Testing of Calibration Models in Order to Certify the Overall Reliability of the Trisonic Blowdown Wind Tunnel of VTI

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It is strongly recommended that wind tunnel calibrations become a regular part of the operational cycle for any wind tunnel. They facilitate tunnel-to-tunnel data comparisons. Standard calibration model, representing a generic winged missile configuration, was tested on several occasions in the T-38 1.5 m × 1.5 m trisonic blowdown wind tunnel of VTI in Belgrade in order to ensure that the wind tunnel is operating properly. Tests comprised determination of aerodynamic coefficients. Test results were compared with previous T-38 test results and with available database of results from a canadian wind tunnel facility. Very good agreement of data was obtained in the tests, confirming that high quality of the wind tunnel, instrumentation and data processing is being maintained. These tests also confirm that this wind tunnel facility is available for international cooperation, as has been put to practice in a number of test campaigns executed for foreign customers.

Keywords: *trisonic wind tunnel, calibration model, quality of air flow.*

1. INTRODUCTION

One of the objectives of Experimental Aerodynamic Division of Military Technical Institute (VTI) is maintaining the wind tunnels in user-friendly condition, and establishing them as Serbian standard wind tunnels competitive with the top wind tunnels in the world.

For these purposes, it is very important to certify the overall reliability of VTI's wind tunnels by comparing standard wind tunnel test data with data acquired in leading overseas wind tunnels.

In this paper, some test results of a standard calibration model obtained in VTI's trisonic blowdown wind tunnel are presented.

2. WIND TUNNEL CALIBRATIONS

It is strongly recommended that wind tunnel calibrations become a regular part of the operational cycle for any wind tunnel. A planned schedule of calibration tests should be created and executed to ensure that the wind tunnel is operating properly. Beyond this baseline requirement, planned calibration tests offer the advantage of constructing an extensive database describing the tunnel operation, which can be very useful in determining the cause of changes in a flow field. In brief, wind tunnel calibrations should be thought of as a regularly scheduled maintenance activity or diagnostic test. Instead of a series of disconnected tests, the calibration activities should take the form of an ongoing test program, [1,2].

Properly planned, recurring, and well-documented calibrations of a wind tunnel provide several benefits to the tunnel operator and end user:

- They ensure that the wind tunnel is operating as expected and are useful in identifying problems in the wind tunnel circuit;
- They provide potential customers with a documented assessment of the tunnel calibration and are essential in determining overall data quality;
- They provide data essential for interpretation and correction of test data;
- They provide archival documentation of tunnel operating conditions, so that modifications to the wind tunnel may be assessed for their impact on the operating conditions;
- They aid in establishing statistical process control on wind tunnel test data by providing a database of wind tunnel parameter variability;
- They aid in identifying data anomalies that are attributable to the wind tunnel itself, not to the variability in the calibration process;
- They may indicate, by comparison with previous calibrations, that portions of the wind tunnel circuit or instrumentation are in need of repair or recalibration;
- They facilitate tunnel-to-tunnel data comparisons.

The essential point is the strategic importance of a properly calibrated wind tunnel. A properly calibrated wind tunnel is required for timely, effective product development.

In the current environment of increased data accuracy requirements and reduced time available for tunnel tests, it is imperative that accurate and complete wind tunnel calibrations are established, maintained, and placed under process control.

3. THE T-38 WIND TUNNEL FACILITY

The T-38 wind tunnel facility of Military Technical Institute in Belgrade is a trisonic blowdown-type

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pressurized wind tunnel with a 1.5 m × 1.5 m square test section (see Figure 1), [3-5].

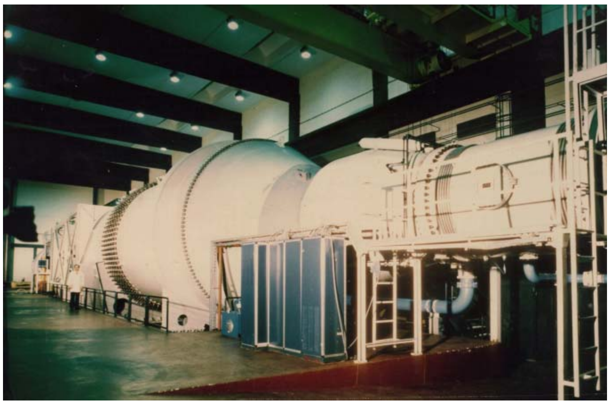

Figure 1. The T-38 trisonic blowdown wind tunnel

For subsonic and supersonic tests, the test section is with solid walls, while for transonic tests, a section with porous walls is inserted in the tunnel configuration. The porosity of walls can be varied between 1.5 % and 8 %, depending on Mach number, so as to achieve the best flow quality.

