TESTING OF THE AGARD B/C, ONERA AND SDM CALIBRATION MODELS IN THE T-38 1.5m × 1.5m TRISONIC WIND TUNNEL

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Abstract

During commissioning of the T-38 Trisonic wind tunnel of VTI, AGARD B/C, ONERA M4 and SDM models were tested. AGARD models were tested in the subsonic, transonic and supersonic speed regimes. The test results are confined to the results from similar facilities as Boeing 4T, INCREST 1.2m and NAE 5ft. wind tunnels at Mach numbers from 0.7 to 2.0. Description of mesuring equipment and analysis of results are presented. ONERA M4 model was tested in transonic speed regime to check out the transonic test section force, moment measurement and flowstream quality. Obtained test results on ONERA M4 model are in satisfied agreement with published data obtained on ONERA M5 model in other reference wind tunnels. The equipment for derivative stability measurement was verified investigating SDM (Standard Dynamic Model) in the subsonic test section at M = 0.6. Brief description of the model and equipment are presented. Main static and dynamic derivatives are plotted as a function of angle of attack and compared with the results obtained in NAE and AEDC wind tunnels.

I Nomenclature

ALFA, α	incidence
β	side slip angle
b	wing span
Cpb	base pressure coeff. = (Pbase- Pst)/q
C_D	drag coefficient = drag/qS
C_L	lift coefficient = lift/qs
C_z	normal force coefficient
C_m	pitching moment coefficient = moment/qSL
$CMALFA$	$C_{m\alpha}$
$CIBETA$	$(\partial C_i/\partial\beta)\, sin\alpha, i = l, n$
$CNBALF$	$(\partial C_n/\partial\beta)\, cos\alpha$
CMQ^*	dynamic composite fixed axis pitch derivative
CNR^*	dynamic composite fixed axis yaw derivative
CIP^*	dynamic composite fixed axis roll derivative
D	model diametar
M	Mach number
MRe	Mega Reynolds number based on mean aerodynamic chord

subscripts

n	nominal condition

II Introduction

During the commissioning of the Vazduhoplovnotehnicki Institut (VTI) trisonic blowdown wind tunnel T-38 a series of tests were performed to check the test section flow quality and used measuring equipment and to compare the results with the same obtained in other wind tunnels. T-38 wind tunnel has been operational since 1986. Subsonic and supersonic test sections are with solid walls while transonic test section has porous walls, with variable porosity of up to 8 %. Dimensions of the 3D working section are 1.5m × 1.5m. 2D test section size is 0.38m × 1.5 m. Mach number range is 0.2 to 4. with stagnation pressure 1.8 to 14 bar. Run time duration depends on both Mach number and stagnation pressure, varing from 6 sec. to 60 sec. More information is given in [(1)].

AGARD B and C and ONERA M4 calibration models were used for force and moments comparison tests and SDM model for dynamic derivatives testing. AGARD models were taken on loan from DSMA/Boeing company. ONERA M4 model was manufactured because the existing ONERA M3/M5 models are not quite representative both in scale and load capacity for the T-38 1.5m transonic test section. SDM model was fabricated with the identical geometry as the corresponding AEDC model. Brief description of models and used test technique are presented.

III Testing of the AGARD models B/C

Model description

The AGARD B and C wind tunnel calibration models used in the test programme were supplied by DSMA/Boeing company. In Fig.1 are shown models

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with the pertinent dimensions given in terms of the body diametar D. Model B consists of a wing and body combination, where the wing is an equilateral triangle with a span of four times the body diametar. Model C is identical to Model B, except that the body is extended aft by 1.5 body diameters and vertical and horizontal tail surfaces are added as shown in the Figure. Both models have been used in previous wind tunnel calibrations and therefore there is an extensive data base already existing with which to compare the results obtained from the present programme.

Measuring equipment and test programme

Aerodynamic forces and moments were measured with a six-component 2-inch diametar internal lineary calibrated Able MKXVIII balance. There was found a max. error of 0.4% relative to the applied max. load in calibration, including interactions and hysteresis.

The model was mounted on a sting specially designed in accordance with AGARD recommendation for such tests. The models were used to provide force and moment data and only one KULITE 7 bars absolute pressure sensor was used for base pressure measurements. Stagnation and static pressure were measured with 17 bar and 7 bar Mensor abs. transducers in the settling chamber and test section side wall, respectively.

The outputs from the balance, base pressure transducer and other measuring sensors (model positions and primary measuring systems) were transmitted to TELEDYNE 64 channel, 16 bit A/D conversion data acquisition system. Max. sampling rate is 125.000 samples/sec and overall precision is less than 0.1% F.S. In the present test approx. 200 samples per channel were taken at 500 samples/sec. sampling rate. Data acquisition was controlled by PDP 11/34 computer. Row data were transferred to a VAX 11/780 computer, where data reduction was performed. An application software package developed by VTI was used in this test,by which most of the data reduction process was automated.

The model forces were converted to the wind axes system. All measurements were made with natural transition.

The initial test programme called for approx. 40 wind tunnel runs. Most of those were in the transonic test section. Tests were conducted at Mach Number between 0.5 and 2.0 at moderate blowing pressure. Reynolds number based on mean aerodynamic chord was very high, eg. M=1.0 MRe=8.

