DEVELOPMENT OF A MEASUREMENT TECHNIQUE FOR DAMPING DERIVATIVES IN PITCH.

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Summary

The performances of the new generation of fighter aircraft require to investigate their behaviour at high angles of attack. The high non-linearity of the aerodynamic problems related to post-stall conditions introduces a good deal of complications in the theoretical analysis of the phenomena and increases the importance of wind tunnel testing.

On the other side, the development of experimental programs for the measurement of the dynamic derivatives needs a careful identification of the technical design and configuration of the experimental system, involving a deep analysis of problems concerning mechanics and electronics.

The Turin Polytechnic Institute is involved in a long range research program, in cooperation with italian industries. This program will mainly concern with the evaluation of the damping derivatives in linear and non-linear field. The first phase of activity is consisted in the development of an experimental system, tested in the low speed wind tunnel of the Aeronautical Laboratory of the Turin Polytechnic Institute.

In order to have a comparison with the results of other existing facilities, the configuration of the model tested corresponds to the AGARD S.D.M. (Standard Dynamic Model), designed and manufactured taking into account the opportunity to have the minimum weight, in order to make easier the design of the supporting and moving rigs.

The motion in pitch around the center of gravity of the model is generated by a system of levers and rods, driven by a motor, that is controlled by a programmable electronic unit, that allows to change frequency and amplitude of the forced oscillation.

The aerodynamic reactions are mesured by an internal strain-gauge balance.

The data acquisition system stores the dynamic output signals after amplification and filtering.

The results have been compared with others obtained in analogous experiments. In the paper they will be presented and discussed.

Introduction

The most important problem in flight dynamics studies is to investigate the relationship between the aerodynamic actions and the variables of the motion in the motion equations of a flight vehicle.

This was a serious problem when the studies about flight dynamics started, about sixty years ago, but it is still a great problem; in fact if it is true that analytical and experimental tools have been improved substantially in the years, it has also to be taken into account that the flight envelopes of the modern airplanes have been expanded considerably and, consequently, the separated three dimensional flows, due to the flight at high angles of attack, involve non-linear

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aerodynamic effects. Asymmetric vortices and vortex break-down influence the aerodynamic behaviour of the flight vehicles and produce non-linearities of the dynamic stability parameters, with respect to the angles of attack and sideslip, cross-coupled mode between longitudinal, lateral and directional motions, effects of hysteresis, influence of the configuration.

There are computational and experimental approaches to the problem of determining the aerodynamic response of an airplane to a maneuver, but analytical methods to evaluate the asymmetric forces due to vortex formation and break-down is not well developed.

Therefore, considering that the best method to obtain information on dynamic stability of an aircraft is to perform experimental tests in the wind tunnel on a model, at the Turin Polytechnic Institute, an experimental research program has been developed, in order to evaluate dynamic stability derivatives on scale models in the wind tunnel.

The apparatus and the first results will be presented in this paper.

Experimental Program

The experimental program under development at the Aerospace Engineering Department of the Turin Polytechnic Institute is based on the design and manufacturing of a system for the measurement of stability parameters in the wind tunnel using the direct force oscillation technique.

The first phase has been focused to the design and the manufacturing of an apparatus able to measure the damping derivatives in the longitudinal degree of freedom. Obviously, this preliminary part of the work has the aim to provide a knowledge for the second phase of the research, when translational acceleration derivatives will be evaluated, always in longitudinal motion. The final result will be the development of an experimental apparatus for the measurement of oscillation derivatives around the three axes and the translational acceleration derivatives related to incidence and sideslip angles.

The technique is well known: the model is forced to oscillate in a single degree of freedom with constant amplitude. The forcing motion is called primary motion and the aerodynamic forces resulting are only consequent to this motion.

This method permits to evaluate in a very simple way the aerodynamic derivatives without solving the equations of the motion.

The mathematical model used in this experimental application is a second order linear differential equation related to the longitudinal motion:

$$I_{yy}\ddot{\theta} + C\dot{\theta} + K\theta = M(t)$$

where I_{yy} is the moment of inertia of the system moving around Y axis, C is the damping coefficient and K is the stiffness; θ is taken as model attitude related to the wind tunnel axis and M(t) is the primary driving moment.

Generally, in dynamic tests, the excitation is a pure harmonic:

$$\theta = \theta_0 \sin(\omega t)$$

where θ_0 is the amplitude of the motion and ω is the primary oscillation frequency.

