Scientific Technical Review, 2012,Vol.62,No.3-4,pp.14-20

UDK: 533.6.071.3:355.4.24, 5:629.735
COSATI: 01-01, 19-07, 16-04

Testing an Anti Tank Missile Model with Jet Simulation in the T-35 Subsonic Wind Tunnel

Goran Ocokoljić[1)]
Boško Rašuo[2)]

In this paper, the wind tunnel test results of an Anti Tank Missile Model (ATM) with and without thrust vector control (TVC) jet simulation are presented. Since the lateral jets have influence on missile aerodynamic characteristics, the aerodynamic coefficients of the missile with lateral jets have to be known. This is especially important in the process of defining an accurate and efficient guidance algorithm. The main task of these experiments was to provide an experimental data base for the estimation of real effects of jets. A high pressure air installation for the jet simulation in the wind tunnel test section was described. The analysis was presented for Mach number 0.2, model configurations with and without jets, and three jet tab positions: tabs out of the jets and the upper or lower tabs in the jets. The experimental results are presented by the normal force and the pitching moment coefficients. The results obtained by flow visualization with tufts are also shown.

Key words: **aerodynamic testing, anti tank missile, aerodynamic characteristics, thrust vector, subsonic flow, wind tunnel.**

Labels

FDY – side force, N
FRZ – normal force, N
FDL – rolling moment, Nm
FDM – pitching moment, Nm
FDN – yawing moment, Nm
C_N – normal force coefficient
C_m – pitching moment coefficient
C_Y – side force coefficient
C_l – rolling moment coefficient
C_n – yawing moment coefficient
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, °
β' – sideslip angle, °
ϕ' – rolling angle, °
F.S. – Transducer full scale
ATM – Anti Tank Missile
MSS – Model Support System
TVC Trust Vecor Control
VTI Military Technical Institute

Introduction

IN the experimental aerodynamics, the effect of jet influence on data obtained in wind tunnels is a very important issue. Base pressure and base drag are significantly affected by jet influence, as well as body drag, lift forces, static moment and damping derivatives. The wind tunnel measurements of an ATM model were done in the T-35 large subsonic wind tunnel of the Military Technical Institute (VTI) [1,9].

The T-35 wind tunnel is not designed for testing wind tunnel models with started rocket motors, so a simulation of lateral jets was done [2].

In the T-35 wind tunnel, high pressure air was used for the jet simulation. For the measurements of the aerodynamic load, a five-component monoblock strain gauge balance was used.

The test includes the determination of the model aerodynamic coefficients and flow visualization.

The boundary layer flow visualization on the model was included in the test program to get more information about the flow, especially on the tail section. The deviation of the test results can be analyzed using the images of flow visualization.

The boundary layer flow visualization was performed at Mach number M=0.2 and the visualization by tufts was therefore the best choice with a number of opportunities.

Besides the ATM model, the T-35 wind tunnel, the instrumentation, data recording, data reduction, the visualization method and the course of the experiment are described in this paper. The comparative analysis of the aerodynamic coefficient results and the flow visualization images was performed. The summary of the investigation results is given in the conclusion.

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

---

1) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA
2) University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade, SERBIA

Experiment

Test program

The testing of the ATM model in the T-35 wind tunnel, Fig.1, is a part of the project of the ATM model with trust vector control.

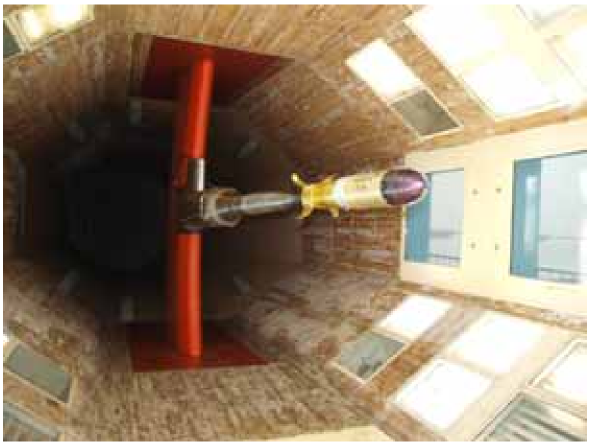

Figure 1. The ATM model on the MSS in the T-35 wind tunnel

The test objective was to determine the model aerodynamic characteristics with and without lateral jets and the flow visualization around the model. The test program included the testing of the ATM model in the subsonic velocity range, in the T-35 wind tunnel test section with a rear support for the range of angles of attack $-6^o < \alpha < +6^o$, with an increment of 1^o, and the rolling angles of $\phi = 0^o$ (nozzles in the horizontal plane) and $\phi = 90^o$ (nozzles in the vertical plane), Figs. 2 and 3, respectively.

