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BLOCKAGE CORRECTIONS AT HIGH ANGLES OF ATTACK IN A WIND TUNNEL

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ABSTRACT

The opportunity to investigate the flight conditions at high angles of attack arose in the last years. This makes necessary to set a new measurement standard in the wind tunnels. This is why AERITALIA decided to validate results obtained in their 4 sqm low speed wind tunnel in post-stall conditions and to investigate a method of data correction of blockage for application in the on-line (quick look) data reduction problem.

Tests were done in AERITALIA and Emmen wind tunnels.*The size of the latter , compared to the model size* made boundary interference corrections negligible.

Two similar suspension rigs were used, so that results would be comparable without introducing suspension interference corrections.

The aim was to use Emmen data like reference to correct AERITALIA values.

In a first time we tried to use the Maskell formula introducing constant coefficient, according to the test conditions, but this results were not satisfying.

In a second time, elaborating the Maskell formula, we decided to get out the reference areas, by using the flat plate base pressure coefficient or viceversa. In all this cases the induced drag coefficient was expressed as a *function of lift coefficient.*

To check the validity of this choise the pressure coefficient trend available for a calibration model tested in AERITALIA wind tunnel, were compared with that one for the flat plate: the trend are similar.

The final corections for lift and moment coefficients are very satisfying, while for the drag coefficient the corrections are slightly excessive.

INTRODUCTION

Flight conditions at high angles of attack have to be assessed with great care for a new generation of figther aircrafts requiring high manouvering performances and, for *civilian aircrafts, to guarantee safe flying in the presence of* gust.

Owing to the non-linear behavior of aerodynamic forces at high angles of attack, it is hard to evaluate theoretically aerodynamic coefficients in the stall and post-stall region, and so wind tunnel and fligth tests become absolutely necessary.

About wind tunnel tests, one of the most important problems is the blockage constrain which could be not negligible at high angles of attack, with regard to the model size compared with the tunnel one.

Several techniques have been used in attempts to minimize wall corrections of the test section. For instance we can use models that are small relative to the test section size or apply *linearized corrections to the model data.* Generally more than one of these techniques are used together. But we now demand accurate measurements from wind tunnel testing and conventional techniques are inadequate.

Modern techniques (1) have demonstrated superior performances adapting test section boundaries, or, better, wall plus boundary layer, to free air streamline shapes around the model.

The principle itself it's simple and benefits are large (higher Reynolds numbers, reduced tunnel drive power, reduced off line corrections,etc.), but wall must be continually adapted for each test condition. We need an adequate very complex hardware (both mechanical and instrumental) and operational problems arise. It is not simple nor it is istantaneous to take data and it looks almost impossible to use adaptive walls techniques performing dynamic tests.

A possible method to evalute separation blockage *corrections is to measure wall static pressure* (2). This technique is complex and it requires a long time to take and elaborate data. We want to check that we could use base pressure coefficients, C_{pb}, that may be *evaluated* measuring static pressure in few points on wings and fuselage in the non-streamline flow. The base pressure of sharp-edged flat plates in two dimensional flow, can be utilized instead of the model one when data are not available.

To verify the methodology used to determine the *stationary aerodynamic derivatives and refine separation* blockage corrections on full aircraft configurations, AERITALIA decided to validate results obtained in their 4 sqm low speed wind tunnel located in Torino (Italy). Among the models available, the characteristics of the one used were rigthto conder it as a standard calibration.

Tests were performed in the AERITALIA wind tunnel as well as in the 32.4 sqm F+W Emmen (Switzerland) one. The size of the latter compared to the model makes wall and blockage correction of Emmen results, with good approximation neglegible.

Because of the foresaid requirements, to investigate in the stall and post-stall region angle of attach reached 52°.

WIND TUNNELS AND MODEL DESCRIPTION

F+W Emmen is a closed-circuit low speed wind tunnel and has closed rectangular 5m x 7m test section with blunted corners (32.4 sqm).It was used as comparison because of its well known reliability. (See figure 1a).

