11TH INTERNATIONAL SCIENTIFIC CONFERENCE
ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

EXPERIMENTAL RESULTS FROM THE MISSILE MODEL TEST CAMPAIGN IN THE VTI T-38 WIND TUNNEL

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Abstract: *Testing of the missile model in the VTI T-38 trisonic wind tunnel is presented. Tests were carried out at Mach numer range from 0.3 to 2.0. In the subsonic speed range tests were done at different values of the stagnation pressure, while the missile model was tested at nineteen values of Mach number in the transonic speed range. Aerodynamic loads were measured using six-component internal wind tunnel balance. The measured values of normal force, drag force and pitching moment obtained under varying conditions in the wind tunnel test section are shown.*

Keywords: *wind tunnel, missile model, strain gauge balance*

1. INTRODUCTION

This paper presents the initial part of the supersonic projectile model test campaign within the new research project of the Experimental Aerodynamic Department of the Military Technical Institute (VTI) in Belgrade. The main goal of the project is experimental investigation of the side jet interactions in control of a supersonic projectile. The supersonic projectile model was tested in the VTI T-38 trisonic wind tunnel [1,2]. Within the initial part of the testing, wind tunnel measurements were conducted on the model without side jet system and with six-component internal wind tunnel balance. In the wind tunnel tests without side jet system aerodynamic characteristics of the model in the range of Mach numbers from 0.5 to 2.0 are obtained. The measured aerodynamic loads will be compared with the results obtained in the main, final, part of the experiential investigation with side jet system operating and with five-component internal wind tunnel balance.

2. SUPERSONIC PROJECTILE MODEL

Supersonic projectile model is shown in Figure 1. The model has a cylindrical body, ogive nose and wing section with four wraparound wings.

This projectile model is characterized with large slenderness ratio, so that the ratio of the model length to the model base diameter is L/D=21.78. The reference point for force/moment calculation is located a distance 10.83D upstream of the model base.

Figure 1. Supersonic projectile model

The projectile model mounted on the sting in the VTI T-38 wind tunnel test section is shown in Figure 2. Sting vs. model base diameter ratio was 0.75. The pressure in the cavity surrounding the sting at the model base (i.e. the base pressure) was measured by a single orifice at the end of a tube, which was routed through the sting to the sensor located in the model support.

Figure 2. Supersonic projectile model in the VTI T-38 test section

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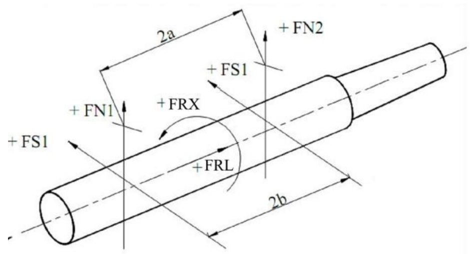
DOI: 10.5937/OTEH24009S

3. AERODYNAMIC LOAD MASUREMENTS

Aerodynamic forces and moments acting on the model were measured by 2 inch ABLE internal six-component strain gauge balance. The six basic components of the balance consist of two normal force element (*FN1* and *FN2*), two side force (*FS1* and *FS2*), dual force element (*FRX*) and dual rolling moment element (*FRL*), Figure 3 [3-5]. Normal force (*FRZ*) and pitching moment (*FRM*) are determined from components *FN1* and *FN2*, while side force (*FRY*) and yawing moment (*FRN*) are determined from *FS1* and *FS2*.



a=0.092075 mm , b=0.0762 mm

Figure 3. Components of the 2 inch ABLE internal balance

The balance nominl operating load range and accuracy is shown in Table 1.

Table 1. Balance load ranges and accuracy

Component	*FRX* [N]	*FRY* [N]	*FRZ* [N]	*FRL* [Nm]	*FRM* [Nm]	*FRN* [Nm]
Load range	1800	8900	8900	170	820	680
Err. [N, Nm]	3.467	23.214	34.303	-0.406	0.887	1.114
P. Err. [%]	0.193	0.261	0.385	-0.239	0.108	0.164
Std.d. [%]	0.053	0.075	0.083	0.051	0.029	0.041

4. WIND TUNNEL MEASUREMENTS IN THE SUBSONIC SPEED RANGE

In the subsonic speed range tests were done at different values of the stagnation pressure in the wind tunnel test section. Table 2-4 show the values of the stagnation pressure, dynamic pressure, as well as measured values of axial force, normal force and pitching moment. Results referee to Mach number 0.3 and 0.5 and angle of attack in the interval of -10° to +10°.