Figure 2. The ATM model on the MSS in the T-35 wind tunnel, $\phi = 0^o$

Figure 3. The ATM model on the MSS in the T-35 wind tunnel, $\phi = 90^o$

Testing with these rolling angles was intended to determine jet influence in two cases: with the jets acting in the yaw plane and with the jets acting in the pitch (moving) plane. The objective was the preliminary estimation of the influence of jets on the results, taking into account the difference between the obtained values of the aerodynamic coefficients.

T-35 Wind tunnel

The T-35 wind tunnel of the VTI is located in Belgrade. The wind tunnel is of continual type. The test section has an octagonal cross-section, 4.4 m wide and 3.23 m high. The test section cross-section area is 11.93 m^2. The length of the test section is 5.5 m.

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

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

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

The value of Reynolds number is up to 12 millions/m.

The value of the total pressure in the test section is 1bar.

Theoretically speaking, the duration of the test is unlimited.

Model

The BUMBAR ATM model was designed and produced by the Military Technical Institute. The model is scaled 1:1. The model length is 931.7 mm and the diameter is 136 mm. The geometric characteristics of the model are shown in Fig.4. The CAD/CAM model of the Anti Tank Missile model is shown in Fig.5.

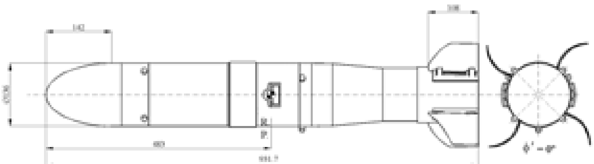

Figure 4. ATM model BUMBAR basic dimension, roll angle $\phi' = 0^o$

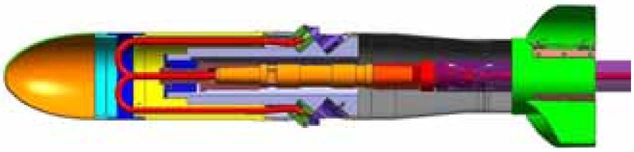

Figure 5. CAD/CAM model with the jet simulation installation, roll angle $\phi' = 90°$

Figure 6. Jet simulation installation

The model was made of aluminium alloy. Its main part is the central body made of duralumin. The model central body was designed for the setting of the internal wind tunnel balance as well as for a complicated system for the jet simulation in Fig.6.

The deflector details, the areas for housing the nozzles and the tabs for jets direction change are shown in Fig.7. The model has two lateral nozzles. The angle between the model axis and the nozzle axis is 40°, and the nozzles are positioned in the centre of gravity of the model. Three positions can be achieved with tabs: tabs out of the jets and the upper or lower tabs in the jets, see Fig.7.

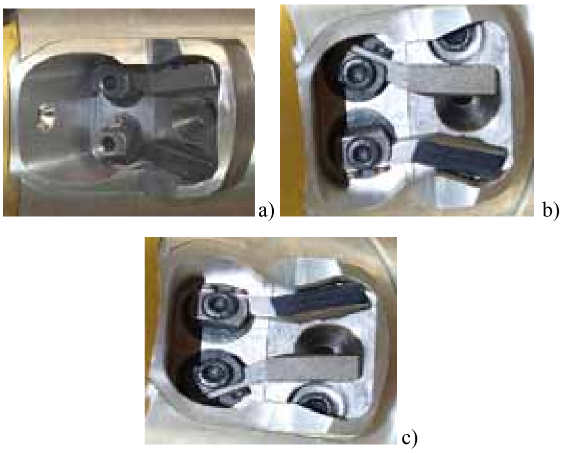
a) b) c)

Figure 7. Deflector details – a) tabs out of the jets, b)upper tabs in the jets, c) lower tabs in the jets

Instrumentation and data acquisition

An absolute pressure transducer, manufactured by Mensor, with a Bourdon quartz pipe, is used for the measurement of 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. The non-linearity and hysteresis of these transducers are 0.02% F.S. The transducer is calibrated along with the system for data acquisition.