Mach number in the range 0.2 to 4.0 can be achieved in the test section, with Reynolds numbers up to 110 million per metre. Mach number can be set and regulated to within 0.5 % of the nominal value.

In the subsonic configuration, Mach number is set by sidewall flaps in the tunnel diffuser. In the supersonic configuration, Mach number is set by the flexible nozzle contour, while in transonic configuration, Mach number is both set by sidewall flaps and the flexible nozzle, and actively regulated by blow-off system.

Stagnation pressure in the test section can be maintained between 1.1 bar and 15 bar, depending on Mach number, and regulated to 0.3 % of nominal value.

Run times are in the range 6 s to 60 s, depending on Mach number and stagnation pressure.

The model is supported in the test section by a tail sting mounted on a pitch-and-roll mechanism by which the desired aerodynamic angles can be achieved. Positioning accuracy is 0.05° in pitch and 0.02° in roll.

The facility supports both step-by-step model movement and continuous (pitch-sweep) movement of model during measurements.

The T-38 wind tunnel facility was designed by the Canadian company Dilworth, Secord, Meagher and Associates Limited (DSMA), today operating as AIOLOS. The 60 % of tunnel components were manufactured in former Yugoslavia and 40 % in USA, Canada and countries of the Western Europe.

Design and building lasted from 1977 to 1983. First run was made in the year 1983. Commissioning runs were made in the 1983 – 1986 period. Officially, the wind tunnel became operational in the year 1986.

Usual test types executed in the wind tunnel are:

- Static measurement of forces and moments;
- Dynamic measurement of stability derivatives;
- Measurement of pressure distributions;
- Flow visualisation using optical methods.

About 9000 runs have been made in its exploitation period and about 50 models were tested in an about 80 various test programs, [6].

4. PREVIOUS T-38 WIND TUNNEL CALIBRATION

Initial calibration of 2D and 3D test sections of the T-38 wind tunnel was performed during, and shortly after, the commissioning programme for this facility, [6]. This extensive calibration comprised a number of measurements, such as:

- measurement of the distribution of Mach number along the axis of the 2D and 3D test sections with a centreline pole,
- measurement of the longitudinal and transversal distribution of Mach number and flow angle in the 3D test section using a multiprobe traversing rake,
- measurement of transversal distribution of Mach number and flow angle across the 2D and 3D test section using a single traversing probe,
- measurement of aerodynamic noise and turbulence,
- measurement of centreline Mach number correction by an optical method using stand-off models,
- determination of optimum porosity of perforated walls of the transonic test section using a high-blockage cone-cylinder probe,
- testing of the AGARD calibration models B and C,
- testing of the ONERA calibration models M2 and M4, and
- testing of the NACA 0012 half-model.

Summary conclusion from these initial calibrations was that performance of the wind tunnel was up to design specifications. It was also confirmed that quality of air flow was up to the initial specified values of aerodynamic parameters.

A number of calibration updates were performed in later years, comprising:

- Checkout of the distribution of Mach number along the axis of the 3D test section with a centreline pole;
- Static and dynamic tests of SDM calibration model;
- Static and dynamic tests of BFM and MBFM calibration model.

5. CURRENT CALIBRATION UPDATE

It was felt necessary to make a new set of basic calibration measurements, [6]. Such measurements were performed through two test campaigns in the years 2006 and 2008, and they comprised:

- measurements of flow angle in the centre of the 3D test sections in subsonic, transonic and supersonic speed range,
- measurement of Mach number and stagnation pressure in the centre of the 3D test section and determination of their corrections, and
- wind tunnel tests of the AGARD-B calibration model at Mach numbers up to 1.8.

Measurements of Mach number correction and flow angle in the test section were considered to be the most essential to perform, as they directly influence the calculation of aerodynamic coefficients.

Wind tunnel tests of standard calibration models as one of the main parts of calibration procedures are considered a critical item in the health monitoring of a wind tunnel.

