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PROBLEMS INVOLVED IN SUBSONIC AND SUPERSONIC PROBES CALIBRATION IN OPEN TUNNELS

by

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SUMMARY

The EPF Wedge probe WP11.3 was calibrated over the Mach number range .70 to 1.50 in the D.I.Me.Ca supersonic blowdown wind tunnel.

In order to evaluate the general response, the probe was calibrated for two Mach numbers (.70 and .90) in subsonic flow and for two Mach numbers (1.25 and 1.50) in supersonic flow for different yaw and pitch angles.

The calibration results are in good agrement with those reported by other workers \1\ but the scatter for the coefficent K1 was not reliable enough, also considering the very trend of the dimensionless pressures, with respect P_{teff}.

It would be very interesting to compare with the results obtained by the other laboratories using these parameters directly.

1. INTRODUCTION

This paper reports on the results of tests carried out on a four hole wedge probe, WP 11.3 (Fig. 1), constructed by EPF of Lausanne and used as a test probe in the European Workshop on Probe Calibration 1981-1983 (Aachen, December, 1984).

Investigations undertaken at that time revealed wide discrepancies in the results obtained, especially for pitch angle coefficient K1, and one of the likely causes suggested were the different geometric set ups of the test sections /1/.

In the light of the above considerations, the tests in the tunnel of D.I.Me.Ca /2/ were performed with three different test section configurations: a) free jet, b) half open 1, c) half open 2 (Fig. 2).

Already in the first trials (at $M_a = 1,5$), the results of the last two configurations were found to be identical (Fig. 3); subsequent

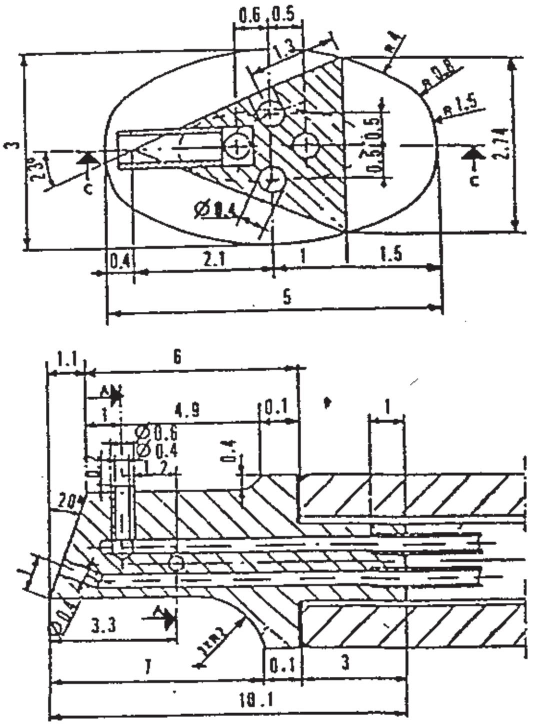
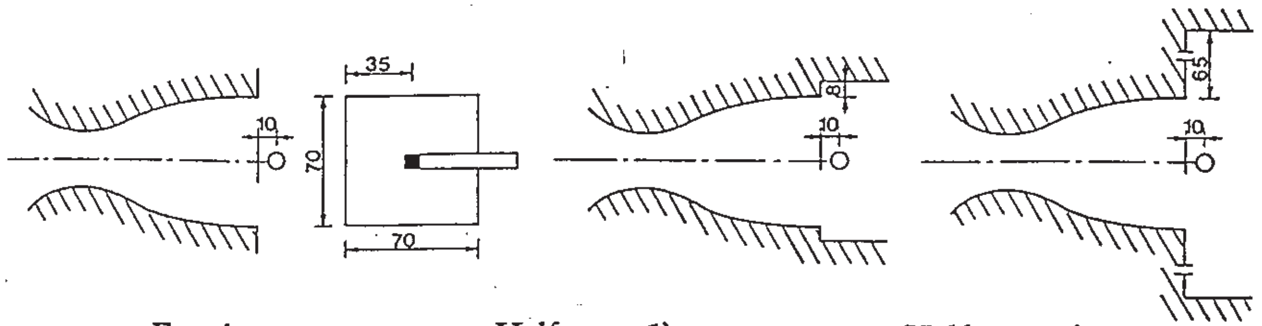


Fig. 1



Free jet Half open 1) Half open 2)

Fig. 2

investigations were thus restricted to cases a) and b). In order to evaluate its general response, the probe was first completely calibrated for two Mach numbers in subsonic flow (0.7 and 0.9) and two in supersonic flow (1.25 and 1.5) with yaw angles ranging from -25° to +25° and in the free jet set up also with pitch angles of between -15° and +15°. An investigation was then conducted with zero yaw and pitch angles to assess the effect of Mach number on calibration parameters. These tests were run a number of times to check the general reproducibility of the different curves.

2. TEST APPARATUS

The test apparatus consisted of an intermittent blowdown wind tunnel with a 70x70 mm^2 test section and different symmetric nozzles.

The probe is mounted manually on a yaw - pitch calibration device that allows two rotations around axes that intersect at a characteristic point of the probe head (generally the total pressure tap).

Pressure signals are measured with strain gauge (Schaevitz Ltd.P2100: ± 0.70 bar, ± 1.0 bar ± 2.0 bar, ± 5.0 bar) and variable capacitance (Rosemount 1151 DP: ± 50 mbar, ± 200 mbar, ± 300 mbar) differential pressure transducers. Measurements were taken using a digital voltmeter (Fluke Mod 8840A) for each transducer and acquired via interface IEEE488 by an HP 310 computer.

3. CALIBRATION PROCEDURES

The probe was mounted for zero pitch angle with the stem perpendicular to the tunnel walls and with the probe head in the middle of the tunnel, 10 mm from the nozzle outlet section. The plane obtained on the probe stem marked P3 was taken as a reference for yaw angle.

