COMPARISON BETWEEN PROBE AND LASER MEASUREMENTS AT THE OUTLET OF A CENTRIFUGAL IMPELLER

by

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Two differents types of probes have been calibrated at different Mach numbers (0.2 to 0.8). The results of static pressure obtain by theses probes were rather good in an axial transonic compressor of 50 mm blade height but completely wrong for the case of a vaneless diffusor of a centrifugal impeller of 20 mm width.

However, a complete data reduction analysis using equilibrium and continuity equations, wall static pressures and a LASER velocimetry technic shows we can rely with confidence on the method used.

1 - INTRODUCTION

Two types of probes have been built in order to obtain detailed measurements in the vaneless diffuser of a centrifugal compressor in a minimum test facility time. These probes are shown in figure 1.

The "cobra" type probe is used to give results on the opposite side of the probe support. The "straight" probe is used for the other part of the channel An overlapping region exists in order to compare the results given by these two probes. Each probe also has a thermocouple to give total temperature.

2 - PROBE CALIBRATION

The two probes have been calibrated for different Mach numbers from 0.2 to 0.8 in a free jet. The β and γ angles vary between -15 and +15 degrees. The angle definition is given fig. 2. The results of the calibration are given fig. 3 to 10.

We have found convenient to define the different calibration parameters as follows :

- for the "cobra" type probe :

p: probe. s: static.
L: left. R: Right
$Q_p = P_{Tp} - P_{sp}$

CBETA = $\Delta P_{LR} / Q_p$

CGAMA = $\left[\dfrac{(P_L + P_R)}{2} - P_{sp}\right] / Q_{REF}$

CQ = $(P_{S\,REF} - P_{sp}) / Q_{REF}$

CP = $(P_{T\,REF} - P_{Tp}) / Q_{REF}$.

- for the "straight" type probe :

$Q_p = P_{Tp} - \dfrac{P_L + P_R}{2}$

$P_{sp} = \dfrac{P_L + P_R}{2}$

CBETA = $\Delta P_{LR} / Q_p$

CGAMA = —

CQ = $(P_{S\,REF} - P_{sp}) / Q_{REF}$.

CP = $(P_{T\,REF} - P_{Tp}) / Q_{REF}$.

For the "cobra" type probe, one can see fig. 3 that the Mach number effects, and the relative small discrepancies of CBETA for different γ angles values can be observed.

In order to know the γ angle value, we have chosen the parameter called CGAMA fig. 4. The probe response is quite stable over a wide range of ξ angle values for different γ values (-15° to +3°).

For the straight probe type, however, the coefficient we directly derived ξ values is quite independent with the respect of γ values fig. 7. Of course, this probe is not useful to predict γ angle values.

3 - THE RESULTS OBTAINED IN AXIAL TRANSONIC COMPRESSORS

These two probes have been used in two axial flow compressors. The static pressure measurements derived from the probes are quite in good agreement with the wall static pressure taps as shown fig. 11 behind the rotor of the first machine, and fig. 12 and 13 behind the inlet guide vane and the stator of the other axial machines. The channels of these axial machines are both about 50 mm width.

The mass flow calculated value obtained with the probes data and the one obtained with a venturi tube are quite similar as it is shown fig. 14.

4 - THE RESULTS OBTAINED IN A VANELESS DIFFUSOR OF A CENTRIFUGAL COMPRESSOR.

We can see fig. 15, for this case, how different are the probe static pressures compared with wall static pressures. In a 20 mm diffusor width, these observed differences decrease in the shroud region where probe blocage effects are almost negligeable. The differences between the two probes values are also very important, but tend to decrease when the measurements are performed with increasing radius.

5 - THE USE OF PROBE MEASUREMENTS FOR DATA REDUCTION PROBLEM.

A lot of people usually use in radial compressors a linear evolution of static pressure derived from wall static pressure. The use of equilibrium equation can also give an answer as it is shown fig. 16. The static pressure evolution we obtained here is derived by using, through equilibrium equation, the following probe data :

- total pressure ;
- total temperature ;
- absolute flow angle ;
- assume $\gamma = 0$;
- given "venturi" mass flow.

The calculated static pressure well correspond to the one given by wall pressure taps. The linear evolution is also confirmed for this case.

6 - LASER VELOCIMETRY MEASUREMENTS AT THE EXIT OF THE IMPELLER.

The measurements have been done for three stations in the upstream part of the vaneless diffusor (radius ratios R/R_2 = 1.018, 1.059 and 1.107). These measurements lead to circumferentially averaged values because they are not synchronised with the rotation of the rotor.

Mean absolute flow angle distributions are presented in fig. 17. We can make one remark concerning the comparison between laser and directional pressure probe measurements at station R/R_2 = 1.059. We have ascertained a consistent four degree shift between the two measurements, whatever the different probability histogram reductions we have done. This can only be explained by a defective initial angular location of the probe volume. However, the shape of the distributions are in good agreement.

Mean absolute velocity distributions can be seen in fig. 18. The agreement of laser and pressure probe measurements is quite good, the maximum registered disparity being below one per cent. In addition, accurate measurements have been performed up to one millimeter from the solid walls.

7 - CONCLUSION

Comparisons between results obtained by pressure probe measurements, wall static pressures and by a two focus laser system have been presented.

The two sets of experimental results are rather close together and tend to confirm one another.

Detailed measurements in such vaneless diffusors of centrifugal compressors can be done in spite of probe perturbation effects.

