UDK: 533.6.011.72:623.451.74
COSATI: 01-01

Testing of the Calibration Model ONERA M4 in the Subsonic Wind Tunnel T-35

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In this paper, testing results of the calibration model *ONERA M4* in the wind tunnel T-35, VTI, at Mach number *M*=0.25 are shown. The paper also contains comparative analysis with the testing results of *ONERA M1* model in the wind tunnel *N.A.E. 5ft x 5ft*. Testing conditions for both model M4 and model M1 are the same. The goal is to check the functionality and reliability of the model support system (MSS) and establish its influence on the flow parameters in the wind tunnel test section. Six-component balance *ABLE 2" MK XVIII* is used for measuring the aerodynamic forces and moments.

Key words: **aerodynamic testing, aerodynamic model, aerodynamic tunnel, subsonic flow.**

Labels

C_x	−drag coefficient
C_y	−side force coefficient
C_z	−lift coefficient
C_l	−rolling moment coefficient
C_m	−pitching moment coefficient
C_n	−yawing moment coefficient
C_{xb}	−base drag coefficient
C_{pb}	−base pressure coefficient
D	−diameter of the model, (m)
D_b	−diameter of the model base, (m)
L	−length of the model, m
L_{ref}	−referent length of the model, (m)
S_b	−area of the model base, (m^2)
S_{ref}	−referent area of the model, (m^2)
M	−Mach number
p_b	−base pressure, (bar)
p_{st}	−static pressure, (bar)
p_0	−total pressure, (bar)
q	−dynamic pressure, (bar)
Re	−Reynolds number
T_0	−total temperature, (K)
α	−angle of attack, (º)
β	−sideslip angle, (º)
ϕ	−rolling angle, º
ONERA	−Office National d'Etudes et de Recherches Aeronautiques
N.A.E.	−National Aeronautical Establishment

Introduction

FLOW quality research in wind tunnels is a significant part of experimental aerodynamics, which includes a number of different methods.

First, there are methods based on pressure distribution measurements with probes or scanning devices. These methods enable the determination of velocity field and pressure field, calculation of the Mach number of flow examination of boundary layer nature and width, etc.

Second significant group encompasses anemometric methods: laser Doppler anemometry, hot-wire and hot-film anemometry, acoustic anemometry, anemometry based on particles image, etc. These methods enable direct measurement of flow velocity, determination of flow velocity vector field, Mach number and turbulence intensity.

Unavoidable methods for flow quality examination are also visualization methods. Optical methods are dominant, with the largest possibilities and the broadest applications (Schlieren method, holography and holographic interferometry). There are also visualization methods with smoke, threads, coats, etc. Methods for Reynolds number and aerodynamic noise are also used.

Confirmation of flow quality in the test section and its verification are possible after testing of calibration (standard) models, comparing results obtained in the test with the results obtained in the tests of the same model in internationally recognised laboratories

In this test, calibration model *ONERA M4* is used.

ONERA models are made on several scales, to enable comparison of results obtained in a number of wind tunnels with different test section dimensions. As this was the first testing of ONERA M4 model in this velocity range, results which are obtained are compared with the results of testing *ONERA M1* model in the wind tunnel *N.A.E. 5ft x 5ft,* under the same aerodynamic conditions.

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Test includes the determination of model aerodynamic coefficients, based on which qualitative estimation of functionality and reliability of the wind tunnel's T-35 new test section "C", and also preliminary estimation of the test section flow quality.

In this article, testing results are shown in the form of tables and diagrams.

Along with the calibration model *ONERA M4*, the wind tunnel T-35, instrumentation, methods of data acquisition and reduction, and the course of experiment, are described.

Comparative analysis of the results of aerodynamic coefficients measurement is also given. In the conclusion, results of the examination are summed up.

Experiment

Testing of the calibration model *ONERA M4* in the wind tunnel T-35 is a part of the project of flow quality research in the test section "C".

The goal is to check the functionality of the model support system (MSS), which is a part of the test section "C", and determine the aerodynamic characteristics of the model. Experiment included testing of the calibration model *ONERA M4* in subsonic velocity range, in the wind tunnel T-35 test section "C", for the range of the angle of attack $-6^\circ < \alpha < +6^\circ$, with increment 1˚, and the rolling angles of $\phi = 0^\circ$ and $\phi = 180^\circ$.

Testing with these rolling angles was intended to check the repeatability of results. Another goal was the preliminary estimation of flow quality in the test section, taking into account the difference between the obtained values of aerodynamic coefficients.

Model

ONERA has designed the family of models for the purpose of testing them in its own wind tunnels. Nowadays, these models are used as standard for checking and controlling the new wind tunnel installations. To test the functionality and reliability of the model support system (MSS) in the wind tunnel T-35, and for preliminary estimation of the flow quality, a model from *ONERA* family is used.