The static and total pressure difference P_{st}-P_0 is measured by the differential pressure transducer, manufactured by Druck, with a range of 0.07 bars. The measurement points are openings on the wind tunnel wall, at the exit of the collector. The 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.

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

The aerodynamic forces and moments acting on the model were measured by the five-component monoblock strain gauge balance in Fig.8.

This balance was designed with the hollow center allowing the passage of the high pressurized air used for jets simulation. The balance was used as a part of a high pressure installation.

The accuracy of the balance was approximately 0.3% of the full scale for the axial-force component and 0.20% of the full scale for other components.

The range of balance is 2200 N for the normal force, 2200 N for the side force, 220 Nm for the pitching moment and yawing moment and 120 Nm for the rolling moment. The balance was calibrated before the T-35 wind tunnel tests [2-3].

The balance check is performed by applying dead weights at known locations immediately prior to testing, and it is confirmed that the accuracy is within the nominal limits [4].

Figure 8. Five-component monoblock wind tunnel balance

The resolvers are located in the mechanism for model movement, measuring the angle of attack, the sideslip angle and the rolling angle of the model.

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

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

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

The A/D converter with a resolution of 16 bits digitalizes data from the analogue channel. The 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.

The 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 T35-APS wind tunnel reduction software. The data reduction has several phases:

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

There is a different software module for each reduction phase.

Several axes systems were used in data reduction. The axes system used for the presentation of the results in this article is the non-rotated body axes system (see Fig.6).

The origin of the non-rotated body axes system is in the moment's reference point of the model. The X_p axis is parallel to the longitudinal axis of the model and positive towards the nose. The Z_p axis lies in a plane whose orientation is chosen as parallel to the "nominal" orientation of the transverse velocity component (i.e. for this model, in the pitch plane of the model support mechanism) and it is positive in the direction opposite to that of the cross-flow component of air velocity relative to the model when the angle of attack is positive. The Y_p axis completes the right-hand coordinate system. The aerodynamic coefficients C_A and C_N of the axial and normal force are in the directions opposite to the directions of the X_p and Z_p axes. In tables presenting data in this axes system, the aerodynamic angles are expressed as the angle of attack α' and the angle of sideslip β' (defined later in this paper). When both α' and β' are zero, all three axes of this system are in the opposite directions to those of the body axes system. The non-rotated body axes system is also referred to as the non-rolling body axes system or the semi-fixed axes system. Fig.9 shows the orientation of the non-rotated body axes system relative to the test section axes system.

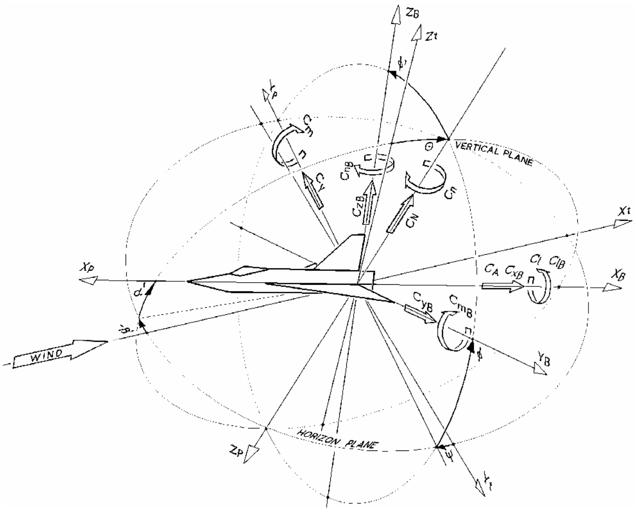

Figure 9. The non-rotated body axes system

Jets simulation installation

The simulation of the ATM engine was performed with the high pressure installation where the high pressurized air was used instead of combustion products [5]. The installation includes the following elements, Fig.10:

- two stages pistons air compressor Bauer 300 bar,
- high pressure pipelines 200 bar,
- air storage tanks, total volume 10 m^3,
- Druck absolute transducer range 50 bar, used for the static pressure measurement in the jets installation, accuracy 0.02% of the full scale,
- Druck absolute transducer range 100 bar, used for the total pressure measurement in the jets installation, nonlinearity and hysteresis 0.02% of the full scale,
- power supply Hottinger Baldwin, which supplies Druck transducers, digital data were received by the NEFF data acquisition system and written on the disc for further processing,
- copper-constantan thermocouple probe with a closed head 2mm in diameter, used for the temperature measurement in the jets installation, accuracy of ±1K,
- two lateral nozzles,
- four tabs (two upper and two lower ones) for changing jet directions.

The wind tunnel experiment included the testing of the model at Mach number 0.2, with and without jets. During the testing with jet simulation, the following conditions were realized:

- the regulation of the pressure in the installation had manual control,
- the tabs were out of the jets,
- the pressure in the tanks was 40 bar

The value of the high pressure air flow in the installation was about 0.3 kg/s.

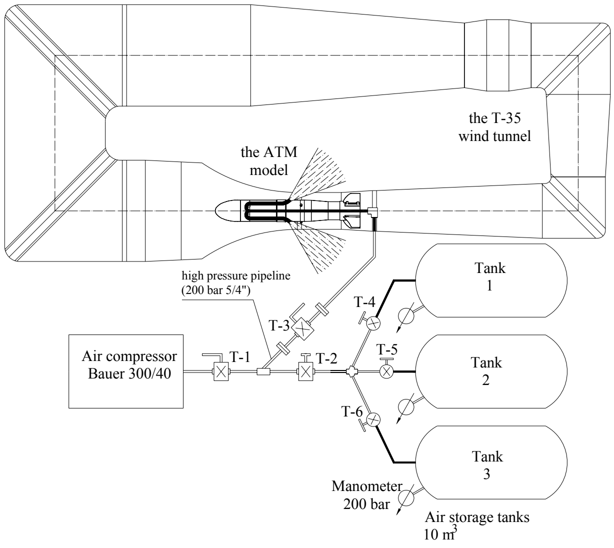

Figure 10. Jets simulation installation

Flow visualization

Flow visualization by tufts was used for the flow field investigation around the ATM model. The tufts were glued onto the model surface and bending of tufts was recorded since, being considered to be thin enough and without inertia, they are able to follow all changes of the local velocity vector. During the course of selection of tufts characteristics and a technique of gluing and spreading them on the model surface, one must have in mind to bring a minimum disturbance into the flow in order to obtain the most possible authentic record.

Experimental results

The test results are given for the model referent point (R.P.) located at the distance of 483 mm from the model nose. The model referent length was 136 mm.

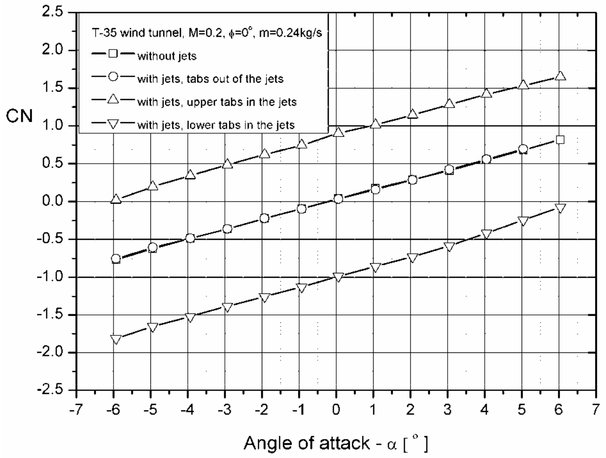

Figure 11. Normal force coefficient, ϕ = 0°

In the wind tunnel testing with lateral jets it can be expected that the static pressure will decrease in the area of the model which is behind the nozzles. This can be explained by the presence of jets which behave like barriers in the undisturbed flow [6].

In the testing with lateral jets, in the model fins region, an intense decreasing of the static pressure was expected. The decrease of the static pressure results in pitching moment decreasing.