The first apparatus designed and utilized for the research presented gives the possibility to force the model with a small amplitude oscillatory motion in the primary (longitudinal) DOF and to measure the aerodynamic reaction and its phase with respect to this primary motion.

This system will be described in a next section.

Description of the Wind Tunnel

The D3M low speed wind tunnel of the Turin Polytechnic Institute, where the tests have been done, is a closed circuit wind tunnel with a circular test section having a diameter of 3 meters and a length of 5 meters. The contraction ratio is 5.44. The turbulence factor is 1.22 and the turbulence level is 0.3%. The maximum speed is 100 m/s, and the driving motor is a DC electrical motor, having a power of 1.1 Mwatt at 800 r.p.m.. The propelling system consists of two counter-rotating fans, having each four blades.

The lay-out is shown in Fig.1.

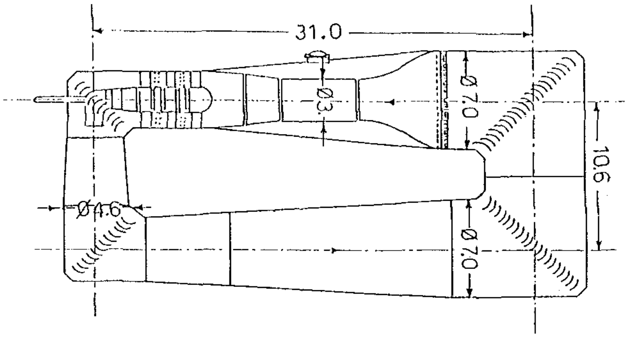

Fig.1 - Turin Polytechnic Institute low speed wind tunnel.

Description of the model

Since these kind of tests are new for the D3M low speed wind tunnel of the Turin Polytechnic Institute, the system previously described had to be qualified and for this reason the first model realized and tested, instead of a simple configuration airplane, is the Standard Dynamic Model, henceforth denoted SDM that has been introduced by NRC/NAE in 1978.

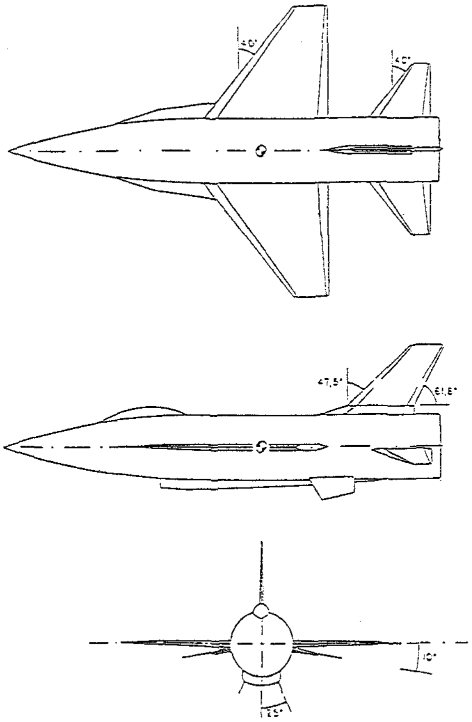

Fig.2 - Standard Dynamic Model.

The SDM characteristics are typical for a calibration model: relatively simple configuration, materials stable in time (aluminum alloy) and good accuracy in manufacturing due to the simplicity of the geometry.

It was designed and manufactured taking into account the requirement of having the minimun weight; the geometrical characteristics of this model are: length = 0.943m, wing span = 0.609m, weight = 8Kg.

Its configuration is presented in Fig.2.

A large number of bibliographical data are available on tests related to this model, because it has been designed and tested in AGARD programs in different research centers.

Description of the Apparatus

Mechanical configuration

In order to evaluate the possibility to perform dynamic tests in the D3M wind tunnel, the mechanical apparatus has been designed as simple as possible.

The wind tunnel, designed in the past essentially for static tests, has an external balance located under the floor of the test section: this configuration caused

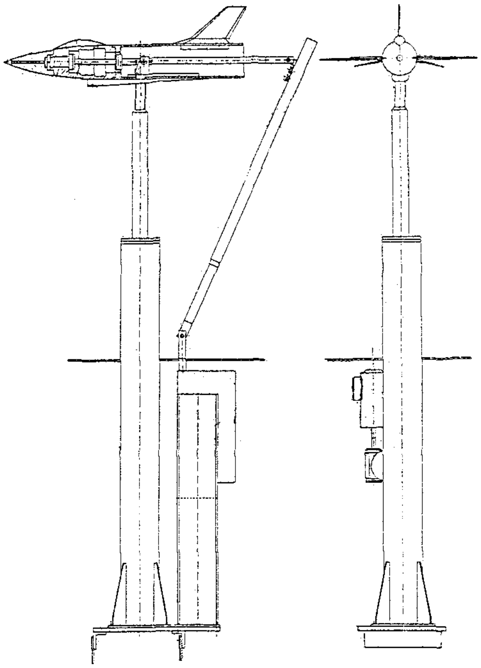

Fig.3 - Mechanical rig.

some difficulties in the design of the dynamic support system.