The wing span of the series of *ONERA* models ranges from 0.3m to 1.0m. These models have extremely high accuracy of manufacture; maximum error does not exceed 0.03mm. Labels of the models are M1, M2, M3, M4 and M5, depending on their scale [6].

ONERA M4 model (Fig.1) has internal space of adequate size for setting up six-component wind tunnel balance *ABLE 2" MK XVIII*, with diameter of 50.8 mm (Fig.3). Geometric characteristics of the model are shown in the Fig.2, with the fuselage diameter of 102mm. Airfoils of the wing, and airfoils of the horizontal and vertical tails are symmetrical, of "peaky" type, with maximum thickness of 10.5% at the 37.5% of the chord. The angle between the leading edge of the swept wing and the fuselage axis is 30º, aspect ratio of the wing is 7.31, and its installation angle is 4º with relation to the fuselage axis. The angles between the leading edge of the horizontal and vertical tails and the fuselage axis are 37.5º and 47.5º, respectively. The cylindrical fuselage has three sections. The wing and the horizontal tail have dihedral angle of 3º and they are not warped.

The model is designed for the installation on the sting (Fig.4) with strictly defined geometry. The sting diameter is 75% of the diameter of the model base. Sting is cylindrical at the length of three diameters of the model base, and its rear part is a cone with the angle of 15˚.

Experimental results of testing *ONERA M1* model in the wind tunnel *N.A.E. 5ft x 5ft* were used in comparative analysis, and therefore the basic geometric parameters of both models are given in Table 1.

Table 1.

ONERA model	Fuselage diameter [m]	Wing area [m^2]	Wing span [m]	I_{sat} [m]	Fuselage length [m]	Maximum cross-section [m^2]
M1	0.036	0.011	0.287	0.040	0.309	0.0015
M4	0.102	0.088	0.800	0.112	0.861	0.0079