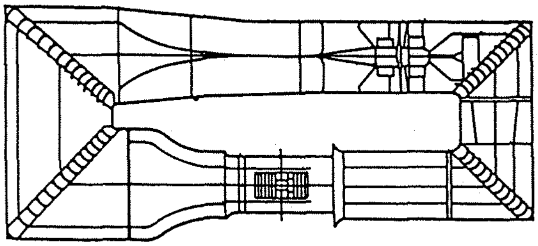


Figure 1a - Emmen F+W wind tunnel

The AERITALIA (AIT) wind tunnel in Torino is an open-circuit facility with closed square 2.1m x 2.1m test section, with blunted corners (4 sqm). (See figure 1b).

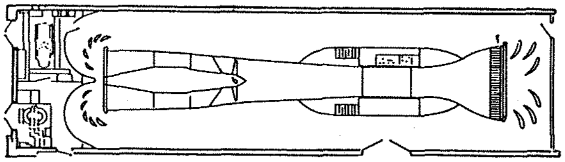


Figure 1b - AERITALIA-Torino wind tunnel

The comparison between the test sections of the two tunnels is shown in figure 1c.

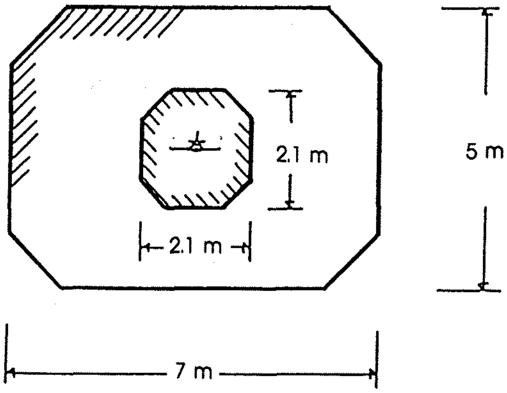
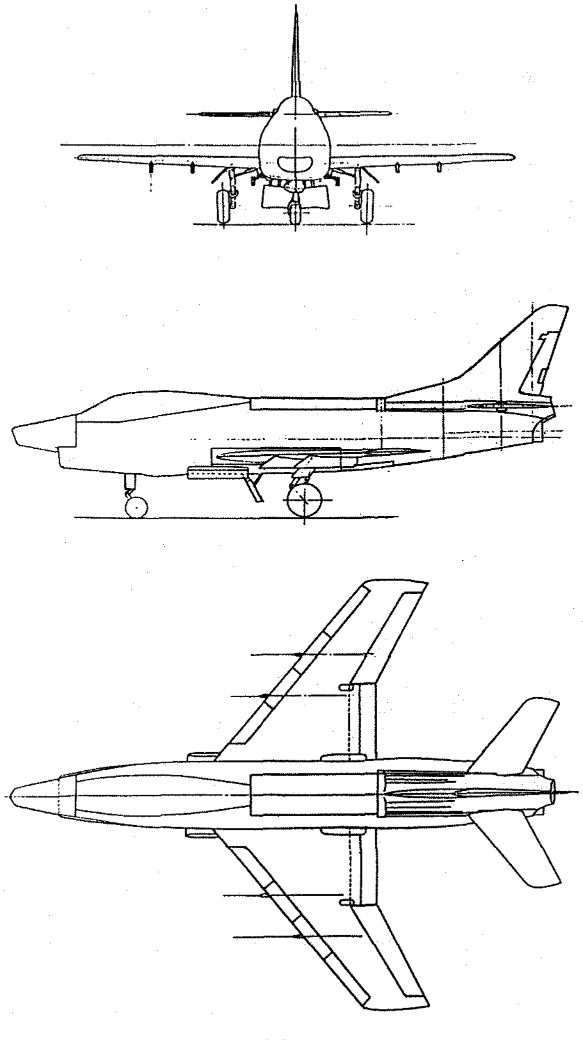


Figure 1c - Test section comparison

Usually, for validation tests, the model is chosen according to these requirements:
- simple geometry
- material's steadiness to guarantee repeatability.

