

Subsonic Dynamic Stability Experiment on the Anti Tank Missile Model

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One of the most difficult aspects of aircraft and missile development is defining stability and control characteristics. The best way to obtain model-scale dynamic stability derivatives is to perform experiments in wind tunnels having high Reynolds number. In the T-38 wind tunnel the forced oscillation technique is used for the measurement of stability derivatives. This technique enables measurements of the full complement of damping, cross and cross-coupling moment derivative due rolling, pitching and yawing. Results of the experimental determination of the roll-damping derivative for the Anti Tank Missile Model are presented in this paper. The missile model was designed and produced by Military Technical Institute. The roll damping tests were conducted at Mach numbers 0.2, 0.4 and 0.6. The roll-apparatus, used in these tests, is apparatus with primary angular oscillation around a longitudinal axis of a model. Roll-damping coefficients, measured in the T-38 wind tunnel, are compared with results obtained by the semi-empirical method DMAC.

Keywords: wind tunnel, missile model, stability derivative, roll-damping derivative, oscillations, forced oscillation technique.

1. INTRODUCTION

In the past, most of the dynamic stability parameters were relatively easy to predict analytically, especially at low angles of attack. The dynamic stability derivatives were exhibited as rule only smaller variations with varying flight conditions and, therefore, had only a relatively insignificant or at least a relatively constant effect on the resulting flight characteristics of the aircraft or missile. In many cases it was therefore satisfactory in the flight mechanics analysis to use a constant value of a particular dynamic stability parameter [1].

With the advent of flight at high angles of attack and at high speeds, all that has drastically changed. The dynamic stability parameters are now found to depend strongly on nonlinear effects involving phenomena such as separated flows, vortex shedding, vortex bursts, etc., and can no longer be calculated using relatively simple linear analytical methods. In addition, these parameters are known now to sometimes undergo very large changes, perhaps of one or even two orders of magnitude often involving a change of sign, as a result of only minor variation in flow conditions (such as in the angle of attack) and therefore can easily become of significant importance for the flight behaviour of the aircraft or missile.

It is well known that many of the high-performance military aircraft have flight characteristics that become rather unsatisfactory when aircraft is performing manoeuvres near or above the stall or during the spin motion. The loss of control that often results has been

named as the direct cause of a large number of fatal accidents.

Dynamic stability information can in principle be obtained from model experiments in many different types of facilities. Here belong tests in aeroballistics or hypervelocity ranges, wind tunnel tests with free-flight tests, out-door free flight tests using either rocket-propelled or radio-controlled gliding models, wind-tunnel free-flight tests using remotely controlled dynamic models, or spin-tunnel experiments. All these techniques, however, have one common disadvantage—they are not suitable for experiment at high Reynolds numbers. In addition, although some of them can be used for extraction of dynamic stability derivatives from the model motion history, this is rarely done. Thus the main use of these techniques is for visual studies of the stability characteristics and motions of the aircraft or missile at low Reynolds numbers. The only possibility to obtain model-scale dynamic stability information at realistic Reynolds and Mach numbers lies in performing captive-model experiments in high Reynolds number wind tunnels. Dynamic stability derivatives can also be extracted from full-scale flight tests. But, the results of such tests are obtained too late to significantly affect the design of a new aircraft or missile. However, full-scale flight experiments are most essential for correlating the values various dynamic stability parameters and the flight behaviour of already existing aircraft [2].

This paper describes the dynamic stability experiments on the Anti Tank Missile Model, which was performed as part of the research program of the Military Technical Institute in Belgrade. The paper contains the selection of the direct damping derivative in roll and rolling moment due to angle of sideslip. The short range Anti Tank Missile with thrust vector control is shown in Figure 1 [3,4]. One of the most important flight characteristics of the Anti Tank Missile is rotation motion around its longitudinal axis. This flight

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characteristic caused the need for the wind tunnel measurements of the roll damping derivative. These measurements provided the necessary dynamic stability informations in the design phase of the new missile. The experiments were conducted in the T-38 wind tunnel [5, 6]. The T-38 test facility is blowdown-type pressurized wind tunnel with 1.5 x 1.5 m² square test section. The T-38 wind tunnel is high Reynolds number wind tunnel. Its Reynolds number capability is up to 140 millions per meter.