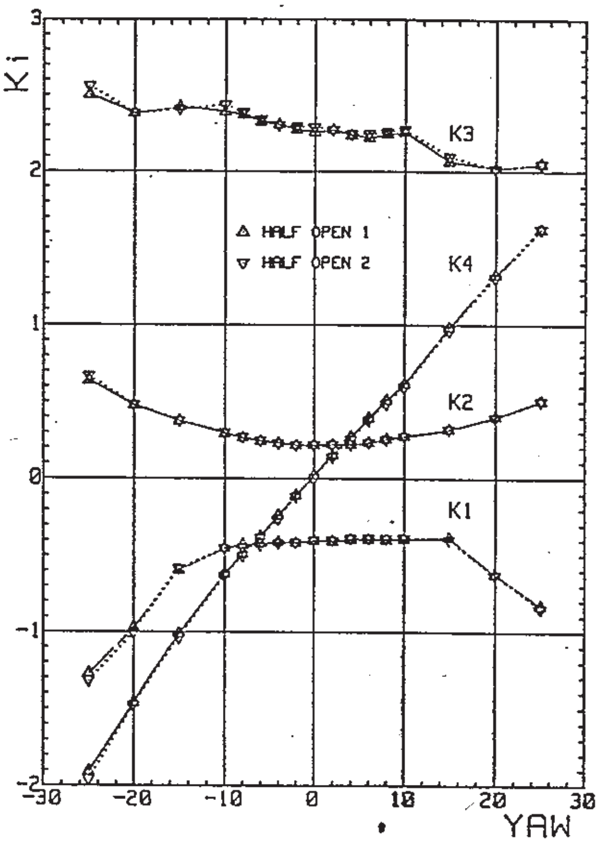


Fig. 3

Total reference pressure P_{teff} was measured in the settling chamber with a series of static pressure taps arranged in a circumferential fashion while a suitable wall tap was taken as reference for static pressure, except for the case of free jet in subsonic flow conditions where atmospheric pressure was taken as the reference. The reliability of the pressure measured in the wall tap was checked through a broad series of measurements wich revelead that pressure remainde constant throughout the test section with maximun appreciable deviation on the third figure of the Mach number.

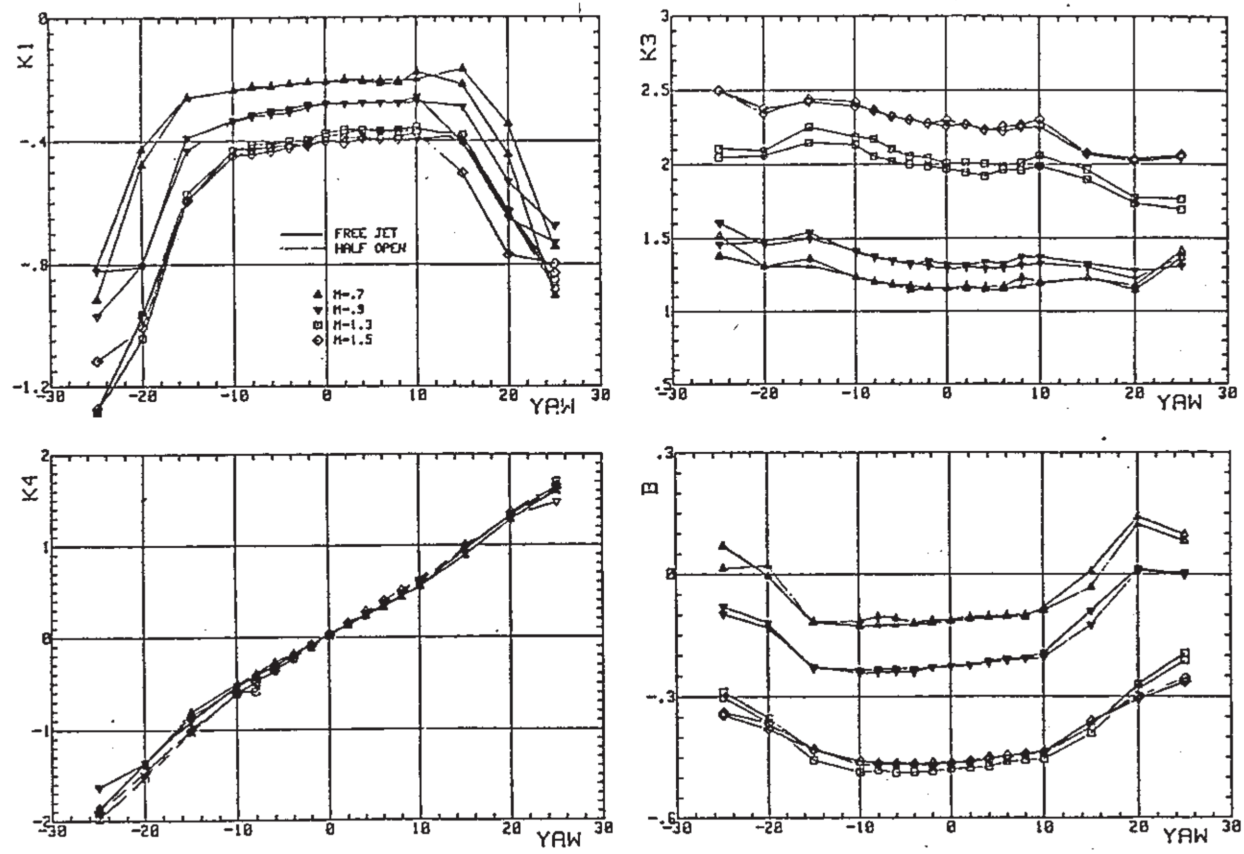


Fig. 4

4 TEST RESULTS

a) Calibration with variable yaw and pitch angles.