AIT decided to use a pre-existing model (M2). Even if the M2 hasn't a very simple geometry it was chosen because of its stability, its processing quality, and the large data available. (See figure 2)



Wing span 0.9 m
Wing reference surface 0.21 sqm

Figure 2 - Calibration model (M2)

DATA PROCESSING

AIT data were corrected using conventional correction without considering separation blockage.

Support interference was not considered neither for AIT nor for Emmen measurements. In fact two identical rigs (of slightly different sizes only far from the model) were used so that results would be comparable.

As figures 3, 4, and 5 show, AIT and Emmen data coincide untill the angle of attack becomes so high that we enter the stall region. It happens for values about 15°. We could think that the discordance is due to separation blockage no more neglegible.

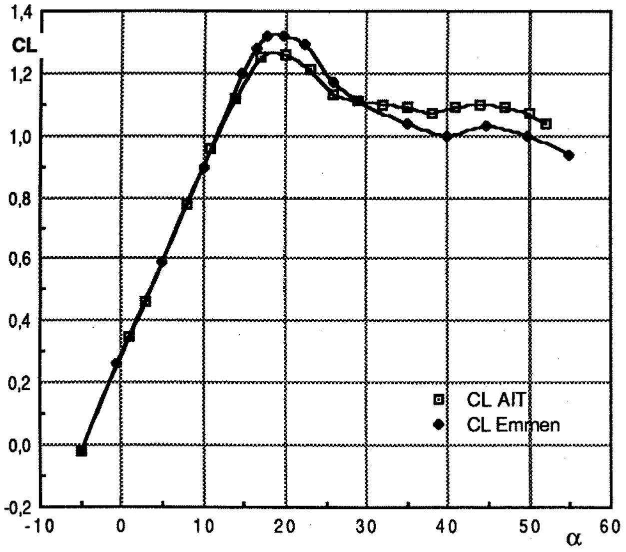


Figure 3 - Lift coefficients

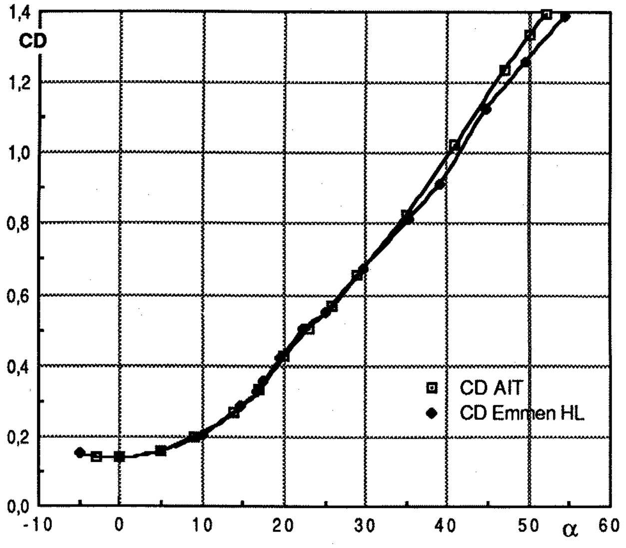


Figure 4 - Drag coefficients

Corrections suggested in (3) and (4) are not able to work suitably with these data.

If we agree that the dominant effect is taken to be equivalent to a simple increase in the free-stream velocity, it should be verifyied the following relation

$$\frac{C_i}{C_{ic}} = 1 + \frac{\Delta q}{q} \qquad (1)$$

where C_i is the measured value of the i-aerodynamic coefficient and C_{ic} is its corrected value, while Δq is the effective increase in dynamic pressure. At fixed flight configuration the ratio is constant.