Figure 1. Anti Tank Missile with thrust vector control

2. DESCRIPTION OF THE EXPERIMENT

For the measurement of the stability derivatives in the T-38 wind tunnel the forced oscillation technique is used [7]. In this technique oscillatory motion is imparted to a model by an external force or moment. External force and moment between a model and forcing part of the wind tunnel apparatus are measured. A model motion is angular and sinusoidal and derivatives are obtained from in-phase and out-phase components of the measured aerodynamic reactions. Using this method, in principle both force and moment derivatives can be measured. The measurement can be made in same degree of freedom (primary degree of freedom) as the imparted oscillations resulting in damping derivatives. Also, the measurement can be made in other degree of freedom (secondary degrees of freedom) resulting in cross and cross-coupling derivatives.

A model oscillatory motion in roll is given by (1):

$$I_x \ddot{\varphi} + (\gamma_\varphi - J_{damp}) \dot{\varphi} + (k_\varphi - J_{st}) \varphi = |L_T| e^{j\omega t} \quad (1)$$

where I_x is the roll moment of inertia, φ is a model angular oscillatory motion in roll, γ_φ is the mechanical damping, k_φ the is mechanical stiffness, J_{damp} is the aerodynamic damping, J_{st} the is aerodynamic stiffness, $|L_T|$ is the amplitude of the excitation moment in roll, ω is a model angular velocity and t is time.

A model angular oscillatory motion in roll may be written as:

$$\varphi = |\varphi| \sin \omega t \quad (2)$$

where $|\varphi|$ is the amplitude of a model angular oscillatory motion.

The stiffness and damping can be obtained using (3) and (4):

$$k_\varphi, J_{st} = \frac{|L_T|}{|\varphi|} \cos \eta + I_x \omega^2 \quad (3)$$

$$\gamma_\varphi, J_{damp} = \frac{|L_T|}{|\varphi|} \sin \eta \quad (4)$$

where η is the phase shift between a model angular oscillatory motion in roll and the excitation moment.

Measurement of the aerodynamic damping using forced oscillation technique includes two stages: the tare run and wind-on run. In the tare run a model is oscillated but a wind tunnel is not running. The tare run enables measurements of the mechanical damping and mechanical stiffness. In the wind-on run a model is oscillated at the same frequency and amplitude as during the tare run, but with a wind tunnel running. The wind-on run enables measurement of the total damping and total stiffness. The aerodynamic damping and aerodynamic stiffness are obtained as a difference between the total damping and total stiffness obtained in the presence of aerodynamic load and mechanical damping and mechanical stiffness which are obtained in absence of aerodynamic load.

The equations for determination of the static and dynamic stability derivatives in roll may be written as:

$$J_{st} = -I_x (\omega^2 - \omega_o^2) - \left(\frac{|L_T|}{|\varphi|} \cos \eta - \frac{|L_{To}|}{|\varphi_o|} \cos \eta_o \right) \quad (5)$$

$$J_{damp} = \left(\frac{|L_{To}|}{|\varphi_o|} \frac{\sin \eta_o}{\omega_o} - \frac{|L_T|}{|\varphi|} \frac{\sin \eta}{\omega} \right) \quad (6)$$

In the (5) and (6) all values with index (o) are measured in the tare run.

In the body axis system (see Figure 2), formulas for the determination of the static and dynamic derivative in roll may be written as:

$$J_{st} = L_\beta \sin \alpha \quad (7)$$

$$J_{damp} = L_p + L_{\dot{\beta}} \sin \alpha \quad (8)$$

where $L_\beta \sin \alpha$ is rolling moment due to angle of attack and $L_p + L_{\dot{\beta}} \sin \alpha$ is direct damping derivative in roll.

Non-dimensional coefficients are obtained in the following forms:

$$C_{l\beta} \sin \alpha = \frac{L_\beta \sin \alpha}{q_\infty S d} \quad (9)$$

$$C_{lp} + C_{l\dot{\beta}} \sin \alpha = \frac{L_p + L_{\dot{\beta}} \sin \alpha}{\frac{q_\infty S d^2}{2V}} \quad (10)$$

where q_∞ is dynamic pressure, d is a model reference length, S is a model reference area and V is free stream velocity.