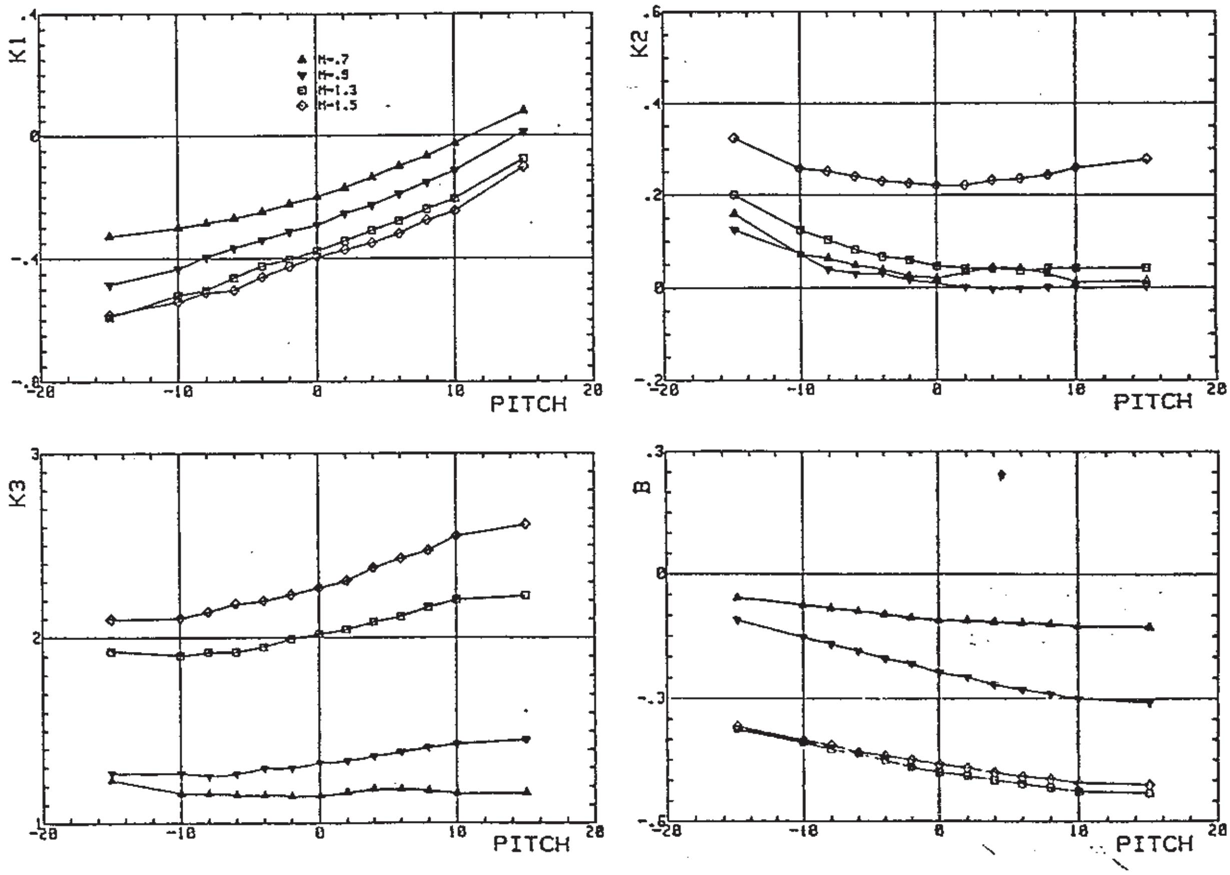


Fig .5

The calibration curves versus yaw angle (Fig.4) for the different Mach numbers indicate a satifactory behaviour of the probe in the range ± 20° with the exception of the coefficient K_3, which restricts the field of application to ± 15°. This limitation can be surmounted using the coefficient B which exhibits a much steadier trend for static pressure. The trend of the coefficients K_1 and K_3 indicate that the probe's response is not perfectly symmetrical, due to a slight dissymmetry in the probe head.

The calibration curves versus pitch angle also indicate good response over the investigated range ± 15° and, as in the previous cas, the coefficient B exhibits a more regular trend compared to the coefficient K_3; the latter shows however, greater sensitivity to Mach number (Fig.5).

Moreover, as can be observed from the different diagrams, the response of the probe did not differ substantially in calibration in free jet and half open tunnel.

b) Calibration with zero pitch and yaw angles.

As can be seen from the diagrams (Figs. 6, 7, 8, 9), the results obtained for the coefficients K_2, P_1/P_{teff}, K_3 and B compare favourably with those reported by the other workers /1/, both in free jet and half open tunnel.

Regarding the coefficient B, no appreciable differences were observed between the two configurations investigated, contrary to the findings in /1/, where the wide scatter of the points at low Mach numbers was correlated to the different tunnel set-ups (free jet, half open and closed).