Table 2. Results for M=0.3 and FRX

FRX [N] *M*=0.3				
α [°]	RSN=1 p_0=2.0 bar q=0.118 bar	RSN=2 p_0=2.5 bar q=0.150 bar	RSN=3 p_0=3.0 bar q=0.150 bar	RSN=4 p_0=3.5 bar q=0.150 bar
-11.68	10.791	12.924	14.884	17.025
-10.06	10.810	13.006	14.980	17.251
-8.06	10.835	13.236	15.227	17.470
-6.05	10.788	13.301	15.278	17.596
-4.05	10.418	13.040	14.999	17.040
-2.05	10.331	12.907	14.865	16.773
-0.05	10.346	12.728	14.606	16.699
1.96	10.449	12.653	14.808	16.757
3.96	10.676	12.938	14.871	17.077
5.97	11.110	13.383	15.293	17.181
7.97	11.165	13.373	15.394	17.216
9.98	11.020	13.192	15.119	16.984
11.8	10.895	12.936	14.867	16.526

Table 3. Results for *M*=0.5 and FRZ

FRZ [N] M=0.5				
α [°]	RSN=6 p_0=2.0 bar q=0.118 bar	RSN=7 p_0=2.5 bar q=0.150 bar	RSN=8 p_0=3.0 bar q=0.150 bar	RSN=14 p_0=2.3 bar q=0.150 bar
-11.66	-213.055	-268.584	-325.821	-251.708
-10.03	-172.194	-218.170	-272.170	-208.920
-8.01	-129.528	-164.479	-200.762	-152.830
-6.00	-85.947	-113.568	-142.09	-107.152
-3.99	-52.088	-68.573	-89.635	-62.64
-1.99	-18.450	-27.569	-35.681	-23.783
-0.02	7.573	4.935	-3.645	7.161
2.04	32.092	36.223	40.523	36.490
4.04	67.164	76.640	88.012	75.112
6.05	104.277	124.559	143.695	115.907
8.06	144.380	171.249	201.282	160.155
10.07	188.047	224.675	262.211	210.739
11.92	231.416	282.919	323.930	261.015

Table 4. Results for *M*=0.5 and FRM

FRZ [N] M=0.3				
α [°]	RSN=6 p_0=2.0 bar q=0.118 bar	RSN=7 p_0=2.5 bar q=0.150 bar	RSN=8 p_0=3.0 bar q=0.150 bar	RSN=14 p_0=2.3 bar q=0.150 bar
-11.66	52.511	67.551	80.178	61.924
-10.03	43.485	54.551	69.471	53.603
-8.01	33.472	42.248	52.273	40.102
-6.00	22.183	29.391	37.718	28.547
-3.99	13.419	17.870	23.467	15.986
-1.99	3.469	5.830	7.910	4.791
-0.02	-2.687	-1.743	-1.108	-2.937
2.04	-8.170	-8.656	-9.185	-9.254
4.04	-18.260	-20.643	-22.654	-20.577
6.05	-28.245	-33.423	-38.087	-31.640
8.06	-38.716	-45.54	-53.305	-42.701
10.07	-48.460	-58.093	-66.861	-54.895
11.92	-57.990	-70.120	-80.597	-65.395

Nondimensional aerodynamic coefficients in the non-rotadted axes system are calculated from the aerodynamic forces and moments according to the following equations:

$$C_A = \frac{FRX}{q \cdot S_{ref}}, C_N = \frac{FRZ}{q \cdot S_{ref}}, C_M = \frac{FRM}{q \cdot L_{ref} S_{ref}}$$

Compared graphs on Figures 4-9 show drag force coefficients, lift force coefficients and pitching moment coefficients in relation to the angle of attack for Mach number *M*=0.3 and *M*=0.5.

