MULTI-COMPONENT MEASUREMENTS OF AERODYNAMIC LOADS AT THE SHORT-DURATION WIND TUNNEL “TRANZIT-M”

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Introduction

It is a problem to achieve an acceptable confidence level in the determination of the aerodynamic coefficients in short duration facilities. Measurements of non-stationary aerodynamic load in this sort of wind tunnels require the application of special designed high-rigidity sting-mounted strain gauge balances. Natural mass of the model causes to develop special methods, which can remove the dynamic errors due to inertial forces from the balance data. Some of possible compensation techniques are described in [1]. It was the purpose of present study to investigate the possibilities of non-stationary aerodynamic load measurements when the mass of the model is small and dynamic errors are negligible.

Description of experimental technique

The experiments were carried out in the pulse supersonic wind tunnel “Tranzit-M” based in the Institute of Theoretical and Applied Mechanics [2]. Wind tunnel "Tranzit-M" is dedicated for aerodynamic testing at high level of Reynolds number in the range of Mach number from M = 4 to M = 8. The photo of the wind tunnel are shown in Fig. 1.

The basis of the facility have been formed by high pressure chambers set, which consists of the main settling chamber, additional settling chamber and two high pressure vessels, connected to the main settling chamber. Air is gathered in the settling chamber under pressure of 200 bar. Before the run the main settling chamber and two high-pressure vessels are filled by cold working gas and 4 electric heaters inside vessels switched on. The wind tunnel is equipped by axisymmetric contoured nozzle which was originally designed for Mach = 8. Removable throat inserts with special calculated contour provide different values of Mach number, namely M = 4, M = 5, M = 6, M = 7, M = 8.

The working section with diameter of 500 mm is dedicated for tested model and measurement equipment accommodation. Two optical windows with vision field of 350 mm in di-

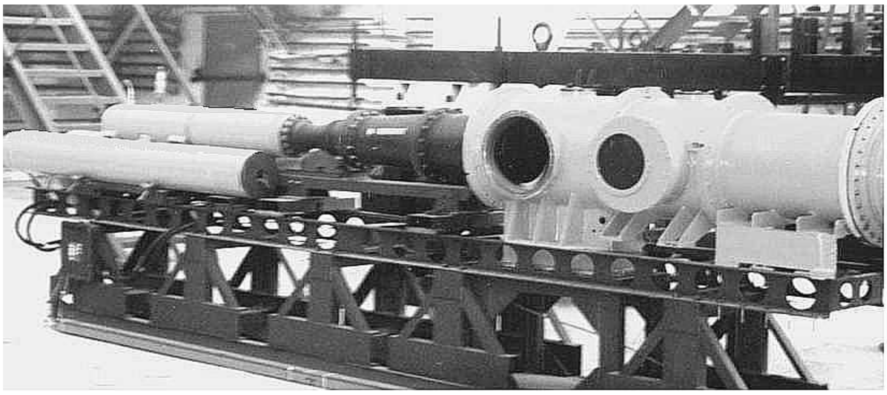

Fig. 1. Photo of wind tunnel “Tranzit-M’

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Abstract

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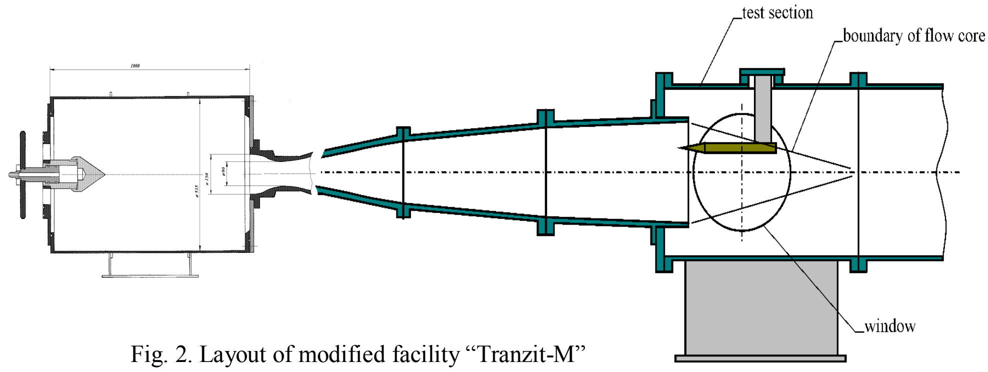

Fig. 2. Layout of modified facility “Tranzit-M”

ameter for flow visualization are located from each side of the working section. After working section the air is flowing through the diffuser with diameter of 400 mm into the atmosphere (Mach number equal or below M = 7) or into the vacuum tank (Mach number more than M = 7). All parts of the wind tunnel are placed on the common frame, which gives possibilities for these parts movement along the longitudinal axis.