AGARD Test Results

This paper will present the results of only a few typical runs . In order to compare the results with those in other facilities, three similar wind tunnels were selected : NAE 5ft. [2] BOEING 4T [3] and INCREST 1.2m × 1.2m. [4]

Fig.2 presents a comparison of AGARD B data for selected subsonic Mach numbers in the range from 0.76 to 0.80 in Boeing, INCREST and NAE wind tunnels. The data obtained in the present test (VTI) are in good agreement with the other data, except for the pitching moment, C_m obtained in Boeing and INCREST. C_m in the present and NAE tests is significantly larger than both Boeing and INCREST values, and has the opposite sign. In order to confirm which data are correct, a review of measurements on AGARD calibration models[5] was examined. It was found that the T-38 and NAE values of C_m agreed well with standard results of [5] and two data points from this reference are plotted in the Figure. It is possible that in the Boeing and INCREST tests, C_m was computed in a different manner. The Mach number variation is plotted in Fig.2 for the present data. Variations are very small during the run.

A comparison of AGARD-C data obtained in the VTI T-38 transonic test section is shown in Fig.3. All four sets of C_L data agree very well and have the same slope. Values of C_D from the data sets agree well over the range of C_L for which comparable data are available. The VTI and NAE values of C_D lie between the INCREST and Boeing values. C_m data from the three data sets, however, show no similarity whatsoever. C_m in the T-38 and NAE data is always positive, even for negative incidence, whereas for the INCREST and Boeing data, it tends to be negative for positive incidence and vice versa. Points for C_m corresponding to C_L=0.,0.2 and 0.4 obtained from [5] are plotted in the Figure. They very well agree with the results obtained in the present test. Note, however, that [5] states that AGARD-C pitching moment results from different tests have a lot of scatter. The results in Fig.3 confirm that observation.

Fig.4 compares the VTI data obtained in the supersonic test section at M=2.0 with data from the other facilities. The agreement between the four data sets is very good, including the agreement of the C_m data. VTI values of C_m agree with the INCREST and Boeing data, not only in magnitude, but also in sign.

IV Testing of the ONERA M4 model

Model description

ONERA designed a family of hypothetical models which represents typical transport aircraft configuration for research aerodynamic phenomenon in transonic regime enclosed by tunnel walls, such as: blockage and Reynolds number effect and effect of downwash. For that reason ONERA model, the geometry illustrated in Fig.5 is designed and constructed in scale M1, M2, M3 and M5 covering wing span of 0.3m to 1.0m approx. for testing in various wind tunnels world-wide .

Since the ONERA M5 model would produce a significant interference effect in the T-38 test section while ONERA M3 model aerodynamic loads are not representative for designed model load capacity, it was decided to manufacture ONERA M4 model (D=0.102m, b=0.8m). Global measured dimension accuracy is better than 0.03mm. The inside space of model is adopted to accept ABLE strain gauge balance of 2 inch diam., MK-XVIII installed on specially designed ONERA sting the geometry of which is presented in Fig.5.

Measuring equipment and test programme

The test programme, concerning Mach number, incidence and Reynolds number is based on the programme carried out in other wind tunnels with ONERA M5 model. Testing is performed at nominal Mach numbers of: 0.7, 0.78, 0.82, 0.86, 0.88, 0.92 and 0.94 at moderate blowing pressures. The pitch angle range was -6° to +6° . Model positioning was performed in a step by step mode with accuracy better than +/-0.05° . The data acqusition was performed by Teledyne front ends. Each transducer was supported by a separate channel from which were taken 200 samples per angle at the rate of 500 samples/sec/ channel . Electrical signals passed through 10 Hz low-pass Butterworth filters. The force and moment measurements were done with lineary recalibrated ABLE 2.0 inch MKXVIII balance which had been used in AGARD tests mentioned above. The base pressure was measured by the DRUCK PDCR-42 differential transducer, 0.35 bars. The ROSEMOUNT absolute transducer was used for measurement of athmospheric pressure. Stagnation and static pressures were measured with the same tranducers as mentioned in III.

ONERA Test Results

Among other requirements, the chosen scale of the ONERA M4 model was selected so, that the frontal area of the model does not exceed 1% of the wind tunnel cross-section, because the test results are not corrected due to blockage effect. On the other hand, the experiment was not able to reach condition of aerodynamic similarity (the same or similar M and Re) with those in North-American wind tunnels. The cause is safety loading factor 2 for ONERA M4 model which limited the stagnation pressure bellow 4 bars in testing.

The results are corrected due to base drag as well as model-sting deflection. Here are presented comparative tests results at nominal Mach number M=0.7 and M=0.94 obtained with the ONERA M4 model (VTI-T38) and with the ONERA M5 model (NAE,AEDC,NASA).

The two experimental data sets at Mach number M=0.709, MRe=4.29 and MRe=5.9, are presented in Fig.6 and Fig.7 respectively, to show typical C_m dependence on Reynolds number at higher incidence. Fig.6 presents the coefficients C_D, C_L and C_m versus α in comparison with results published by AEDC [6] and NAE [7]. Neither the magnitude nor the sign of C_D coefficient, obtained in NAE could be comparable with the same, obtained in other wind tunnels including VTI-T38 results. [8]. Fig.8 shows curves of the C_D, C_L and C_m coefficients versus α at Mach number M=0.942 and Mre=4.34, [8] compared to the corresponding AEDC,NASA [6] and NAE [7] results. The results are in good agreement, except for C_D coefficients obtained in NAE.

V Standard Dynamic Model Experiments

Model

Dimensions of the VTI Standard Dynamic Model (SDM) are presented in Fig. 9. The model was fabricated in VTI workshop from an alluminium alloy. The geometry of the model is indentical to the corresponding AEDC model[9]. All presented results are referred to the 35 % mean aerodynamic chord point.

The model mass is 12.4 kg excluding balance. Dynamic wind-off measurements on the apparatuses yielded the following torsional moments of inertia : in pitch 0.328 kgm^2 ; in yaw 0.338 kgm^2 and in roll 0.042 kgm^2

Measuring System

According to Orlik-Ruckemann's classification[10], the VTI apparatuses are sting supported mechanisms for inexorable small-amplitude angular oscillation of wind tunnel models.