Tests of the AGARD-B calibration model served to confirm the overall accuracy of measurements in the T-38 wind tunnel facility and to confirm confidence in results obtained.

Other calibration measurements, such as those of turbulence and distribution of flow parameters across the test section, were not so critical, and besides, they were not likely to have changed since previous calibration.

6. AGARD-B CALIBRATION MODEL

AGARD calibration model B is an ogive-cylinder with a delta wing, originally designed by AGARD (Advisory Group for Aeronautical Research and Development) committee for the calibration of supersonic wind tunnels, but it is also often used for calibrating transonic wind tunnels [7]. This model is a configuration consisting of a wing and body combination.

The wing is a delta in the form of an equilateral triangle with a span four times body diameter. The body is a cylindrical body of revolution with an ogive nose.

At the disposal of VTI is a 115 mm diameter AGARD-B/C model produced by BOEING and model size was chosen with respect to the tunnel's test section size. It is physically the same model that had earlier been tested in NAE 5ft wind tunnel and several other wind tunnel in USA and other countries.

AGARD-B model mounted in the T-38 test section is shown in Figure 2 and is more fully described in [7].

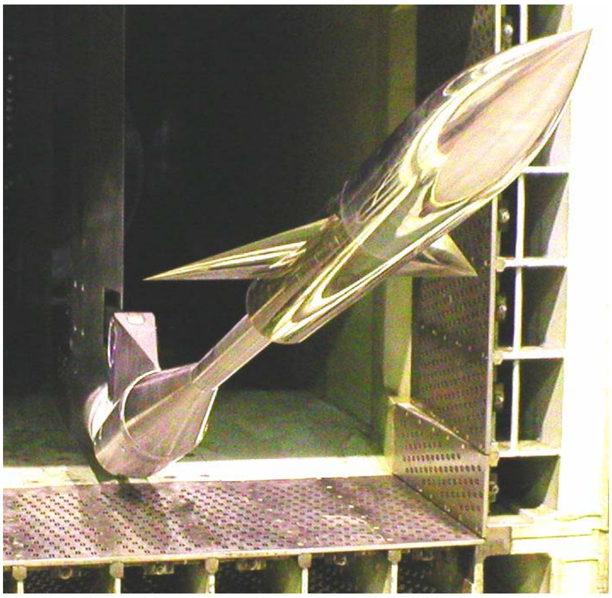

Figure 2. AGARD-B model mounted in the T-38 test section

Earlier T-38 test campaigns were performed using ABLE multipiece six-component balance [8], and in a present VTI's own monoblock balance was used (see Figure 3).

Standard tail sting was used to support the model and recommended values of sting dimensions vs. model base diameter for minimum sting interference were satisfied for both wind tunnel balances.

Model was used to provide force and moment data and only one pressure sensor was used. The pressure in the cavity surrounding the sting at the model base (i.e. the base pressure) was sensed by a single orifice at the end of a tube, which was routed through the balance adaptor to the sensor located below the strut of the model support.

Figure 3. VTI's own monoblock six-component balance

7. A SERIES OF WIND TUNNEL TESTS

A series of wind tunnel tests of the AGARD-B calibration model were performed in the T-38 wind tunnel in the years 2006 and 2008 [6,9,10] to verify the wind tunnel facility, its instrumentation and the data reduction process.

Tests of the AGARD-B model comprised measurements of aerodynamic forces and moments on the model with the purpose of determining its aerodynamic coefficients.

Tests of the AGARD-B model were performed at Mach number up to 1.8 at the complex angles of attack in the interval from – 4° to + 10° and the roll angle 0°.

Calibrations of pressure and model position transducers, wind tunnel balance and the data acquisition system itself are routinely executed before wind tunnel test. These calibrations are performed to a high accuracy using primary and secondary standards of the relevant physical quantities. Expected and generally achieved accuracies of some of these devices are:

- Pressure transducers of the primary measurement system of flow parameters in the test section: 0.01 % FS to 0.02 % FS;
- Other pressure transducers e.g. for base pressure: 0.05 % FS;
- Force balance: 0.2 % FS;
- Transducers for control of various wind tunnel components: generally 0.1 % FS.

7.1 Data acquisition and reduction system

The data acquisition system consisted of a Teledyne 64 channel "front end". Main features of the data acquisition system used were:

- produced by Teledyne (USA),
- 64 analog input channels,
- 16 bit A/D resolution,
- 60 kHz total sampling rate,
- programmable (per channel) gain, low-pass filter and sampling rate,
- adjustable (per channel) sensor excitation, and
- controlled by a PC.