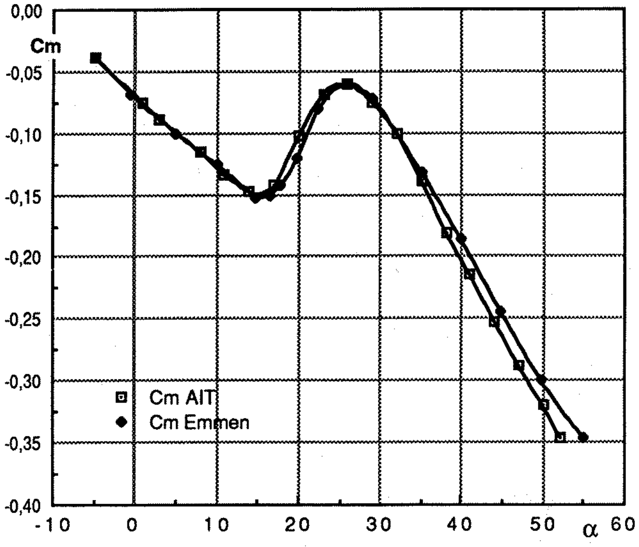


Figure 5 - Moment coefficients

To check the validity of equation (1) lift, drag and pitch moment AIT to Emmen values ratios were calculated.(See fig 6).

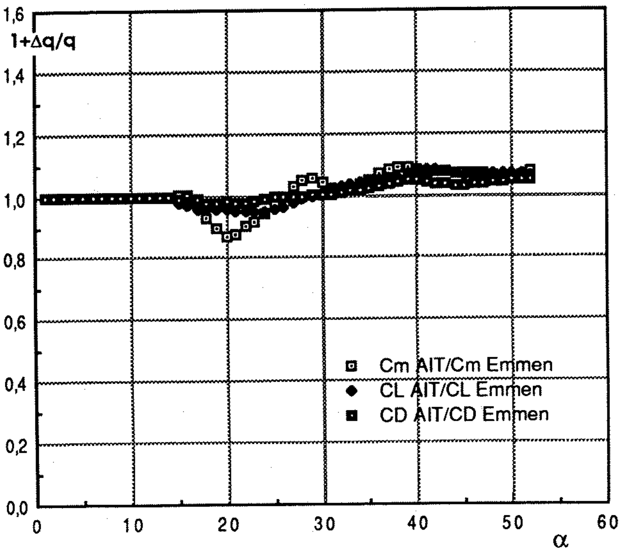


Fig. 6 - AIT to Emmen coefficients ratio

The suggested correction (4) for stalled wings of finite span is

$$\frac{\Delta q}{q} = \mu \cdot C_{Ds} \cdot \frac{S}{C} \qquad (2)$$

$$C_{Ds} = C_D - C_{Di} - C_{D0} \qquad (3)$$

$$\mu = \frac{5}{2} \qquad (4)$$

where μ is an appropriate coefficient, D_s the drag associated with the stalled regions, S the reference surface, C the test section size, D_i the induced drag, D_0 the conventional profile drag.

As you can see in fig.6, the assumption that the main separation blockage effect could be taken equivalent to a velocity increase is not checked if angle of attack is lower than 30°. In fact

$$1 + \frac{\Delta q}{q} < 1$$

It can be attribute to the different conditions through the model enter the stall in the two wind tunnels.