For the first phase of the research the support was designed and manufactured as shown in Fig.3, with the base on a very stiff beam connected to the external wall of the wind tunnel.

Two different supports are taken on the base: one for the model and the other for the driving unit; in this way the mechanical interference between the model and the driving motor is reduced.

The design of the model support required some care, due to the opportunity of using a good shape both aerodynamically and mechanically (flexional stiffness). The stiffness matrix of the support was evaluated.

Photographs in Figg.4 and 5 reproduce the model in the wind tunnel.

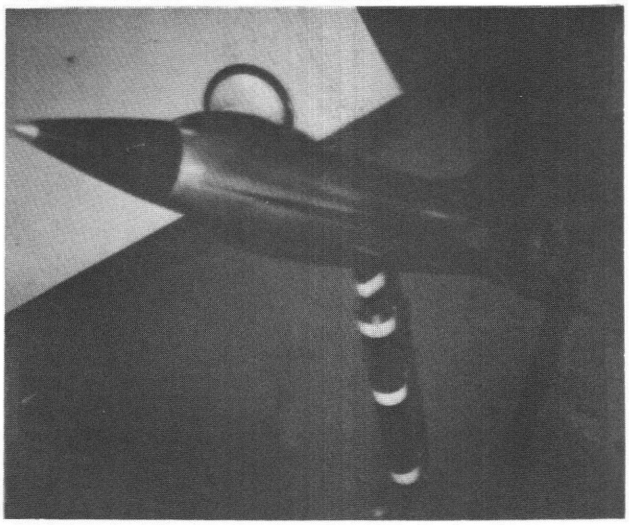

Fig.4 - SDM mounted in the wind tunnel.

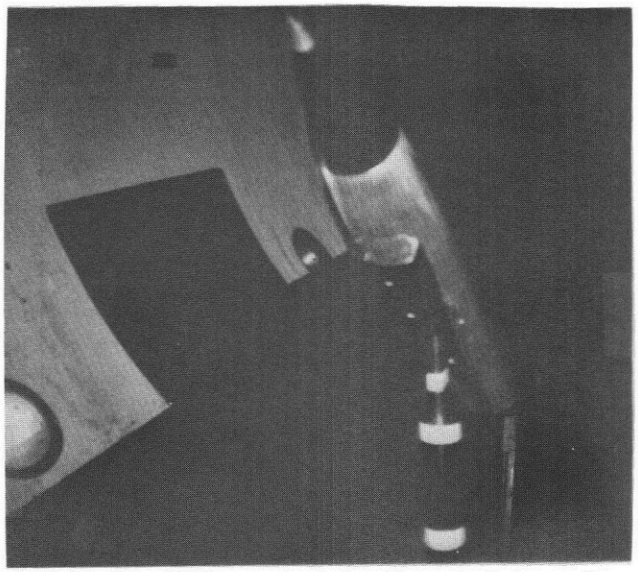

Fig.5 - SDM mounted in the wind tunnel.

The Driving unit

The driving apparatus used to move the model according to a sinusoidal primary motion is a compromise between different aims: accuracy, efficiency, versatility and low cost manufacturing.

The actuator is a DC electrical motor working in an indipendent unit, that can generate any wave-shape composed by a special gear-box connected to a flywheel by an adjustable mechanical system. This in order to modify the amplitude of the motion. This unit is linked to the oscillating lever in the rear of the model by a rod, that can vary its length in accordance to the angle of attack of the model.

The angle of attack can be set from -10° to +50° and the maximum oscillation amplitude of the model is +/- 2°.

The driver of the motor is a PWM (Pulse Width Modulator), which is necessary to obtain the features requested by the motion of the model (speed and accuracy).

The driving electro-mechanical system is controlled by a servo-controller unit that is linked to the motion and velocity transducers of the apparatus and to the driver of the motor.

The function of the servo-controller is to control the motor in order to obtain a sinusoidal wave-form for the motion of the model, at a maximum oscillation frequency of 5 Hz.

