UDK: 533.6.071.3
COSATI: 01-01, 16-04

Some Experimental Results of Subsonic Derivative Obtained in the T-38 Wind Tunnel by Forced Oscillation

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The results of an experimental determination of the subsonic direct damping derivative in roll are presented. The method applied in the T-38 wind tunnel is the rigidly forced oscillation technique [1-4]. The wind tunnel tests were conducted on two missile models: a Modified Basic Finner Model (*MBFM*), and a missile model developed in the *VTI* (*BUMBAR*) [5,8]. The tests were made at Mach number 0.6 for the *MBFM* model, and at Mach numbers 0.2, 0.4, 0.6 for the *BUMBAR* model. The obtained test results are compared with theoretical values for roll-damping coefficients obtained by the "*DMAC*" semi-empirical method [6] and for the *MBFM* model with results obtained in the *AEDC* wind tunnel [7].

Key words: **wind tunnel, experimental aerodynamics, aerodynamic derivatives, stability derivatives, subsonic flow, forced oscillation.**

Nomenclature

CLP, $C_{lp}+C_{\dot{\beta}}\sin\alpha$	– non-dimensional dynamic direct derivative in roll, [1/rad];
CLBETA, $C_{l\beta}\sin\alpha$	– non-dimensional static direct derivative in roll, [1/rad];
d	– model diameter, [m];
L_T	– amplitude of excitation moment, [Nm];
S	– model reference area, [m^2];
q	– dynamic pressure, [bar];
I_x	– moment of inertia, [kgm^2];
V	– velocity, [m/s];
M	– free stream Mach number,
α	– aerodynamic angle of attack, [°];
β	– aerodynamic sideslip angle,;[°]
φ	– amplitude of the primary motion, [°];
ω_R	– reduced frequency, $(\omega\cdot d/2V)$;
ω	– angular velocity, [1/s];
η	– phase shift.

Introduction

A technique for stability derivative testing in the T-38 wind tunnel is the forced oscillation technique, measurements of reactions. All the experiments are based on the application of small/amplitude oscillatory motion to a model in the primary degree of freedom and the measurement of aerodynamic reactions produced by such motion in that particular (primary motion) and in other (secondary motion) degrees of freedom [1-4]. These reactions yield relevant direct and cross as well as cross-coupling derivatives due the motion considered herein.

The results of the experimental determination of the subsonic direct damping derivative in roll for two missile models are presented in this paper. The first test was conducted on the Modified Basic Finner Model (*MBFM*) for the sake of verification of the roll apparatus [5]. This paper presents the results only for a Mach number of 0.6 in the range of the angle of attack from α = -5° up to α = 4.5°. The measured roll-damping coefficients were compared with the calculated roll-damping coefficient values by the semi-empirical methods "*DMAC*" [6] for α = 0° and with published experimental data from the *AEDC* wind tunnel (Arnold Engineering Development Center-von Karman - USA, [7]). A semi-empirical method "*DMAC*" is used in the VTI.

The second roll oscillations experiment was the roll-damping test on the *BUMBAR* model at Mach numbers 0.2; 0.4 and 0.6 in the range of the angle of attack from α = -6° up to α = 6°. The measured roll-damping coefficients for α = 0° were compared to the values calculated by the "*DMAC*". For Mach number 0.2 and for each angle of attack two test runs were done for checking repeatability of the measurement [8].

Apparatus and experimental procedure

Wind tunnel. The T-38 test facility of the Military Technical Institute (Vojnotehnički Institut) is a blowdown-type pressurized wind tunnel with a 1.5m x 1.5m square test section, [9]. For subsonic and supersonic tests, the test section is with solid walls, while for transonic tests a section with porous walls is inserted in the tunnel configuration. The porosity of walls can be varied between 1.5% and 8%, depending on Mach number, so as to achieve the best flow quality. The Mach numbers in the range 0.2 to 4.0 can be achieved in the test section, with Reynolds

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numbers up to 110 million per meter.

Models. The modified Basic Finner model geometry is a 2.5 caliber tangent-ogive cylinder fuselage with trapezoidal fins in the + configuration. The center of the mass is located 5 diameters from the nose along the longitudinal axis of the body. The basic dimensions of the *MBFM* model are presented in Fig.1. This model is a standard calibration model for dynamic wind tunnel tests.

