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Testing of a Standard Model in the VTI's Large-subsonic Wind-tunnel Facility to Establish Users' Confidence

A necessity to test a standard model testing for establishing confidence in the wind-tunnel flow quality and the validity of the test-data has been recognized in the Experimental Aerodynamics Laboratory of the Military Technical Institute (VTI) in Belgrade. A new-implemented procedure for data quality assurance has been applied to the standard AGARD-B model testing in the VTI's large-subsonic wind-tunnel. Test-data obtained at Mach number 0.4 have been analized and correlated with those of the physically same model performed in the Canadian NAE (today operates as IAR) 5ft trisonic wind-tunnel and the T-38 trisonic wind-tunnel of VTI. Within-facility comparisons and inter-facility correlations of the standard test-data were done to certify an overall reliabilty of the subsonic facility as an initial step in the establishing the confidence prior to a forthcoming customer test.

Keywords: *subsonic wind tunnel, standard model, test-data, inter-facility correlations.*

1. INTRODUCTION

Tests with standard models 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 wind-tunnel calibration and are essential in determining overall data quality.

It is imperative that the calibration and standard test data, and any related implications to the wind-tunnel, be quickly communicated to the facility staff and to end users (test customers). Although a wind-tunnel standard testing procedure is intended more for the practitioners who conduct the wind-tunnel calibration and verification activities it also contains important points that managers in charge of wind-tunnel operations should consider, because a properly calibrated and verified wind-tunnel is required for timely, effective product development.

The wind-tunnel standard testing procedure includes inter-facilities correlations. It can be difficult to achieve the identical result in multiple facilities because of such differences as scale effects, when the same test article is installed in test sections, that are of different size, for example, notwithstanding wall-effects corrections (that differ from facility to facility), which are applied to account for these differences. Different procedures, different instrumentation, and different levels of operator skill, training, and experience from one facility to the next can also make it difficult to precisely reproduce results across facilities, [1,2].

The Military Technical Institute (VTI) in Belgrade has recognized that the testing of standard models is an important item in monitoring the health of a wind-tunnel facility and complete wind-tunnel testing process. A new-implemented standard testing procedure, an acquired database and an experience in the VTI's trisonic test facility were an excellent background in the process of verification of the other VTI's facilities, [3,4].

This paper presents an analysis of data acquired in support of the new-implemented procedure in VTI's Experimental Aerodynamic Laboratory, in which similarities and differences among VTI's wind-tunnel facilities were studied by executing nominally similar test matrices in each facility on the same test article, balance, and sting. A similar analysis was applied in the wellknown aerodynamics laboratories as NASA Langley Research Center, where data acquired in similar wind-tunnel tests executed in four different U.S. transonic facilities were a part of the FAVOR (Facility Analysis Verification and Operational Reliability) project, [1].

The objective of the performed standard experiments in the VTI's large-subsonic wind-tunnel facility, just prior to a forthcoming customer test, was to compare flow quality and standard aerodynamic data acquired in the two most-used VTI's wind-tunnel facilities in nominally identical wind tunnel tests, [5,6]. The same test methods, techniques, and procedures, as well as data reduction methods, were applied. The same test article (AGARD-B model), balance, and sting were used. The only differences were test article's environment and data-acquisition system used.

The final intention of the standard AGARD-B model testing was to verify the test section with tail – sting model support system of the T-35 large-subsonic wind-

Received: April 2013, Accepted: May 2013
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doi:10.5937/fmet1403212O
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tunnel facility of the VTI prior to a customer test based on within-facility comparisons and inter-facility correlations of the standard test-data.

2. VTI WIND-TUNNEL STANDARD TESTING POLICY

VTI has recognized the necessity of the standard model testing as an aid for establishing statistical control on test data by providing a database of standard test results variability and has established a procedure for wind-tunnel data quality assurance, [3,4].