The wind tunnel reconstruction was carried out in 2000. The major idea of wind tunnel reconstruction lies in creation of a regime with constant parameters of the flow. To achieve necessary effect a short duration flow of air from ambient atmosphere trough wind tunnel nozzle into a vacuum tank was organized. New settling chamber with fast-acting valve of large size (210 mm) was developed and fabricated. Layout of new experimental setup is shown in Fig.2. Under these conditions the total pressure and total temperature inside the settling chamber will be the same as ambient atmosphere has.

After the reconstruction the following parameters of the wind tunnel are ensured: Mach numbers M = 3 and M = 4, stagnation pressure 10^5 Pa, stagnation temperature 290 K, dynamic pressure 20000 and 8000 Pa, Reynolds number on nozzle exit diameter $2.4*10^6$ and $1.5*10^6$, Operation period on working regime is correspondingly from 0.1 to 0.2 s.

The acceptance trials have discovered the dependence of working regime prolongation upon the initial pressure in the vacuum tank. When the initial pressure in the vacuum tank was higher than 8000 Pa, the working regime was not realized at Mach number M = 4. The maximum duration of the working regime at M = 4 was up to 260 ms.

Measurements of the flow field in the test-section

To study flow field the measurements of Pitot pressure distributions in the test section were carried out with the help of a rake with 17 total pressure tubes of 2 mm in diameter. The rake was installed in the test section of the wind tunnel. Each tube was connected to a corresponding pressure sensor, which was located inside the rake. Small-scale differential pressure sensors of inductive type were used in the experiment. A 16-channel apparatus was applied for pressure measuring. The apparatus realized sensor feeding with voltage of 5 V and frequency of 8000 Hz, and demodulation of output signals of the sensors. The signals reading were carried out with the help of high-accuracy fast-acting 20-channel system of data acquisition.

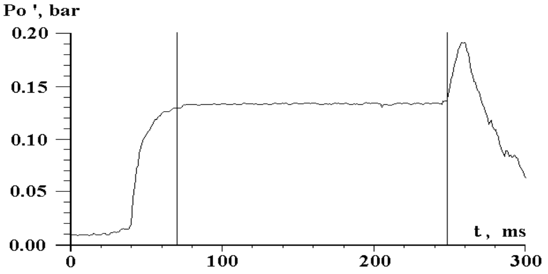

Fig. 3. Typical record of Pitot pressure

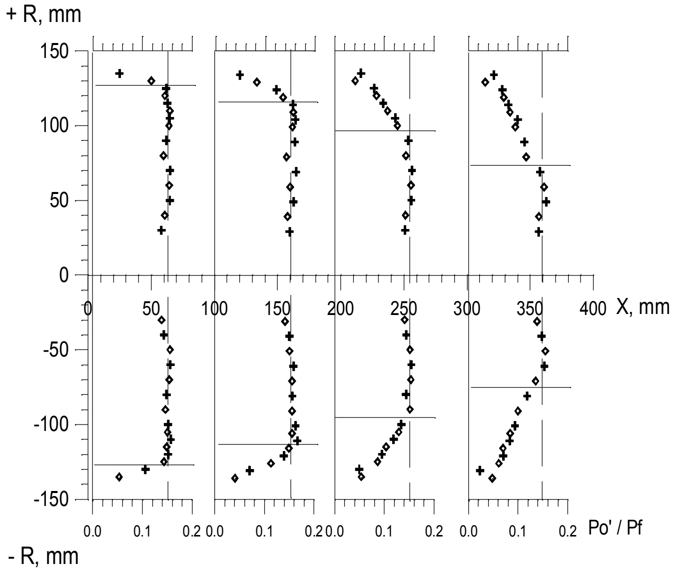

Fig. 4. Flow parameters along test section axis

A typical time trace of Pitot pressure (P_0') at nozzle cut at M = 4 is shown in Fig. 3. As the valve is open, the stationary flow regime is established in the supersonic nozzle. The process of establishment of stationary flow continues for about 0.025 sec. The stationary flow in the nozzle (up to 260 ms) is broken down because of pressure growth in the vacuum tank, and subsequently in the tunnel test section. After regime break down, the sensor indicates continuous pressure growth and it corresponds to the process of filling of the vacuum tank with atmosphere air.