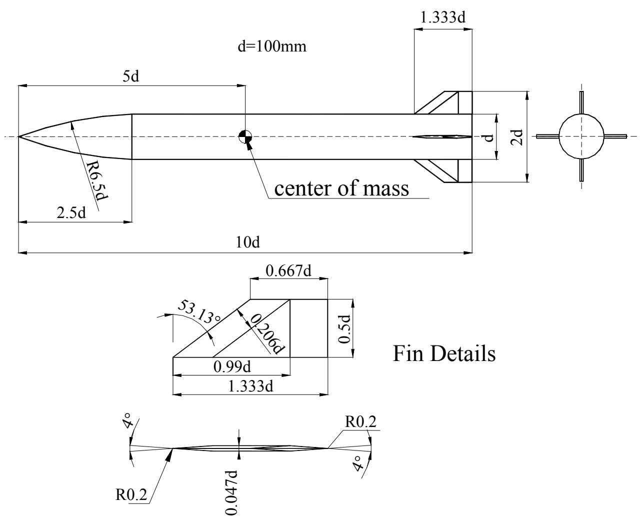

Figure1. Basic dimensions of the MBFM model

The basic dimensions of the *BUMBAR* model are presented in Fig.2.

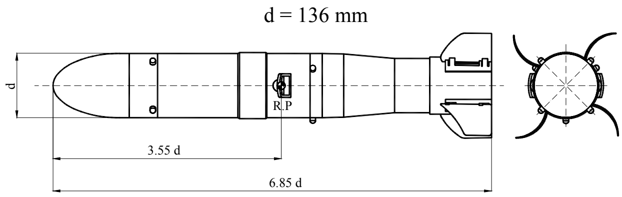

Figure 2. Basic dimensions of the BUMBAR model

The *MBFM* model and *BUMBAR* model mounted in the T-38 test section are shown in Figures 3a) and 3b)

a)

b)

Figure 3. *MBFM* model a) and *BUMBAR* model b) mounted in the T-38 test section

Forced-oscillation Apparatus. The oscillatory rolling motion is impaired by a hydraulic driving mechanism. The device includes the following sensors: primary oscillatory motion sensor, excitation moment sensor and feedback position sensor. A five-component internal balance is of a monoblock type and semiconductor strain gauges are used in order to increase its sensitivity, and consequently, signal to noise ratio as well [10].

Test Procedure. A typical wind tunnel run includes the following stages:

– tare run (wind-off run), when the model is oscillated but the tunnel is not running. This measurement enables determination of inertial forces,
– wind-on run, when model is oscillated at the same frequency as during the tare run but with the wind tunnel running.

The static and dynamic direct derivatives in roll are calculated using the following data for the wind-on and wind-off measurements: moment of inertia in the primary degree of freedom, amplitude and frequency of the primary oscillations, amplitude of the excitation moment, and phase shift between the signal from excitation moment sensor and the signal from the primary motion sensor. Non-dimensional coefficients of direct damping derivative in roll are calculated as:

$$C_{LBETA} = C_{l\beta}\sin\alpha$$
$$= \frac{1}{q\cdot S\cdot d}\left(-I_x\left(\omega^2-\omega_0^2\right)-\left(\left|\frac{L_T}{\varphi}\right|\cos\eta-\left|\frac{L_{T0}}{\varphi_0}\right|\cos\eta_0\right)\right)$$

The values determined from wind-off run are marked with index “0”.

The static (C_{LBETA}) and dynamic direct derivatives (*CLP*) are respectively obtained from the in-phase and quadrature components of the excitation moment, and from the amplitude and frequency of the primary motion. To obtain the frequency and amplitude of the primary motion, the power spectral density in the frequency domain is calculated from the measured primary motion. The amplitude and phase shift of the excitation moment are calculated in the frequency domain by applying the cross-power spectral density. The signals from the excitation moment sensor are cross-correlated with the primary signals generated by the primary oscillation motion sensor.

Experimental results and discussion

Static direct derivative in roll

Static direct derivative in roll for both of the models are presented in Fig.4.

