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COMPARISON OF MISSILE AERODYNAMIC DATA OBTAINED IN WIND TUNNEL TESTS USING TWO INTERNAL STRAIN GAUGE BALANCES

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Abstract: *This paper presents experimental data obtained in testing of the generic missile model in the VTI T-38 blowdown wind tunnel. Two internal strain gauge balances were used to measure aerodynamic load. Force-type six-component balance with two measurement sections, placed in both the forward and the aft section of the balance, was used in the initial part of the tests. In the subsequent tests, aerodynamic load was measured using monoblock moment - type five-component balance with three measuring section shaped as a five-bar cage. The five-component balance has cylindrical cavity that allows flow of high-pressure gas through its load-bearing parts. The tests were conducted in the subsonic, transonic and supersonic conditions. The aerodynamic load values measured using these two balances are compared for the angle of attack of the missile model in the range from -12° to +12°.*

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

1. INTRODUSCTION

The paper presents the results of testing the generic missile model at VTI T-38 blowdown wind tunnel [1-3]. The main aim of the tests was investigation of the side jet interactions with crossflow. Tests were done in two phases: in the initial phase of the testing, i.e. in the first phase of the testing, measurements of the aerodynamic forces and moments were conducted on the generic missile model without side jet system and with six-component internal wind tunnel balance [4]. In the second phase of testing, measurements of aerodynamic forces and moments were conducted with side jet system and with five-component flow-through balance. Nominal load ranges of the flow-through balance, used in the tests with side jet system, is significant lower compared to the nominal load ranges of the six-component balance. The experimental results obtained in tests with six-component balance were used to determine the optimum position of the five-component balance within the model and maximum Mach number in supersonic testing of the model with side jet system.

During the second phase of the testing a certain number of tests were done without side jet system operating. Aerodynamic loads measured in these tests represent the aerodynamic loads without the influence of the jet's reactive force. Also, these tests without the side jet system operating were used as control measurements for comparing the aerodynamic loads measured using the six-component balance and aerodynamic loads measured using flow-through balance. The paper presents comparative values of the aerodynamic loads measured using both wind tunnel balances without side jet system operating in the subsonic, transonic and supersonic speed ranges.

2. GENERIC MISSILE MODEL

Generic missile model has a cylindrical body, ogive nose and wing section with for wraparound wings. The model is characterized with large slenderness ratio. Ratio of the model length to the model base diameter is L/D=21.6.

Generic missile model, in the initial phase of the testing with six-component balance, in the VTI T-38 wind tunnel is shown in Figure 1.

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Figure 1. Generic missile model in the VTI T-38 wind tunnel test section [4]

For the tests with the side jet system, it was necessary to make some modifications on the front part of the model. Modification of the model baseline geometry enabled high pressure air supply from through flow-through balance to the settling chamber installed inside the model. On the upper surface of the settling chamber two interchangeable nozzles, a sonic (Mach 1) nozzle and supersonic (Mach 4) nozzle, can be installed. Generic missile model on the flow-through five-component balance are shown in Figure 2.

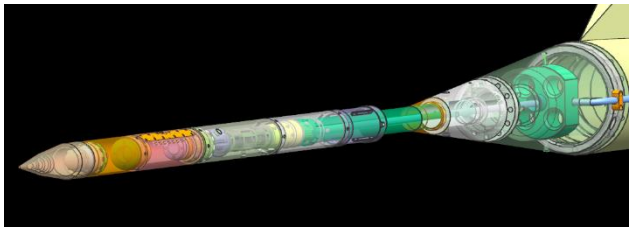


Figure 2. Generic missile model on the flow-through five component balance

Center of the six-component balance was located at 13.3*D* downstream of the model nose tip, while center of the flow-through balance was located at 13.7*D* downstream of the model nose tip. The reference point for force/moment calculation is located at 10.9*D* downstream of the model nose tip.