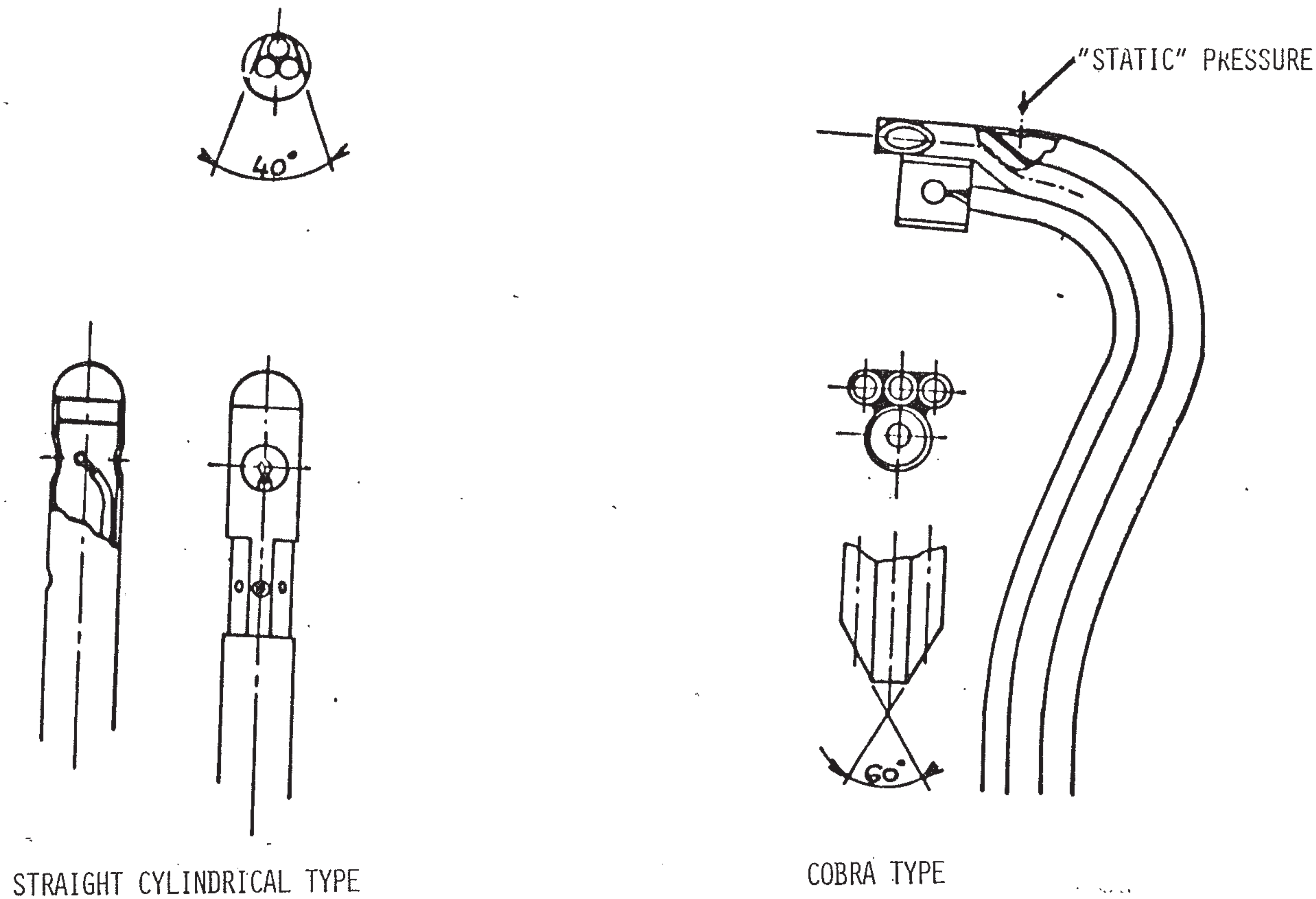


Fig. 1 - THE TWO TYPE OF PROBES