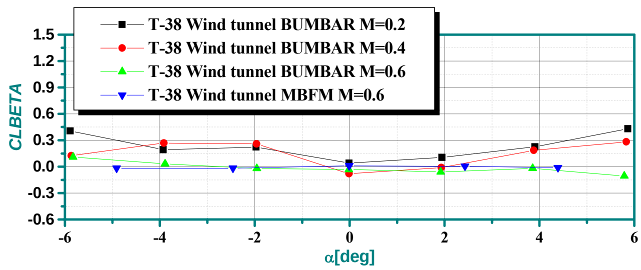

Figure 4. Static direct derivative in roll for the *BUMBAR* and the *MBFM* model

The configuration of the MBFM model is symmetrical, and therefore the static direct derivative coefficient C_{LBETA} for MBFM is equal to zero in the entire range of attack. The wing section of the BUMBAR model is asymmetrical, so the coefficient C_{LBETA} is not equal to zero, except for $\alpha = 0^o$.

Dynamic derivative in roll

Modified Basic Finner Model. Fig.5 depicts the direct dynamic derivative in roll as a function of α for the *MBFM* model, for $M = 0.6$.

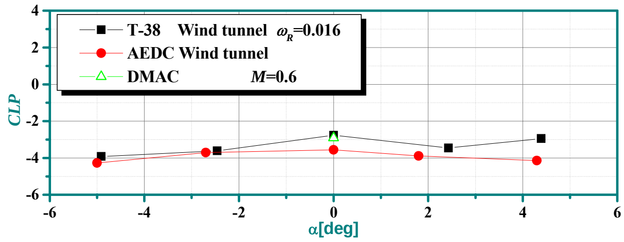

Figure 5. Direct dynamic derivative in roll for the *MBFM* model, $M = 0.6$

The roll-damping coefficients measured in the T-38 wind tunnel showed a good agreement with the results obtained in the *AEDC* wind tunnel and the values calculated by "*DMAC*".

***BUMBAR* model.** Figures 6 - 8 depict direct the dynamic derivatives in roll as a function of α for the *BUMBAR* model, for $M = 0.2$, $M = 0.4$, $M = 0.6$.

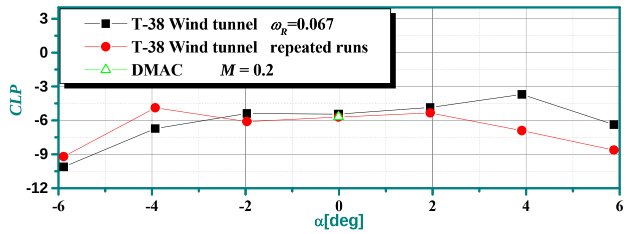

Figure 6. Direct dynamic derivative in roll for the *BUMBAR* model, M=0.2

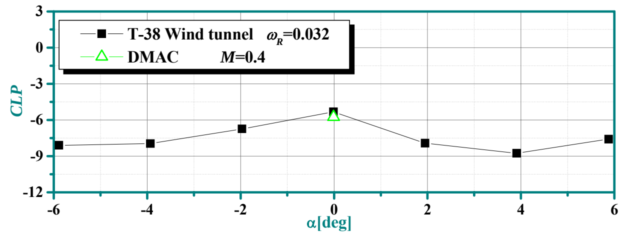

Figure 7. Direct dynamic derivative in roll for the *BUMBAR* model, M=0.4

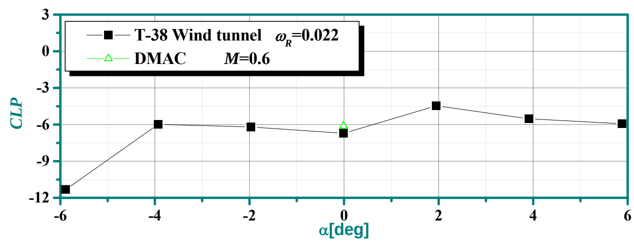

Figure 8. Direct dynamic derivative in roll for the *BUMBAR* model, M=0.6

The roll-damping coefficients for the *BUMBAR* model for the angle of attack $\alpha = 0^o$ showed a good agreement with the values calculated by the "*DMAC*". For Mach number 0.2 for each angle of attack additional runs were done for checking repeatability of the stability derivatives measurement. For the angle of attack $\alpha = 0^o$, $\pm 2^o$ a high level of repeatability of the obtained results can be noticed. Account the difficulties in dynamic stability derivatives measurements, especially in intermittent wind tunnels; it can be assumed that repeatability is good in the entire range of the angle of attack.