The comparison between the testing with and without lateral jets is shown in Figs. 11-14. The results are presented by the normal force C_N and the pitching moment coefficients C_m.

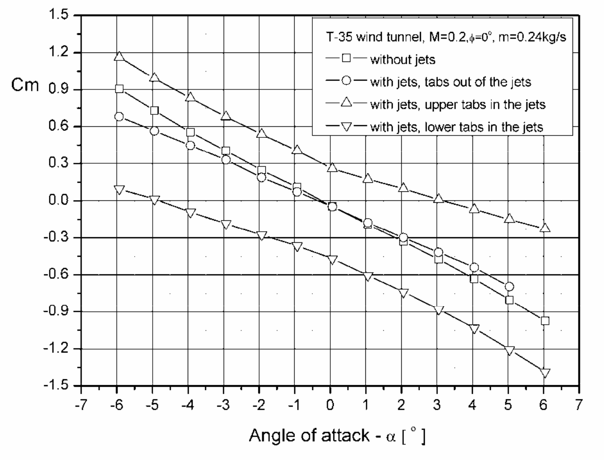

Figure 12. Pitching moment coefficient, $\phi = 0°$

In Figs. 12 and 13, the diagrams of the normal force and the pitching moment coefficients are shown, obtained by testing at $M = 0.2$, at the model rolling angle of $\phi' = 0°$.

The jets have the biggest effect on the test results at high angles of attack. It can be concluded from these graphs that the influence on the pitching moment coefficient C_m is much bigger than on other coefficients. The jet effects on the normal force coefficient C_N are the smallest. The influence on the axial force coefficient C_A was not determined because the axial force was not measured in these measurements.

The unexpected big effect on the pitching moment coefficient C_m was at a roll angle of 90°, when the lateral jets have acted in the pitch plane. Then we cannot expect significant changes in the value of the C_m coefficient because when the jets acted in the pitch plane we controlled the ATM in the yaw plane. However, in this case, the experiment revealed a huge influence of lateral jets on the pitching moment coefficient [7].

It can also be concluded from these graphs that the bigger mass flow causes the bigger jets influence on the pitching moment coefficient.

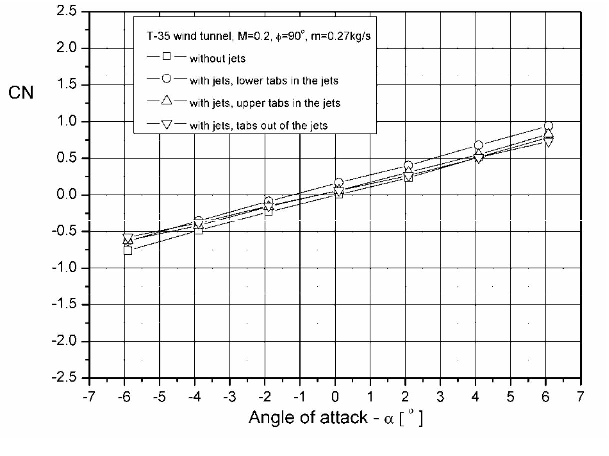

Figure 13. Normal force coefficient, $\phi = 90°$

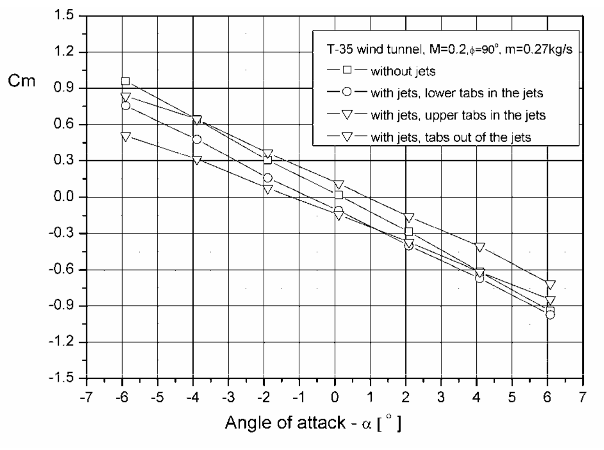

Figure 14. Pitching moment coefficient, $\phi = 90°$

In this analysis, the relative influence is obtained as the difference between different setup conditions. The obtained test results cannot be generalized. Nevertheless, as expected, the experiment has shown that there are significant differences in the obtained test results with and without jets in which the authors of this paper were convinced during the ATM model wind tunnel testing.