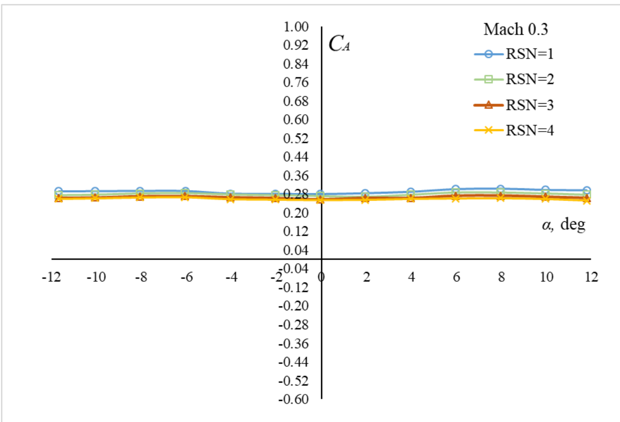


Figure 4. Drag force coefficient, *M*=0.3

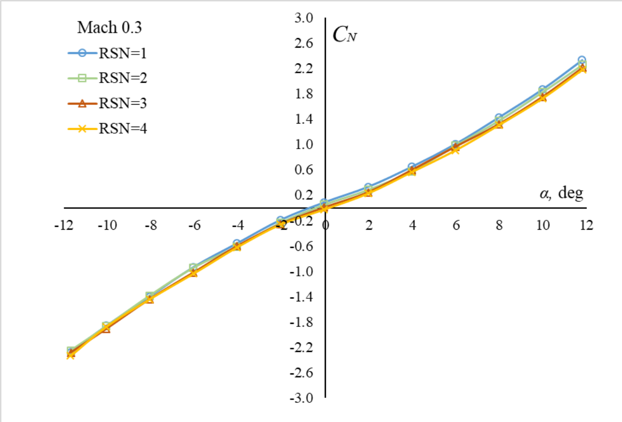


Figure 5. Normal force coefficient, M=0.3

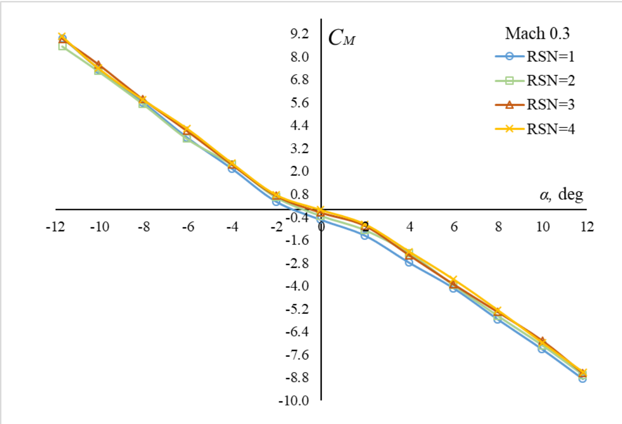


Figure 6. Pitching moment coefficient, M=0.3

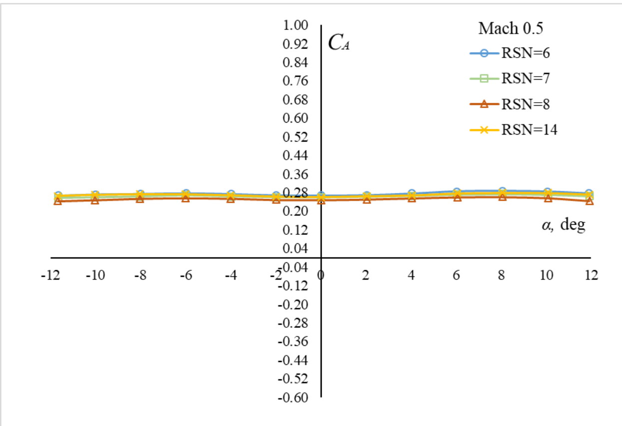


Figure 7. Drag force coefficient, M=0.5

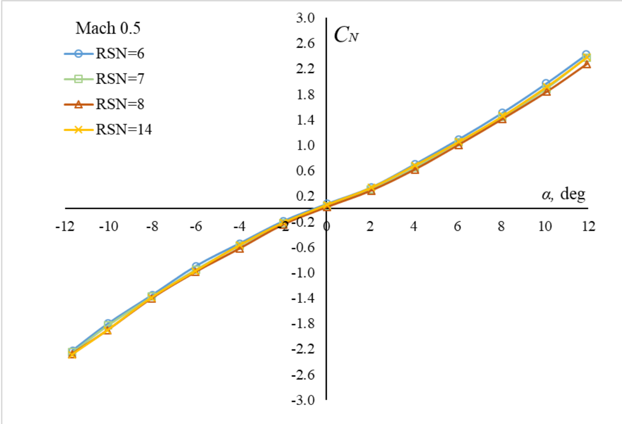


Figure 8. Normal force coefficient, M=0.5

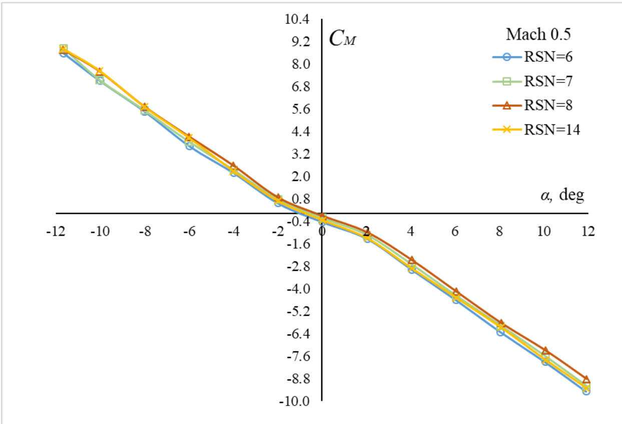


Figure 9. Pitching moment coefficient, M=0.5

5. WIND TUNNEL MEASUREMENTS IN THE TRANSONIC SPEED RANGE

The supersonic projectile model was tested at nineteen values of Mach number in the transonic speed range. In the transonic speed range tests were conducted for one value of the stagnation pressure ($2.3 \cdot 