Framework for determining the overall wind-tunnel data quality and verification in the standard testing includes the following steps:

1) Result of a measurement and its uncertainty are to be reported;

2) All levels of wind-tunnel data repeatability in balance measurement are to be analyzed;

3) The test data from the point of symmetry are to be analyzed;

4) The test data based on correlations with other experimental aerodynamics laboratories are to be validated.

VTI has adopted the policy of periodically testing a selection of standard configurations of wind-tunnel models, [7-11]. Some of them, used in static measurements of forces and moments are shown, with usable Mach number range, in Figure 1. The groups of selected standard models are for static tests: ONERA M, AGARD-B and AGARD-C, and hypersonic-ballistic models HB-1 and HB-2.

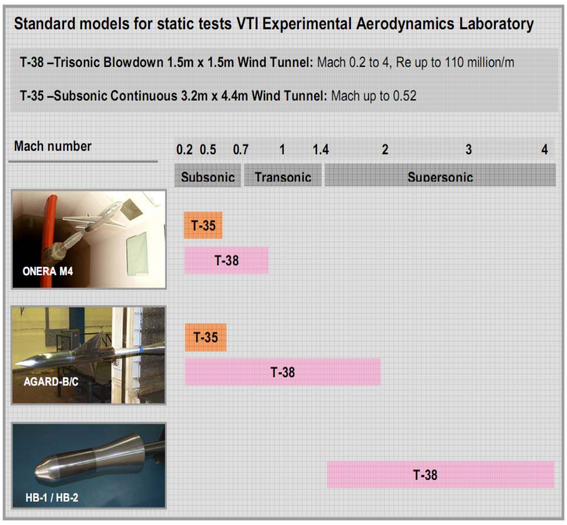

Figure 1. Mach number ranges of standard models used in VTI for static tests

3. STANDARD TEST ARTICLE

The standard test article for the VTI's large-subsonic wind-tunnel facility has so far been a hypothetical transport aircraft configuration – ONERA M model in M4 size. It was adopted as representative, both in scale and expected loads, for standard testing and verifying the wind-tunnel installations and new measurement techniques.

The M4 model has been used to test the functionality and reliability of a new model support system in the T-35 wind-tunnel, and a preliminary estimation of flow quality, [7].

More recently, the standard AGARD-B model was tested (for the first time in the T-35) as a part of a short test campaign prior to a forthcoming customer test

3.1 AGARD-B standard model

The AGARD-B model represents a generic winged missile or a delta-wing airplane configuration. AGARD-B model is an ogive-cylinder with a delta wing, originally designed by the AGARD (Advisory Group for Aerospace Research and Development) committee for the calibration of supersonic wind-tunnels, but it is also often used in transonic and subsonic wind-tunnels, [12].

AGARD-B standard 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 wing has a 4% thickness/chord ratio bi-convex section. The body is a cylindrical body of revolution with an ogive nose. Geometric characteristics of the AGARD-B model are given in Figure 2 in terms of the body diameter D.

The AGARD-B wind-tunnel standard model used in the VTI Experimental Aerodynamics Laboratory was supplied by Boeing, USA, [12]. The 115.8 mm dia. model has been using in the initial and periodical calibrations of the VTI's T-38 wind-tunnel at Mach numbers ranging from subsonic, through transonic and supersonic up to Mach 2, and, therefore, there is an extensive database already existing with which to compare the results obtained from the T-35 test campaign, [7-12].

Model was used to provide force and moment data and only one pressure sensor was used. The base-pressure in the cavity surrounding the sting at the model base 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.