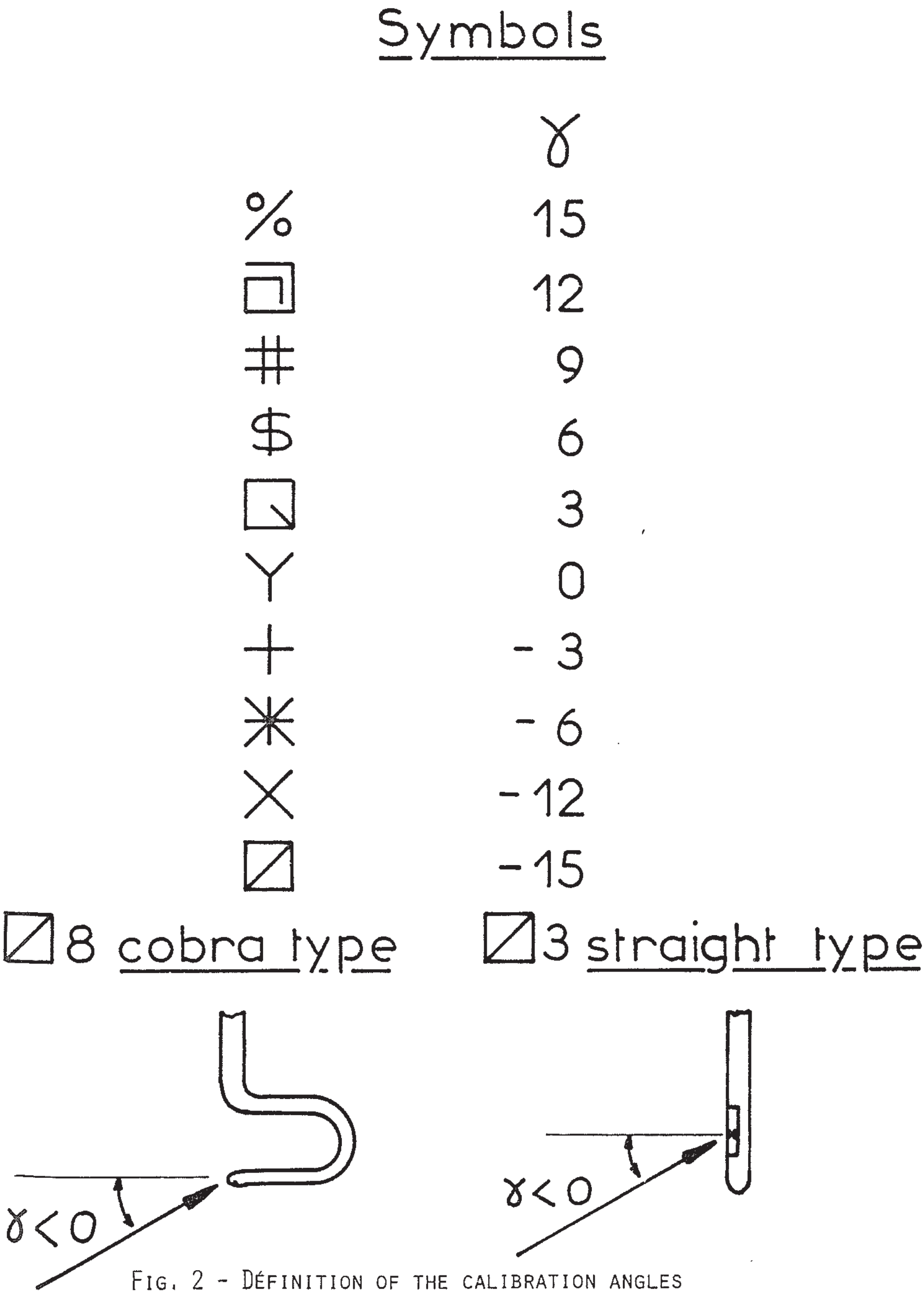
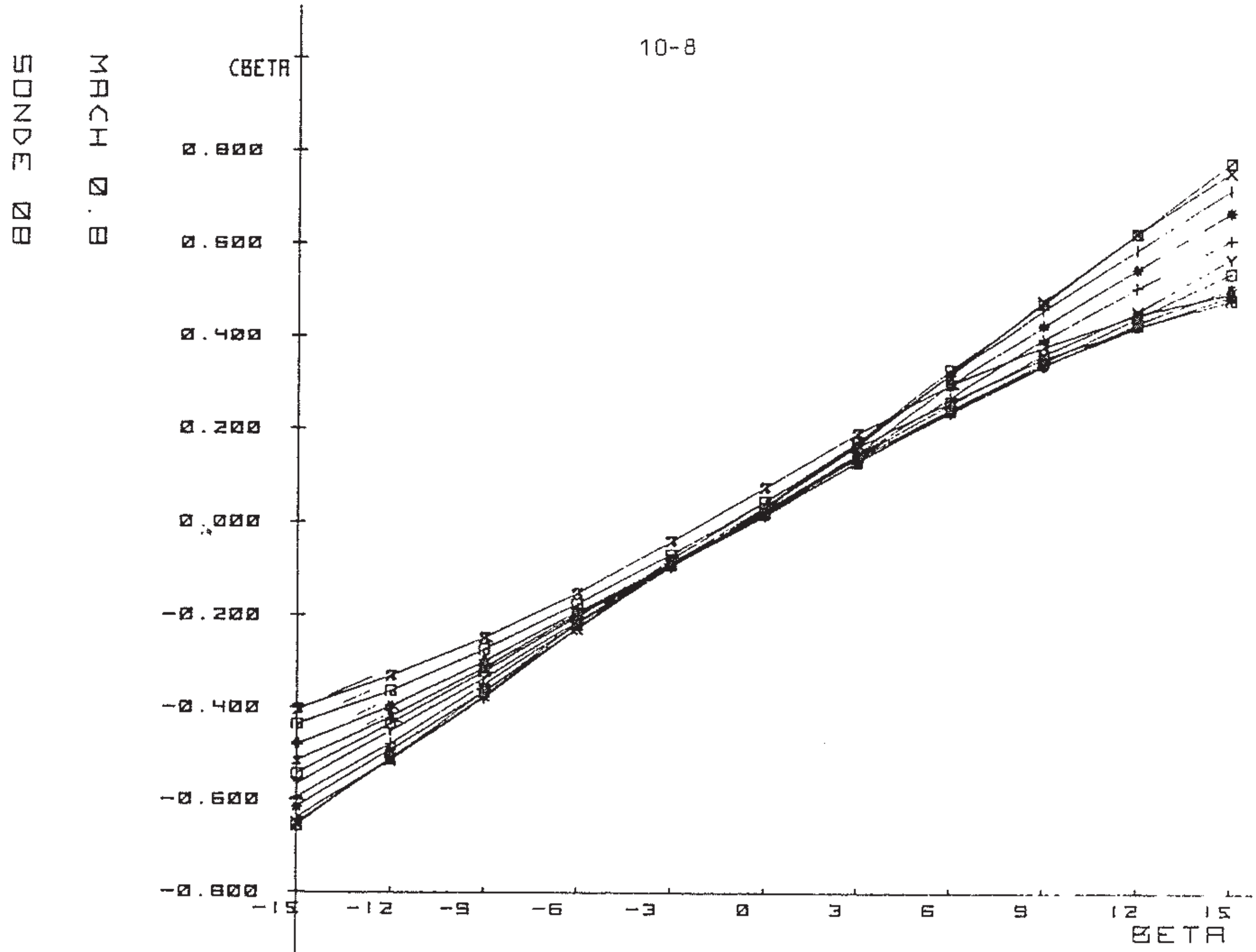