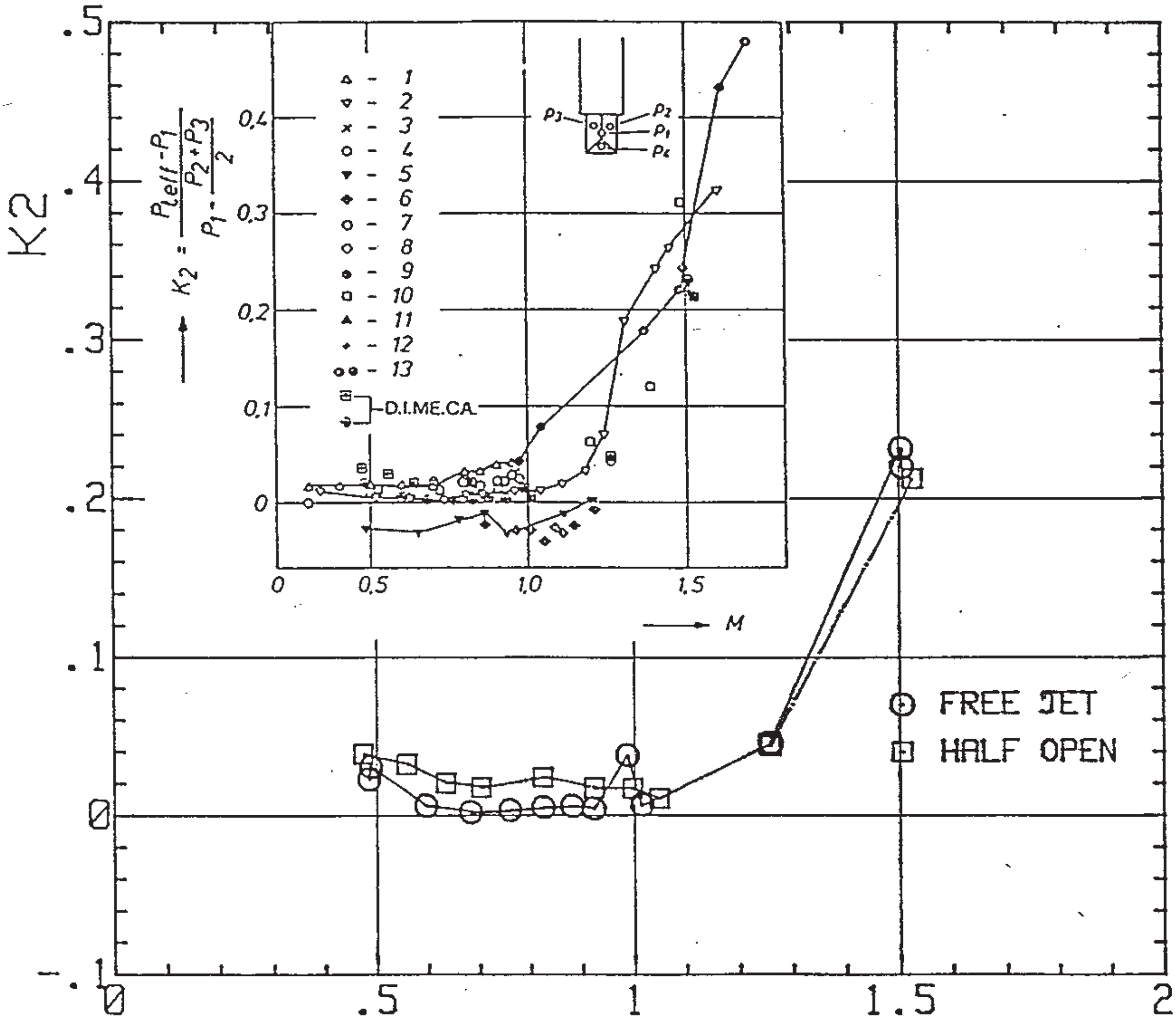


Fig. 6

Further investigation is needed before attempting to explain the trend of the coefficient K_1, which was also found by the other workers to exhibit very large discrepancies that are unlikely to be caused by incorrect mounting alone. Indeed, it is evident from Fig.11a that with varying pitch angle, rather than a variation of the curves' slope, there is above all a pronounced vertical translation even for low Mach numbers.