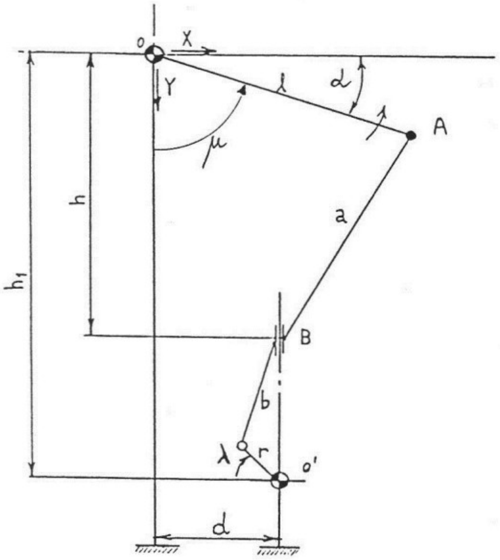

Fig. 6 - Kinematical configuration.

This system allows the generation of any kind of oscillation within the limits of the maximum amplitudes, frequencies and stresses of the mechanical rig.

The position and the lenght of the rod causes a deformation of the sinusoidal oscillation generated by the driving unit, when performed at constant speed of the electrical DC motor. In order to correct this kinematic error, the geometrical deformation of the motion has been analyzed trough the relationship between the angles λ and μ and their time derivatives. The final kinematic equation correlates the angular velocity of the crank (λ) in the driving unit to the frequency of the model oscillation (μ) in function of the geometrical lenghts of the system. Therefore is sufficient to change continuosly the velocity of the motor to obtain a correct sinusoidal motion of the SDM. Obviously the features of the servo-actuator used for the driving unit depend upon the frequency of this angular speed corrections: high torque, low inertial loads and high frequency dynamic response.

The servo-controller is connected to a computer that manages the control system and talks with the data acquisition unit, verifying the position of adjustable mechanical components and generating the correlation table between positions of the motor and its speed corrections.

The balance.

An internal balance was designed, according to the required mechanical features, the statical and dynamical loads on the model. The project was a compromise between the stiffness required by the maximal loads (aerodynamical and inertial) and the sensitivity of the trasducer to the minimal variation of the forces acting on the system. In particular the resonant frequency of the balance has been evaluated, in order to avoid resonances with the mechanical system during the oscillating tests.

The data acquisition unit.

The electrical balance supply and the handling of the output signals (amplification and filtering) were done by a conventional signal conditioning amplifier system.

The conditioned output signals were sampled by an acquisition unit connected to a computer that could finally evaluate the damping coefficients of the SDM, according to the before mentioned mathematical model.

For the next phase of tests a new data acquisition and reduction system has been designed and qualified. Some preliminary experimental results have already been obtained.

Experimental results

As first step of the experimental program, static polars of the SDM were obtained and compared with those found in other laboratories.

After that the dynamic test program was started, obtaining the pitch stiffness derivative $C_{m\alpha}$ and the damping derivative in pitch $(C_{mq}+C_{m\dot{\alpha}})$.

Performing wind-on and wind-off tests, it is possible to measure the aerodynamic effect in dynamic conditions without taking into account the inertial loads. The mathematical solution of this method is reported in Ref.4.

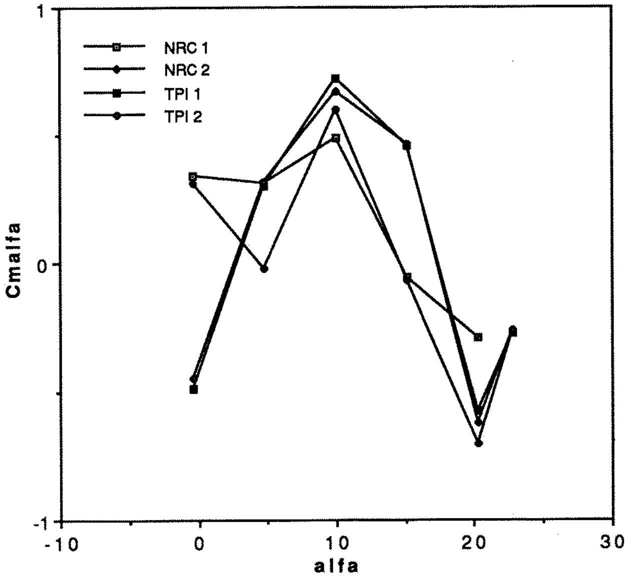

Fig.7-$C_{m\alpha}$ derivative versus angle of attack. Results of NAE and Turin Polytechnic Institute.