Figure 1. *ONERA M4* calibration model

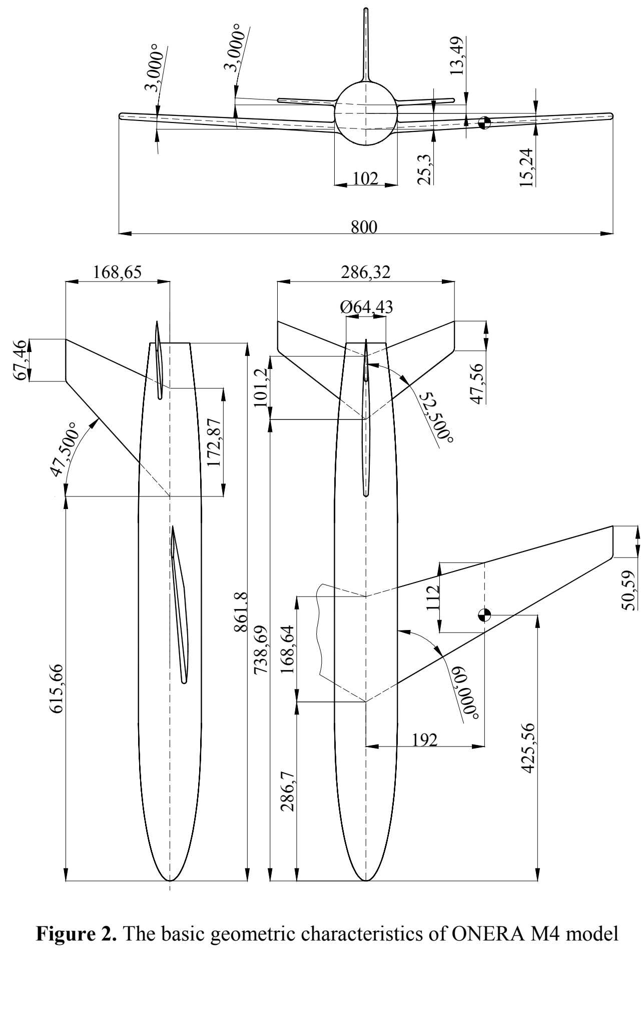

Figure 2. The basic geometric characteristics of ONERA M4 model

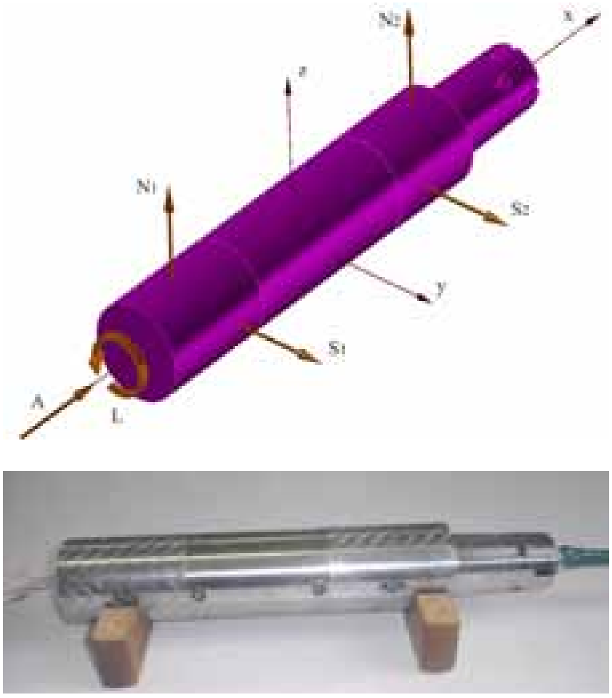

Figure 3. Internal six-component wind tunnel balance *ABLE 2" MK XVIII*

Figure 4. *ONERA M4* calibration model on the model support system in the wind tunnel T-35 test section

Wind tunnel T-35

Wind tunnel T-35 of the VTI is located in Žarkovo. The wind tunnel is of continual type. The test section has octagonal cross-section, with the width of 4.4m and height of 3.23m. The test section cross-section area is 11.93m^2. The length of the test section is 5.5m.

The range of Mach number, which can be achieved with fan only, is from 0.1 to 0.52, and the combination of fan and injector is from 0.52 to 0.8.

The test section "C" with model support system (MSS) is used in this test. Model support system enables step-by-step movement of the model and continual movement of the model ("sweep") for all of the three axes, i.e. change of the angle of attack, sideslip angle and rolling angle.

Mach number regulation is achieved by changing the fan rotation rate and angle of fan blades.

The value of Reynolds number is up to 12 million/m using fan only, and up to 23 million/m with the combination of fan and injector.

The value of the total pressure in the test section is 1 bar using fan only, and up to 1.52 bar with the fan and injector combination.

Theoretically speaking, the duration of the test with fan only is unlimited, and with the combination of fan and injector is up to 120 s.

Instrumentation and data acquisition

Absolute pressure transducer, manufactured by Mensor, with Bourdon quartz pipe, is used for measuring the total pressure P_0 in the test section. The transducer is pneumatically connected with the Pitot probe, located in the upper part of the collector. The range of the transducer is 1.65 bars. Non-linearity and hysteresis of these transducers are 0.02% F.S. The transducer is calibrated along with the system for data acquisition.

Static and total pressure difference P_{st}-P_0 is measured by differential pressure transducer, manufactured by Druck, with the range of 0.07 bars. Measurement points are openings on the wind tunnel wall, at the exit of the collector. Non-linearity and hysteresis of these transducers are 0.02% F.S. The calibration procedure for this transducer is the same as the procedure for the total pressure transducer.

Total temperature T_0 is measured by RTD probe, which is placed on the same support as the probe for total pressure. The transducer accuracy is ± 0.5 K.

Resolvers, located in the mechanism for model movement, measure the angle of attack, sideslip angle and rolling angle of the model.

Output of the accurate digital watch is used as time base for data segmentation, and it is sampled along with other transducer signals.

Data acquisition system is 64-channel system Neff 620/600, controlled by VAX 8250 computer. Control of the model support system movement is implemented by software on the PC computer. Software on PDP 11/84 computer is used for the control of the wind tunnel operation.

Input signals of the flow parameter transducers (i.e. P_0, P_{st}-P_0 and T_0) are adequately amplified and filtered, with low pass fourth order Butherworth filters, which have cut off frequency of 1 Hz.

A/D converter, with resolution of 16 bits, digitalizes data from the analogue channels. Accuracy of A/D conversion is 0.1% F.S. of the respective channel. The sampling rate for all channels was the same, 200 samples per second.

Digitalized data are sent at the AlphaServer DS20E computer through the fast receiver, where they are saved for the purpose of consequent reduction.

Data reduction

After each testing sequence data reduction is done using the standard wind tunnel reduction software T35-APS. Data reduction has several phases:

- Reading of raw data, normalization and translating into the standard format;
- Determination of the flow parameters;
- Determination of the model position;
- Determination of aerodynamic coefficients.

There is a different software module for each reduction phase.

Experimental results

Experimental results of testing *ONERA M4* model at Mach number M = 0.25 in the wind tunnel T-35 are shown in Tables 2 - 3 and in diagrams (Figures 5, 6, 7 and 8).

Figures 5-8 show results of aerodynamic measurements in the graphic form. In the Figures 5 and 7 diagrams of drag and lift coefficients are shown, and pitching moment coefficients, which are obtained by testing at M = 0.25, at the model rolling angle of $\phi = 0^\circ$ and $\phi = 180^\circ$, respectively.