Digitized data were sent through the network to a COMPAQ Alpha server DS20E computer and stored on disk for later reduction.

Data reduction was performed after each run, using the standard application software package in use with the wind tunnel facility. It was done in several stages:

- data acquisition system interfacing and signals normalization,
- determination of flow parameters,
- determination of model position (orientation), and
- determination of aerodynamic coefficients.

Each stage was performed by a different software module.

7.2 Flow visualisation system

Schlieren system of Töepler type with parallel rays and 900 mm diameter of light beam is used for flow visualisation in the T-38 wind tunnel test section. System has been operating since 1985.

The system was modernized by introduction of digital cameras and automation of the image recording process, which became integrated with the wind tunnel data acquisition system [11]. Image recording is controlled by custom-developed software. Optical configuration of the system was changed as well in order to simplify setup and to make the key components more accessible to the operator. Parts of the Schlieren system configuration of the T-38 wind tunnel are shown in Figure 4.

Figure 4. Diagonal mirror and optical receiver in Schlieren system configuration of the T-38 wind tunnel

During supersonic AGARD-B runs flow visualisation based on Schlieren method was required.

Flow visualisation around rear part of AGARD-B calibration model done using Schlieren method in Mach 1.75 run is shown in Figure 5.

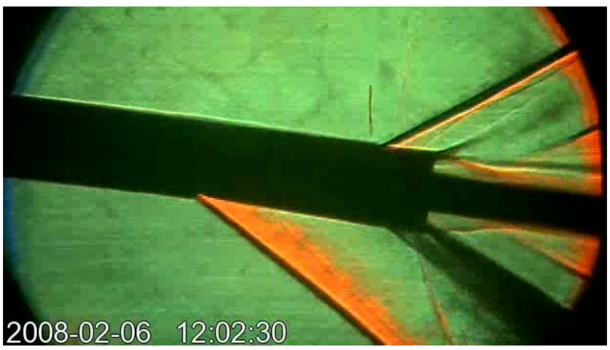

Figure 5. Flow visualisation around rear part of AGARD-B calibration model done using Schlieren method

Schlieren method is sensitive to change of the gradient of density or refractive index and it can record the angular deflection of the disturbed ray relative to the undisturbed one in transparent medium with local inhomogenities.

8. TEST RESULTS

AGARD-B model has been used in previous wind tunnel calibrations, including that of the T-38, and therefore there is an extensive database already existing with which to compare the results obtained from the present test programme.

The database consists of test results of the same model performed in the NAE (today operating as IAR) 5ft Canadian trisonic wind tunnel in the year 1981 [12], and during the commissioning of the T-38 wind tunnel in the year 1986 [8].

Results obtained in Mach 1.60 run of these three test campaigns are compared and presented in a form of graphs in Figures 6, 7 and 8.