10^5$ Pa) and angle of attack in the interval of -10° to +10°. The angle of attack was covered by a continuous pitching movement of the model during the run with 2°/s rate of change. The results are presented through three groups of Mach numbers range. Drag force coefficients for each group of Mach numbers range are presented in Figures 10-12.

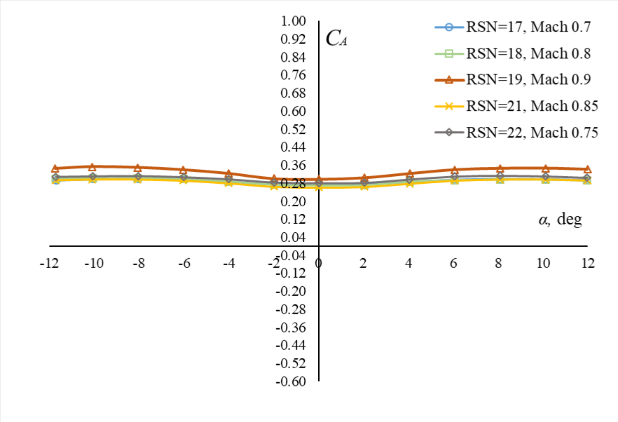


Figure 10. Drag force coefficient, Mach number range from 0.7 to 0.9

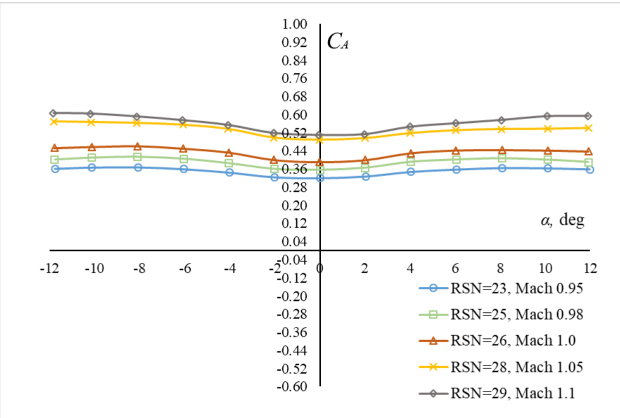


Figure 11. Drag force coefficient, Mach number range from 0.95 to 1.1

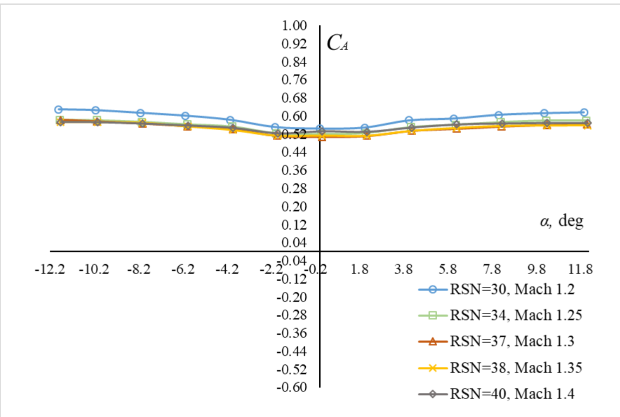


Figure 12. Drag force coefficient, Mach number range from 1.2 to 1.4

Normal force coefficients for each group of Mach numbers range are presented in Figures 13-15.