In Figures 6 and 8 diagrams of side force coefficient are shown, and yawing and rolling moment coefficients, which are obtained by testing at M = 0.25, at the model rolling angle of $\phi = 0^\circ$ and $\phi = 180^\circ$, respectively.

Table 2. Testing of *ONERA M4* model at M = 0.25, with the rolling angle $\phi = 0^\circ$.

i	*α*	*Cx*	*Cy*	*Cz*	*Cl*	*Cm*	*Cn*	*Cpb*	*Cxb*	*Cx+Cxb*
1	-6.02	0.0145	0.007	-0.261	0.0028	0.152	0.0004	0.0589	-0.0021	0.0124
2	-5.03	0.0142	0.000	-0.186	0.0007	0.132	-0.0003	0.0606	-0.0022	0.0119
3	-4.03	0.0093	0.005	-0.102	0.0019	0.111	0.0001	0.0613	-0.0022	0.0071
4	-3.01	0.0094	0.001	-0.016	0.0012	0.096	-0.0001	0.0615	-0.0022	0.0072
5	-1.97	0.0065	0.005	0.076	0.0018	0.075	0.0002	0.0621	-0.0023	0.0042
6	-1.07	0.0108	0.003	0.157	0.0017	0.059	0.0001	0.0626	-0.0023	0.0085
7	0.03	0.0111	0.007	0.255	0.0018	0.044	0.0006	0.0626	-0.0023	0.0088
8	1.02	0.0146	0.004	0.354	0.0019	0.035	0.0003	0.0624	-0.0023	0.0123
9	2.06	0.0166	0.009	0.448	0.0033	0.037	0.0009	0.0610	-0.0022	0.0144
10	3.06	0.0247	0.010	0.515	0.0015	0.027	0.0008	0.0601	-0.0022	0.0225
11	4.12	0.0402	0.009	0.596	0.0022	0.029	0.0006	0.0591	-0.0022	0.0381
12	5.16	0.0616	0.006	0.653	0.0031	0.028	0.0010	0.0569	-0.0021	0.0595
13	6.09	0.0881	0.009	0.687	0.0041	0.039	0.0009	0.0565	-0.0021	0.0860

Table 3. Testing of *ONERA M4* model at M = 0.25, with the rolling angle $\phi = 180^\circ$.

i	*α*	*Cx*	*Cy*	*Cz*	*Cl*	*Cm*	*Cn*	*Cpb*	*Cxb*	*Cx+Cxb*
1	-6.11	0.0250	0.003	-0.266	-0.0017	0.148	0.0000	0.0591	-0.0021	0.0229
2	-5.15	0.0164	0.007	-0.170	0.0022	0.135	0.0005	0.0611	-0.0022	0.0141
3	-4.08	0.0150	0.005	-0.088	0.0006	0.120	0.0003	0.0624	-0.0023	0.0127
4	-3.05	0.0136	0.004	0.003	0.0002	0.105	0.0002	0.0576	-0.0021	0.0115
5	-2.01	0.0146	0.004	0.085	-0.0004	0.092	0.0001	0.0648	-0.0024	0.0122
6	-1.02	0.0167	0.002	0.171	-0.0008	0.072	-0.0002	0.0612	-0.0022	0.0145
7	-0.01	0.0198	0.001	0.274	-0.0012	0.057	-0.0001	0.0672	-0.0025	0.0173
8	1.04	0.0223	0.000	0.372	-0.0003	0.050	-0.0001	0.0661	-0.0024	0.0199
9	1.99	0.0256	-0.001	0.465	-0.0009	0.052	-0.0004	0.0649	-0.0024	0.0233
10	3.04	0.0347	0.049	0.537	-0.0032	0.046	0.0041	0.0642	-0.0023	0.0323
11	4.05	0.0494	-0.001	0.612	0.0003	0.045	-0.0007	0.0632	-0.0023	0.0471
12	5.01	0.0694	-0.002	0.671	0.0001	0.049	-0.0007	0.0622	-0.0023	0.0672
13	6.01	0.0962	-0.003	0.703	0.0046	0.059	-0.0007	0.0612	-0.0022	0.0940

In Figures 5 and 6 aerodynamic coefficients of *ONERA M4* model are shown, obtained by testing at Mach number M= 0.25, at the rolling angle $\phi = 0^\circ$.