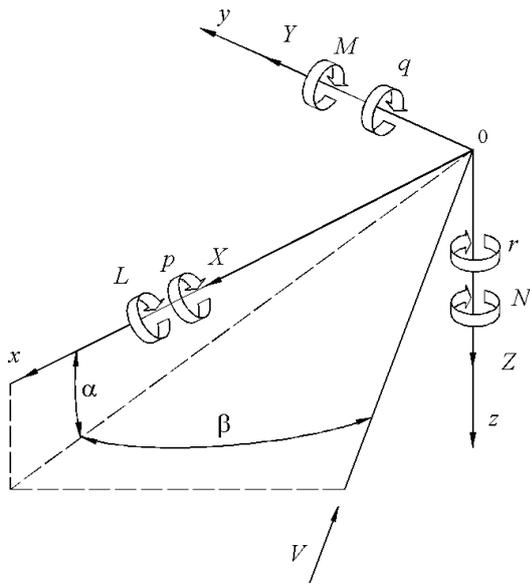


Figure 2. Body axis system



Figure 3. Roll apparatus

The roll apparatus in the T-38 wind tunnel is a full-model forced oscillation apparatus with the primary angular oscillation around a longitudinal axis of a model. Forward part of this apparatus is shown in Figure 3 [8, 9]. Basic elements of the apparatus are: sting support system, elastic suspension system, five-component wind tunnel balance, hydraulic driving mechanism and servomechanism which ensures a constant amplitude primary motion.

The basic performance parameters of the roll apparatus are:

- model oscillation amplitude: 0.25°-1.5°;
- model oscillation frequency: 1-15 Hz;
- sting diameter: 76 mm;
- hydraulic pressure: 200 bar;
- maximum axial force: 5500 N;
- maximum side force: 7000 N;
- maximum normal force: 18 000N;
- maximum rolling moment: 300 Nm;
- maximum pitching moment: 660 Nm;
- maximum yawing moment: 350 Nm.

The elastic suspension system consists of the two rings jointed by axially oriented beams equally spaced around the periphery of the rings. Two suspensions systems are designed and manufactured for this

apparatus: one for low aerodynamic loads and second for high aerodynamic loads. The five-component wind tunnel balance is mounted on the front and of the drive shaft, protruding forward through the cavity surrounded by the suspension beams, while the aft part of suspension system is firmly fixed to the end of the sting. Hydraulic driving mechanism is located at the rear end of the sting. The oscillatory rolling motion is imparted via drive shaft whose front end is attached to the balance. The apparatus includes the primary oscillatory motion sensor and excitation moment sensor.

In order to obtain the static and dynamic stability derivatives, the following data are required:

- amplitude and frequency of a model angular oscillatory motion;
- amplitude of the excitation moment;
- phase shift between a model angular oscillatory motion and excitation moment.

All of the above data are obtained by signals from the five-component wind tunnel balance and sensors on the roll apparatus. The forces and moments, that act on the model during experiments, are measured by the five-component wind tunnel balance [8, 9]. The amplitude of a model primary motion is measured by the sensor located on the elastic suspension system. The amplitude of the excitation moment is measured by the sensor located on the drive shaft or by suitable measuring bridge on the five-component wind tunnel balance.

During the wind tunnel experiments, all the sensors signals are amplified, filtered and then digitized by a 16-bit resolution A/D converter. The data acquisition system consists of a Teledyne 64 channel "front end". It is controlled by a PC computer. The data from the wind tunnel test runs are processed in the following steps:

- data acquisition system interfacing and signals normalization;
- determination of flow parameters;
- determination of model attitude;
- determination of the static aerodynamic coefficients;
- determination of the frequency, amplitude and phase shift of each signal with respect to the signal from a model oscillatory motion sensor;
- determination of the direct damping derivatives;
- calculation of the non-dimensional coefficients of the direct damping derivatives.