The problems of a small amplitude of output signals from the force and moment sensors are common in measurements of dynamic stability derivatives. It should be emphasized that in the applied technique for stability derivative testing uncertainty in measurements is mainly a result of raw data scatter. For this reason, the regime of data acquisition process is very demanding. The duration of a typical dynamic test in the intermittent wind tunnel is approximately 10 seconds [11]. In the presented roll-oscillation experiments one test run was done for each angle of attack. The duration of test runs was 12 seconds, where approximately 8 seconds was the sampling time. Finally, the cross-correlation functions were determined from 82 periods of model oscillations and from 8192 samples. The applied regime of data acquisition process showed very good results.

Conclusions

This paper presents the experimental results of the subsonic derivative for two models: Modified Basic Finner Model and *BUMBAR* model. The experimental data obtained in the T-38 wind tunnel, for both models, showed a good agreement with the values calculated by "*DMAC*". Also, the roll-damping coefficients for the *MBFM* model measured in the T-38 wind tunnel showed a good agreement with the results obtained in the *AEDC* wind tunnel.

Measurements of aerodynamic stability derivatives are one of the most complex wind tunnel tests. On the basis of the presented results it can be concluded that the Experimental Aerodynamics Division in the VTI developed high quality equipment and software for data acquisition and reduction for these measurements.

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Received: 20.12.2007.

Eksperimentalni rezultati merenja aerodinamičkih derivativa stabilnosti u subsoničnoj oblasti brzina u aerotunelu T-38 prinudnim oscilacijama

Izvod Prikazani su rezultati eksperimentalnog određivanja direktnog derivativa stabilnosti u valjanju u subsoničnoj oblasti brzina. U aerotunelu T-38 primenjuje se metoda krutih prinudnih oscilacija [1-4]. Aerotunelska ispitivanja urađena su za dva modela: Modified Basic Finner model (*MBFM*) i model rakete razvijene u VTI (*BUMBAR*) [5,8]. Ispitivanja su urađena na Mahovom broju 0.6 za model *MBFM* i na Mahovim brojevima 0.2, 0.4, 0.6 za model *BUMBAR*-a. Dobijeni rezultati upoređeni su sa izračunatim vrednostima koeficijenta prigušenja u valjanju pomoću poluempirijske metode "*DMAC*" [6], a za *MBFM* model i sa rezultatima dobijenim u *AEDC* aerotunelu [7].

Ključne reči: **aerodinamički tunel, eksperimentalna aerodinamika, aerodinamički derivativi, derivativi stabilnosti, subsonično strujanje, prinudne oscilacije.**

Les résultats des mesurements expérimentaux des dérivées aérodynamiques de stabilité dans le domaine subsonique des vitesses obtenus par les oscillations contraintes dans la soufflerie T-38

Les résultats de la détermination expérimentale de la dérivée directe de stabilité du roulement dans le domaine subsonique des vitesses sont exposés dans ce papier. Dans la soufflerie aérodynamique on applique la méthode des oscillations contraintes rigides [1-3]. Les essais aérodynamiques ont été effectués pour deux modèles: Modified Basic Finner model (MBFM) et modèle du missile développé à VTI (Bumbar)[4, 7]. Les essais ont été faits à 0.6 de Mach pour le modèle MBFM et à 0.2, 0.4, 0.6 de Mach pour le modèle Bumbar. Les résultats obtenus ont été comparés avec les valeurs calculées des coefficients d'étouffement du roulement par la méthode semi-empirique "DMAC" [5], et pour le modèle MBFM avec les résultats obtenus dans la soufflerie aérodynamique AEDC [6].

***Mots clés*: soufflerie aérodynamique, aérodynamique expérimentale, dérivées aérodynamiques, dérivées de stabilité, courant subsonique, oscillations contraintes.**