A flow field was studied in the test section at distances of X = 2, 100, 190 and 300 mm downstream from the nozzle cut. Five experiments were carried out with rake turning of 45° in each section along X-axis. The measurement results of these experiments are shown in Fig. 4. It is evident that a boundary layer on nozzle walls was of 20 – 25 mm. The region of uniform flow decreased downstream from the nozzle cut. It agreed easily with the velocity distribution expected. The uniform flow region is pointed in the Fig. 4 with solid lines.

Description of tested model and strain-gages balance system

It was supposed that two similar tested models as a cylinder with conical nose (total angle 20°) will be used. The first of them (large scale) is 1" (25.4 mm) in diameter and 10" (254 mm) length. The second model (small scale) is 1/4" (6.35 mm) and 2.5" (63.5 mm) respectively. For dynamic errors reduction both models were fabricated from aluminum. Consequently mass of the models will be 282 grams and 4.4 grams. Pursuant to available dimensions of free flow the large scale model could be tested in a range of angle α^o from 0° to 30°, while small scale model could be tested from 0° to 180°.

For model displacement in different points of the flow a special support device have been designed and fabricated (see Fig. 5 and 6). This support allows model movement at 240 mm along X-axis, at 185 mm along the Y-axis and rotation up to +20 / –20 de-

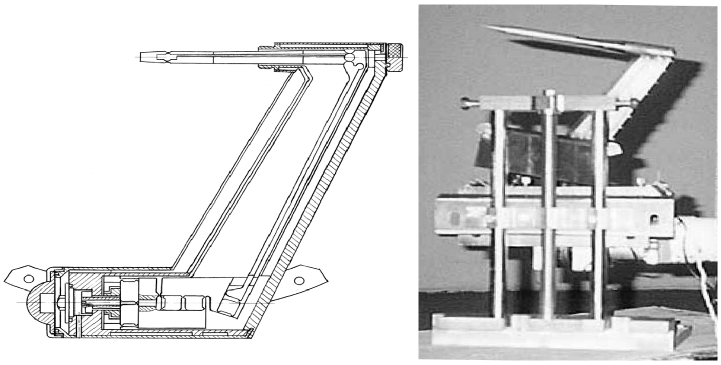

Fig. 5. Arrangement of sting-mounted 3-component strain gages balance system

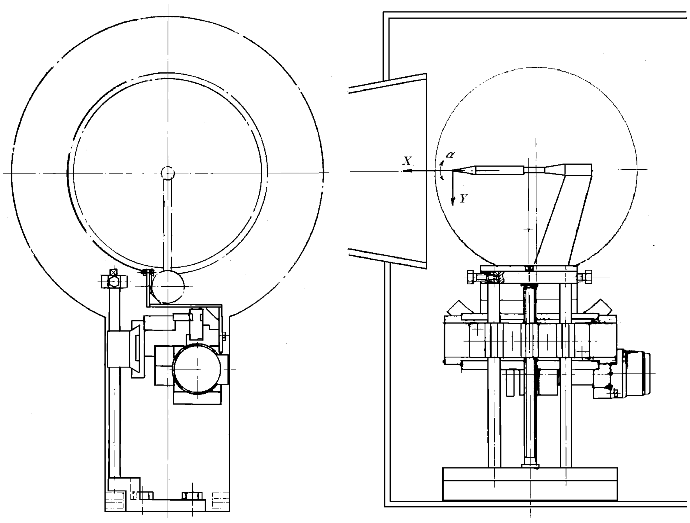

Fig. 6. Sketch of support device with balance system N1 accommodation inside the working section

grees around Z-axis (angle of attack). All operations with model displacement and fixing are produced by hands between the test runs.

Precautions have been taken to reduce effects of vibrations on balance measurements. The rigid platform of a large mass is harnessing as model support basement. This platform is divided from the working section by ribbon seal. Each component is equipped by fixing elements.