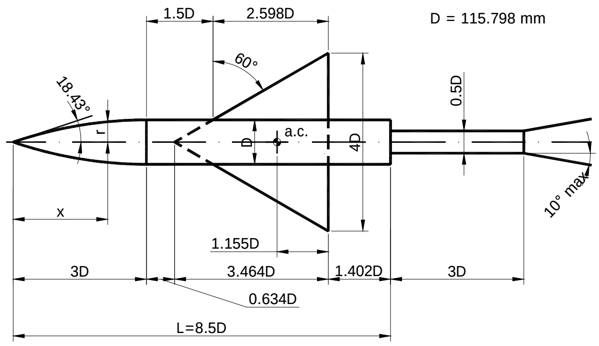

Figure 2. AGARD-B standard model – Overall geometry

The model was mounted on a tail sting. Sting vs. model base diameter ratio was 0.5, sting length vs. model base diameter ratio was 5.2 and the included angle of a conical transition of the sting into support being 7.9°, which satisfied recommended values for minimum sting interference (Figure 2), [12].

Test-data were reduced for model aerodynamic centre (a.c.) and the model reference length was the mean aerodynamic chord.

4. WIND-TUNNEL FACILITY

The VTI's T-35 experimental facility is a large subsonic wind-tunnel of a continual type with two interchangeable, 3.2 m x 4.4 m, octagonal test sections. The wind tunnel was designed by VTI. It has been operating since 1964 and has been modernized two times.

Mach number range is up to 0.52. Mach number regulation is achieved by changing fan rotation rate and pitch angle of fan blades. Reynolds number is up to 12 millions/m. The value of the total pressure in the test section is up to 1.2 bar (static pressure is atmospheric) and, theoretically, the duration of a test is unlimited.

Two test sections are available, one with an under-floor external balance and another with a tail sting support on a vertical quadrant. The six-component under-floor balance permits movements in yaw and pitch. The tail sting support enables step-by-step and continuous (sweep) movement of the model in all three axes, i.e. change of angle of attack, sideslip angle and rolling angle. Figure 3 presents AGARD-B model mounted on the tail sting support system in the T-35 test section.

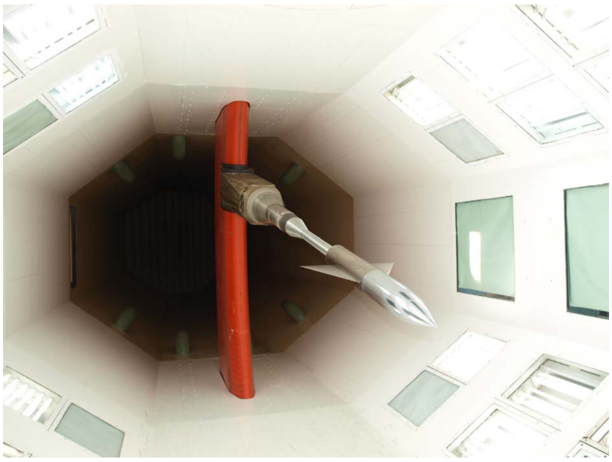

Figure 3. AGARD-B standard model mounted in the T-35 test section

5. EXPERIMENT SET-UP

Experiment included determination of the standard model aerodynamic characteristics in subsonic range, in the ±10° angle of attack range, in both upright and inverted AGARD-B model position, to obtain confidence in flow quality and level of the measurements repeatability.

Standard T-35 primary measuring system set-up was used. Absolute pressure Mensor transducer of 1.65 bar range, with Bourdon quartz pipe, was used for the measurement of the test section total pressure. The transducer was pneumatically connected with Pitot probe, located in the upper part of the collector.

Static and total pressures difference was measured using differential pressure Druck transducer of 0.07 bar range. Pressure orifices were on the wind tunnel wall at the exit of the collector.

Total temperature was measured by a RTD probe, placed on the same support as the probe for total pressure. The base pressure was measured using Druck PDCR42 piezoresistive differential pressure transducer (with reference static pressure) of 0.07 bar range.

Aerodynamic forces and moments acting on the model were measured using VTI's internal six-component strain gauge balance (Figure 4). Resolvers in the mechanism of the model support were used for measuring the angle of attack, side-slip angle and rolling angle of the model.