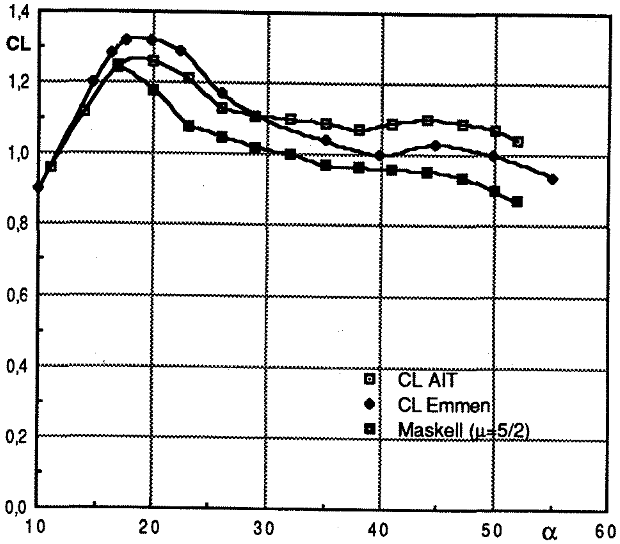


Figure 7 - Maskell correction with μ constant

The range of interest can be chosen from 30°. However, above 30° correction results excessive (see figure 7). We have to look for a more appropriate value of μ.

MASKELL FORMULA WITH BASE PRESSURE COEFFICIENTS

For the above mentioned reason, id est the Emmen wind tunnel size is large compared with the model one, and so the flow around the model can be considered not influenced by boundaries, we have considered the Emmen data as "exact".

In that way we have found a Maskell formula application that make as near as possible the AIT rough data to Emmen ones.

Having this target we have marked out the Maskell formula. In Maskell theory the corrective coefficient is:

$$w = 1 + \frac{\Delta q}{q} = 1 + \frac{1}{k_c^2 - 1} \cdot C_{Ds} \cdot \frac{S}{C} \qquad (5)$$

id est

$$\mu = \frac{1}{k_c^2 - 1}$$

We can also write

$$w = \frac{k^2}{k_c^2} \qquad (6)$$

where k^2 is a function of base pressure coefficient C_{pb}

$$k^2 = 1 - C_{pb} \qquad (7)$$

From (5) and (6) follow:

$$k_c^4 - k_c^2 \cdot \left(k^2 + 1 - C_{Ds} \cdot \frac{S}{C}\right) + k^2 = 0 \qquad (8)$$

This quartic equation solved as regards k_c^2, with right sign, gives

$$k_c^2 = \frac{1}{2} \cdot B + \sqrt{\frac{B^2}{4} - k^2} \qquad (9)$$

where

$$B = k^2 + 1 - C_{Ds} \cdot \frac{S}{C}$$

with k_c^2 and k^2 from (7) we can get out the correction coefficient w, with formula (6).

In this case we had w thanks from the equation (1), where the measured coefficients C_l are the AIT data and the corrected coefficients C_{lc} are the Emmen data.

We decided - by the equations (6) (7) and (8) - to compute the reference areas, using a known value of the base pressure coefficient, or viceversa.

Since the C_{pb} values were not available for the calibration model the base pressure coefficients for sharp-edged flat plate in two-dimensional flow were taken, in the first case. C_{Ds} was evaluated as difference between AIT and Emmen data.

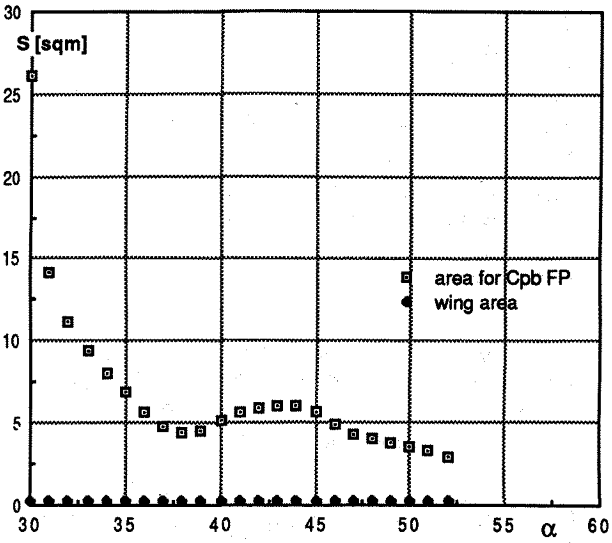


Figure 8 - Reference surface for Cpb FP(flat plate) and CDs = CD ait - CD emmen.