3. DESCRIPTION OF THE WIND TUNNEL BALANCES

3.1 Six-component wind tunnel balance

Six-component internal wind tunnel balance is shown in Figure 3. This is assembled balance with 50.8 mm-diameter (2 inch), marked as 2″Mk XVIII. This balance has construction and arrangement of measuring elements that are standard for balances produced by Able Corporation, USA. The 2″Mk XVIII balance is "force" balance, measuring five components of force and one moment component. From these six balance components six components of the aerodynamic load can be determined: the three total forces and three total moments. Two normal force elements (aft normal force element and forward normal force element) are used for measurement of the total normal force and pitching moment. Also, two side force elements (aft side force element and forward side force element) are used for measurement of the total side force and yawing moment. Rolling moment and axial force are directly measured using a dual roll element, i.e. dual axial element. The measuring bridges of all measuring elements are formed from Micro-Measurements strain gauges with a resistance of 350Ω. Rolling moment gage section is torque tube type, while all other gauge sections are bending beam type.

The nominal balance components load range is given in Table 1. Load range of the balance components relative to the balance center is given in Table 2 in the form of the "load rhombs", i.e. as maximum side/normal force at zero yawing/pitching moment and as maximum yawing/pitching moment at zero side/normal force.

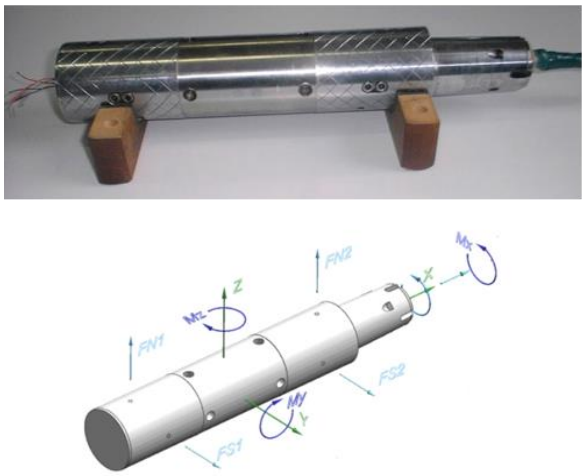


Figure 3. Six-component 2″ Mk XVIII balance

Table 1. Six-component balance load ranges

2″ Mk XVIII balance components load ranges	
Axial force, *X*	2699 N
Forward normal force, *FN1*	8896 N
Aft normal force, *FN2*	8896 N
Forward side force, *FS1*	8896 N
Aft side force, *FS2*	8896 N
Rolling moment, *Mx*	340 Nm

Table 2. Six-component balance load ranges relative to the balance center

2″ Mk XVIII balance components load ranges relative to the balance center	
Axial force, *X*	2699 N
Side force, *Y*	17792 Nm at *Mz=0* Nm, 0 N at *Mz*=1356 Nm
Normal force, *Z*	17792 Nm at *My=0* Nm, 0 N at *My*=1638 Nm
Rolling moment, *Mx*	340 Nm
Pitching moment, *My*	1638 Nm at *Z=0* N, 0 Nm at *Z*=17792 Nm
Yawing moment, *Mz*	1356 Nm at *Y=0* N, 0 Nm at *Y*=17792 Nm

The balance accuracy obtained in a checkout after the

calculation of the calibration matrix is given in Table 3. Accuracy is interpreted as equal to two standard deviations of the back-calculated error for all data points in the calibration process (corresponding to 95% measurements certainty).

Table 3. Six-component balance accuracy

2″ Mk XVIII balance accuracy (balance components)						
	FN1 [N]	*FN2* [N]	*FS2* [N]	*FS2* [N]	*Fx* [N]	*Mx,* [Nm]
Err, [N]	13.412	21.522	-11.704	-14.170	3.467	-0.406
P.Err, [%FS]	0.151	0.242	-0.132	-0.159	0.193	-0.239
Std.d, [%FS]	±0.039	±0.049	±0.041	±0.045	±0.053	±0.051
Acc, [%FS]	±0.078	±0.098	±0.082	±0.090	±0.106	±0.102
2″ Mk XVIII balance accuracy (relative to the balance center)						
	X [N]	*Y* [N]	*Z* [N]	*Mx* [Nm]	*My* [Nm]	*Mz* [Nm]
Err, [N]	3.467	23.214	34.303	-0.406	0.887	1.114
P.Err, [%FS]	0.193	0.261	0.385	-0.239	0.108	0.164
Std.d, [%FS]	±0.053	±0.075	±0.083	±0.051	±0.029	±0.041
Acc, [%FS]	±0.106	±0.150	±0.166	±0.102	±0.058	±0.082

In Table 3 Err is maximum difference between applied and measured load in the balance calibration, P.Err is maximum difference between applied and measured load calculated in relation to the component full scale (FS) load range, Std.d is standard deviation of the errors, Acc is balance component accuracy.