Fig.10 shows the pitch/yaw apparatus[11]. The suspension system consists of a pair of cross flexures that provide the necessary compliance in pitch or yaw, depending on the model orientation relative to the apparatus. The primary motion is imparted by the hydraulic driving mechanism in which the piston moves applying the driving force on the actuator arm. The forward end of the actuator arm is firmly attached to the moving end of the cross flexures. The cross flexures and hydraulic cylinder are manufactured as integral parts of the sting. In order to obtain the desired primary oscillation, the hydraulic actuator is driven by a hydraulic servo valve located at the sting base which is, in turn, driven by a signal from the control system. Provision is made to augment the suspension stiffness by adding a pair of adequate auxiliary leaf springs.

Fig.11 shows the roll apparatus[11]. The suspension system consists of two rings joined by axially oriented beams equally spaced around the periphery of the rings. There are two suspension systems for low and high loads. The front end of the drive shaft is firmly fixed to the forward end of the suspension flexure. The oscillatory rolling motion is imparted by the hydraulic driving mechanism located at the rear end of the sting.

Apparatuses are mounted on the wind tunnel model support system.

The total force and moment acting on the model are measured with a five component balance, with no axial measuring capability. The balance is made in a single piece and very stiff to keep any natural frequencies well above the oscillation frequencies. Because of its stiff design it is equipped with semiconductor strain gages. The strain gages are temperature compensated with the same precision as conventional wind tunnel balances.

The primary motion is sensed by strain gages located at the cross flexure system, in case of the pitch/yaw apparatus, or at the flexural support in case of the roll apparatus. Drive torques are sensed by strain gages located on the actuator arm or on the drive shaft. For measurement of the sting oscillation, the stings are fitted with strain gages that form a 3-component balance.

Table 1 lists the performance specifications of relevant apparatuses.

The standard data acquisition and control equipment of the wind tunnel are used for derivative measurement. The stability derivative control unit is a part of WTCS (Wind Tunnel Control System) and provides an automatic operating mode.

A typical wind tunnel run includes the following three stages :

- an amplifier calibration run, when known AC signals from the signal generator are fed to the data acquisition system;
- tare run, when the model is oscillated but the tunnel is not running;
- wind-on run, when the model is oscillated at the same frequency as during the tare run but with the wind tunnel running.

During the above measurements, all the sensor signals are amplified, filtered and then digitized by a 16-bit A/D converter. The sampling record of data covers, approximately, 20 - 70 cycles of the primary oscillation.

The data from test runs are processed by DEC computer VAX 11/780 by appropriate software package developed by VTI.

SDM Test Results

The test was conducted in the 1.5 × 1.5 m subsonic test section. The nominal Mach number was $M_\infty =$ 0.6 and the Reynolds number $MR_e = 4.3$ based on the mean aerodynamic chord of the model. The stagnation pressure was 1.8 bar and the stagnation temperature was close to ambient temperatures. The symmetrical condition ($\beta = 0^\circ$) was tested for $-2.5^\circ \leq \alpha \leq 21^\circ$ The amplitude of primary motion was 1° and excitation frequency of 5 Hz. Reduced frequency in pitch was $\omega_r = 0.016$ and in yaw and roll $\omega_r = 0.041$.

Fig.12 shows curves of the longitudinal coefficients C_z and C_m compared to corresponding AEDC[9] and NAE[12] results. Discrepancy between measured coefficients C_m in VTI and NAE is probably attributable to wall and strut-interference effects in the solid-wall tunnel used for NAE tests[13].

The test results of the direct dynamic and static stability derivatives in pitch, yaw and roll are presented in Figures 13 to 15, as a function of α, in comparision with results published by AEDC[9] and NAE[12][14]. Nonlinear trends in the derivatives as a function of angle of attack are repeated with small discrepancies. Dynamic and static cross derivatives are presented in Fig.16. The discrepancies between these two sets of data are the same as those obtained by DFVLR[15].

VI Conclusion

Experiments carried out using a AGARD B/C, ONERA M4 and SDM models in the VTI 1.5m blowdown wind tunnel have shown a good agreement with results from other wind tunnels. It can be stated that the present AGARD tests data agree quite well with Boeing, INCREST and NAE data, except for the pitching moment data. However, the VTI data show better agreement with NAE and the published results than the Cm results from two other data sets. These comparisons thus confirm the integrity of the VTI/T-38 and NAE AGARD data sets.

Small differences in flowstream conditions and geometrical similarity of ONERA M4 and ONERA M5 models should be the source of scattering in the compared results, because it could not be adequately aerodynamically quantified. Obtained C_D test resluts at VTI-T38 are not comparable with the same from NAE.

Presented test results of the SDM model verified the functionality, quality and precision of the new designed apparatuses for the derivative stability measurements in the T-38 wind tunnel. High load capacity of the apparatuses permit measurements of the derivative stability, at very high Re number in the subsonic, transonic and supersonic speed regimes.

References

1 Medved,B. and Elfstrom,G.M. "The Yugoslav 1.5m Trisonic Blowdown wind Tunnel", AIAA Paper 86-0746-CP, 1986.

2 Thain,J. "Report on test conducted on NACA 0012 and AGARD B and C models in the NAE 5 ft. Blowdown wind tunnel during training of VTI personal"; DSMA report number: 4001/R84, 1983.

3 "Lift, Drag and Pitching moment characteristics of

AGARD calibration models in the Boeing supersonic wind tunnel", BOEING Company, document no. D2-23094

[4] Muntenau,F.; Neamty,M.S. " The Calibration of the Transonic and Supersonic test section Using the AGARD Models B an C" Report RL-ST-14, INCREST ROMANIA, 1979.