Figure 8 shows the S trend as a funcion of the angle of attack. The values are not constant and far away from the model wing area (0.21 sqm).

About C_{pb}, it was computed for different reference areas and compared with the base pressure coefficients of the two-dimensional flat plate.(See figure 9). The gap is too wide as well, even if, with the wing area, the slope is fairly the same.

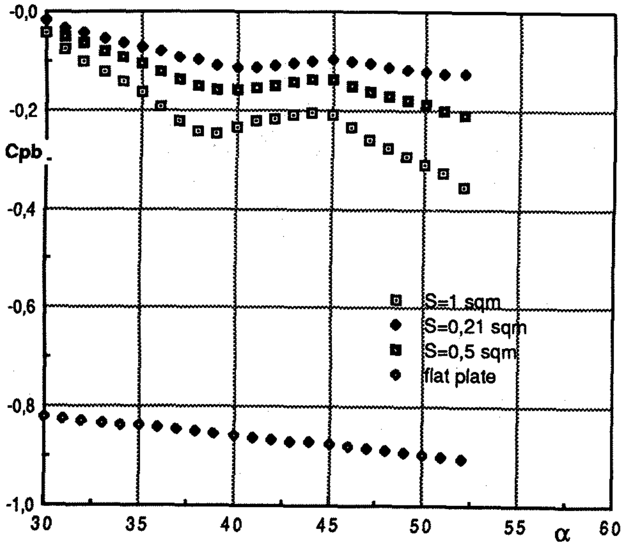


Figure 9 - Cpb for different reference surfaces and CDs as fig. 8.

These results induced to follow an other method to evaluate C_{Ds}; therefore it was computed on the base of equation (3) where C_{Di} is defined as

$$C_{Di} = \frac{C_L^2}{e\pi A} \qquad (10)$$

The reference area, for the Cpb of the two-dimensional flat plate, is fairly constant as a function of the angle of attack (See figure 10) and the values are close to that of the wing area.

Figure 11 represents the C_{pb} trend as a function of alfa. When the reference area is the wing area the results agree with the flat plate ones, while using the area of planform as reference this is not true.

FINAL CORRECTIONS

The previous considerations lead to the conclusion that the last C_{Ds} computation has to be used instead of extrapolating C_{Di} from the measured properties of the unstalled model as suggested in (4).

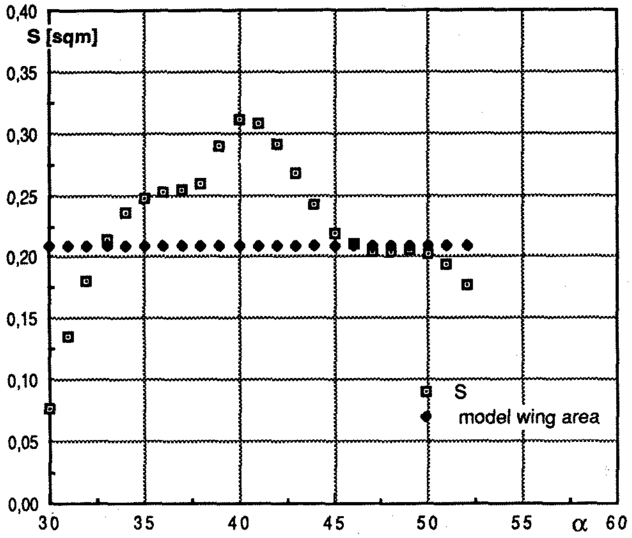


Figure 10 - Reference surface for Cpb FP and CDs from eq. (3)