3.2 Five-component flow-through wind tunnel balance

Five-component flow-through wind tunnel balance is shown in Figure 4. The VTI 1.5” 385 balance is “direct-read” balance with 38 mm-diameter (1.5 inch) and three measuring sections shaped as a five-bar cage. All measuring bridges are formed from Micro-Measurements strain gauges with a resistance of 350Ω. The normal force and pitching moment, as well as side force and yawing moment are measured using four measuring bridges formed from strain gauges located on the forward and backward measuring sections. Output signals from these four measuring bridges are proportional to the bending stresses in the measuring sections. Half bridges on the forward and backward measuring section are directly wired to the force bridges for measurements of normal and side force, while the other set of half bridges are directly wired to the moment bridges for measurements of pitching and yawing moment. Rolling moment measuring bridge is located on the central measuring section [5]. Due to action of the rolling moment, the four external bars are simultaneously twisted and bended, while the central bar is loaded only in rolling. By the balance design, it is ensured that the bending stress in the external bars is more significant than the twisting stress. The part of rolling moment taken by the central bar is a small portion of the total rolling moment. The appropriate geometry of the central measuring section enables indirect measurement of the rolling moment by bending stress in the external bars. One strain gauge that detects bending stress is located on each external bar.

High-pressure gas for a side jet flows through a cylindrical cavity in the balance, Figure 4. The cylindrical cavity is 10 mm diameter and it is threaded at both ends to connect the high-pressure gas supply tube.

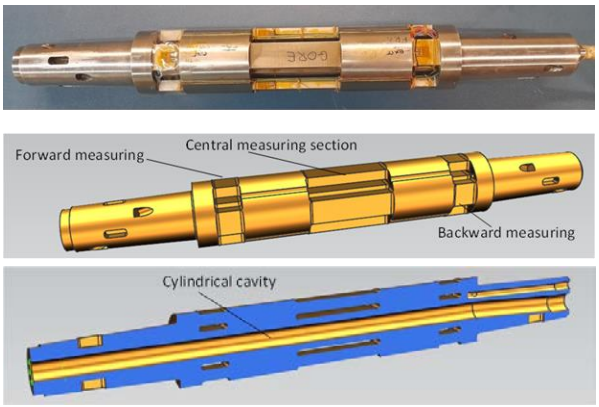


Figure 4. Five-component flow-trough wind tunnel balance

The nominal balance load range relative to the balance center is given in Table 4.

Table 4 Five-component balance load ranges

VTI 1.5” 385 balance components load range relative to the balnce center	
Side force, *Y*	3500 N
Normal force, *Z*	3500 N
Rolling moment, *Mx*	150 Nm
Pitching moment, *My*	350 Nm
Yawing moment, *Mz*	350 Nm

The VTI 1.5” 385 balance accuracy obtained in a checkout after the calculation of the calibration matrix is given in Table 5.

Table 5 Five-component balance accuracy

VTI 1.5” 385 balance accuracy					
	Y [N]	*Z* [N]	*Mx* [Nm]	*My* [Nm]	*Mz* [Nm]
Err, [N]	-4.258	-5.122	-0.389	-0.438	-0.559
P.Err, [%FS]	-0.194	-0.233	-0.324	0.199	-0.254
Std.d, [%FS]	±0.073	±0.072	±0.111	±0.058	±0.069
Acc, [%FS]	±0.156	±0.144	±0.222	±0.116	±0.138

4. EXPERIMENTAL RESULTS AND DISCUSSION

Aerodynamic loads, measured in the subsonic, transonic and supersonic speed range, with both wind tunnel balances are presented. In the subsonic speed range stagnation pressure in the wind tunnel tests section was

2.0 bar, while in transonic and supersonic speed range stagnation pressure was 2.3 bar. The results refer to Mach number 0.3, 0.5, 0.9, 1, 1.2, 1.5 and 1.6.

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

$$C_N = \frac{Z}{q \cdot S_{ref}} \quad C_M = \frac{M_y}{q \cdot S_{ref} \cdot l_{ref}}$$

where C_N is normal force coefficient, C_M is pitching moment coefficient, S_{ref} is model reference area, l_{ref} is model reference length, q is dynamic pressure in the wind tunnel test section.