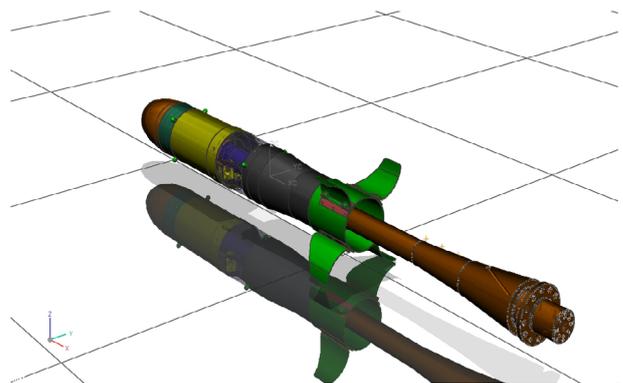


Figure 4. The Anti Tank Missile CAD/CAM model

2.1 The Anti Tank Missile Model

The Anti Tank Missile Model is made from aluminium alloy. The model length is 932 mm and diameter is 136 mm. The model CAD/CAM model is shown in Figure 4. The basic dimensions of the model are shown in Figure 5.

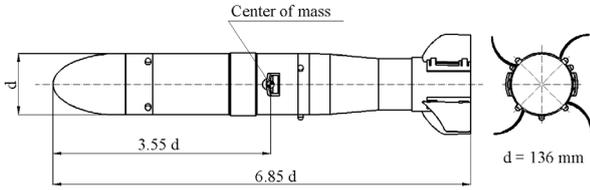


Figure 5. Basic dimensions of the Anti Tank Missile Model

3. EXPERIMENTAL RESULTS

The roll-damping measurements of the Anti Tank Missile Model were done at Mach number 0.2; 0.4 and 0.6. The Anti Tank Missile Model in the T-38 wind tunnel tests section is shown in Figure 6.

Flow parameters are obtained using standard software package from the measurement of stagnation pressure, stagnation temperature and static pressure in the wind tunnel test section.

The amplitude of the model angular oscillatory motion was 1° , as well as the frequency of the model oscillatory motion was 10 Hz. The amplitude of the excitation moment was measured with measuring bridge for the rolling moment on the internal five-component balance. The amplitudes and phase shift of the excitation moment were calculated in frequency domain by applying cross-power spectral density. The excitation moment signal from the balance measuring bridge was cross-correlated with primary signal generated by the primary oscillatory motion sensor.

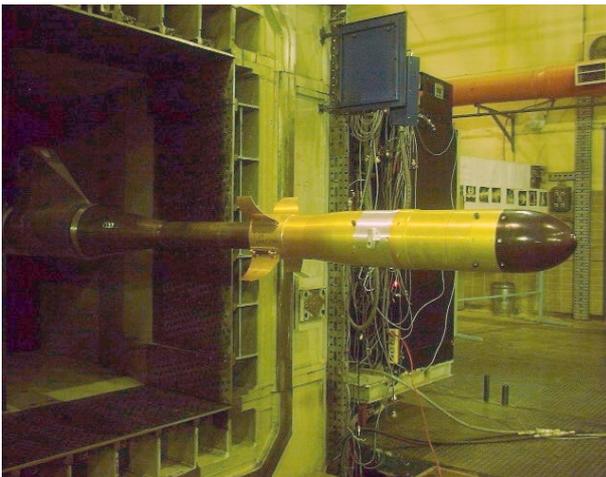


Figure 6. The Anti Tank Missile Model in the T-38 wind tunnel

The T-38 wind tunnel data (static aerodynamic coefficient, static rolling moment derivative, direct damping derivative in roll) are shown in Figures 7-15.

Roll damping coefficient measured in the T-38 wind tunnel are compared with DMAC calculated values for the model angle of attack $\alpha = 0^\circ$ [12].