Calibrations of pressure and model position transducers, wind-tunnel balance and the data-acquisition system itself were routinely executed before wind-tunnel test. These calibrations were performed using primary and secondary standards of the relevant physical quantities. Expected and generally achieved accuracies of some of the measuring devices used in the T-35 wind-tunnel were:

- Pressure transducers of the primary measurement system of flow parameters in the test section: 0.01% F.S. to 0.02% F.S.,
- Base-pressure transducer: 0.05% F.S.,
- VTI-produced monoblock force balance: 0.1% F.S.,
- Transducers for control of various wind tunnel components: generally 0.1% F.S.

The basic flow quality parameters, Mach number and pressures, were within the accuracy limits of the measuring devices and equipment, [5,6].

Figure 4. VTI-produced internal six-component strain-gauge monoblock balance

Used data-acquisition system was the 64-channel system Neff 620/600 under control of the VAX 8250 computer. Input signals of flow parameters transducers were adequately amplified and filtered with low-pass fourth-order Butterworth filters. The A/D converter of 16-bits resolution and of 0.02% F.S. conversion accuracy was used. The sampling rate for all channels was the same of 200 samples per second. Digitalized data were sent to the AlphaServer DS20E computer for data-reduction which was done using the standard VTI's wind-tunnel data-reduction software through several phases using different software modules.

6. WITHIN-FACILITY COMPARISONS

A short wind-tunnel test at Mach 0.4 was performed just prior to a customer test. AGARD-B model was tested for the first time in the large-subsonic facility, so there were not enough data for performing all the segments of the VTI's standard testing procedure.

6.1 Test section and model symmetry check

Analysis of the measured aerodynamic coefficients from the point of the test section and the model symmetry was done for two Mach 0.4 runs at the two opposite roll angles: 0 deg, model-upright and 180 deg, model-inverted.

Test-data of the model in both the upright and the inverted positions, presented in the wind-axes system, show the test section symmetry based on determined flow angularities in the vertical and the horizontal planes. It should be noted that the angle of attack in the wind-axes system is defined as positive if air stream attacks the bottom of the model.

Mach 0.4 data in the wind-axes system at the aerodynamically same angles of attack from model-upright and model-inverted runs were compared to check test section symmetry. Data in a non-rotated wind-axes system from the model-upright run are to be compared with data from the model-inverted run to check the model symmetry, [3,4].

Aerodynamic coefficients and differences between coefficients at the model zero angle of attack are given in Table 1. Only coefficients for in-flow plane should be compared. Compared aerodynamic coefficients are given in graphs in Figures 5, 6 and 7.

Table 1. Test section symmetry check

AGARD-B model, Mach 0.4, Alfa=0, wind-axes system

Run/Fi, deg	Cxf	Cz	Cm	Cpb	Cx
#7/0	0.0133	-0.005	0.000	-0.1051	0.0252
#13/180	0.0135	0.006	0.000	-0.1072	0.0257
ΔC	0.0002	0.011	0.000	0.0013	0.0002

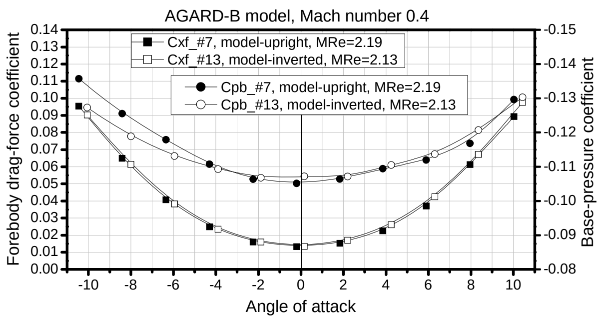

Figure 5. Test section symmetry check: AGARD-B model, drag-force and base-pressure coefficients, Mach 0.4