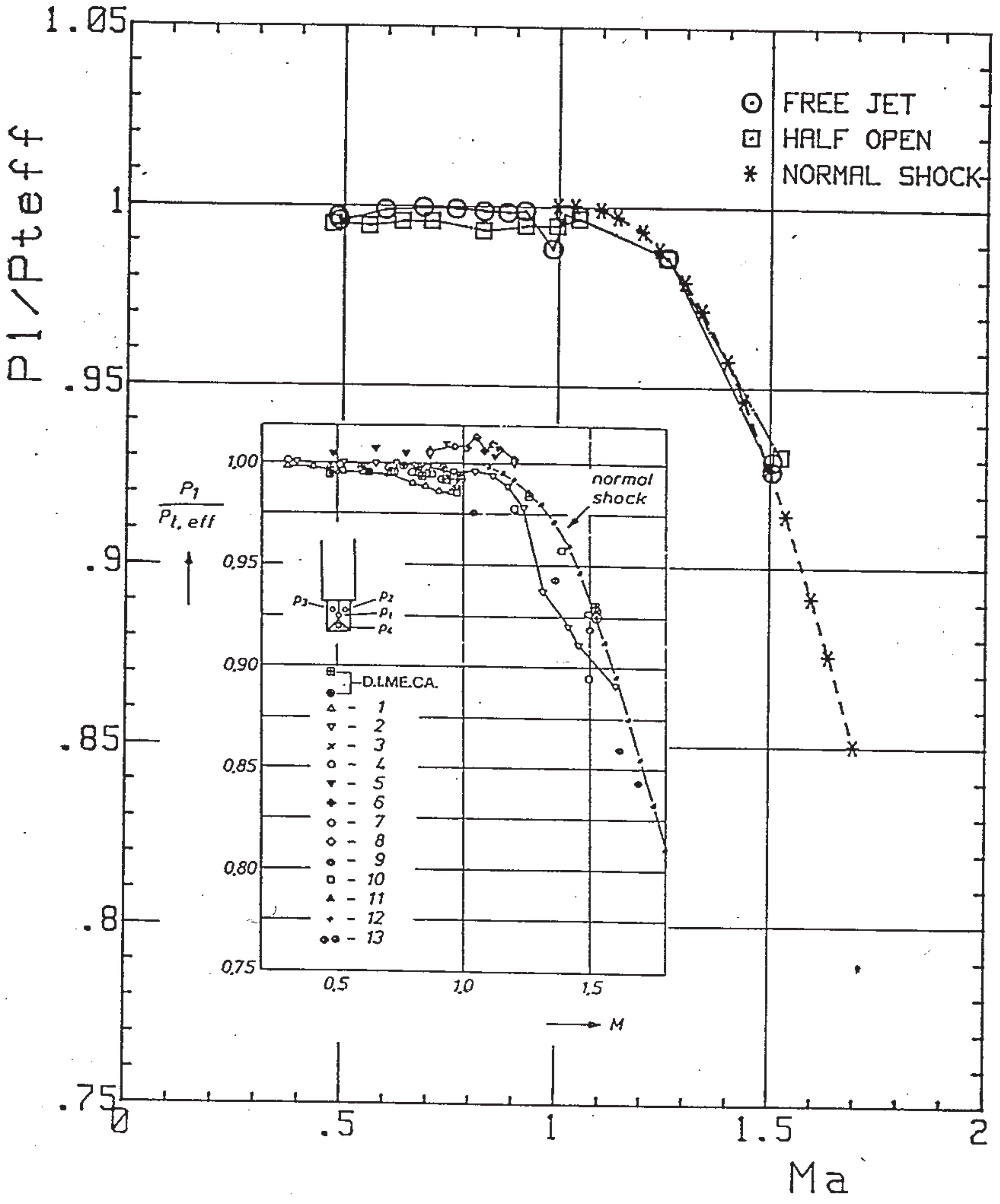


Fig .7

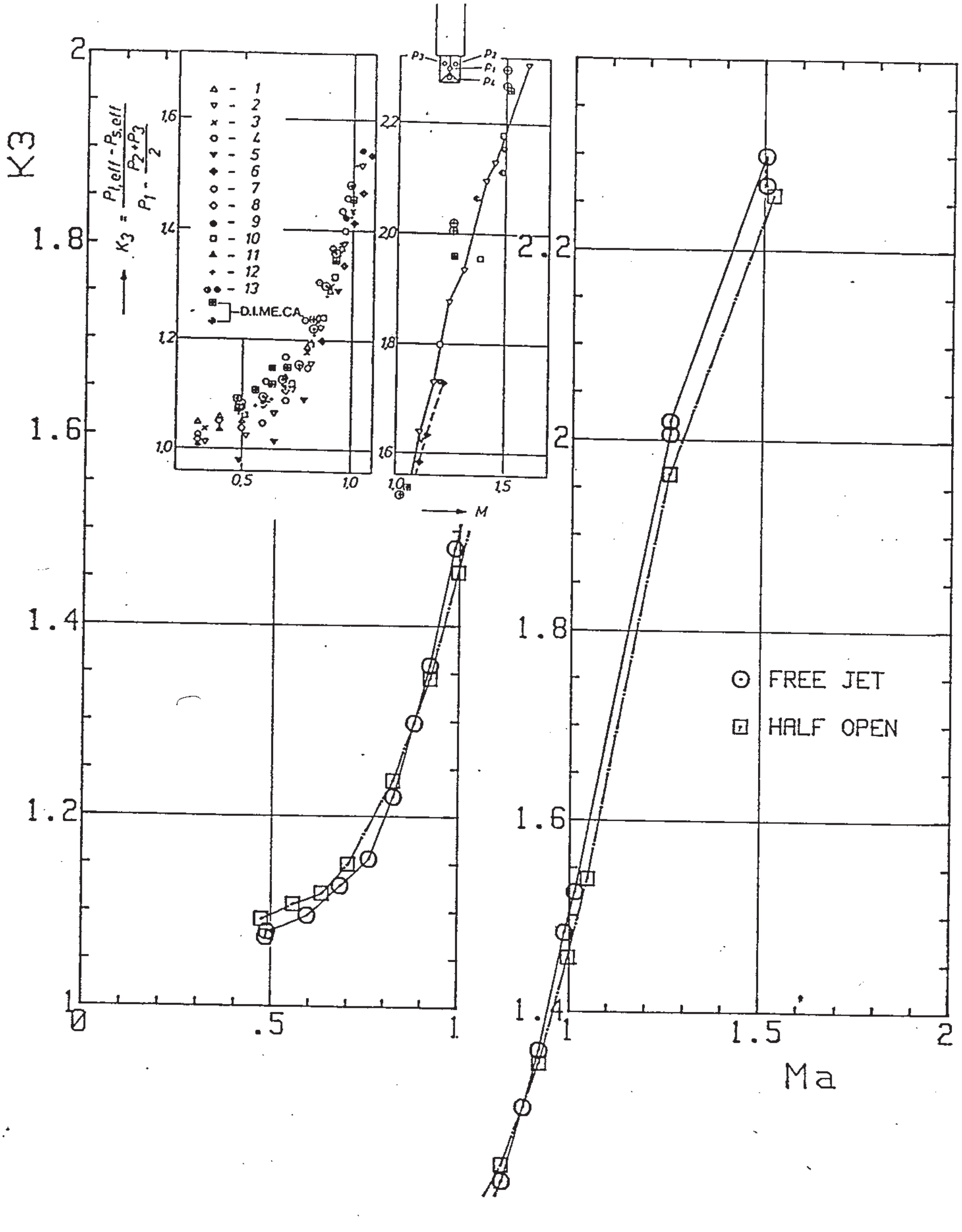

K3
2
1.8
1.6
1.4
1.2
1.0
0
.5
1
$K_3 = \frac{p_{1,eff} - p_{5,eff}}{p_1 - \frac{p_2+p_3}{2}}$
1 2 3 4 5 6 7 8 9 10 11 12 13
D.I.ME.CA
p_1 p_2 p_3 p_4
1,6 1,4 1,2 1,0
0,5 1,0 1,5
2,2 2,0 1,8 1,6
M
2.2
2
1.8
1.6
1.4
1
1.5
2
Ma
FREE JET
HALF OPEN

Fig. 8

In the specific case, the results (Fig.10) are well below the average ones obtained earlier by the different laboratories and the slope is more accentuated with increasing Mach number. This discrepancy is likely due to alterations made to the probe head after it was damaged and these modifications may well have produced changes in its geometry that cannot be disregarded /3/. Again the curves does not differ to any great extent in the two tunnel set ups.