[5] Hill,R. "A Review of measurements on AGARD calibration models" AGARDograph 64, 1961.

[6] Group of authors "Test of The Calibration Models in Three Transonic Wind Tunnels", AEDC-TR-76 133

[7] Galway,R.D. and Mokry M. "Wind Tunnel Tests of ONERA Aircrafte Models", Volumes I and II, nov. 1974.- feb. 1975.

[8] Zrnić, N. "Qualitative Evaluation of Results Obtained in Comparative Full and Half-Model Test Technique in Wind Tunnels", Master thesis, 1988.

[9] Uselton,B.L. "A Description of the Standard Dynamic Model (SDM)" , 56th Supersonic Tunnel Association Meeting, October 1981

[10] Orlik-Ruckemann,K.J. "Techniques for Dynamic Stability Testing in Wind Tunnels" , AGARD LS-114, Sep. 1981.

[11] Janjikopanji,G. "Description of the Forced Oscillation Test Mechanisms for Measuring Dynamic Stability Derivatives in the T38 1.5 x 1.5 m wind tunnel", Aerospace 93., Scientific Proff. meeting, Belgrade, dec. 1993.

[12] Beyers,M.E., Kapoor,K.B. and Moulton,B.E. "Pitch- and Yaw- Oscillation Experiments on the Standard Dynamic Model at Mach 0.6", NRC-LTR-UA-76, Ottawa, June 1984.

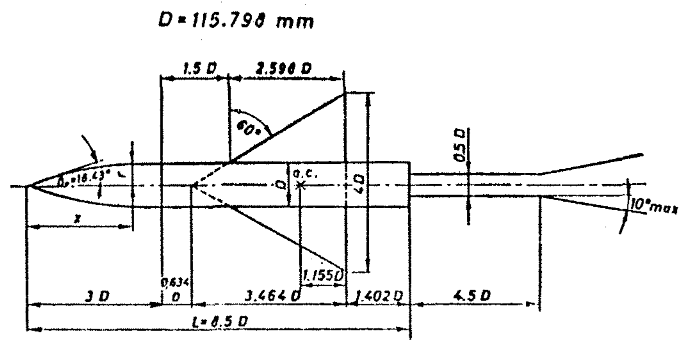
[13] Ericson,J.E. and Reding,J.P. "Dynamic Support Interference in High-Alpha Testing", J.Aircraft, Dec. 1986.

[14] Beyers,M.E. and Moulton,B.E. "Stability Derivatives Due to Oscillation in Roll for the Standard Dynamic Model at Mach 0.6", NRC-LTR-UA-64, Ottawa, Jan 1983.

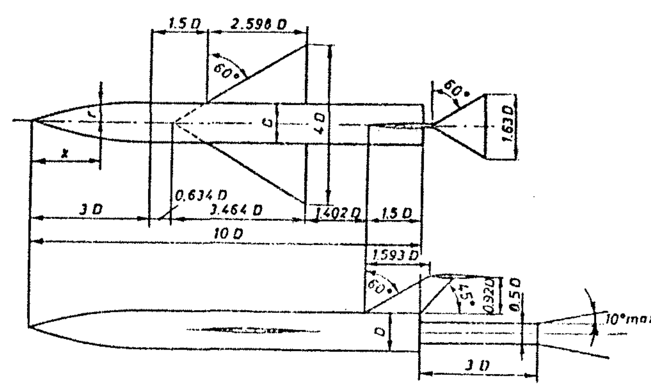
[15] Schmidt,E. "Standard Dynamic Model Experiments with the DFVLR/AVA Transonic Derivative Balance", AGARD CP-386, Nov. 1985.

Table 1. - Performance of the Apparatuses

Apparatus	Pitch/Yaw	Roll
Amplitude	$0.25 \div 1.5^0$	$0.25 \div 1.5^0$
Frequency	$0.2 \div 15Hz$	$0.2 \div 15Hz$
Sting Dia.	eliptic 50 x 72	$\phi 76mm$
Hydr. pressure	200 bar	200 bar
Max. normal force	1000 daN	
Max. incidence	21 °	
Mach number	$M \leq 2$	



