplitude, a longer lasting length and a worse fairness than those of the new one.

Figure 2. Centerline Mach distributions along the orifice rows of the new pipe.
Figure 3. Centerline Mach distributions along the orifice rows of the old pipe.

Figure 4. Comparisons of centerline Mach distributions along the upper or the lower orifice rows of the new and the old pipes respectively.

Through the figures showed above, it can be known that the centerline flow measured by use of the new pipe is more accurate, more reliable than those of the old one. As to the new pipe, no matter the orifice row distributing on the upper or the lower surface, each one has a perfect ability to obtain the accurate testing data. Then figure 5 shows the centerline Mach distributions along the upper and the lower orifice rows of the new pipe in the calibration for Mach number ranged from 0.3 to 1.2. It can be seen that each couple of two curves agree well with the other while Mach number is below 1.0. The two curves obviously separate at the Mach number equals to 1.1 and 1.2, this mainly because of the shocking waves.

Figure 5. Centerline Mach distributions along the upper and the lower orifice row of the new pipe in the calibration for the Mach number ranged from 0.3 to 1.2.
When all centerline flow data was obtained, with other pressure data acquired in the plenum chamber, a primary Mach number correction relationships were calculated out. Then under the guidance of this primary correction relationships, a new flow fields were built up in the tunnel, and at the meanwhile, a secondary centerline flow calibration was carried out to get another set of the calibrating data. Repeating the data processing steps, a newest and an accurate Mach number correction relationships were finally obtained. Through this newest Mach number correction relationships, the most accurate flow fields were built up in the full-span model test section of the 2.4 m TWT at last.

4. A New Measuring Method by Use of the Cone-cylinder Model
The cone-cylinder model is traditionally used to measuring the shock waves’ distributions in high speed wind tunnel. However, it also could be used to check out the symmetries of longitudinal flow fields after an analysis by our calibration team members. It could be used to simulate the testing articles’ movement in pitching zone, and obtain the pressure data at different AOAs. If the AOAs are set in symmetry, then the symmetrical data can be measured through the cone-cylinder model, and the symmetries of longitudinal flow fields can be known as well. Based on this function, a new measuring method was invented by use of the cone-cylinder model, and the meaning of this new calibration is for getting known the detailed information of the longitudinal flow fields and sometimes it’s helpful for troubleshooting the testing articles’ abnormal testing data. Figure 6 shows the diagram of this new method. The steps of this operation are as follows:

Firstly, installing the cone-cylinder model into the AOA mechanism of the test section and then making the the pressure measuring system in preparing state.

Secondly, getting the symmetrical AOAs and calibrate these AOAs on the cone-cylinder model’s surface. When everything is get ready, operating the wind tunnel and making the AOA mechanism move along the symmetrical AOAs from low value to high. The cone-cylinder model is driven by the AOA mechanism at the same time and all the pressure data can be collected in this process.

Thirdly and the last, processing the data and converting them into Mach numbers. Picking up the data which is matching the symmetrical AOAs, and using the non-disturbed data to analyze the flow fields. It’s better to plot the Mach distributions along the cone-cylinder model at each couple of the symmetrical AOAs. In this article, the author set a new parameter marked as $\Delta [M]_{av}$ for estimating the quality of the symmetrical flow in the longitudinal direction. The $\Delta [M]_{av}$ means the difference data of the average Mach which distributing along the orifice row, data at the positive angle minus the negative.

![Figure 6](image)

**Figure 6.** The diagram of measuring the symmetries of longitudinal flow fields by use of the cone-cylinder model.

This new method of measuring the symmetries of the longitudinal flow fields was first operated in the full-span model test section of 2.4 m TWT. Figure 7 shows the photo of a $\Phi$ 136 mm cone-cylinder model installed in the full-span model test section of 2.4 m TWT. This cone-cylinder model consists of
a cone-shaped head with the cone angle is 20 degrees, and a cylinder body with its outer diameter is 136 mm. The total length of this cone-cylinder model is 1980 mm and its blockage ratio in the test section is 0.25%. There are 106 pressure orifices distributing on the upper and lower surfaces in row, 58 orifices on each, and the outer diameter of each orifice is 0.6 mm.

**Figure 7.** The photo of the Φ 136 mm cone-cylinder mode installed in the full-span model test section.

Figure 8 shows the Mach distributions along the orifice rows of the Φ 136 mm cone-cylinder model at the angles of ±2 and ±4 degrees respectively. Table 1 gives the corresponding symmetrical parameter values calculated in this calibration. The chart shows that the Mach numbers distributing on the upper row agrees well with the lower and the parameter Δ [M] av is less than 0.001 in the investigating flow fields.

**Table 1.** The Symmetrical Parameter Values of the Longitudinal flow fields.

| M   | AOAs | Δ[M] av |
|-----|------|---------|
| 0.7 | ±2   | -0.0004 |
| 0.7 | ±4   | 0.0009  |

**Figure 8.** The Mach distributions along the cone-cylinder model for the symmetrical angles at ±2 and ±4 degrees respectively.
5. Conclusion

Two effective calibrations have been completed in the full-span model test section of 2.4 m TWT, including the calibration of centerline flow by use of an updated centerline pipe, and measurement for the symmetries of the longitudinal flow fields measurement by help of a cone-cylinder model. The calibrations contributed a lot to the development of the flow field calibration in the 2.4 m TWT. The main conclusions are as follows:

The new centerline pipe owns a higher quality than the old one. The fluctuation of the Mach distributions along the new pipe’s orifice rows was smaller and better than that of the old pipe. The new pipe helped to obtain the Mach number correction relationships in higher accuracy and build up the flow fields in higher accuracy as well.

The symmetries of the longitudinal flow fields were successfully measured by use of the cone-cylinder model. It could simulate the testing articles’ movement in pitching zone and get known the detailed information of the longitudinal flow fields.

Acknowledgments

The authors would like to gratefully acknowledge the efforts of the calibration team throughout all phases of the calibrations. All staff working in the tunnel had paid hard work for the calibrations.

References

[1] The GTTC Wind Tunnel Calibration Methodology Working Group, “Calibration of Subsonic and Transonic Wind Tunnels,” AIAA book R-093-2003, pp.3,85-104.

[2] Information on http://www.cardc.cn.

[3] Greg Jones, “Unsteady Assessments and Improvements for the National Transonic Facility,” 2nd Joint Conference of the STAI and SATA, 2015.

[4] Masataka Kohzai, Makoto Ueno, Tatsurou Shiohara, Norikazu Sudani, “Calibration of the test section Mach number in the JAXA 2m x 2m Transonic Wind Tunnel,” AIAA paper 2008-848, 46th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, 2008.