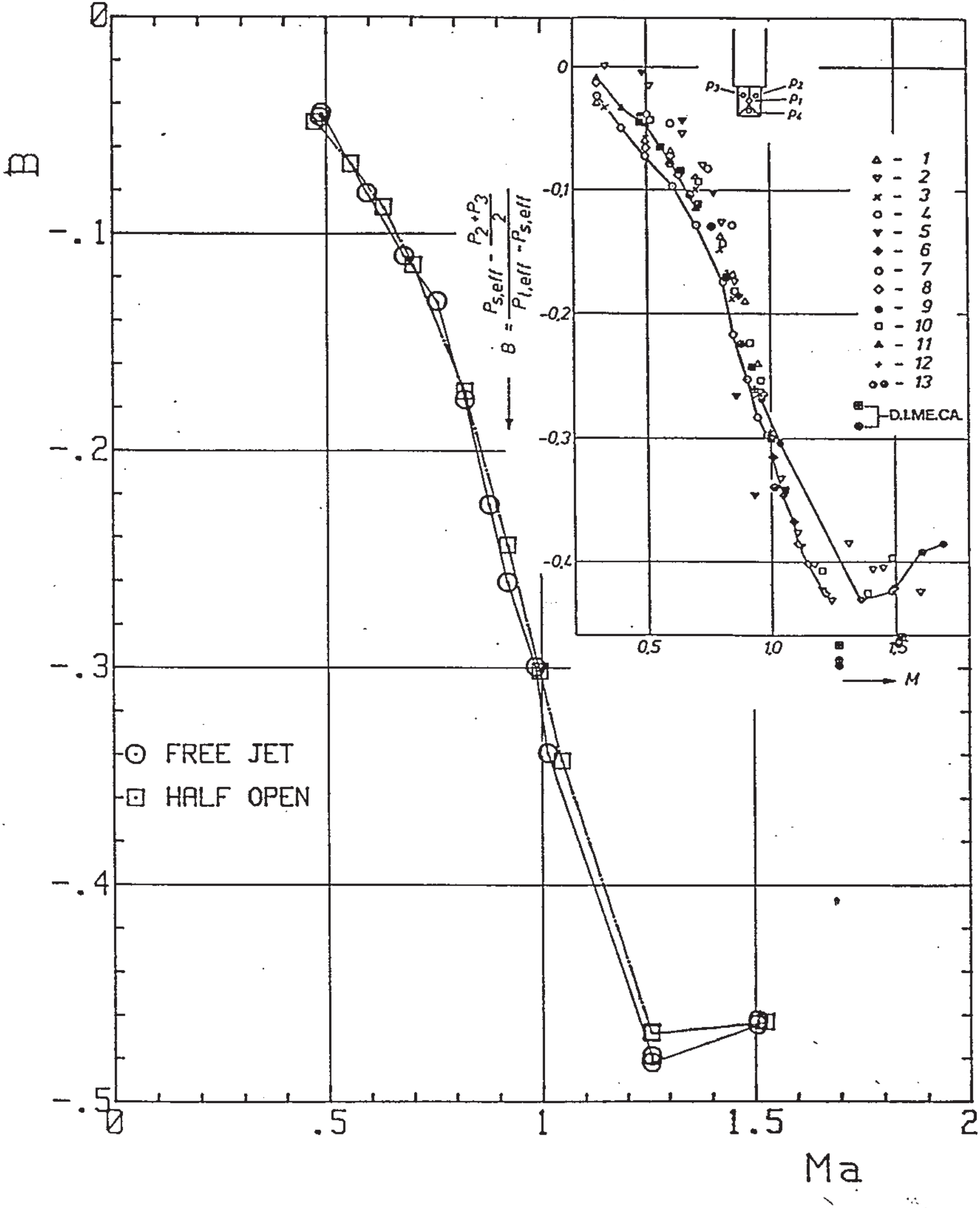


Fig. 9

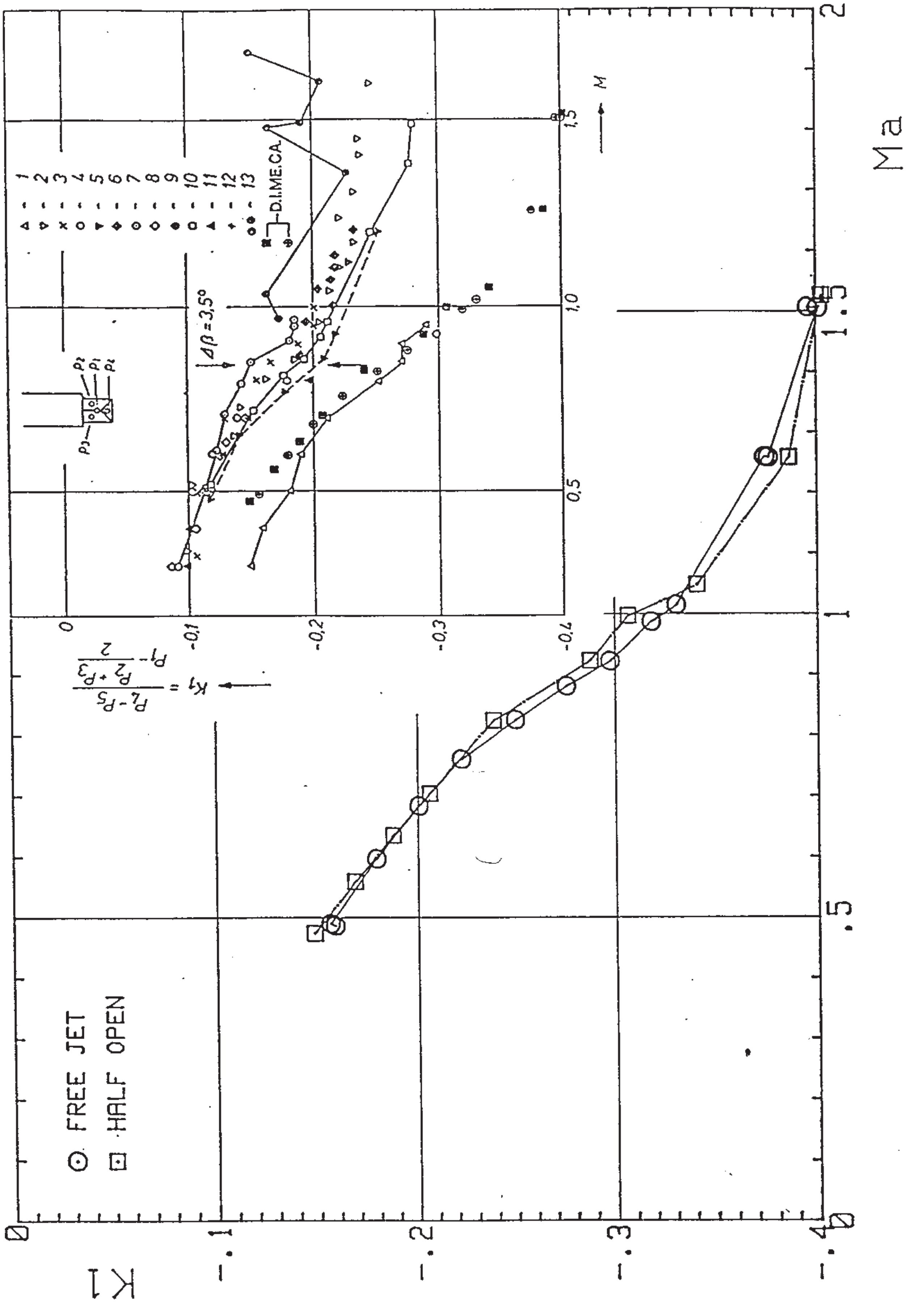

K1
0
.1
.2
.3
.4
0
.5
1
1.5
2
Ma
FREE JET
HALF OPEN
$K_1 = \frac{P_4 - P_5}{P_1 - \frac{P_2 + P_3}{2}}$
0
-0,1
-0,2
-0,3
-0,4
0,5
1,0
1,5
M
Δβ = 3,5°
P1
P2
P3
P4
1
2
3
4
5
6
7
8
9
10
11
12
13
D.I.ME.CA.