The model angle of attack was in the interval -12° to +12°. Pitching moment coefficient is calculated for the reference point located at 10.9 D downstream of the model nose tip.

Figures 5-11 show measured values of the normal force and pitching moment coefficients in all three speed ranges.

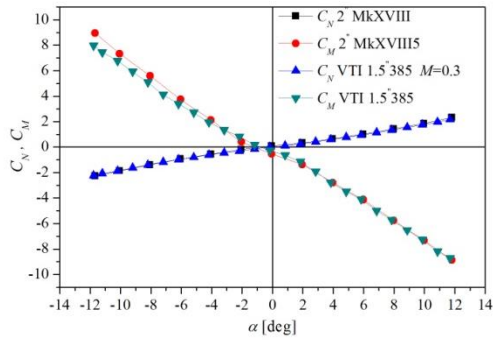


Figure 5. Normal force and pitching moment coefficients, $M = 0.3$

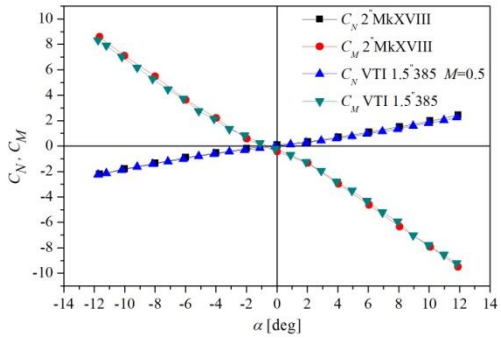


Figure 6. Normal force and pitching moment coefficients, $M = 0.5$

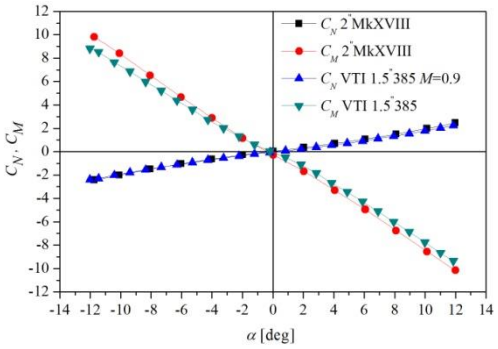


Figure 7. Normal force and pitching moment coefficients, $M = 0.9$

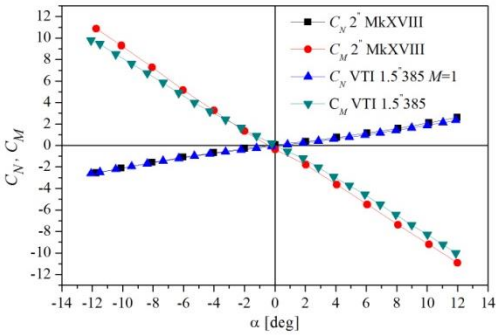


Figure 8. Normal force and pitching moment coefficients, $M = 1$

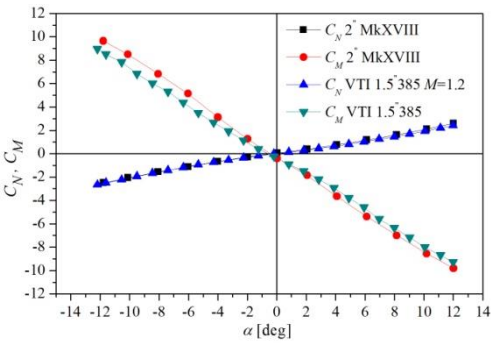


Figure 9. Normal force and pitching moment coefficients, $M = 1.2$

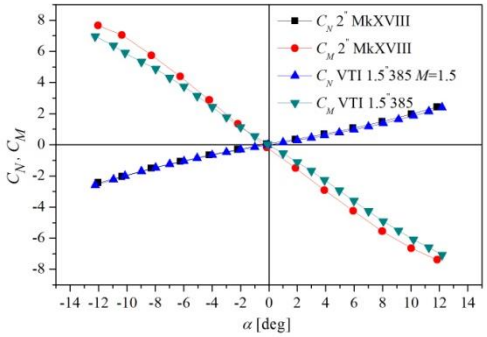


Figure 10. Normal force and pitching moment coefficients, $M = 1.5$

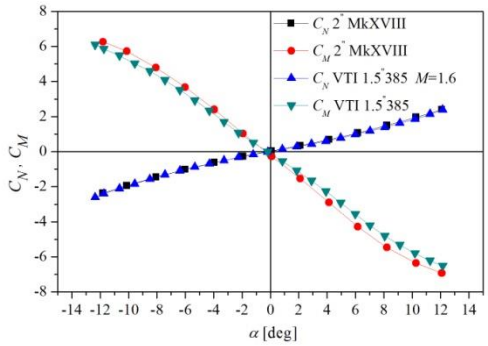


Figure 11. Normal force and pitching moment coefficients, M = 1.6

Figures 12-15 show comparative values of the normal force measured using 2″Mk XVIII and VTI 1.5” 385 wind tunnel balances.

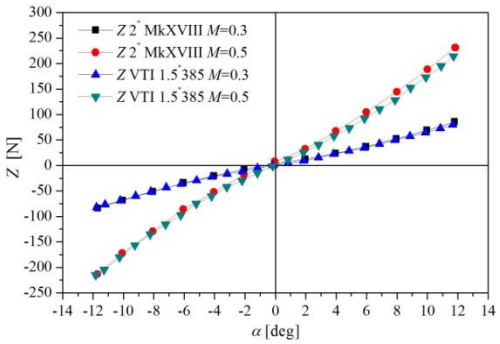


Figure 12. Normal force M = 0.3 and M = 0.5

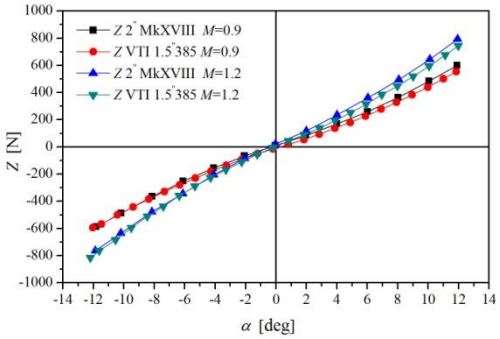