AGARD model B



AGARD model C

Fig.1: Geometrical Arrangement of AGARD Models B and C

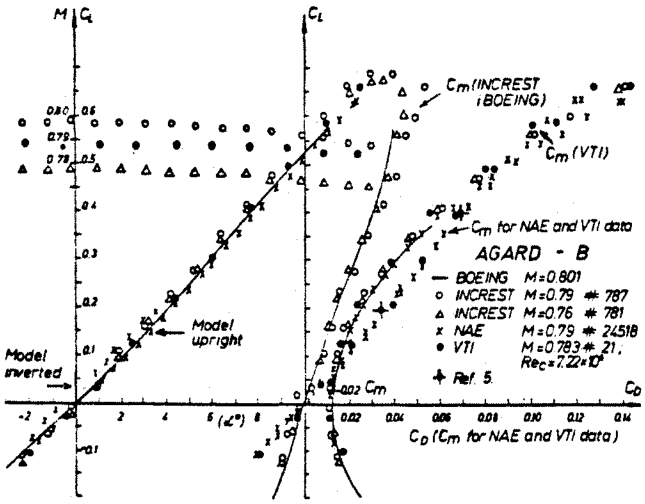


Fig.2: Comparison of AGARD B Data for Subsonic Mach Numbers

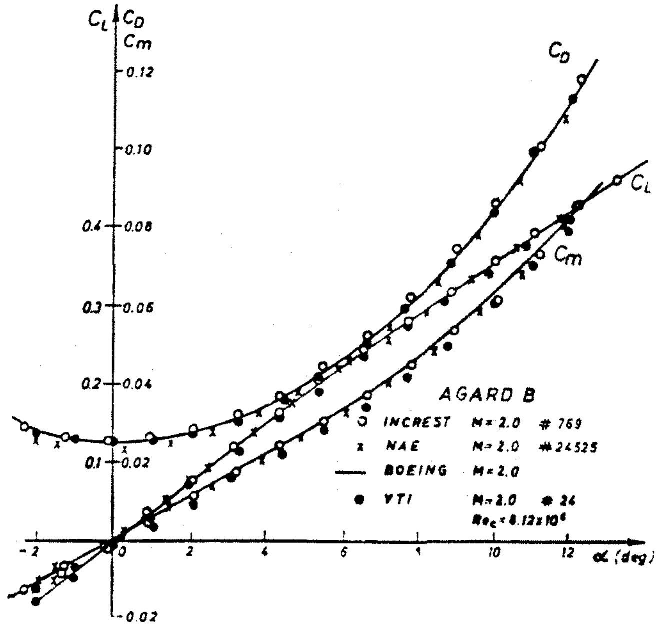


Fig.4: Comparison of AGARD B Data for Supersonic Mach Numbers

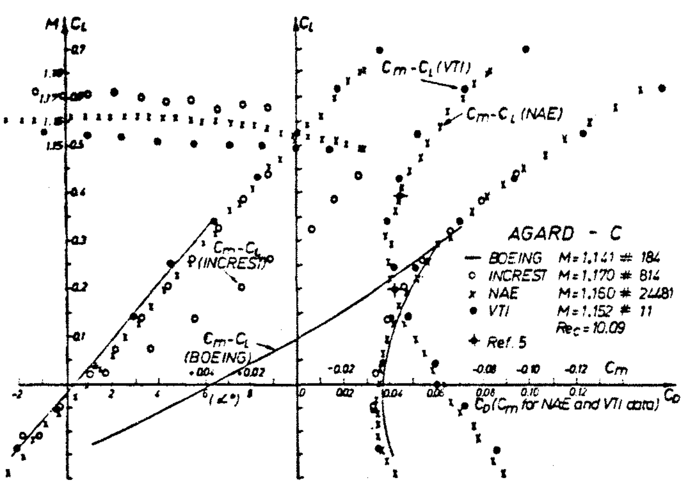