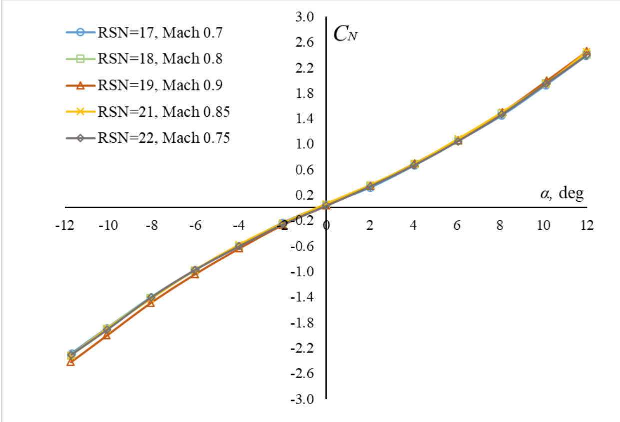


Figure 13. Normal force coefficient, Mach number range from 0.7 to 0.9

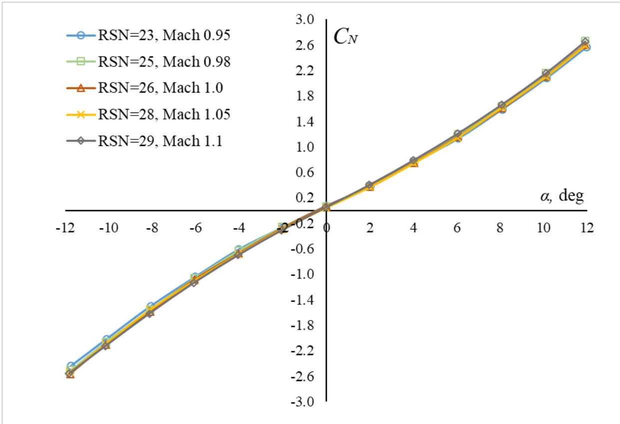


Figure 14. Normal force coefficient, Mach number range from 0.95 to 1.1

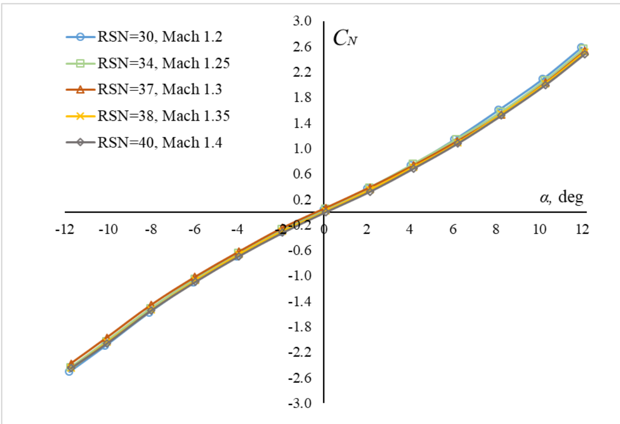


Figure 15. Normal force coefficient, Mach number range from 1.2 to 1.4

Pitching moment coefficients for each group of Mach numbers range are presented in Figures 16-18.