FIG. 2 - DÉFINITION OF THE CALIBRATION ANGLES


CBETA
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA

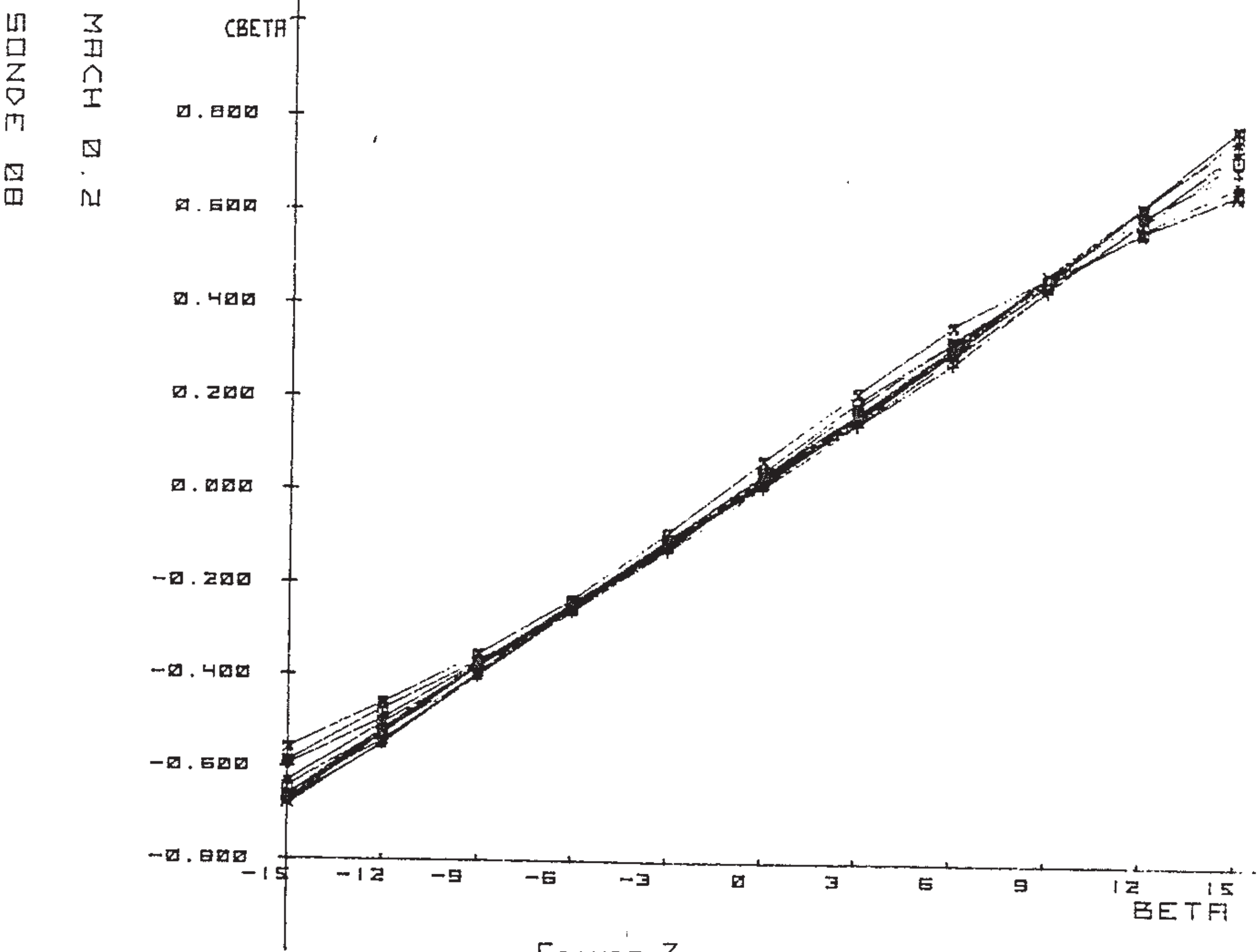

CBETA
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA