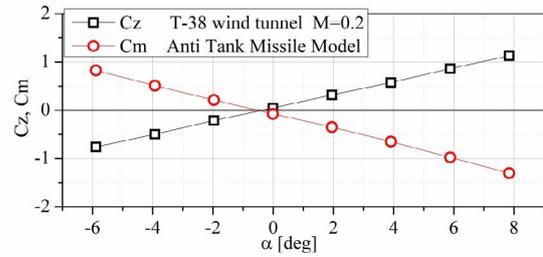


Figure 7. Aerodynamic coefficients, Mach number 0.2

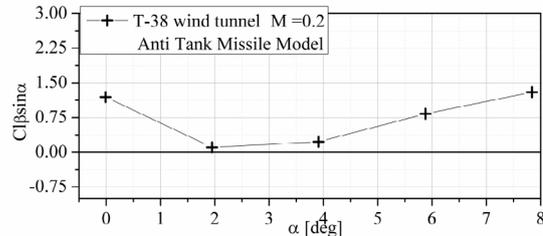


Figure 8. Rolling moment coefficient due to angle of sideslip, Mach number 0.2

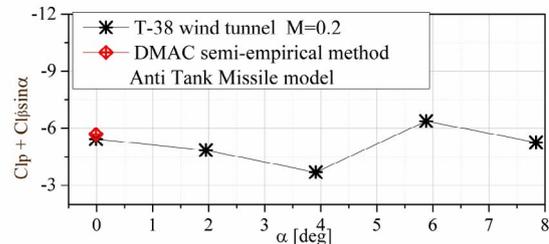


Figure 9. Direct damping coefficient derivative in roll, Mach number 0.2

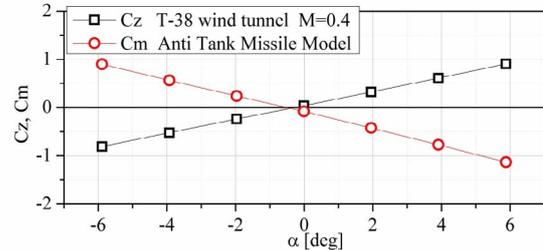


Figure 10. Aerodynamic coefficients, Mach number 0.4

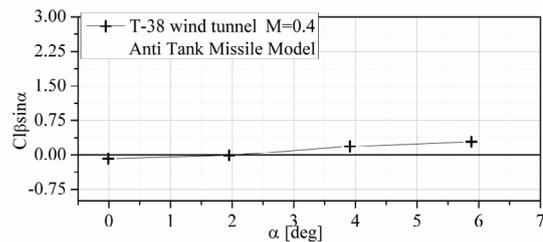


Figure 11. Rolling moment coefficient due to angle of sideslip, Mach number 0.4

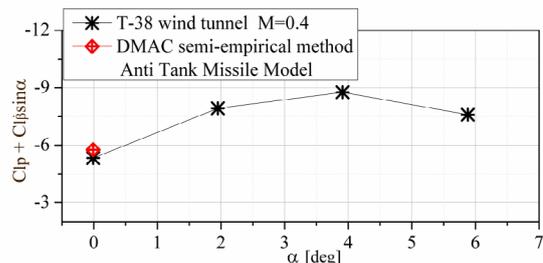


Figure 12. Direct damping coefficient derivative in roll, Mach number 0.4

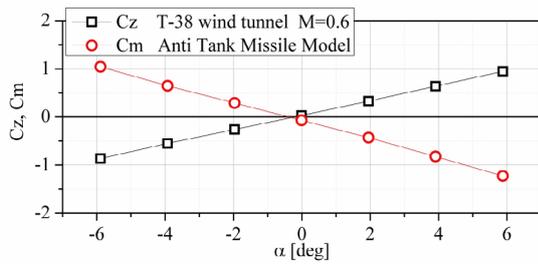


Figure 13. Aerodynamic coefficients, Mach number 0.6

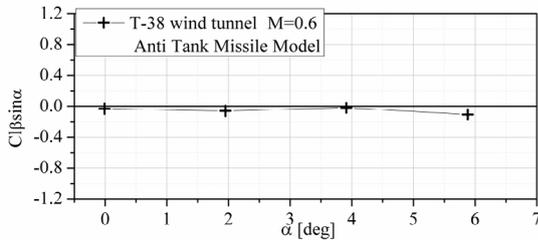


Figure 14. Rolling moment coefficient due to angle of sideslip, Mach number 0.6

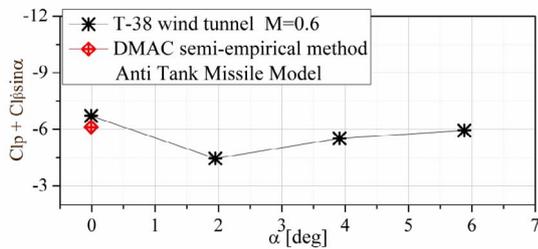


Figure 15. Direct damping coefficient derivative in roll, Mach number 0.6

4. CONCLUSION

The basic equations for determination of the rolling moment due to angle of sideslip and direct damping derivative in roll using forced oscillation technique are shown in this paper.