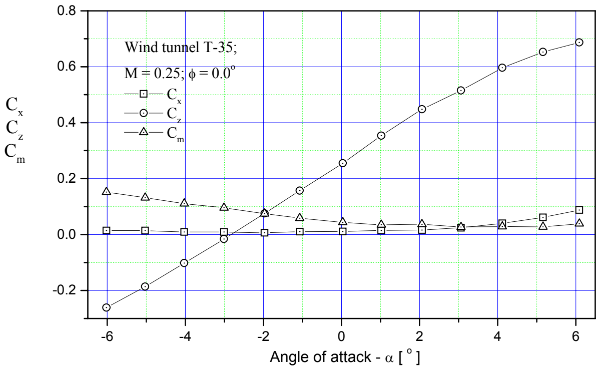

Figure 5.

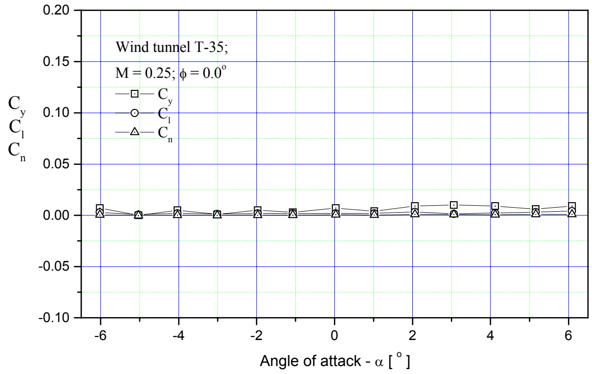

Figure 6.

In figures 7 and 8, aerodynamic coefficients of *ONERA M4* model are shown, obtained by testing at Mach number M = 0.25, at the rolling angle $\phi = 180^\circ$.

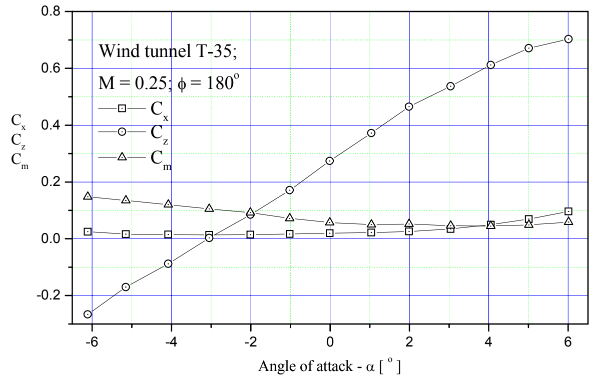

Figure 7.

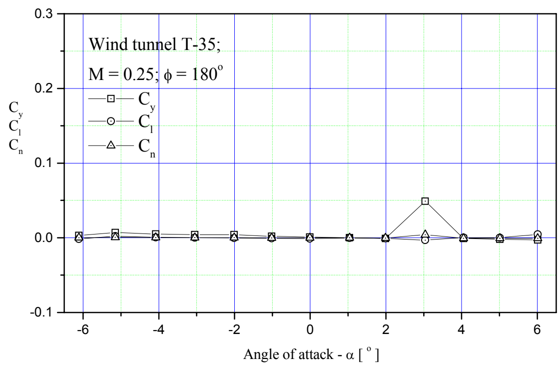

Figure 8.

Analysis of experimental results

Analysis of results of aerodynamic forces and moments measurement

The basic flow parameters, Mach number and pressure, are within the accuracy limits of measuring devices and equipment, which is the same for all tests. During the test, it was observed that the pressure measured on the model base is greater than the static pressure on the wind tunnel walls. This can be explained by the influence of model support system (MSS), i.e., the character of the flow field behind the model. Values of the side force, rolling moment and yawing moment coefficients are very small; they are practically below the accuracy of the used wind tunnel balance, *ABLE 2” MK XVIII*.

Very good repeatability of the results of the model testing at $\phi = 0^\circ$ (Fig.9) and $\phi = 180^\circ$ (Fig.10) is established, with only insignificant deviations. This difference is very small and practically below the accuracy of the wind tunnel balance used. Maximal deviation of the lift force value in these two measurements is observed at the angle of attack of +3º (8.52 N or 0.048% F.S.). Maximal deviation of the drag force is observed at the angle of attack of -6º (5.808 N or 0.215% F.S.). Maximal deviation of the pitching moment value is 0.911 Nm (0.268% F. S.), at the angle of attack of +5º. These differences can be attributed to the character of the flow field in the test section. Taking into account the above mentioned experimental results, it can be confirmed that the flow field in the test section "C" of the wind tunnel T-35 is very good. Comparative review of the lift force coefficient values at the rolling angles $\phi = 0^\circ$ and $\phi = 180^\circ$ is given in Fig.11.

Figure 9.