Fig. 10

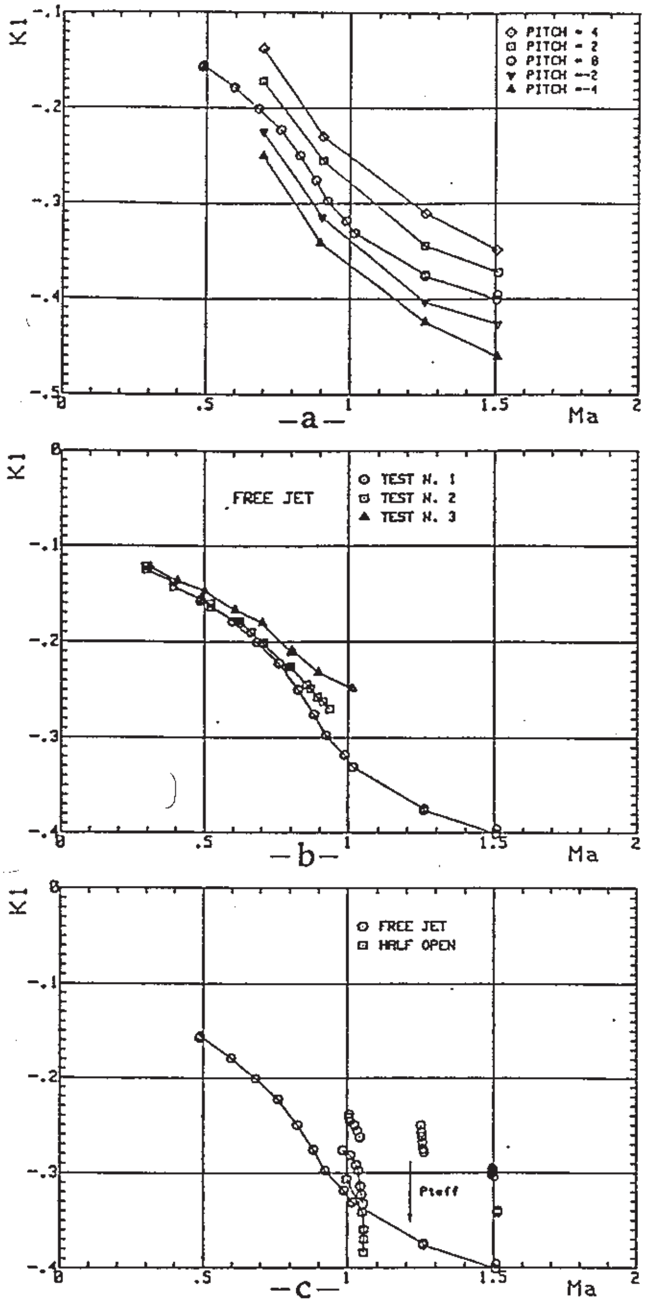


Fig. 11

With a view to evidencing the possible causes of the behaviour of the different parameters, the trend of the different pressures measured by the probe, rendered dimensionless with respect to total pressure P_{teff}, was analysed for all the tests carried out. The diagrams versus yaw angle (Fig, 12a,b) confirm the agreement of the results in the two set ups and the existence of a slight dissymmetry of the lateral pressures P_2 and P_3, which might be the major reason behind the trend observed for K1 in Fig.4.

Contrarily, the trend of P1 is symmetric and, in the range ± 10°, so is

In order to check the reproducibility of the curves, series of tests were then conducted with both tunnel set ups. These tests confirmed the wide scatter already observed in /1/ for the coefficient K_1, which exhibited an appreciable change in slope of the curve with Mach number (Fig.11b). Moreover, under certain conditions (Mach 1.0 and 1.25) the coefficient was also found to vary considerably with total pressure P_{teff} (Fig.11c). On the other hand, this trend was not noticed for the other coefficients where the variations were much smaller.

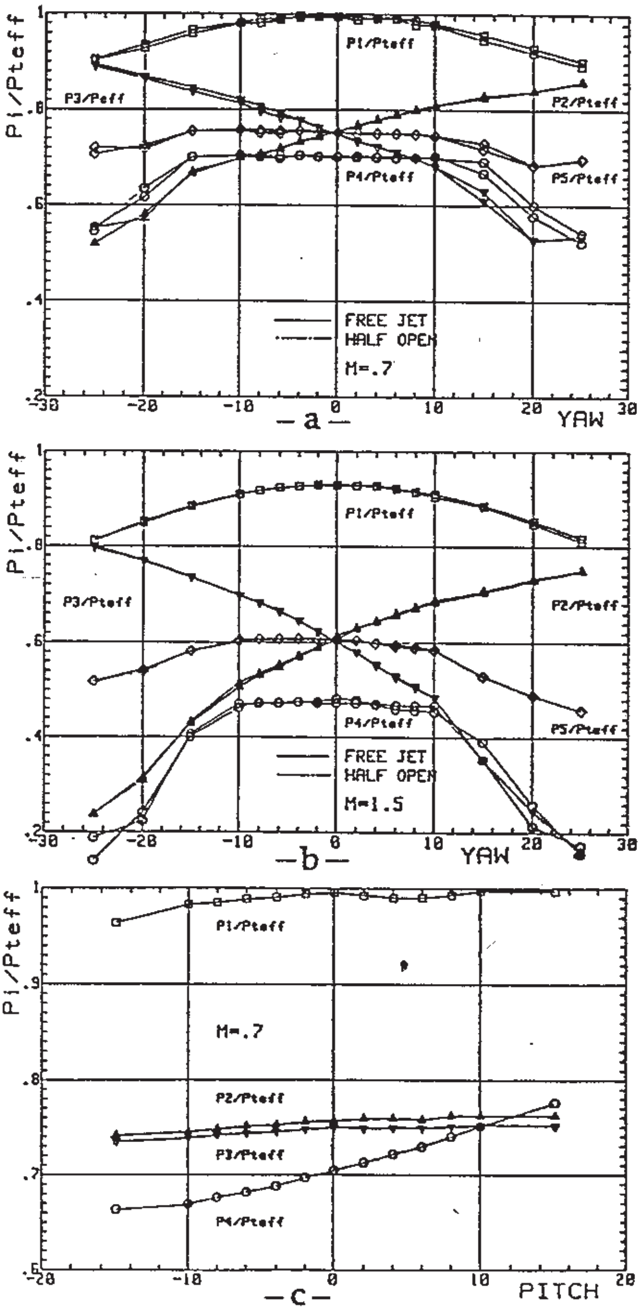


Fig. 12

that of P4, which remains steady even at yaw angles of less than -10°, whereas for angles greater than +10° the curve is not as regular, whit varying tunnel configuration.

The diagrams versus pitch angle (Fig.12c) clearly show the dissymmetry of the probe type, also indicated by the lateral pressure taps P2 and P3. Note also the good response of pressure P4 over the entire range examinde.

Some interesting findings also emerge from analysis of the diagrams versus Mach number. Pressure P2 exhibits a very steady trend over the whole range (Fig.13a) with almost identical values for the two set ups and different test runs.