FIGURE 3

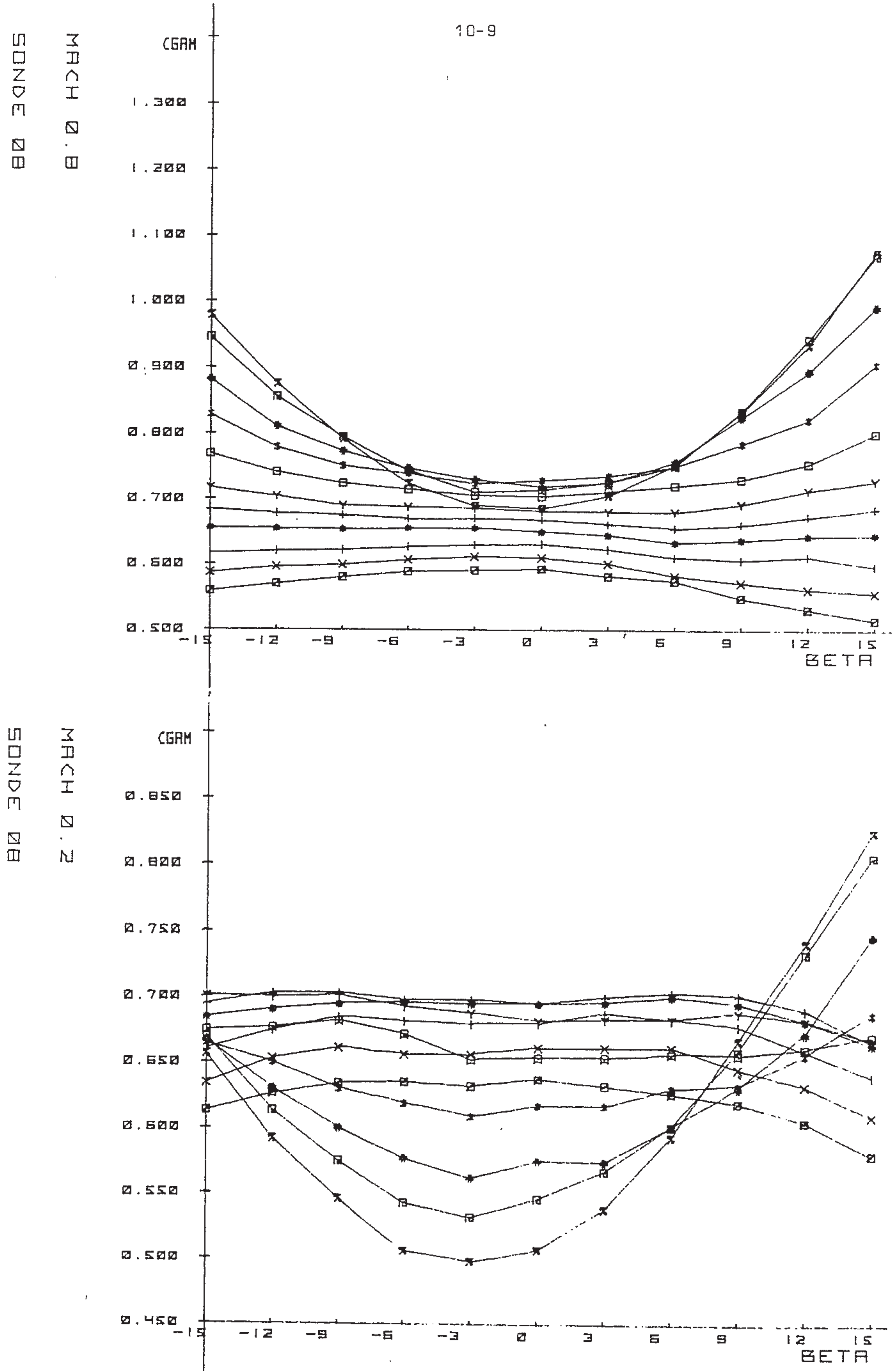

SONDE 08
MACH 0.8
CGAM
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA
SONDE 08
MACH 0.2
CGAM
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA

FIGURE 4

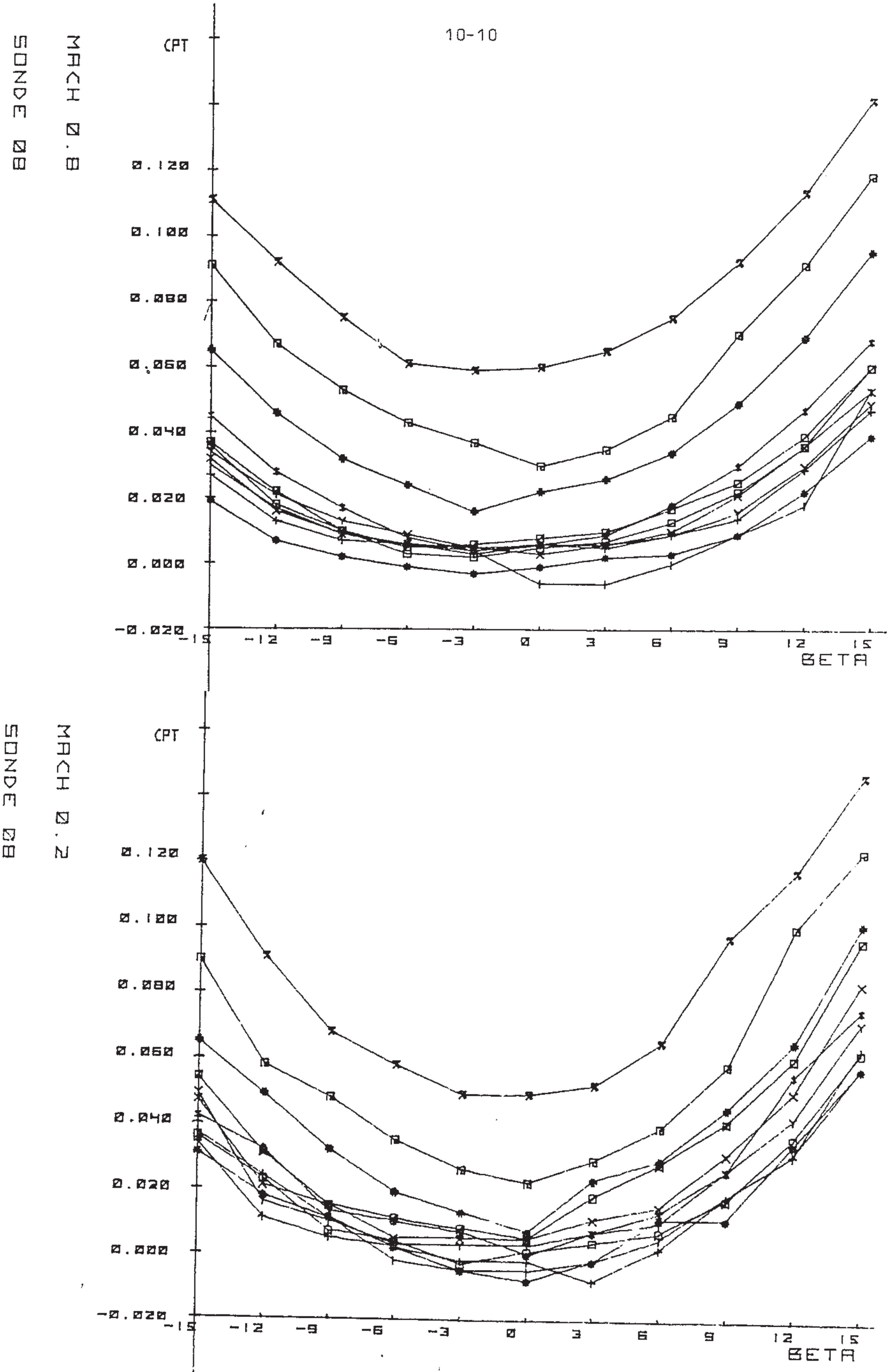

SONDE 08
MACH 0.8
CPT
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA
SONDE 08
MACH 0.2
CPT