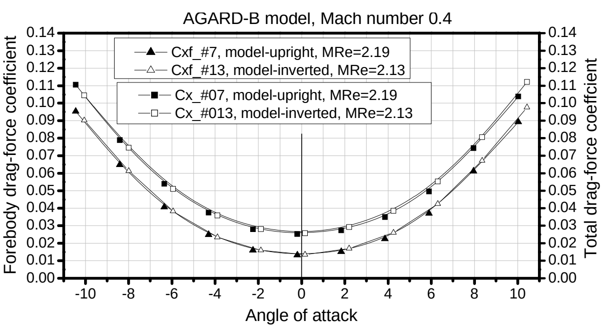

Figure 6. Test section symmetry check: AGARD-B model, forebody and total drag-force coefficients, Mach 0.4

Test results in both the model-upright and model-inverted positions showed very good correlations with only insignificant differences practically bellow the accuracy of the wind-tunnel balance used. Good symmetry of the test section, taking into account determined flow angularities in vertical and horizontal planes, can be confirmed.

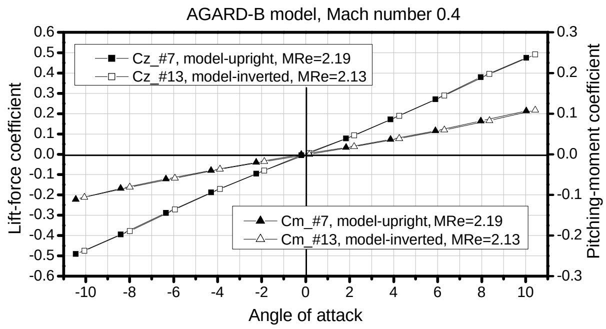

Figure 7. Test section symmetry check: AGARD-B model, lift-force and pitching-moment coefficients, Mach 0.4

When comparing the data one should have in mind that they were not reduced for exactly identical angles of attack in all runs, and that some interpolations were necessary prior to the differences being calculated, so that a certain amount of discrepancies must be allowed.

6.2 Test-data repeatability check

Wind-tunnel data uncertainty is being considered in the form of repeatability from a few supposedly identical wind-tunnel runs of the standard model. The accuracy requirements for standard models wind-tunnel data are specified concerning three different categories, [3,4].

Only run-to-run data repeatability of measurement in the T-35 wind-tunnel testing of the standard model was monitored and assessed which is regarded as a short-term repeatability. As the AGARD-B standard model was tested in the T-35 facility for the first time the long-term repeatability could not be obtained.

Table 2 lists the aerodynamic coefficients and differences between Mach 0.4 runs at –4.3 deg angle of attack. Only coefficients for in-flow plane should be compared. Compared aerodynamic coefficients are given on graphs in Figures 8, 9 and 10.

Table 2. Test-data repeatability check

AGARD-B model, Mach 0.4, wind-axes system

Run/ Alfa, deg	Cxf	Cz	Cm	Cpb	Cx
#7/-4.30	0.0249	-0.188	-0.040	-0.1107	0.0374
#14/ -4.32	0.0255	-0.191	-0.040	-0.1124	0.0382
ΔC	0.0006	0.003	0.000	0.0017	0.0008

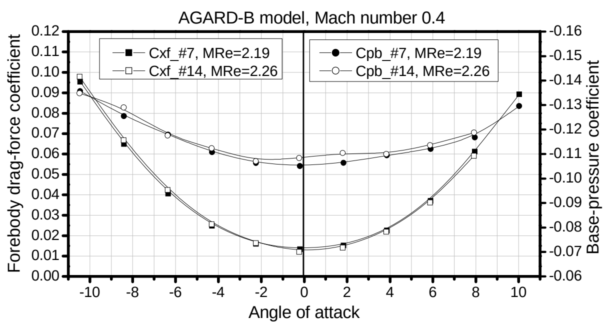

Figure 8. Repeatability check: AGARD-B model, drag-force and base-pressure coefficients, Mach 0.4

Within-test data repeatability levels of app. ±0.0005 in drag measurement, better than ±0.01 in lift measurement, and ±0.001 in pitching-moment measurement were achieved. Very good within-test data repeatability was established.