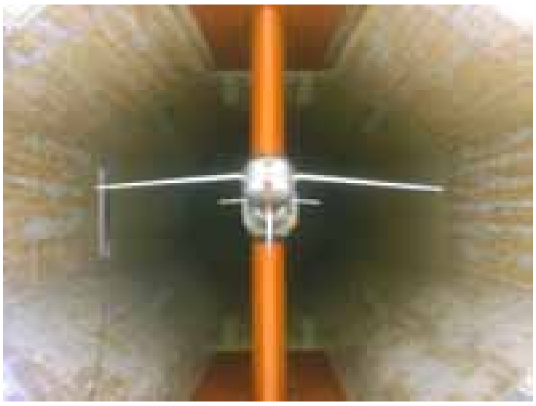

Figure 10.

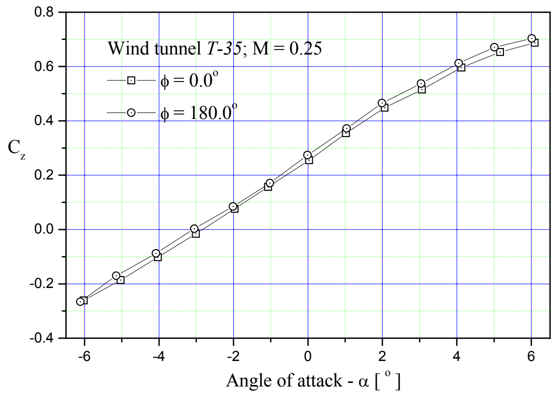

Figure 11.

Comparative analysis of the results

Testing of the calibration model *ONERA M4* in the wind tunnel T-35 at Mach number $M = 0.25$ is the first one in this velocity range. It is the reason for the comparison of the experimental results obtained there with the experimental results of testing *ONERA M1* model in the wind tunnel *N.A.E. 5ft x 5ft*, under the same aerodynamic conditions [2].

Results obtained in the wind tunnel T-35 show good agreement with the results of testing of *ONERA M1* model in the wind tunnel *N.A.E. 5 ft x 5ft*.

Comparative review of the lift force aerodynamic coefficient values, C_z, which are obtained in T-35 and *N.A.E. 5 ft x 5 ft* wind tunnels, is given in Figures 12 ($\phi = 0^\circ$) and 16 ($\phi = 180^\circ$). Lift force coefficient curves obtained in the wind tunnel T-35 actually look like the approximation of the points obtained in the wind tunnel *N.A.E. 5 ft x 5 ft*. Therefore, it can be stated that the lift force coefficient values in the two wind tunnels show exceptionally good agreement.

Drag force coefficient values in the two wind tunnels are shown in diagrams in Figures 13 ($\phi = 0^\circ$) and 17 ($\phi = 180^\circ$). A distinct difference between the results is observed in the range of the angle of attack from +2.5º do +6º.

Pitching moment coefficient values, C_m, are shown in diagrams in Figures 14 ($\phi = 0^\circ$) and 18 ($\phi = 180^\circ$). Exceptionally good agreement of results is observed.

Summary review of the side force, rolling moment and yawing moment coefficients (C_y, C_l and C_n, respectively) is given in Figures 15 and 19, for the rolling angle values $\phi = 0^\circ$ and $\phi = 180^\circ$, respectively. There was no need for the analysis of these results, because values are small and below the accuracy of the wind tunnel balance used.

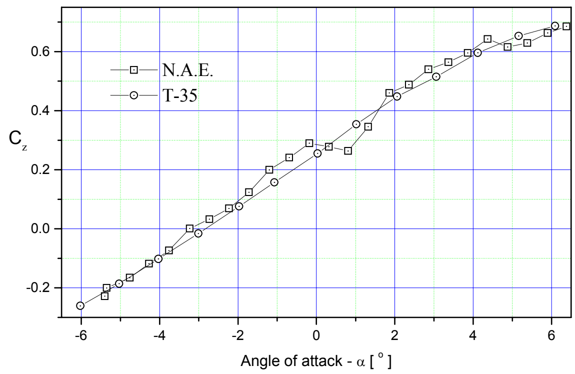

Figure 12.

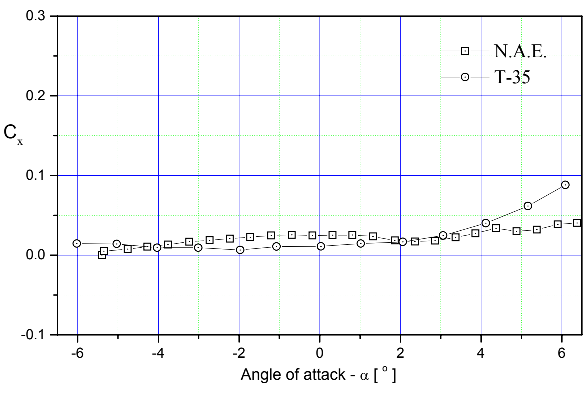

Figure 13.