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA

FIGURE 5

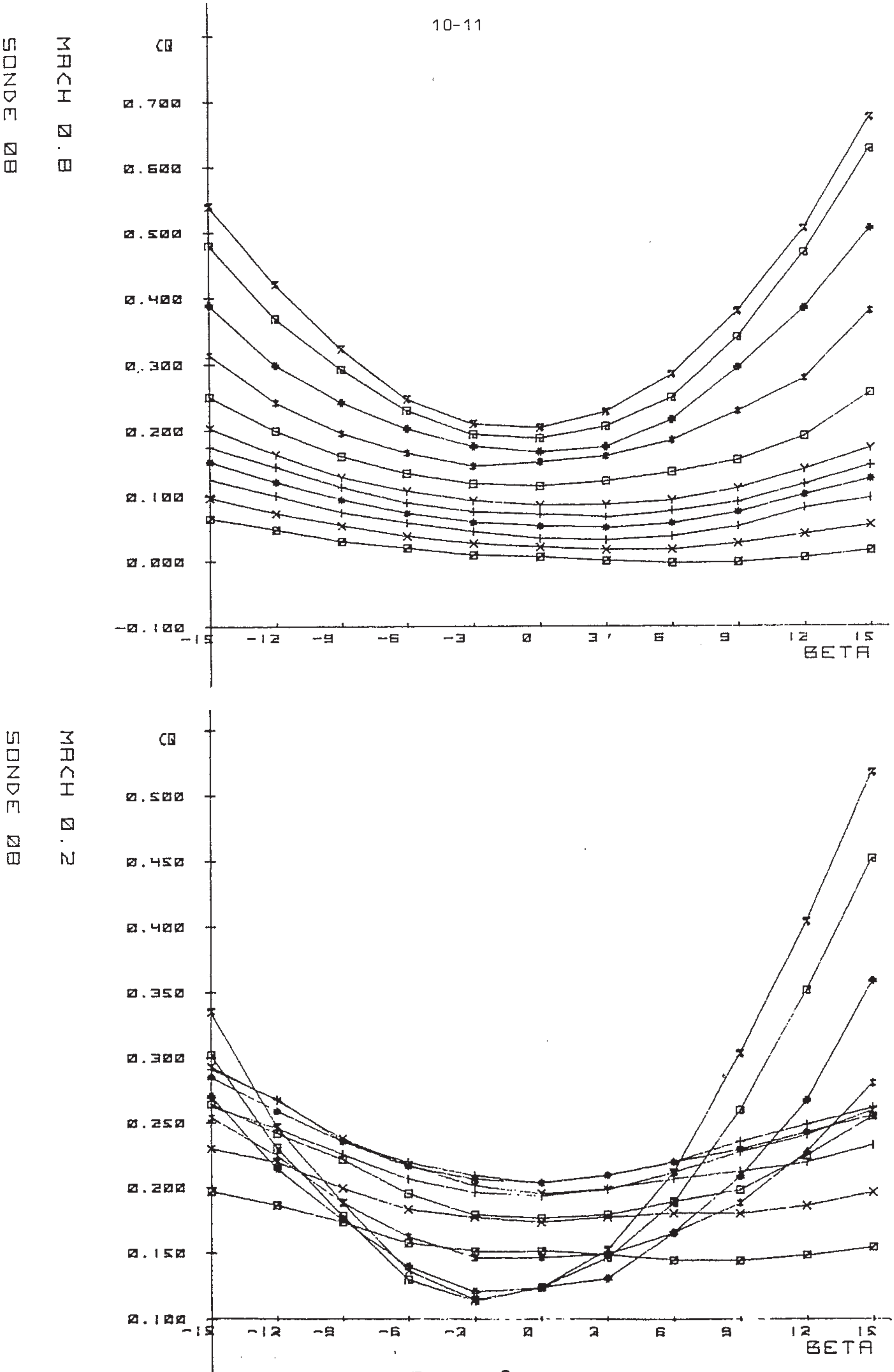
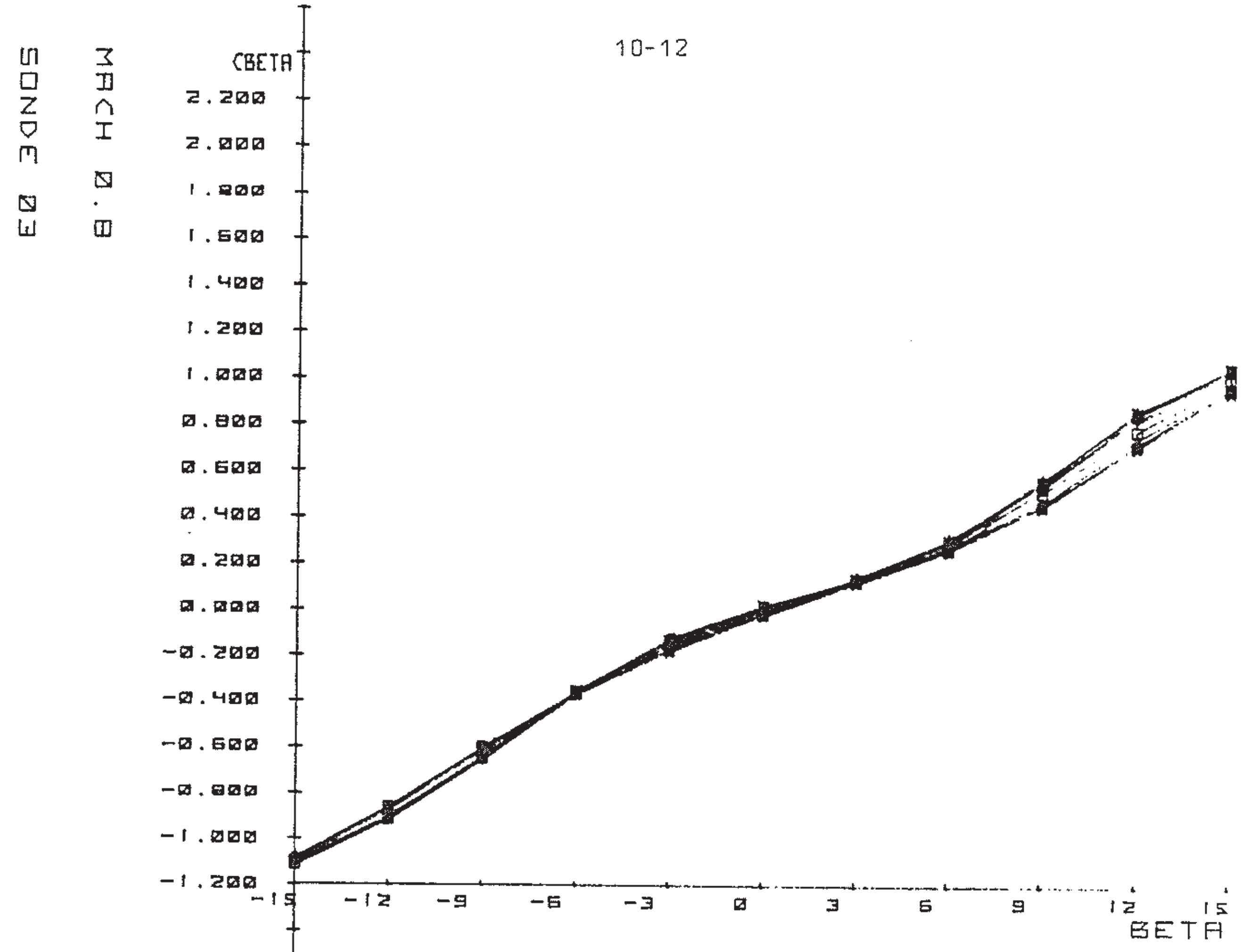