The tests were organized into sets according to the same dynamic pressure, reduced frequency ($\bar{\omega}=\omega\bar{c}/2V$) and oscillation amplitude. The largest quantity of tests, in this first phase, is referred to the oscillation frequencies of 1.8 Hz and 2.7 Hz, wind tunnel speed V=40 m/s and oscillation amplitudes of +/-1°; the mean aerodynamic chord of the model is $\bar{c}$=0.22 m.

The results reported below are referred to an oscillation frequency of 1.8 Hz.

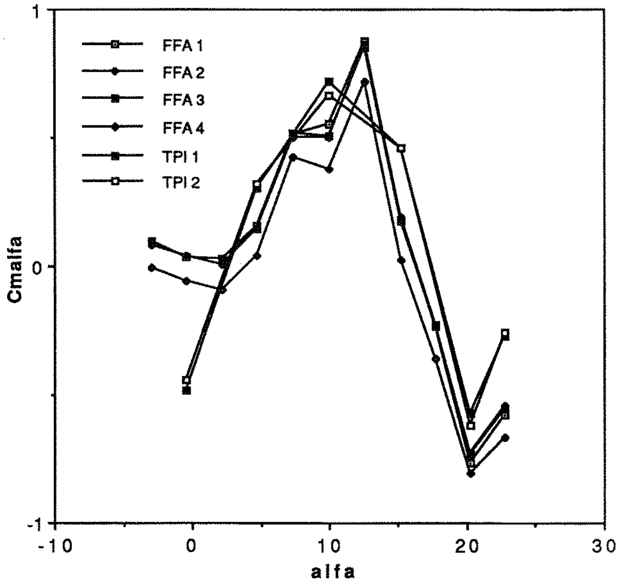

Fig.8-$C_{m\alpha}$ derivative versus angle of attack. Results of FFA and Turin Polytechnic Institute.

In Figg.7, 8 and 9 are represented the values obtained for $C_{m\alpha}$ on SDM, compared with the results of the analogous tests done respectively at FFA-Sweden and NRC/NAE-Canada. Some discrepancies are evident, probably due to the flexibility of the balance and to the different oscillation frequency; as regards the influence of the Mach number, it has been verified that it has not a great influence on the results.

In Figg. 10, 11 and 12 are compared the results related to the derivative $C_{mq}+C_{m\dot{\alpha}}$ (denoted C_{mq}*) evaluated at FFA, NRC/NAE and Turin Polytechnic Institute, always on SDM. Also in these case some discrepancies are present in the values measured due to the same reasons before mentioned.

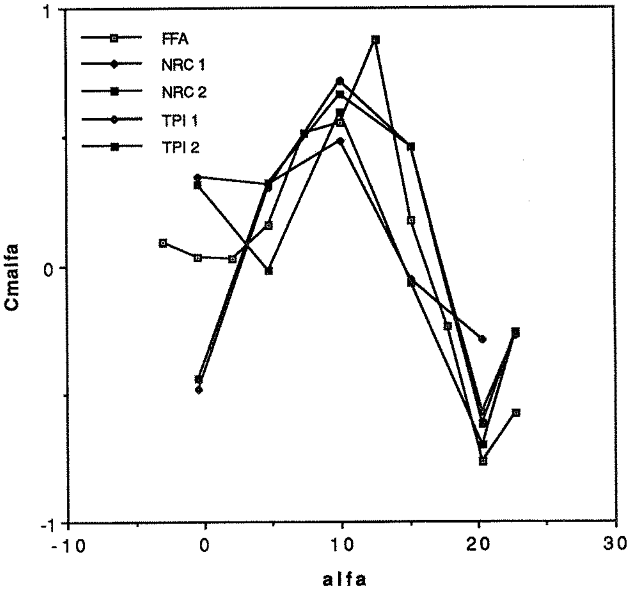

Fig.9-Comparison among results of FFA, NRC/NAE and Turin Polytechnic Institute.