As mentioned above existing support device with balance system made possible to cover the range of angles of attack from 0^{o} to 40^{o}. In order that given support device spans wider range of angles a few small models have been fabricated, which differ by initial angle of positioning. It was supposed that 4 models with different angles of initial inclination (40°, 80°, 120°, 160°) should be harnessed to give us the possibility to cover the range of angles from 0^{o} to 160^{o}. Expected loads for small and large model were accepted as essentially different for the unified balance system. So two balance systems were chosen for large and small model testing. Both these high-rigidity sting-mounted strain-gages balance systems for the experiment were developed and fabricated by V.Ja. Kiselev. Sketch of 3-component strain-gage balance N1 is shown in Fig. 6.

For the measurement and registration of experimental results from the balance system a separate multi-channel data acquisition system (Eckelmann Industrie-automation GmbH, Germany) have been used. Each measurement channel of this system includes an amplifier, low frequencies filter, high-speed ADC (up to 1 Ms/s) and digital memory 0.5 Mbytes. Additional connectors, cables, wires connection, path checking were done.

For determination of transfer relationship for used strain gages the calibration procedure was executed. Validity and reliability of the constructed analytical model can be proven by substitution of output signals derived during the calibration procedure and subsequent comparison of calculation results with known calibration loads. Expected errors with accepted recovery procedure were estimated in order of 0.5%.

Experimental results

Typical records with balance system N1 are shown in the Fig. 7. The large model was installed during these experiments at the angle of attack of 15 degrees to the flow velocity. In the upper part of each picture one could see a row data records with strong oscillations due to balances native frequency. In the lower part these results are shown after Fourier transform filtering. It can be seen from this Figure wind tunnel flow established of about 0.030 s. After that stagnation pressure during the run (during 0.25 s) is sustained as constant with accuracy of 0.4 % and working gas is flowing around the model with Mach number of $M = 3.95$. At the point of 0.32 s the flow in the nozzle is destroyed by adverse pressure in the vacuum tank and the run is finished. During the run useful interval output signals from balance system were registered.

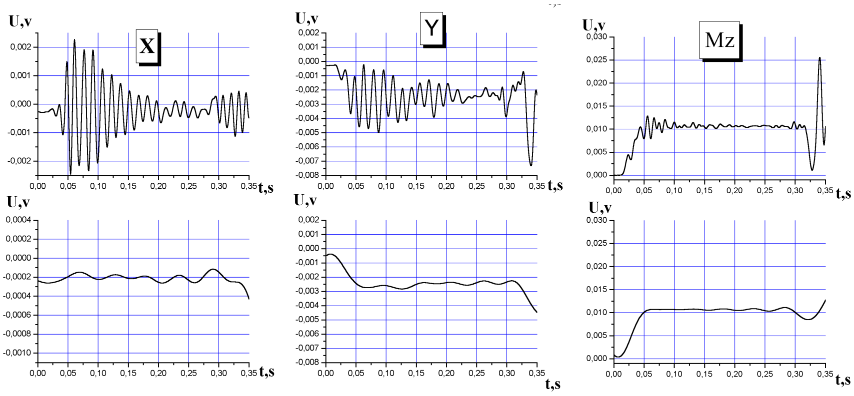

Fig. 7. Typical experimental records
and these results after processing

The main part of these results are plotted in the Fig. 8. Calculations of aerodynamic characteristics were done by A.P. Shaskin and T.A. Korotaeva. Calculated predictions are shown in those figures too. It is seen from the picture a very good agreement occurred between experimental and calculation results on Cy and Cm coefficients for tested model. Experimental results on Cx coefficient demonstrated reasonable accuracy. It was found that co-axial arrangement of the model and balance strut has been adopted in tests is not fit well for X load measurements. This circumstance could be explained to the fact that total value of X loads was not exceed 50 - 60 g (commonly 10 - 20 g) while measurement errors for X component is the same order (approximately 8 g). Moreover some difficulties have met with large value of Mz in this situation. So the non-axial fitting of model and balance strut (side strut) was designed and checked out for small model testing. For evaluation of the force measurement repeatability the large model was tested many times sequentially at the angle of attack of 17.5 degrees. Resulting from 12 runs