Figure 13. Normal force M = 0.9 and M = 1.2

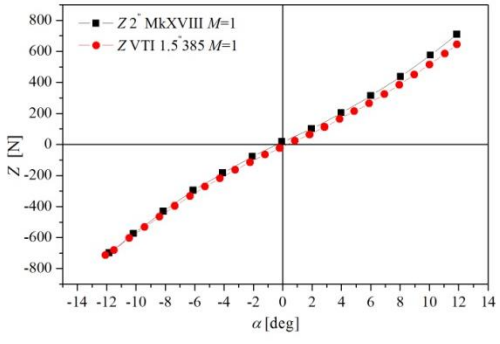


Figure 14. Normal force M = 1

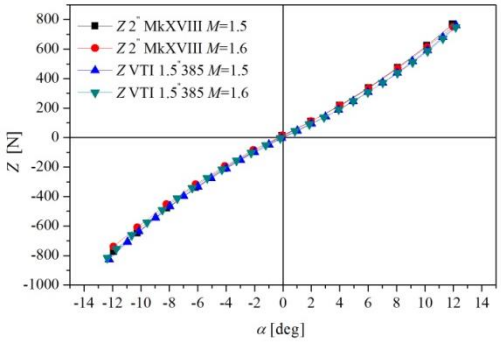


Figure 15. Normal force M = 1.5 and M = 1.6

5. CONCLUSIONS

The diagrams in Figures 5-15 show a good agreement between the normal forces measured using 2″Mk XVIII balance and VTI 1.5” 385 balances. Slightly larger difference in the normal force values can be observed in the transonic speed range. At Mach number M=1, and for the model maximum angle of attack, the difference in normal force measured values is 63.74 N. These deviations can be explained by the significantly larger 2″Mk XVIII balance normal force load range compared to the measured value.

A certain difference in the measured values of the pitching moment coefficient can be noticed at higher values of the model angle of attack. When analyzing these differences, it should be taken into account the significantly larger 2″Mk XVIII balance pitching moment load range. Also, the pitching moment measured using 2″Mk XVIII balance are calculated based on the measured forward and aft normal force components. On the other hand, using the VTI 1.5” 385 balance, the pitching moment is measured directly, i.e. it is achieved using a single measuring bridge.

Acknowledgements

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