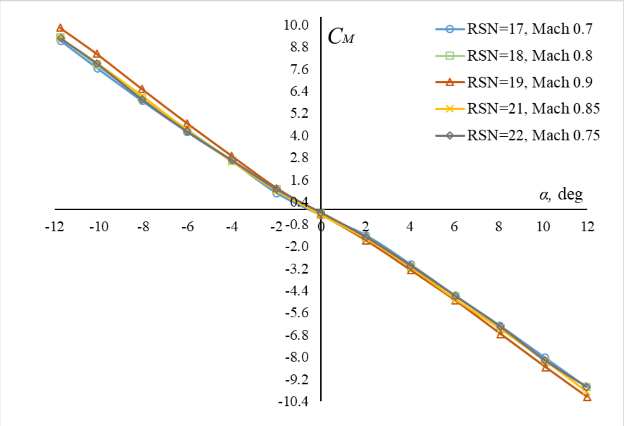


Figure 16. Pitching moment coefficient, Mach number range from 0.7 to 0.9

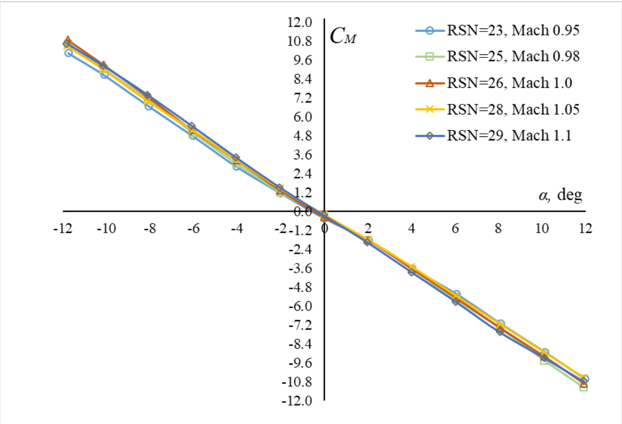


Figure 17. Pitching moment coefficient, Mach number range from 0.95 to 1.1

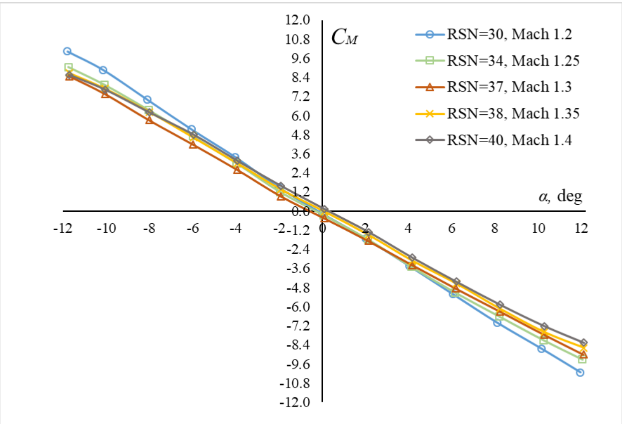


Figure 18. Pitching moment coefficient, Mach number range from 1.2 to 1.4

6. WIND TUNNEL MEASUREMENT IN SUPERSONIC SPEED RANGE

The results of the supersonic model testing on Mach number M=2.0 are shown in Figures 19-21. Stagnation pressure in the wind tunnel test section was $2.3 \cdot 10^5$ Pa, and angle of attack was in the interval of -10° to +10°. Base pressure coefficient and base drag force coefficient were calculated according to the following equations:

$$C_{pb} = \frac{p_b - p_{st}}{q} \qquad C_{Ab} = -C_{pb}\frac{S_b}{S_{ref}}$$

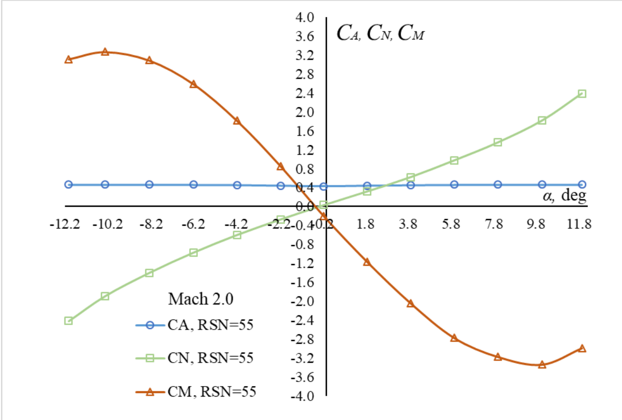


Figure 19. Drag force, normal force and pitching moment coefficients, Mach number 2.0