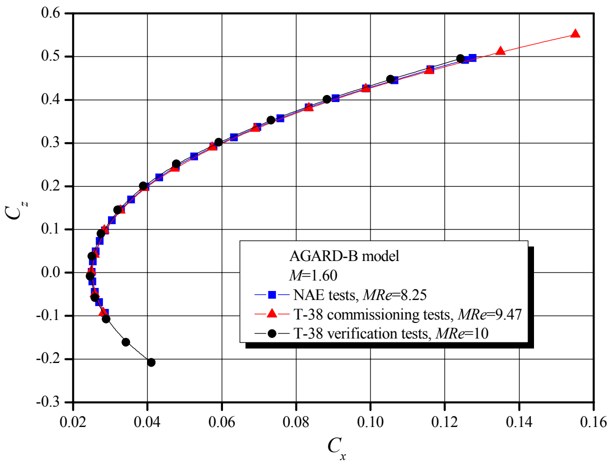

Figure 6. Aerodynamic coefficients of AGARD-B model

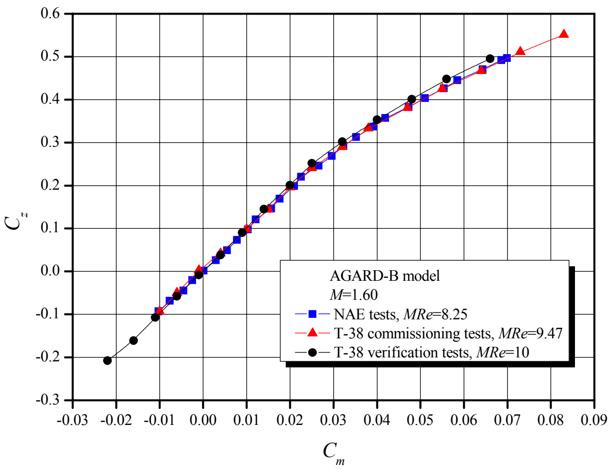

Figure 7. Aerodynamic coefficients of AGARD-B model

Graphs show lift force coefficient in relations of drag force and pitching moment coefficients, and base pressure coefficient in a relation of angle of attack in wind axes system. Test results are given for model aerodynamic centre located a distance 2.557*D* upstream of the model base. Model reference length for Reynolds number calculation is mean aerodynamic chord.

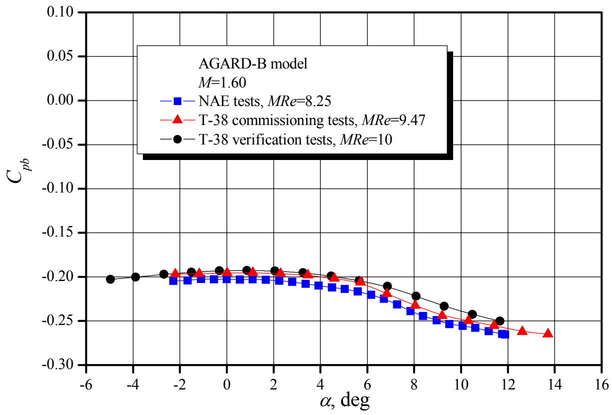

Figure 8. Base pressure coefficients of AGARD-B model

In order to check wind tunnel run-to-run data repeatability a number of runs were performed. Aerodynamic coefficients of AGARD-B model at certain angle of attack obtained in repeated wind tunnel Mach 1.07 runs of same test campaign are presented in Table 1.

Table 1. Wind tunnel run-to-run data repeatability check

AGARD-B Standard Calibration Model M = 1.07, $\alpha = -0.31°$				
Run number	C_x	C_z	C_m	C_{pb}
8	0.0264	– 0.008	– 0.001	– 0.2569
28	0.0264	– 0.010	– 0.001	– 0.2657
29	0.0265	– 0.007	0.000	– 0.2612
Average	0.0264	– 0.008	– 0.001	– 0.2613
Dispersion	0.0001	0.003	0.001	0.0088

Wind tunnel AGARD-B data repeatability was also checked comparing the data from two test campaigns performed in a two-year interval. Aerodynamic coefficients of AGARD-B model at certain angle of attack obtained in wind tunnel Mach 0.6 runs in a two-year interval are presented in Table 2.

Table 2. Wind tunnel data repeatability check in a two-year interval

AGARD-B Standard Calibration Model M = 0.6, $\alpha = -0.32°$				
Run number	C_x	C_z	C_m	C_{pb}
17	0.0104	– 0.012	– 0.002	– 0.1341
37	0.0105	– 0.011	– 0.001	– 0.1334
55	0.0106	– 0.013	– 0.003	– 0.1323
Average	0.0105	– 0.012	– 0.002	– 0.1336
Dispersion	0.0001	0.001	0.001	0.0013

Average values of aerodynamic coefficients of the AGARD-B and their dispersions are also given.

9. DISCUSSION

Analysis of test results for the AGARD-B model showed a good agreement with results obtained in the distinguished NAE (IAR) 5ft wind tunnel, and with earlier tests performed in the T-38 wind tunnel.

There is some disagreement in obtained test results for base pressure coefficient in these tests. It can be explained by the fact that absolute pressure transducers of relatively high range measured base pressure in previous tests (NAE, and T-38 during commissioning) and the present T-38 test was performed using differential pressure transducers of lower range and higher accuracy.

Small differences between aerodynamic coefficients in comparisons of present and previous T-38 wind tunnel measurements are explained by not taking into account deflections of tail sting, in earlier tests, because of the model weight which are about 0.2°.

The maximum dispersion of C_x drag force coefficients in repeated runs is 0.0001 both on Mach number 1.07 and 0.6. Good test repeatability is declared by dispersion of C_x coefficient of no more than 0.0001.