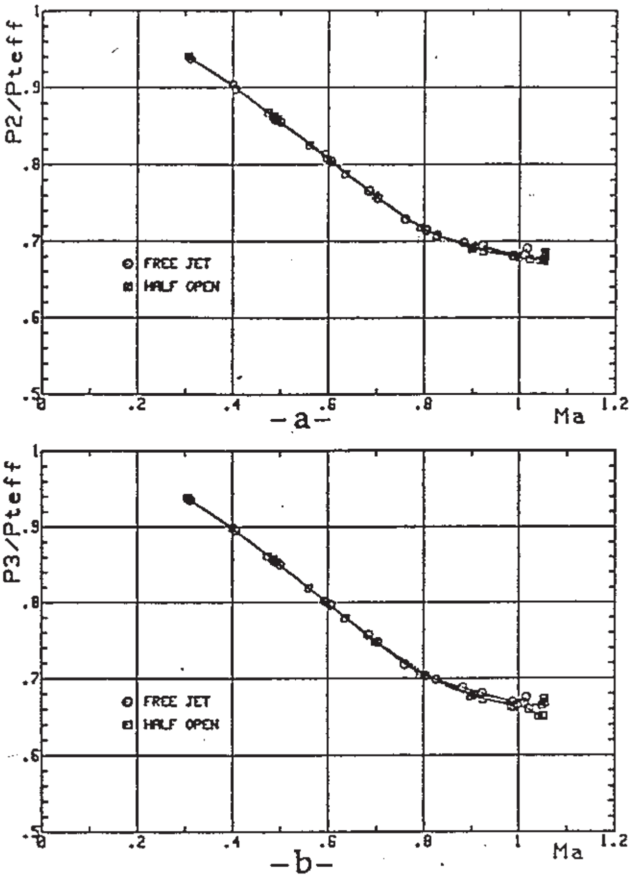


Fig.13

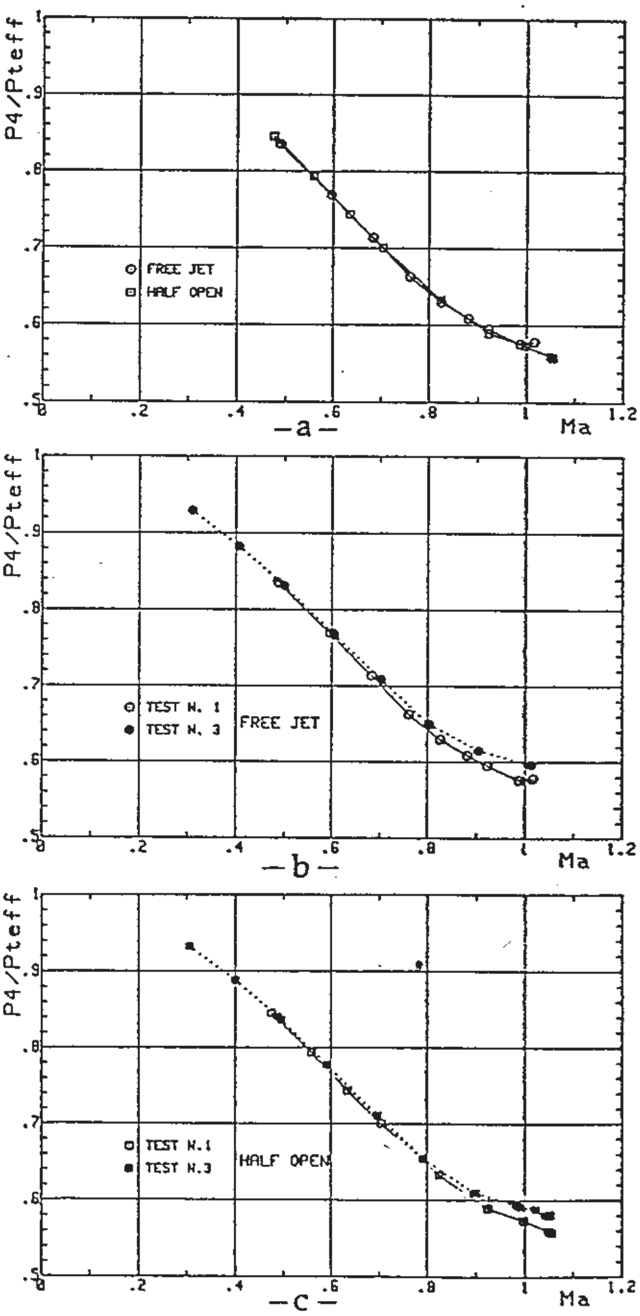


Fig. 14.

Similar considerations apply to pressure P3 (Fig.13b) and thus P5. As for P4, the values are again very similar for the two set ups (Fig.14a) but when tests were repeated the change in slope was greater at higher Mach numbers (Figs.14b, 14c). This is probably attributable to the local changes in flow that are established on the face of the tap P4 and that render the latter particularly sensitive to the influence of the Reynolds number.

Here it is much more apparent that the variation in P4 may be chiefly responsible for the variation observed in K1 (Fig.10).

In the light of the above it seems that the variations in K1 also reported in /1/ may be attributable to the definition of K1 itself, which makes it especially sensitive to changes in the single parameters defining it, as well as for the particular location of the tap P4.

In this regard, it may be interesting to use directly the dimensionless pressures themselves as calibration coefficients, given the very steady trend observed in the various diagrams presented.

5. CONCLUSIONS

- The comprehensive tests performed with the WP11.3 probe have pointed, above all, to its reliability both for sub- and supersonic flow over quite a wide range of yaw and pitch angle (± 15°).
- The calibration results do not differ greatly for the two tunnel set ups (free jet and half open), hence one or the other could be used indifferently.
- The scatter of the data for the calibration coefficients is generally acceptable, except for K1, which was not reliable enough, also considering the very trend of the pressures rendered dimensionless with respect to P_{teff}.

In this regard, a comparison with the results obtained by the other laboratories which took part in the workshop may be interesting, using these parameters directly.

NOMENCLATURE

Total pressure coefficient	$A = \dfrac{P_{teff} - P_1}{P_{teff} - P_{seff}}$
Static pressure coefficient	$B = \dfrac{P_{seff} - P_5}{P_{teff} - P_{seff}}$
Pitch angle coefficient	$K1 = \dfrac{P_4 - P_5}{P_1 - P_5}$
Total head pressure coefficient	$K2 = \dfrac{P_{teff} - P_1}{P_1 - P_5}$
Static head pressure coefficient	$K3 = \dfrac{P_{teff} - P_{seff}}{P_1 - P_5}$
Yaw angle coefficient	$K4 = \dfrac{P_2 - P_3}{P_1 - P_5}$

P_1	Pressure measured at central probe hole
P_2, P_3	Pressures measured in the yaw plane
P_4	Pressure measured in the pitch plane
P_5	Pressure defined as $0.5(P_2+P_3)$

REFERENCES

\1\ Broichhausen,K.D., Fransson, T.,Proceedings of the European Workshop on Probe Calibrations 1981-1983, Aachen, December 1984, Mitteilung Nr.84-02.

\2\ Cabitza, S., Cau, G., Mandas, N., Nurzia, F., "Transonic Facilities of D.I.Me.Ca. For Probe Calibration and Cascade Testing",8th Symposium on Measuring Techniques for Transonic and Supersonic Flow in Cascades and Turbomachines, Genova, October 24-25, 1985.

\3\ Sculc, M. K., Fransson, T., Private Comunication