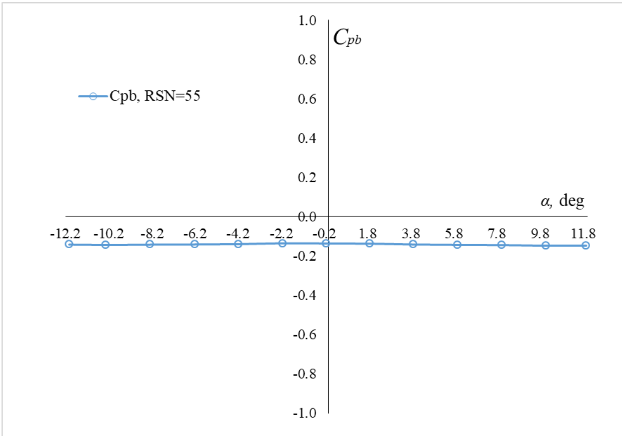


Figure 20. Base pressure coefficient, Mach number 2.0

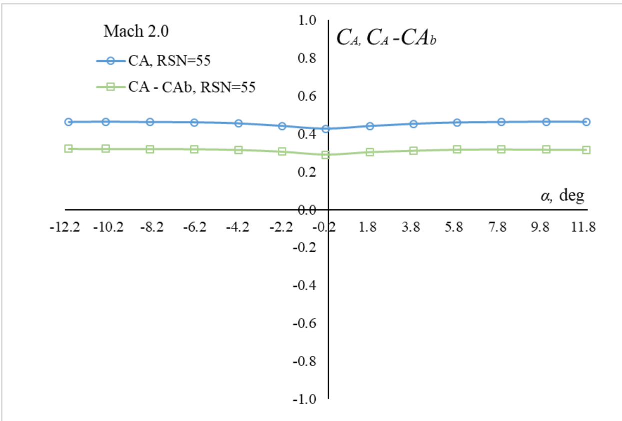


Figure 21. Drag force and total drag force coefficients, Mach number 2.0

On Mach number M=1.75 short-time repeatability check was made. Short time repeatability in drag force, normal force and pitching moment measurements was checked on the basis of five repeated wind tunnel runs. Graphs, in Figures 22-24

, show comparisons of the measured drag force, normal force and pitching moment in relation to the model angle of attack.

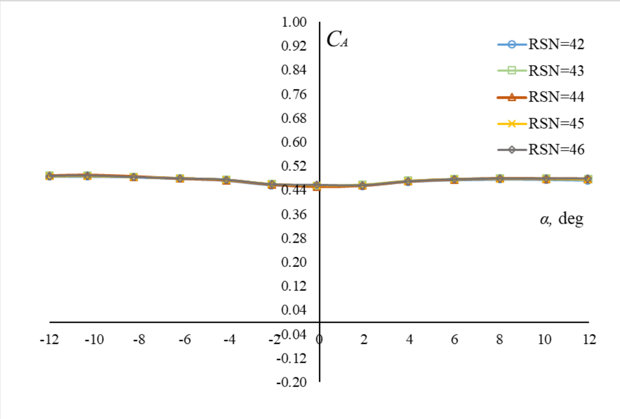


Figure 22. Drag force coefficient, Mach number 1.75

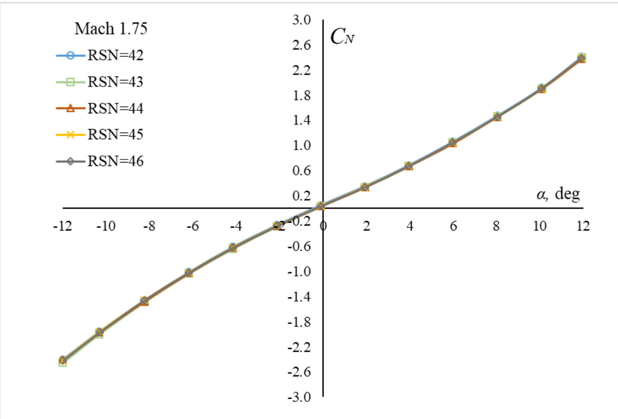


Figure 23. Normal force coefficients, Mach number 1.75

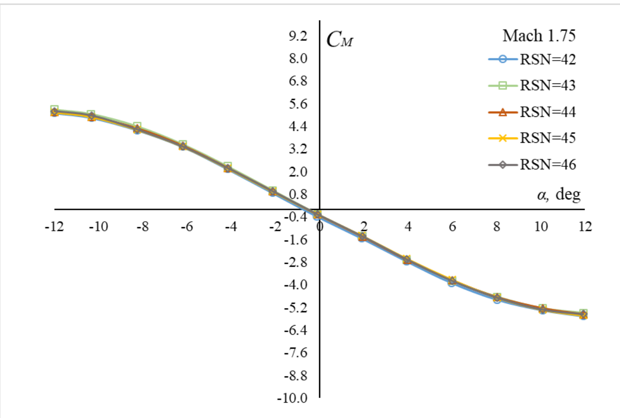


Figure 24. Pitching moment coefficient, Mach number 1.75

In Table 5 aerodynamic coefficient on certain angles of attack for respited wind tunnel runs are given.