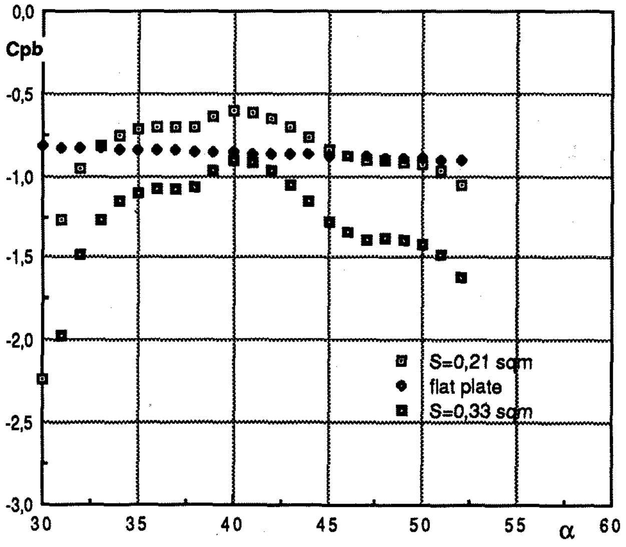


Figure 11 - Cpb for different reference surfaces and CDs from eq. (3).

The problem is to have the right trend of C_{pb} when there are not all the required pressure taps on the model. To check if it is possible to use the two-dimensional flat plate Cpb, data available were used of an other calibration model tested in AIT wind tunnel. It is a classic figther aircraft model equipped with pressure taps along the wing chord at several wing span. Tests were performed for clean and high lift configuratión untill 30° angle of attack only, but the curves trend is undoubtely close to the flat plate ones.

It is clear from figure 12; y1 and y2 are two different positions along the span and HL indicate the high lift configuration.

For this reason flat plate base pressure coefficients could be assumed for the M2 calibration model.

Figures 13, 14 and 15 shows the curves C_L, C_D and C_m respectively as a function of alfa. For every coefficient there are:

1) rough AIT data
2) Emmen data
3) coefficients corrected as foresaid.

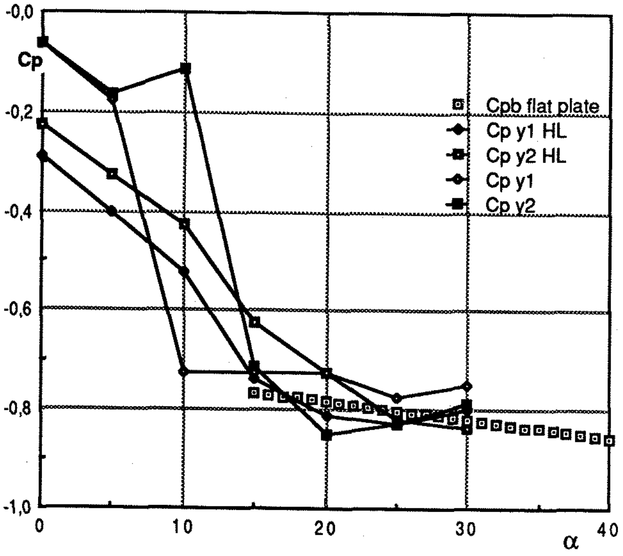


Figure 12 - Pressure coefficients of a calibration model

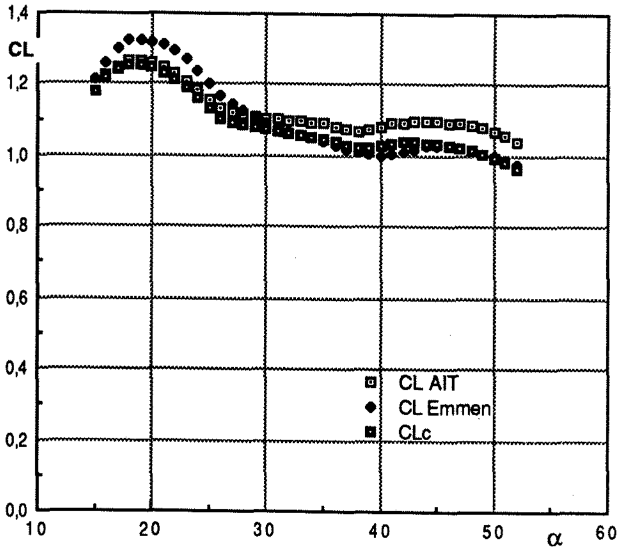


Figure 13 - AIT, Emmen and corrected lift coeff.