Fig.3: Comparison of AGARD C Data for Transonic Mach Numbers

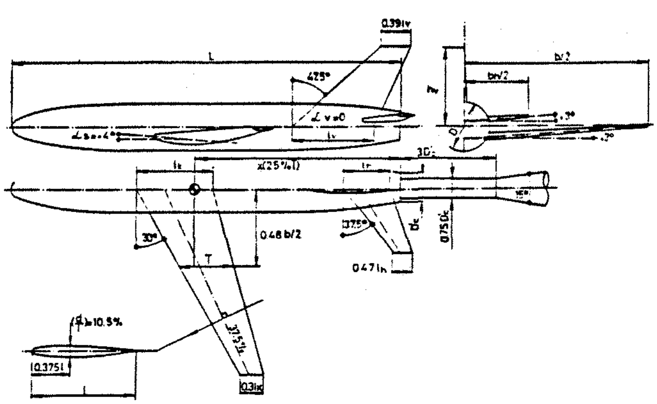


Fig.5: Geometrical Arrangement of ONERA Model-Sting Configuration

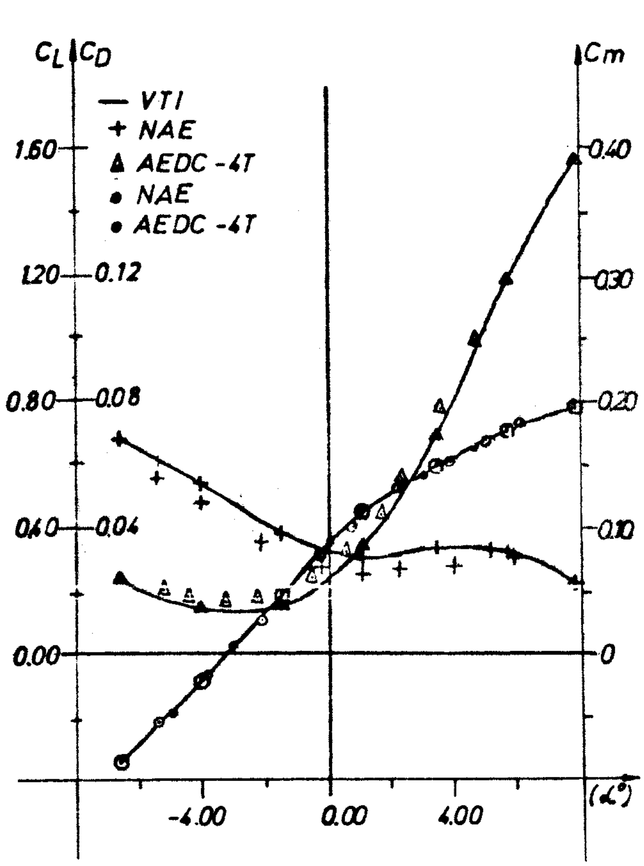


Fig.6: ONERA Data Comparison at $M_n = 0.7$

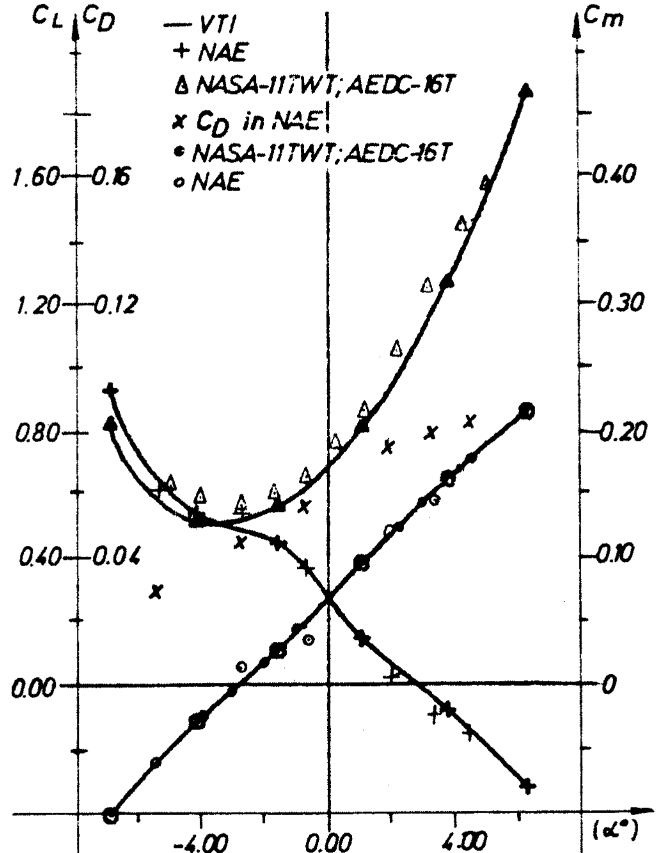


Fig.8: ONERA Data Comparison at $M_n = 0.94$

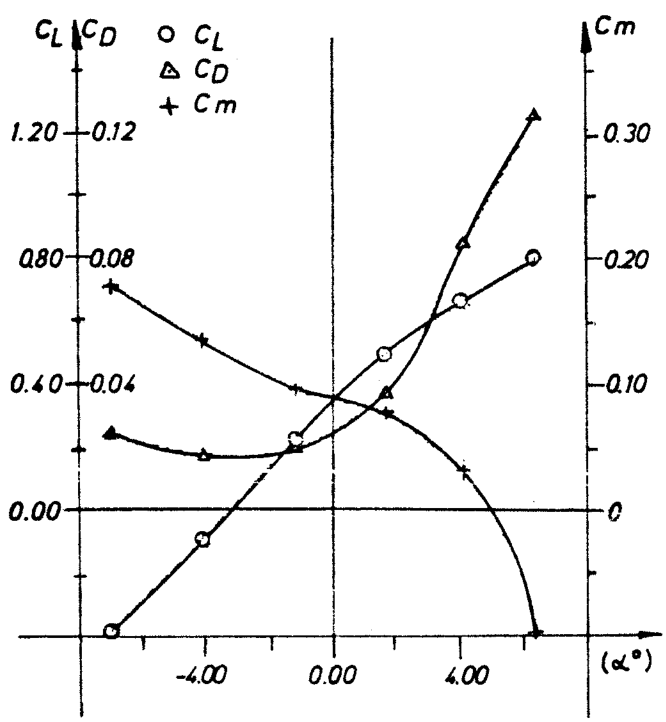