One part of the roll oscillatory test performed on the Anti Tank Missile Model in the T-38 wind tunnel is presented. No roll damping experimental data for this model were available before these tests. Computed roll-damping data for the model angle of attack $\alpha = 0^\circ$ showed very good agreement with the T-38 wind tunnel experimental data. At the time, when these experiments were conducted, DMAC semi-empirical method provided data only for the model angle of attack $\alpha = 0^\circ$. The T-38 wind tunnel experimental data have provided roll damping data for the whole required range of the model angle of attack, as well as verification of the data obtained by DMAC method.

The T-38 wind tunnel experiments presented in this paper are conducted after a series of the wind tunnel experiments on the standard calibration models [8]. These tests on the calibration models were done for the reason to verify modifications made on the roll apparatus. The modifications were primarily concerned to introduction of semiconductor strain gauges in the stability derivatives measurements. The first modification was a replacement of the foil five-component strain gauge balance with the semiconductor

five-component strain gauge balance. In the testing of the Anti Tank Missile Model amplitude of the excitation moment was measured with the rolling moment measuring bridge on the semiconductor balance. The design and manufacturing of the wind tunnel balance for the dynamic measurements in a blowdown wind tunnels are based on the very contrasting requirements. The wind tunnel balance has to be designed for huge loads at the start and the end of the wind tunnel runs. Also, this balance has to enable measurements of the very small values of the excitation moment amplitudes in the stability derivatives measurements. In the roll-damping measurements on the Anti Tank Missile Model measured amplitudes of the excitation moment were approximately 2 Nm. The semiconductor balance rolling moment full scale is 300 Nm [10, 11]. The measured amplitudes are only 0.67 per cent of the rolling moment full scale, but usage of the new balance with semiconductor strain gauges enables accurate determination of the oscillatory components of the signals and measurement of the roll-damping derivative on the Anti Tank Missile Model.

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NOMENCLATURE

C_z	normal force coefficient
C_m	pitching moment coefficient
L	aerodynamic rolling moment
M	aerodynamic pitching moment, Mach number
N	aerodynamic yawing moment
p	rolling angular velocity
q	pitching angular velocity
r	yawing angular velocity

X	aerodynamic axial force
Y	aerodynamic side force
Z	aerodynamic normal force

GREEK SYMBOLS

α	angle of attack
β	angle of sideslip

ЕКСПЕРИМЕНТАЛНО ОДРЕЂИВАЊЕ ДЕРИВАТИВА СТАБИЛНОСТИ НА МОДЕЛУ ПРОТИВТЕНКОВСКЕ РАКТЕ У ПОДЗВУЧНОЈ ОБЛАСТИ БРЗИНА

**Марија Самарџић, Горан Оцокољић,
Бошко Раџуо, Јован Исаковић**

Један од најсложенијих задатака у току развоја нових летелица (авиона и ракета) јесте одређивање карактеристика стабилности и управљивости. Најбољи начин за одређивање дериватива стабилности на моделима летелица јесте извођење експеримената у аеротунелима у којима се могу остварити високи Рејнолдсови бројеви. У аеротунелу Т-38 за мерење дериватива стабилности користи се метода крутих принудних осцилација. Ова метода омогућава одређивање пригушних, унакрсних и унакрсно-спрегнутих дериватива стабилности. У овом раду приказани су резултати експерименталног одређивања пригушног дериватива стабилности у ваљању на моделу противтенковске ракете. Модел је пројектован и израђен у Војнотехничком институту Београду. Мерење пригушења у ваљању урађено је на следећим Маховом бројевима: 0.2; 0.4 и 0.6. У експериментима је коришћен уређај са примарним осцилаторним кретањем око уздужне осе модела. Коефицијент пригушног дериватива стабилности измерен у аеротунелу Т-38 упоређен је са вредностима добијеним полу-емпиријском методом ДМАС.