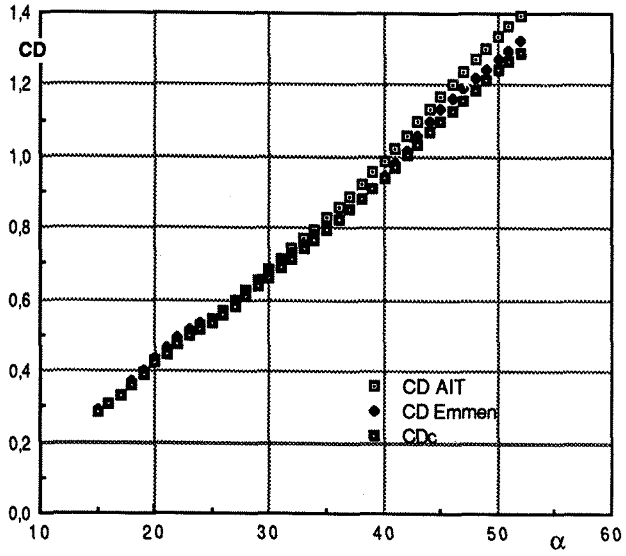


Figure 14 - AIT, Emmen and corrected drag coeff.

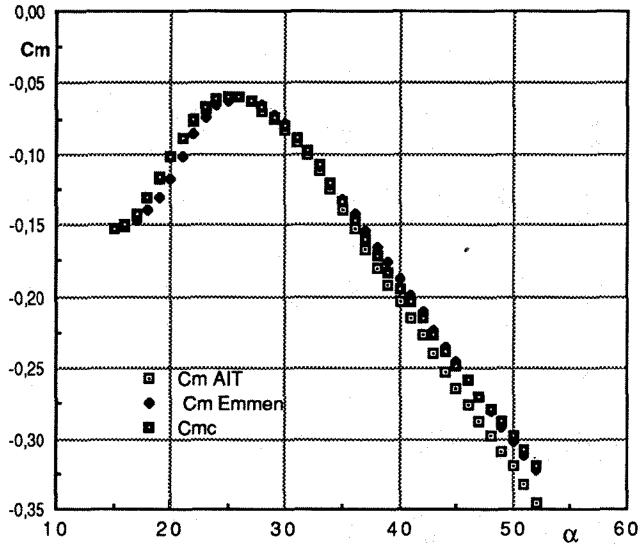


Figure 15 - AIT, Emmen and corrected moment coeff.

The final corrections for C_L, C_D and C_m are very satisfying. A better approximation it is guessed to be reached by using true C_{pb} data.

Guessing that the non-streamline wake blockage is no more neglegible over the stall, a particular care is taken to evaluate the correction in this range.

CONCLUSIONS

The remarkable result of the research is the way to evaluate the separated flow wake blockage effect in a relatively small wind tunnel, compared to the model size.

The philosophy can be applied easily inthe on-line data reduction problem, with simple means.

In fact it is possible to compute corrected values for the aerodynamic coefficients, also at high angles of attack, being known the function $C_{pb}(a)$ for the two-dimensional flat plate.

An improvement of this method can be easily obtained when on the model a few pressure taps are provided on wings and aftbody. This requirement doesn't involves significant complications on the model design: in fact the pressure values must be measured at high angle of attack only, when flow is separated and therefore it is sufficient at the worst to put external probe, without affect the aerodynamic behavior.

When the $C_{pb}(a)$ trend is available, the corrections related to the separated flow blockage can be computed with a good approximation, without providing pressure taps on wind tunnel walls.

The method is applied just to a single configuration, but some performed investigations let believe that it can be used for the most configurations of combact aircraft.

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