Fig.7: ONERA Effect of Reynolds Number at $M_n = 0.7$

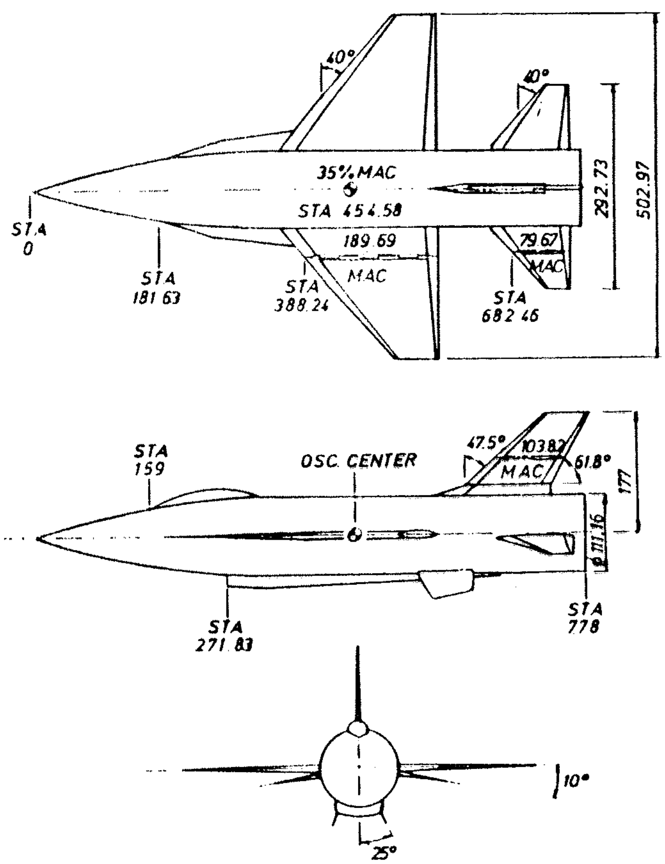


Fig.9: Geometrical Arrangement of SDM Model

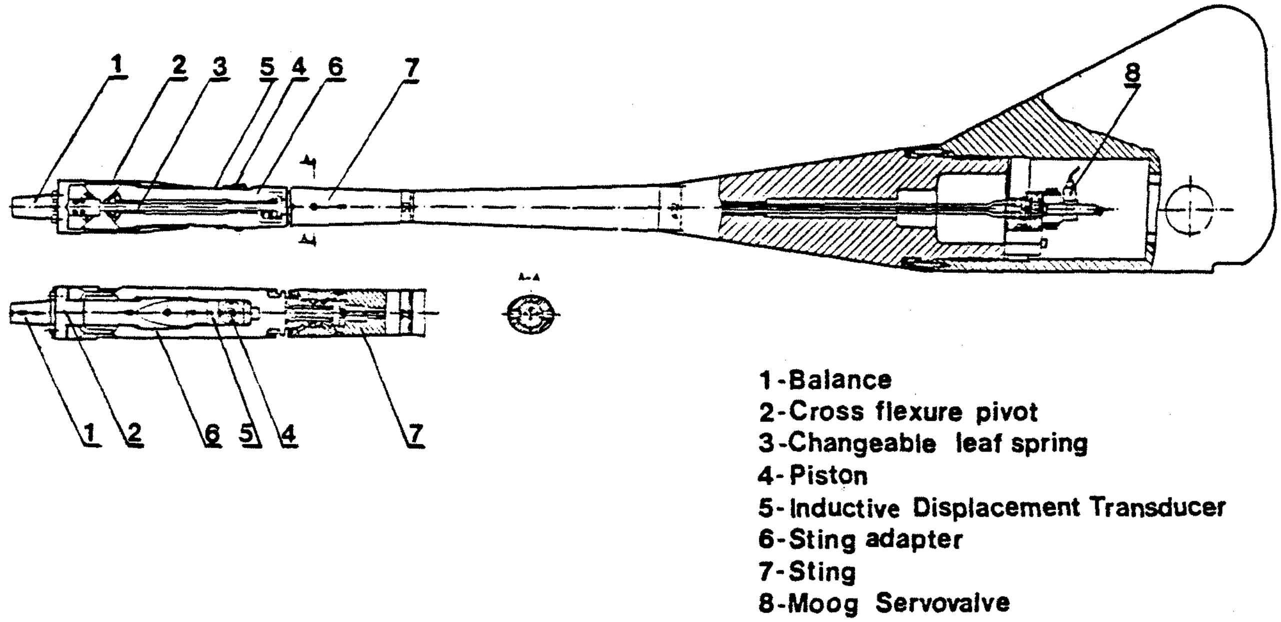


Fig.10: Forced Oscillation Pitch/Yaw Apparatus

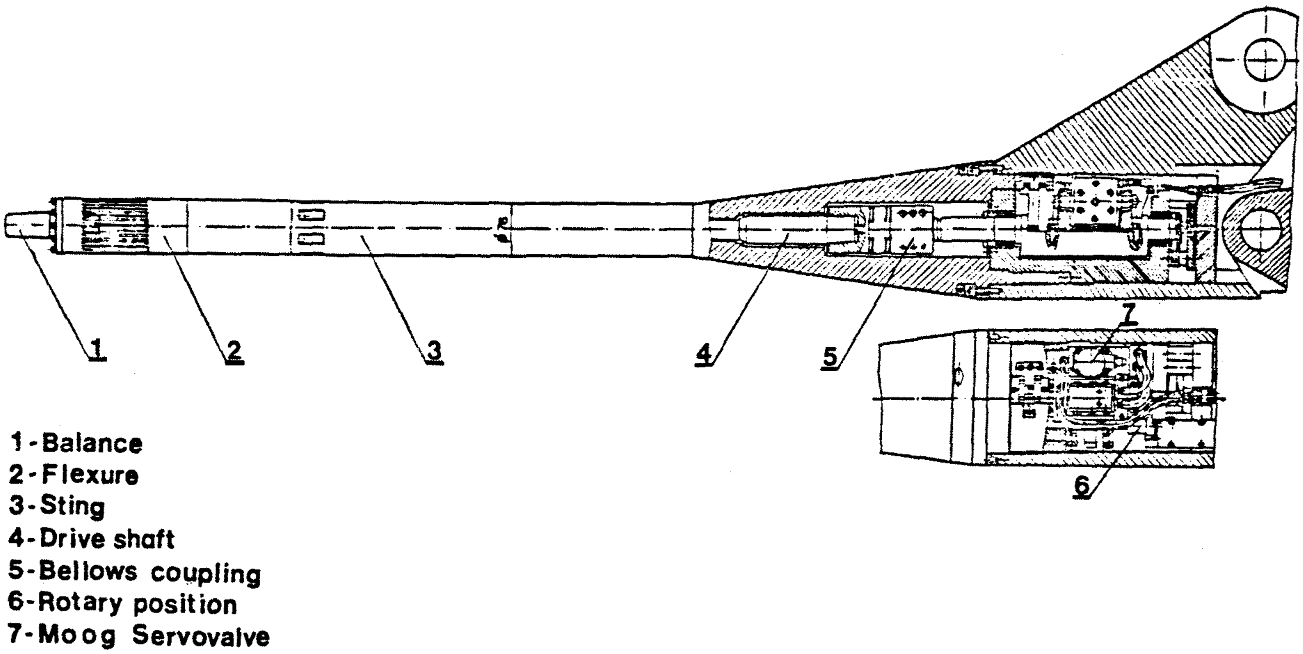


Fig.11: Forced Oscillation ,Roll Apparatus

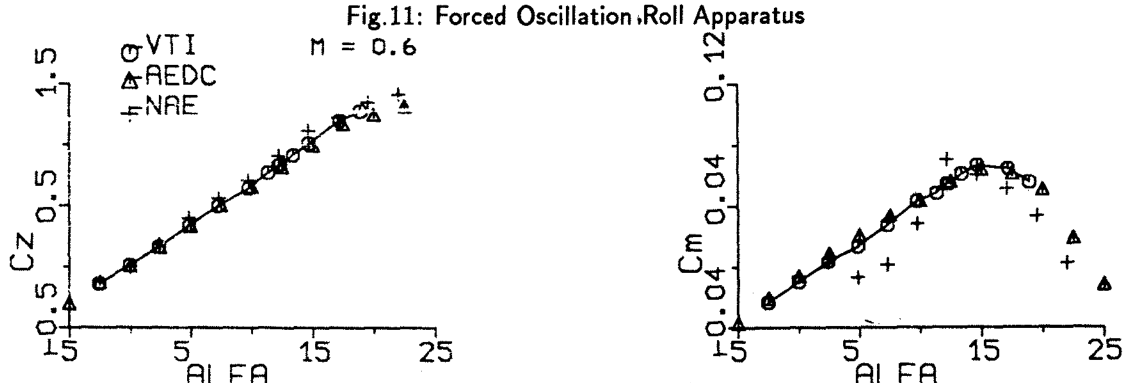