The effects of the flow visualization around the ATM model rear section at Mach number $M = 0.2$ in the T-35 wind tunnel are shown in Figs. from 15 to 18.

Using visualization with tufts, a very good, clear and expected figure of the flow around the ATM model was observed. The results obtained by flow visualization confirmed the results obtained from the previously done experiments without visualization. The effects of the visualization test with tufts are clearly visible. The flow visualization method by tufts in the boundary layer was a very good choice for obtaining a clear picture of a flow around a model.

Figure 15. Flow visualization around the ATM model rear section at $M = 0.2$, $\alpha = 6°$ and $\phi' = 0°$, without jets

Figure 16. Flow visualization around the ATM model rear section at $M = 0.2$, $\alpha = 6°$ and $\phi' = 0°$, with jets, tabs out of the jets

Figure 17. Flow visualization around the ATM model rear section at $M = 0.2$, $\alpha = 6^{\circ}$ and $\phi' = 0^{\circ}$, with jets, upper tabs in the jets

Figure 18. Flow visualization around the ATM model rear section at $M = 0.2$, $\alpha = 6^{\circ}$ and $\phi' = 0^{\circ}$, with jets, lower tabs in the jets

Conclusion

The experimental research in the T-35 wind tunnel enabled the determination of the aerodynamic coefficients of the ATM model. Based on the experimental results, the preliminary estimation of the jets influence is given.

The testing of the ATM model in the T-35 wind tunnel at Mach number M = 0.2 with jets simulation is first carried out. The main goal of the experiment - to provide experimental data for the purpose of uncertainty analysis of the numerical simulation results - has been accomplished.

The basic flow parameters, Mach number and pressure, are within the accuracy limits of the measuring devices and the equipment, the same for all tests.

The test program of the ATM was successfully implemented. In this paper, the results obtained at Mach number $M = 0.2$ were considered. The internal five-component wind tunnel balance was used for the measurement of the model aerodynamic forces and moments.

It should be noted that the obtained values of the aerodynamic coefficients were expected. The results of the ATM model test in the T-35 wind tunnel can be used for further comparative analyses and they will prove to be of great benefit in future tests.

Based on this experiment, it can be concluded that the flow visualization method by tufts is very useful for examinations in wind tunnels and for verifications of some numeric methods.

The results of this experiment are evidence that it is very useful to use more methods of investigation in order to get more reliable results.

Obtained flow visualization results can be completely accepted and stated conclusions used for further activities.

References

[1] OCOKOLJIĆ,G.: *Testing of the ATM model with missile engine simulation in the T-35 wind tunnel*, Internal report V3-3053-I-06.

[2] American Institute of Aeronautic and Astronautics: *Recommended Practice-Calibration and Use of Internal Strain-Gauge Balances with Application to Wind Tunnel Testing*, AIAA-R-091-2003.

[3] VITIĆ,A., OCOKOLJIĆ,G.: *VTI-385 Wind Tunnel Balance Calibration Results*, Internal report V3-3031-I-07.

[4] VUKOVIĆ,Đ.: *An alternative method of the multicomponent wind tunnel balances*, Aeronautics, Belgrade, 2009.

[5] OCOKOLJIĆ,G., ŽIVKOVIĆ,S., VITIĆ,A.: *Design of the ATM model with missile engine simulation*, In Proc. 3rd OTEH Conference, 2009, pp.159-165.

[6] OCOKOLJIĆ,G.: *Flow visualization with tufts around the wing section of the ATM model with missile engine simulation in the T-35 wind tunnel*, Internal report V3-3054-I-06.

[7] OCOKOLJIĆ,G., ŽIVKOVIĆ,S., SUBOTIĆ,S.: *Aerodynamic coefficients determinations for the ATM model with lateral jets simulation-experimental and numerical methods,* In Proc. 4th OTEH Conference, 2011, pp.17-22.