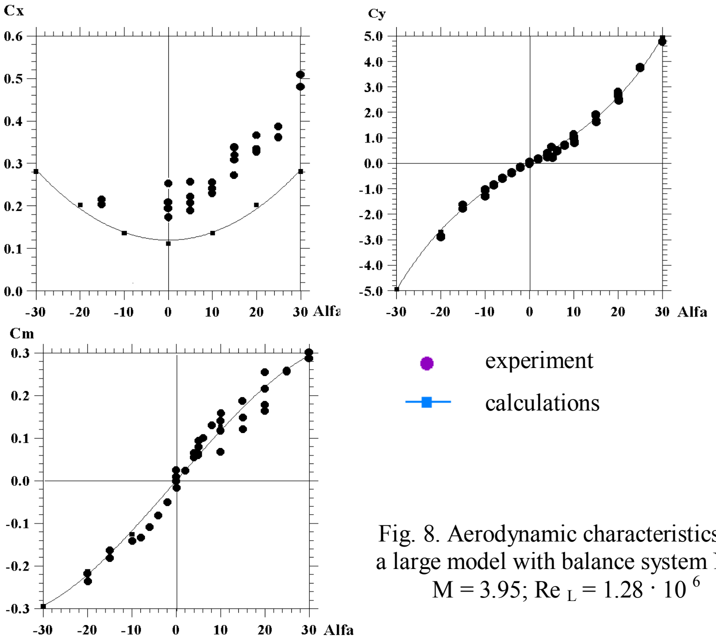

Fig. 8. Aerodynamic characteristics of
a large model with balance system N1.
M = 3.95; Re $_L$ = 1.28 · 10 ^{6}

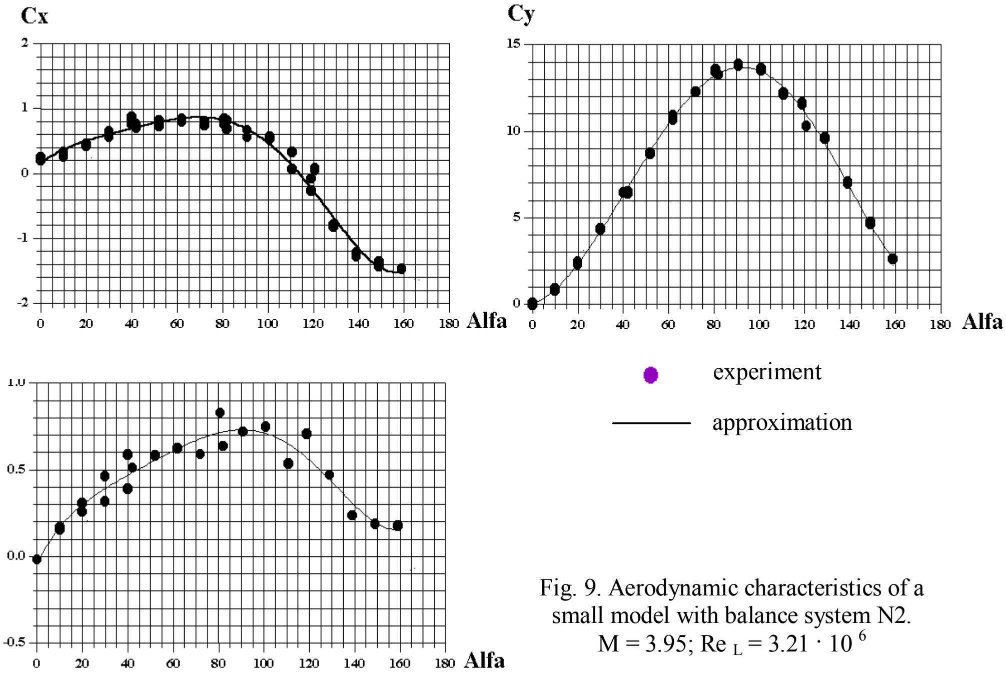

Fig. 9. Aerodynamic characteristics of a small model with balance system N2. M = 3.95; Re $_L$ = 3.21 · 10 ^{6}

measurement deviation (root-mean squares) for each component of used balance system are presented in the table 1.

Mean value	Deviation	Deviation, %
Cx = 0.33	σCx = 0.02075	σCx / Cx = 6.3 %
Cy = 2.3	σCy = 0.03497	σCy / Cy = 1.5 %
Cm = 0.18	σCm = 0.0048	σCm / Cm = 2.7 %

Typical records of balance system N2 with small model show that oscillations are not so noticeable and the simple averaging procedure was enough for obtaining of mean value. Obtained values of aerodynamic coefficient of small model are presented in Fig. 9.

Finally, high level of accuracy of aerodynamic load measurements was achieved in short duration supersonic wind tunnel due to small mass of tested model. The results obtained dilate capabilities of ITAM and led to guidelines to ensure the quality of the aerodynamic coefficients measured in short duration facilities.

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