Fig.12: Longitudinal Coefficients

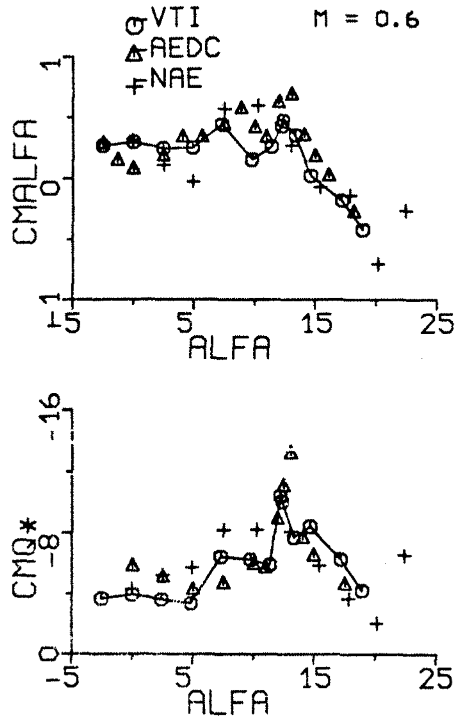


Fig.13: Pitch-Oscillation Coefficients

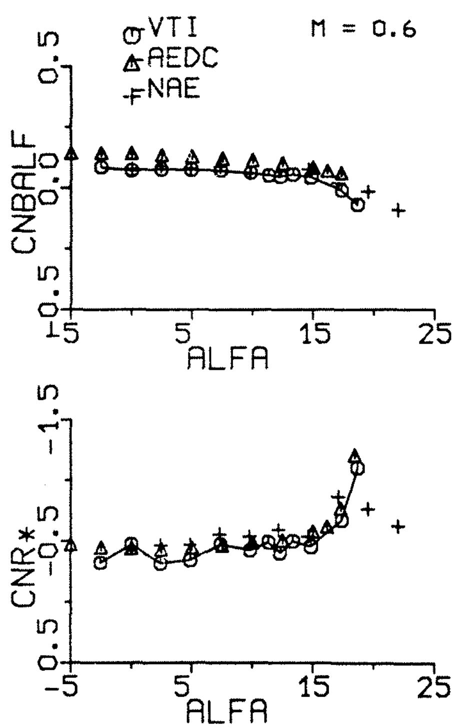


Fig.14: Yaw-Oscillation Coefficients

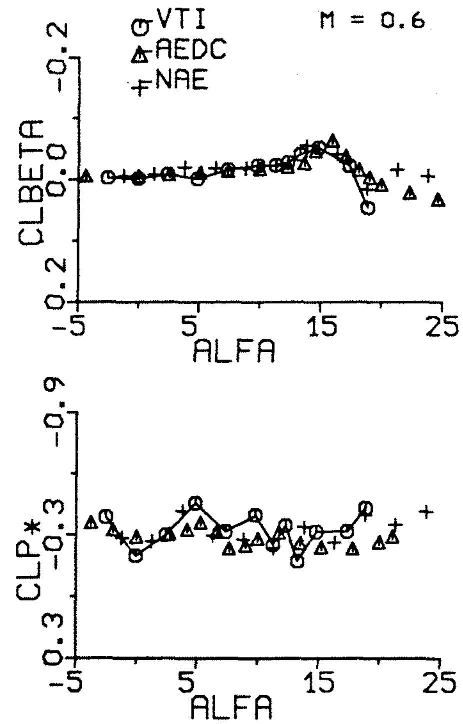


Fig.15: Roll-Oscillation Coefficients

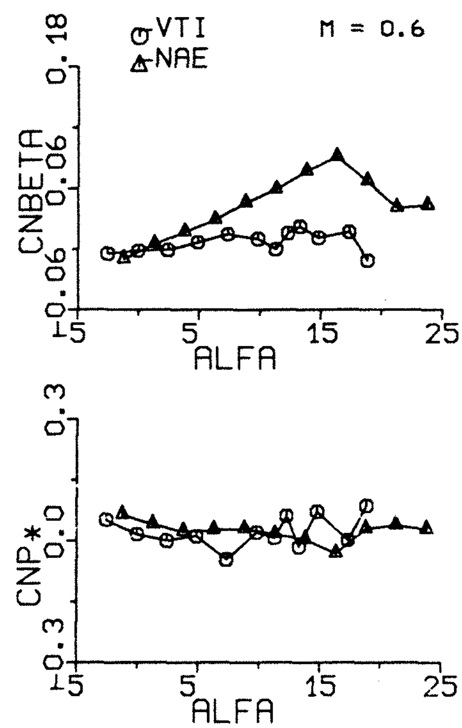


Fig.16: Cross Derivatives