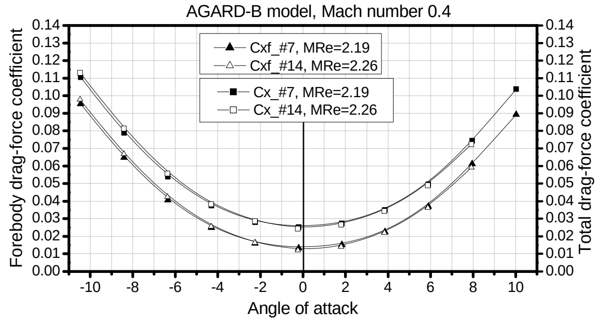

Figure 9. Repeatability check: AGARD-B model, forebody and total drag-force coefficients, Mach 0.4

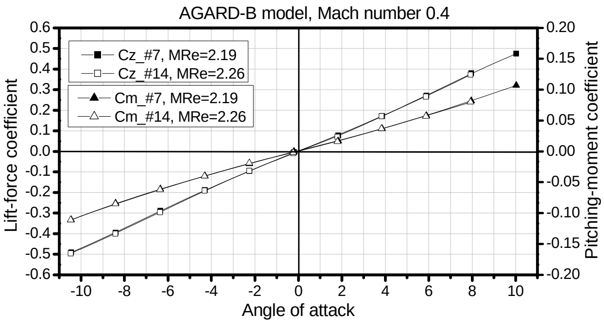

Figure 10. Repeatability check: AGARD-B model, lift-force and pitching-moment coefficients, Mach 0.4

7. INTER-FACILITY CORRELATIONS

All available T-35 wind-tunnel test-data on the standard AGARD-B model have been examined to establish reference characteristics for use in the correlation of experimental results among the various aerodynamic facilities.

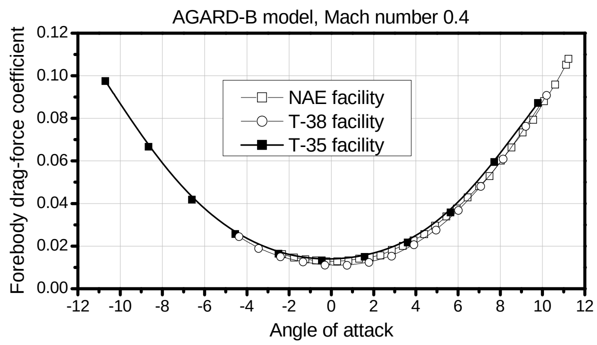

Figure 11. Inter-facility correlation: AGARD-B model, forebody drag-force coefficient, Mach 0.4

As it facilitates tunnel-to-tunnel data correlation, test-data of physically the same model in the Canadian NAE (National Aeronautical Establishment, today operates as IAR – Institute for Aerospace Research) 5 ft and the VTI's T-38 wind-tunnels are given in graphs in Figures 11, 12 and 13.

In general, the excellent correlation was found among the test-data from various facilities.

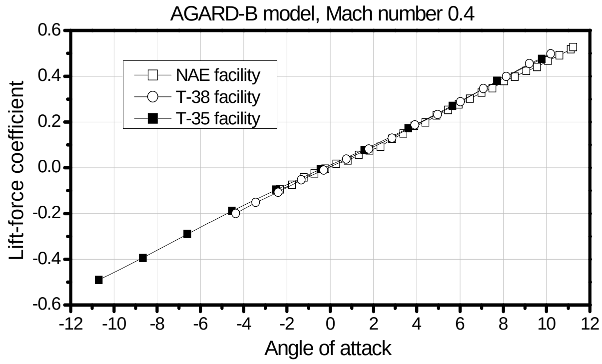

Figure 12. Inter-facility correlation: AGARD-B model, lift-force coefficient, Mach 0.4