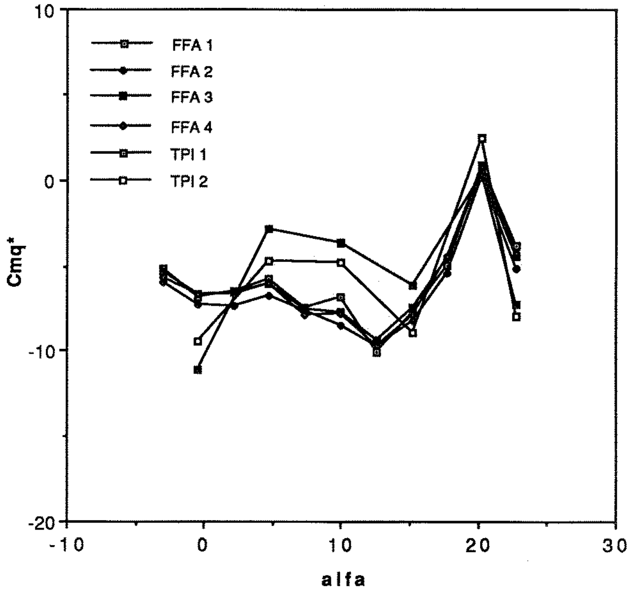

Fig.10-C_{mq*} derivative versus angle of attack. Results of FFA and Turin Polytechnic Institute.

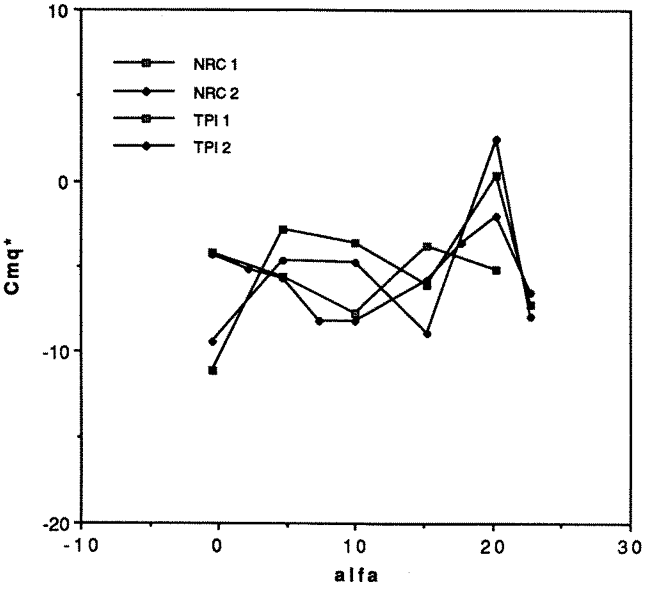

Fig.11-C_{mq*} derivative versus angle of attack. Results of NRC/NAE and Turin Polytechnic Institute.

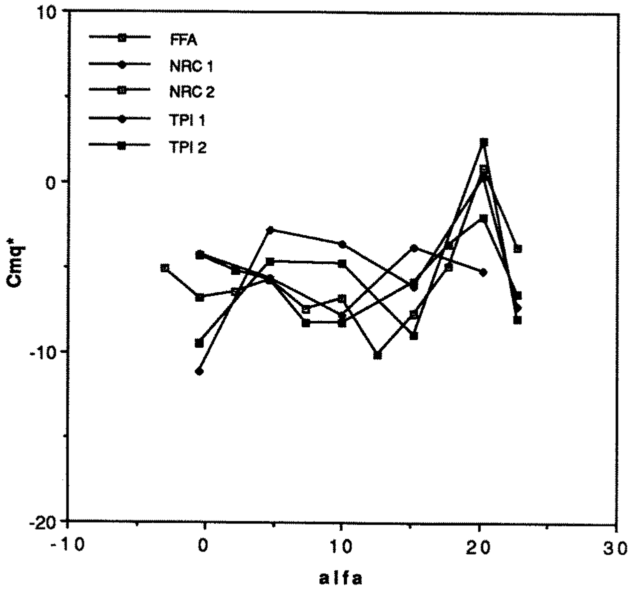

Fig.12-Comparison among results of FFA, NRC/NAE and Turin Polytechnic Institute.

Conclusions

The program presented in this paper is now developing the second part of the preliminary phase, including the improvement of the data acquisition and reduction system, the full automation of the mechanical system, the design and manufacturing of two new balances.

Also the moving rig for plunging tests is in the manufacturing phase and the preliminary tests are foreseen for the end of this year.

In conclusion the first part of this research gave satisfactory results: the methodology as been tested, the system has been qualified by using the Standard Dynamic Model, the system is reliable and the preliminary results are comparable with those obtained in other wind tunnels.

Obviously the development of the whole program for the experimental evaluation of the stability derivatives needs a large amount of work, that will be carried on in the next years.

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