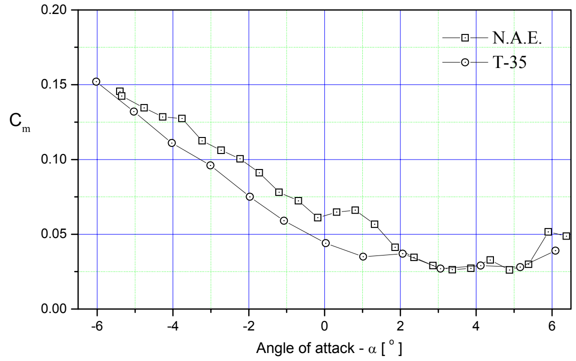

Figure 14.

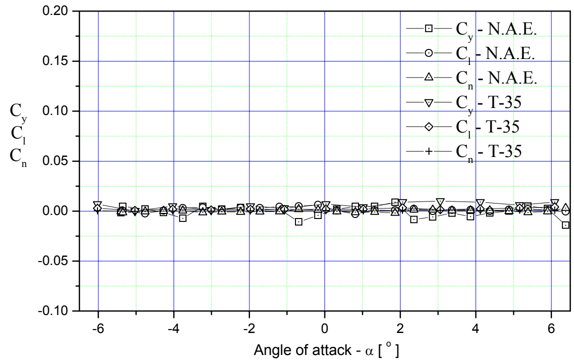

Figure 15.

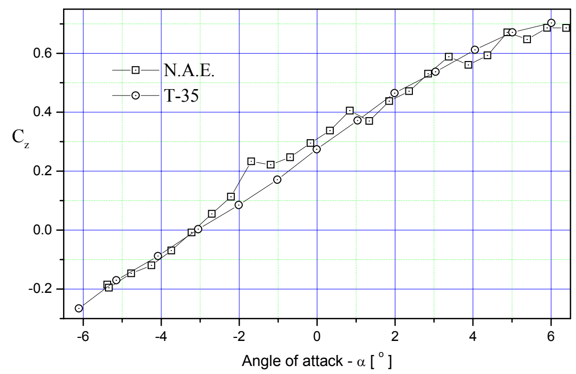

Figure 16.

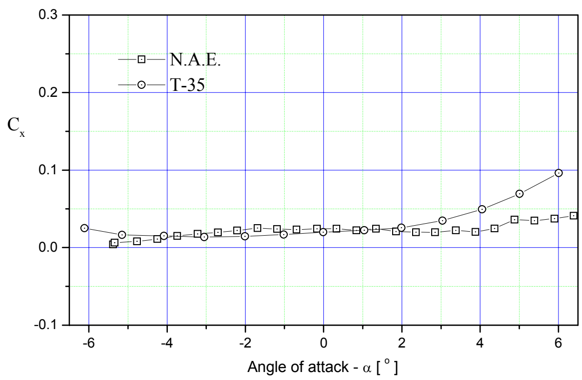

Figure 17.

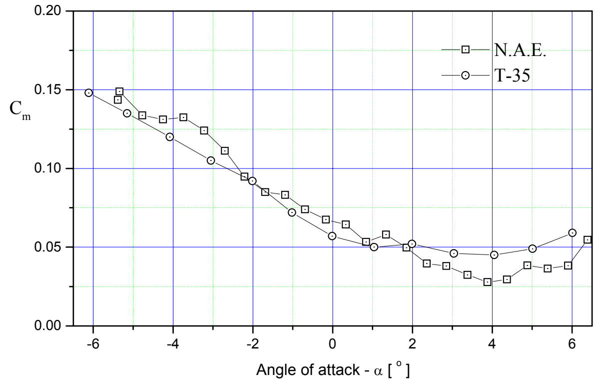

Figure 18.

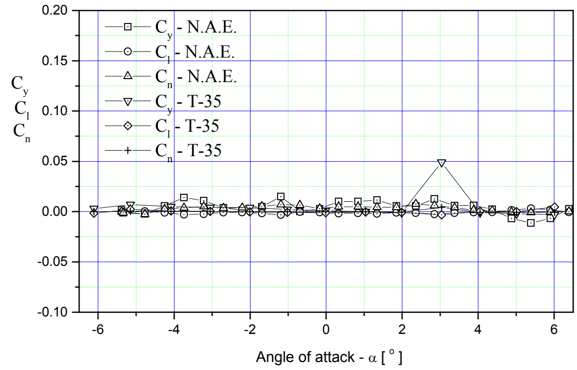

Figure 19.

Conclusion

The experiment in the wind tunnel T-35 enabled the check of functionality and reliability of the model support system (MSS), and also the determination of aerodynamic coefficients of the calibration model *ONERA M4*. Based on the experimental results, preliminary estimation of the flow quality in the test section is given.