[8] OCOKOLJIĆ,G., RADULOVIĆ,J.,: *Flow visualization and aerodynamical determination for the LASTA-95 model in the T-35 wind tunnel,* Scientific Technical Review, ISSN 1820-0206, 2006,Vol.LVI, No.2, pp.63-69.

[9] RISTIĆ,S.,: *Flow visualization techniques in wind tunnels-non optical methods (part I),* Scientific Technical Review, ISSN 1820-0206, 2007, Vol.LVII, No.1, pp.39-50.

Received: 18.09.2012.

Ispitivanje modela protivtenkovske rakete sa simulacijom mlaza u podzvučnom aerotunelu T-35

U radu su prikazani rezultati ispitivanja modela protivtenkovske rakete sa i bez simulacije upravljanja vektorom potiska (UVP). Pošto bočni mlazevi imaju uticaj na aerodinamičke karakteristike rakete, njihov uticaj mora biti poznat. Ovo je posebno važno u procesu definisanja preciznosti i efikasnosti algoritma vođenja. Osnovni zadatak ovog eksperimenta bio je da obezbedi eksperimentalnu bazu podataka za određivanje realnog uticaja mlaza. Takođe, opisana je i instalacija pod visokim pritiskom korišćena za simulaciju mlaza u radnom delu aerotunela. Analiza je izvršena za Mahov broj 0.2, konfiguracije modela sa i bez modela simulacije mlazeva, i tri pozicije brana: brane van mlaza, gornje i donje brane uronjene u mlaz. Eksperimentalni rezultati su predstavljeni preko koeficijenata normalne sile i momenta propinjanja, a takođe, prikazani su i rezultati dobijeni vizualizacijom strujanja pomoću končića.

Ključne reči: **aerodinamičko ispitivanje, PO raketa, aerodinamičke karakteristike, vektor potiska, subsonično strujanje, aerodinamički tunel.**

Тестирование модели противотанковой ракеты с имитирующим потоком в дозвуковых аэродинамических трубах T-35

В данной работе представлены результаты тестирования модели противотанковой ракеты с учётом моделирования и без имитирования управления вектором тяги (УВТ). Так как боковые струи оказывают влияние на аэродинамические характеристики ракеты, их влияние должно быть известным. Это особенно важно в процессе определения точности и эффективности алгоритма управления. Основная цель этого эксперимента заключалась в предоставлении экспериментальной базы данных, чтобы определить реальное воздействие струи. Здесь также описана и установка высокого давления используемая для имитирования струи в тестовом разделе аэродинамической трубы. Анализ проводился по числу Маха 0,2, конфигурации модели со и без имитационной модели потоков, и по три позиции плотин: плотины вне потока, верхние и нижние плотины погружены в поток. Экспериментальные результаты представлены через коэффициенты нормальной силы и момента тангажа, а также представлены и результаты, полученные с помощью проточной визуализации с помощью пучков.

Ключевые слова: **аэродинамические испытания, противотанковые ракеты, аэродинамические характеристики, вектор тяги, дозвуковой поток, аэродинамическая труба.**

Essai du modèle du missile antichar avec la simulation du jet dans la soufflerie subsonique T-35

Les résultats des essais du modèle de missile antichar avec ou sans simulation du contrôle du vecteur de poussée ont été présentés dans ce papier. Comme les jets latéraux influent sur les caractéristiques aérodynamiques du missile leur influence doit être connue. Cela est très important dans le processus de définition de la précision et de l'efficacité de l'algorithme de guidage. La tâche principale de cet essai était d'assurer la base expérimentale des données pour la détermination de l'influence réelle du jet. On a décrit aussi l'installation sous la haute pression utilisée pour la simulation du jet dans la section expérimentale de la soufflerie. L'analyse a été réalisée pour le Mach 0.2 de la configuration du modèle avec ou sans simulation du jet et avec trois positions d'obstacles: obstacles en dehors du jet, obstacles supérieures et inférieures plongés dans le jet. Les résultats expérimentaux ont été présentés par les coefficients de la force normale et du moment de tangage. On a présenté également les résultats obtenus par la visualisation du courant à l'aide du fil.

Mots clés: **essai aérodynamique, missile antichar, caractéristiques aérodynamiques, vecteur de poussée, courant subsonique, aérodynamique.**