Table 5. Aerodynamic coefficient for repeated runs

RSN	α [°]	C_A	C_N	C_M
42	-12.03	0.4856	-2.4031	5.1021
43	-12.04	0.4888	-2.4510	5.2870
44	-12.02	0.4878	-2.4062	5.1522
45	-12.03	0.4857	-2.4112	5.1413
46	-12.02	0.4862	-2.4191	5.2024
42	-0.110	0.4540	0.0510	-0.3771
43	-0.111	0.4539	0.0321	-0.2582
44	-0.109	0.4516	0.0342	-0.2842
45	-0.111	0.4548	0.0351	-0.2591
46	-0.109	0.4573	0.0341	-0.2611
42	11.93	0.4721	2.4070	-5.6620
43	11.92	0.4774	2.4011	-5.4981
44	11.93	0.4768	2.3742	-5.5621
45	11.92	0.4745	2.3878	-5.6313
46	11.93	0.4776	2.3912	-5.5580

7. CONCLUSION

Testing of the supersonic missile model in the VTI T-38 trisonic wind tunnel was conducted in subsonic, transonic and supersonic speed range. Subsonic data from measurements of drag force, normal force and pitching moment show a very good agreement in tests with different values of the stagnation pressure in the wind tunnel test section

The data in the transonic speed range show that internal six-component balance, used in the VTI T-38 wind tunnel tests, provide accurate determination of the increase in drag force coefficients for very small changes of the free stream velocity.

Analysis of the test data obtained through repeated wind tunnel runs showed the excellent agreement confirming high quality of the measurement repeatability. Short-term repeatability checks were done on the basis of five repeated supersonic wind tunnel runs.

Acknowledgements

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-66/2024-03/ 200325).

References

[1] MEDVED, B., ELFSTROM, G.M.: The Yugoslav 1.5m trisonic blowdown wind tunnel, AIAA paper no. 86-0756-CP. American Institute of Aeronautics and Astronautics, Reston, Virginia, 1986.

[2] ILIĆ B., MILOSAVLJEVIĆ M.: FPGA-Based Embedded System for Wind Tunnel Variable-Geometry Nozzle Positioning, *Scientific Technical Review*, Vol.69, No.1, 2019, pp. 3-9. DOI: 10.5937/str1901003I

[3] SAMARDŽIĆ M., PETROVIĆ L., IVKOVIĆ U., ZUROVAC S.: *Measurement of hover performances for mini unmanned aircraft vehicle*, 10th International Scientific Conference on Defensive technologies, OTEH 2022, Belgrdae , Serbia, 13-14 October 2022, pp.2-7.

[4] HUFNAGEL K., SCHEWE G.: Force and moments

measurements, Springer Handbook of Experimental Fluid Mechanics, Part A Experiments in Fluid Mechanics, 2007, ISBN: 978-3-540-25141-5

[5] ABLE Corporation, Document B-3181 (77482), S. Breunle, E.P. Ward, 10/13/81

Notation

C_A - drag force coefficient
C_N - normal force coefficient
C_M - pitching moment coefficient
C_{pb} - base pressure coefficient
C_{Ab} - drag force coefficient
D - model diameter
E_{rr} - maximum difference between applied and measured load in balance calibration
FN1 - forward normal force
FN2 - aft nor11.92mal force
FS1 - aft side force
FS2 - backward side force
FRX - axial force
FRY - side force
FRZ - normal force
FRL - rolling moment
FRM - pitching moment
L - model length
M - Mach number
$P.\ E_{rr}$ - maximum difference between applied and measured load calculated in relation to the component full scale
p_0 - stagnation pressure
p_b - base pressure
p_{st} - static pressure
q - dynamic pressure
RSN - Run sequence number
Std.d - standard deviation of the errors calculated in relation to the component full scale
S_b - model base area
S_{ref} - model reference area
L_{ref} - model reference length
α - aerodynamic angle of attack