There were no problems in the operation of the wind tunnel T-35 with the new test section "C". Model support system (MSS) appeared to be very reliable and functional. Its operation during the test was smooth. Positioning accuracy of the MSS was inside the permitted limits. The test is performed in ***Remote*** mod, using adequate command file, under control of the ***Host*** computer. There were no problems in communication between the ***Host*** (master) and ***PC*** computers, nor with the software for MSS control.

Test program of the calibration model *ONERA M4* was successfully implemented. In this paper, results obtained at the Mach number M = 0.25 were considered and compared with the results obtained in the wind tunnel *N.A.E. 5 ft x 5ft*. Internal six-component wind tunnel balance *ABLE 2" MK XVIII* was used for the measurement of aerodynamic forces and moments of the model.

ONERA M4 model is designed for transonic velocity range, and it implies significantly greater aerodynamic loads than the ones achieved in this test. Due to their small values, below the accuracy of the wind tunnel balance, accuracy of measurement of the side force, and rolling and yawing moments, was insufficient. These coefficient values were near zero, so the accuracy of their measurement was not of vital importance.

Exceptionally good agreement of the lift force and pitching moment coefficients, and relatively good agreement of the drag force coefficients, however, confirm high quality of the test. Good repeatability and small deviations of the results also confirm the test quality. Complete examination of the flow quality in the test section in broad Mach number range is necessary for final estimation of the flow quality.

It should be noted that the obtained values of aerodynamic coefficients were expected. Results of *ONERA M4* model test in the wind tunnel T-35 can be used for further comparative analysis where they will prove to be of great benefit in the future tests.

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Received: 10.09.2004.

Ispitivanje kalibracionog modela ONERA M4 u podzvučnom aerotunelu T-35

U radu su prikazani rezultati ispitivanja kalibracionog modela *ONERA M4* u aerotunelu T-35, Vojnotehničkog instituta, na Mahovom broju *M*=0.25. Data je i uporedna analiza sa rezultatima ispitivanja modela *ONERA M1* u aerotunelu *N.A.E. 5ft x 5ft*. Uslovi ispitivanja modela M4 su istovetni uslovima ispitivanja modela *M1*. Cilj ispitivanja je provera funkcionalnosti i pouzdanosti repnog držača modela (MSS-a), kao i utvrđivanje njegovog uticaja na parametre strujanja u radnom delu aerotunela. Za merenje aerodinamičkih sila i momenata na modelu korišćena je šestokomponentna aerovaga *ABLE 2 MK XVIII*.

Ključne reči: **aerodinamičko ispitivanje, aerodinamički model, aerodinamički tunel, subsonično strujanje.**

Испытывание колибровочной модели ОНЕРА М4 в дозвуковой аэродинамической трубе Т-35

В настоящей работе показаны результаты испытывания калибровочной модели ОНЕРА М4 в дозвуковой аэродинамической трубе Т-35 Военнотехнического института, когда число Маха *M*= 0,25. Здесь тоже сделан и сравнительный анализ с результатами испытывания модели ОНЕРА М1 в аэродинамической трубе Н.А.Е. *5ft x 5ft.* Технические условия для испытывания модели М4 совсем одинаковы с условиями для испытывания модели М1. Целью испытывания является контроль функциональных возможностей и надежности хвостовой стойки модели (МСС), а в том числе и укрепление его влияния на параметры потока в рабочей части аэродинамической трубы. Для измерения аэродинамических сыл и моментов на модели употреблены весы из шести составляющих ***ABLE 2" MK XVIII.***

Ключевые слова: аэродинамическое испытывание, аэродинамическая модель, аэродинамическая труба, дозвуковой поток.

Les essais sur le modèle de calibrage ONERA M4 dans la soufflerie subsonique T-35

Dans ce papier on a présenté les résultats des essais sur le modèle de calibrage ONERA M4, effectués dans la soufflerie aérodynamique T-35 à l'Institut technique militaire, pour le nombre de Mach M=0.25.On a donné aussi l'analyse comparée avec les résultats des essais sur le modèle ONERA M4 dans la soufflerie aérodynamique N.A.E. 5ft×5ft.Les conditions pendant les essais des deux modèles (M4 et M1) étaient identhiques. Le but des essais était de vérifier la fonctionalité et la fiabilité du support arrière du modèle (MSS) et d'établir son influence sur les paramètres du courant dans la chambre d'expérience de la soufflerie. Pour mesures les forces et le moment aérodynamique chez le modèle, on a utilisé une balance aérienne à six componentes ABLE 2"MK XVIII.

Mots clés: **essai aérodynamique, modèle aérodynamique, soufflerie aérodynamique, courant subsonique.**