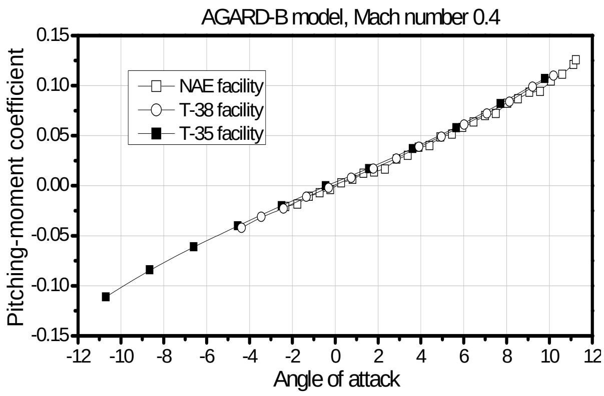

Figure 13. Inter-facility correlation: AGARD-B model, pitching-moment coefficient, Mach 0.4

8. CONCLUSION

The VTI's new-implemented procedure for wind-tunnel standard model testing in the Experimental Aerodynamics Laboratory has been applied to the new set of the T-35 standard test-data.

Confidence in the validity of the standard AGARD-B test-data obtained in the T-35 subsonic wind-tunnel of the VTI has been established based on within-facility and inter-facility comparisons.

Analysis of the test-data obtained through repeated wind-tunnel runs showed a good agreement, confirming the high level of the measurement repeatability. Analysis of the test-data confirmed the good flow quality in the T-35 test section, good condition of the wind-tunnel instrumentation and the correctness of the data-reduction algorithm.

Obtained test-data were compared with the test-data of the same model executed in the Canadian NAE (IAR) 5ft trisonic wind-tunnel and in the T-38 trisonic wind-tunnel of VTI. Correlation of the T-35 with those test-data showed a very good agreement. High level of confidence in the validity of the standard T-35 test-data has been obtained.

Implemented procedures, standard testing database, and acquired experience in the VTI's trisonic test facility showed to be an excellent background in the process of verification of other VTI's facilities, [3]. The VTI's new-implemented procedure for wind-tunnel standard model testing has been reviewed as practical and clear to the wind-tunnel practitioners. Feedback from the actual test-customers was an excellent.

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NOMENCLATURE

C_{xf}	Forebody drag-force coefficient
C_x	Total drag-force coefficient
C_z	Lift-force coefficient
C_m	Pitching-moment coefficient
C_{pb}	Base-pressure coefficient
D	Model diameter, m
Alfa	Angle of attack, deg
Fi	Model roll angle, deg
MRe	Reynolds number in millions for model reference length

ИСПИТИВАЊЕ СТАНДАРДНОГ МОДЕЛА У ВЕЛИКОМ СУБСОНИЧНОМ АЕРОТУНЕЛУ ВТИ-А РАДИ ОБЕЗБЕЂЕЊА ПОВЕРЕЊА КОРИСНИКА

Горан Оцокољић, Дијана Дамљановић, Бошко Рашуо, Јован Исаковић

Неопходност испитивања стандардних модела у циљу обезбеђења поверења у квалитет струјања и валидност експерименталних података је препозната у Експерименталној аеродинамичкој лабораторији Војнотехничког института (ВТИ) у Београду. Новоимплементирана процедура за обезбеђење поверења у квалитет података је примењена у испитивању стандардног модела АГАРД-Б у великом субсоничном аеротунелу ВТИ-а. Резултати испитивања на Маховом броју 0.4 су анализирани и упоређени са резултатима испитивања физички истог модела у канадском NAE (данас оперативан као IAR) аеротунелу и трисоничном аеротунелу Т-38 ВТИ-а. Провера поновљивости мерења и међулабораторијска поређења добијених стандардних података су извршена у циљу потврде опште поузданости субсоничне инсталације Т-35 као иницијални корак у обезбеђењу поверења пре испитивања за клијента.