Analysis of test results obtained in repeated tunnel runs showed a good run-to-run data agreement, confirming a high quality of tunnel repeatability. Good tunnel data repeatability can be also confirmed in a two-year interval.

10. PLANNED TESTING OF CALIBRATION MODELS

The testing of all standard calibration models in T-38 wind tunnel has been limited to Mach numbers up to 2, because of high supersonic transient loads.

Recent developments of Experimental Aerodynamics Laboratory of VTI in design and production of high-rigidity force balance has made tests at Mach above 2 practical, and, consequently, production of HB-1 and HB-2 force models and testing in supersonic Mach range up to 4 is intended for the near future.

The Institute also owns a larger AGARD-B model and future testing in the T-35 low-speed and possibly in the T-38 wind tunnels in order to investigate effects of model size and non-standard model supports is planned.

It is also important to confirm data consistency between the different-speed-range wind tunnels in VTI.

11. AVAILABILITY FOR INTERNATIONAL COOPERATION

The capability of the T-38 wind tunnel of VTI to perform high-quality wind tunnel tests comprising measurements of forces and moments has been confirmed and recently put to practice in a number of test campaigns performed for domestic and foreign customers.

In most of these tests, the models and part of the instrumentation used in them (e.g. the multicomponent force balances) were produced in a well equipped workshop, located within the premises of VTI.

On a number of occasions, wind tunnel models designed and produced in this workshop were also tested in other wind tunnel facilities, such as the F-1 wind tunnel of ONERA in Toulouse or the low speed wind tunnel of LAGG in Serpong, Indonesia.

The T-38 wind tunnel remains available for diverse wind tunnel tests in various forms of international cooperation.

Its location in Belgrade makes it particularly attractive to customers in the area of central or southern Europe, Asia and the Middle East.

12. CONCLUSION

A set of results of standard wind tunnel calibration model is a valuable asset because of the necessity to relate the T-38 wind tunnel to worldwide wind tunnels.

Analysis of test results confirms a high quality of air stream in the 3D test section of the T-38, good condition of wind tunnel instrumentation and the correctness of the data reduction algorithm.

It can be concluded that the capability of the T-38 wind tunnel of VTI to perform high-quality wind tunnel tests comprising measurements of forces and moments for domestic and foreign customers has been confirmed.

The T-38 wind tunnel facility of VTI can be classified among the top of similar world facilities and it remains available for further international cooperation.

The permanent goal of Experimental Aerodynamic Division of VTI is to keep the quality and reliability of T-38 wind tunnel up to the level of the top world tunnels. One of the ways to achieve this is periodical testing of the standard models.

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NOMENCLATURE

C_l	lift force coefficient
C_m	pitching moment coefficient
C_{pb}	base pressure coefficient
C_x	drag force coefficient
D	model diameter
M	Mach number
MRe	mega-*Re* (10^6 *Re*), Reynolds number in millions

Greek symbols

α	angle of attack

ИСПИТИВАЊЕ КАЛИБРАЦИОНИХ МОДЕЛА У ЦИЉУ ПОТВРЂИВАЊА ОПШТЕ ПОУЗДАНОСТИ ТРИСОНИЧНОГ АЕРОТУНЕЛА СА НАДПРИТИСКОМ ВОЈНОТЕХНИЧКОГ ИНСТИТУТА

Дијана Дамљановић, Бошко Рашуо

Препоручује се да калибрације постану стални део радног циклуса сваког аеротунела. Оне олакшавају поређење података добијених у различитим аеротунелима. Стандардни калибрациони модел, који представља општу конфигурацију пројектила са крилима, је неколико пута испитан у трисоничном 1,5 m × 1,5 m аеротунелу са надпритиском Т-38 Војнотехничког института у Београду у циљу провере исправног рада аеротунела. Испитивања су обухватала одређивање аеродинамичких коефицијената. Добијени резултати су упоређени са резултатима ранијих испитивања калибрационог модела у аеротунелу Т-38 и са резултатима из канадског трисоничног аеротунела. Постигнуто је веома добро слагање резултата чиме је потврђено да је одржан висок квалитет аеротунела и инструментације, као и исправност алгоритма за обраду података. Ови тестови су потврдили и да је постројење аеротунела расположиво за међународну сарадњу, што показује и велики број аеротунелских испитивања извршених за иностране наручиоце.