SONDE 08
MACH 0.8
CQ
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA
SONDE 08
MACH 0.2
CQ
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA

FIGURE 6


SONDE 03
MACH 0.8
CBETA
2.200
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA

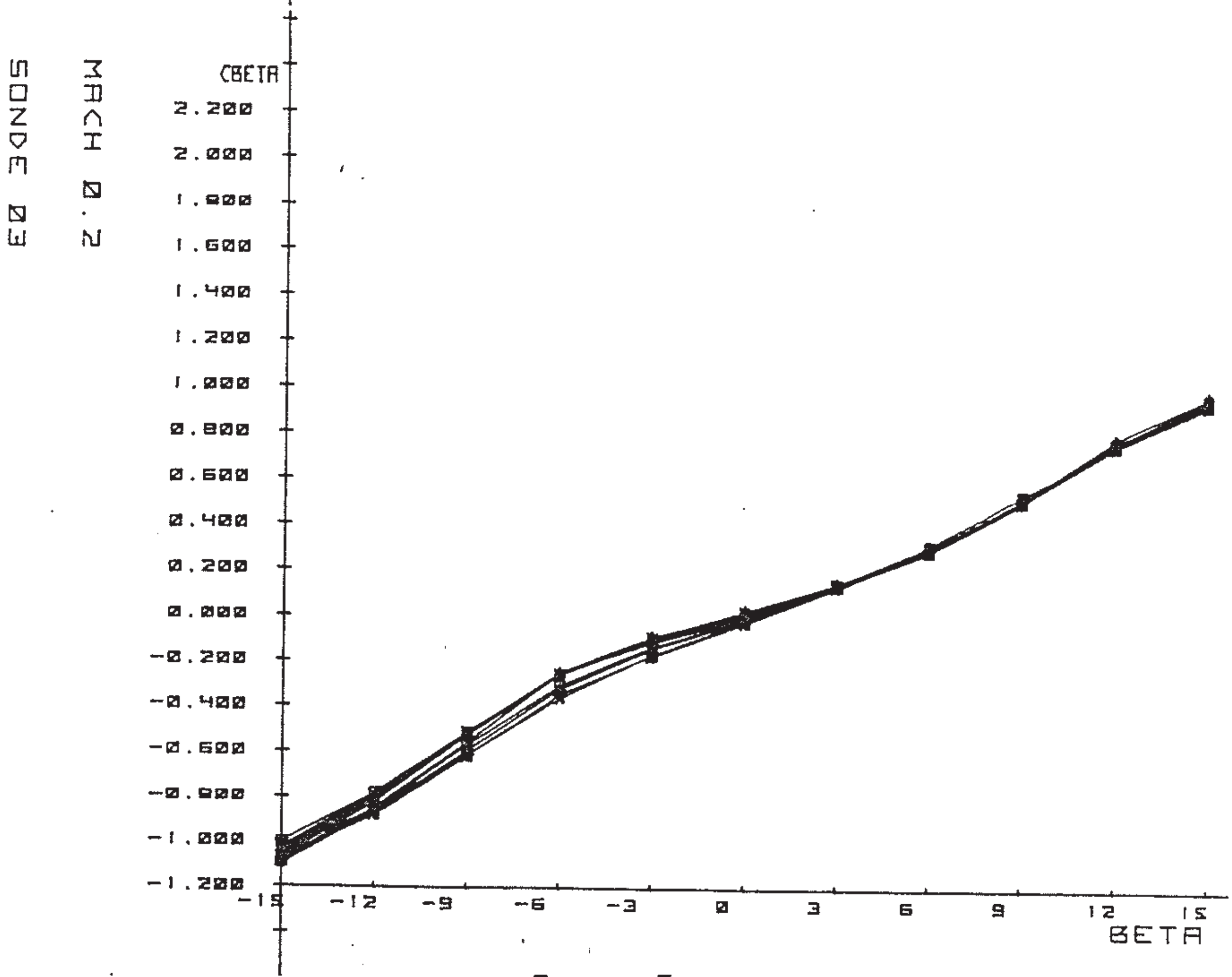
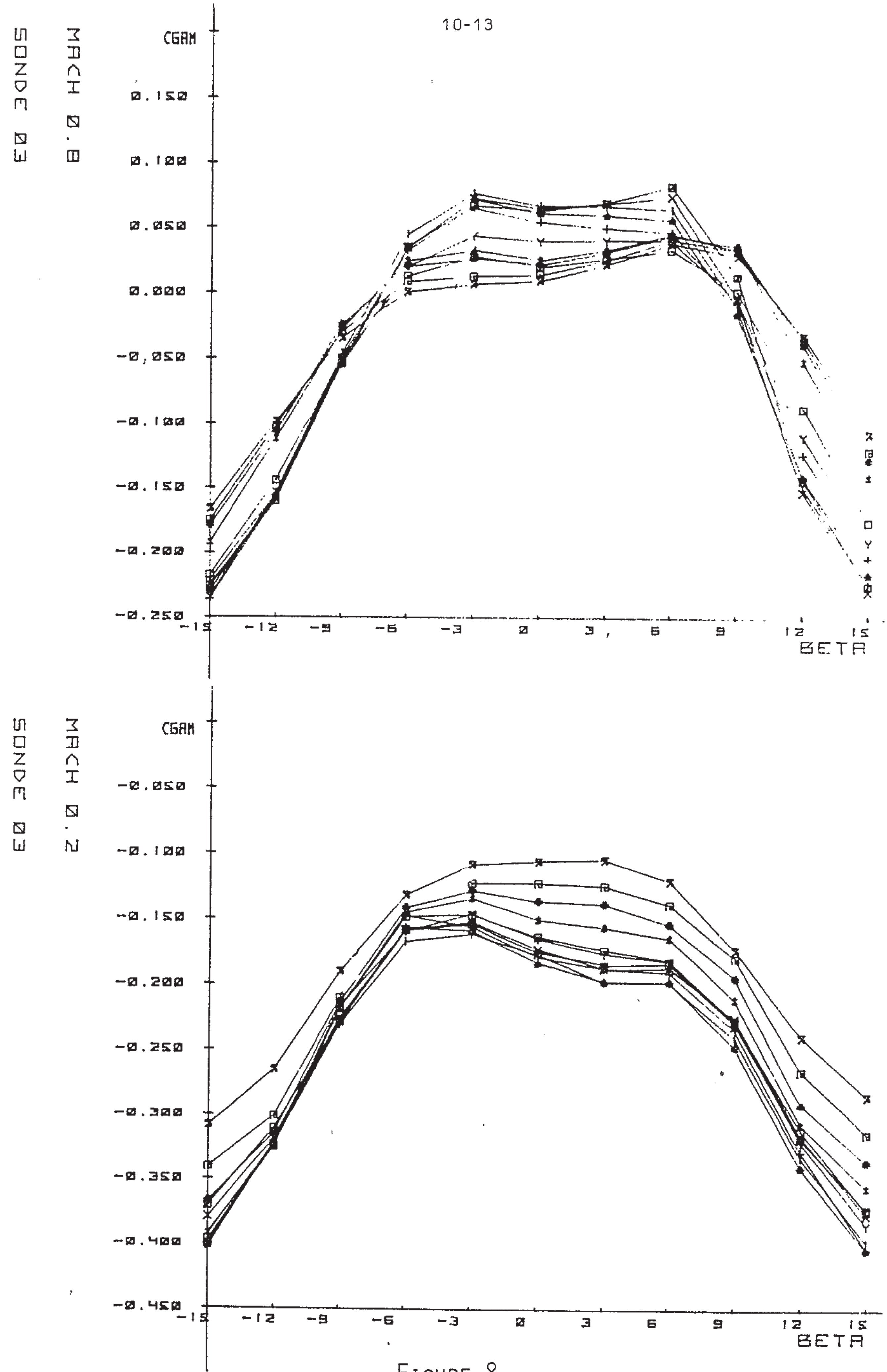
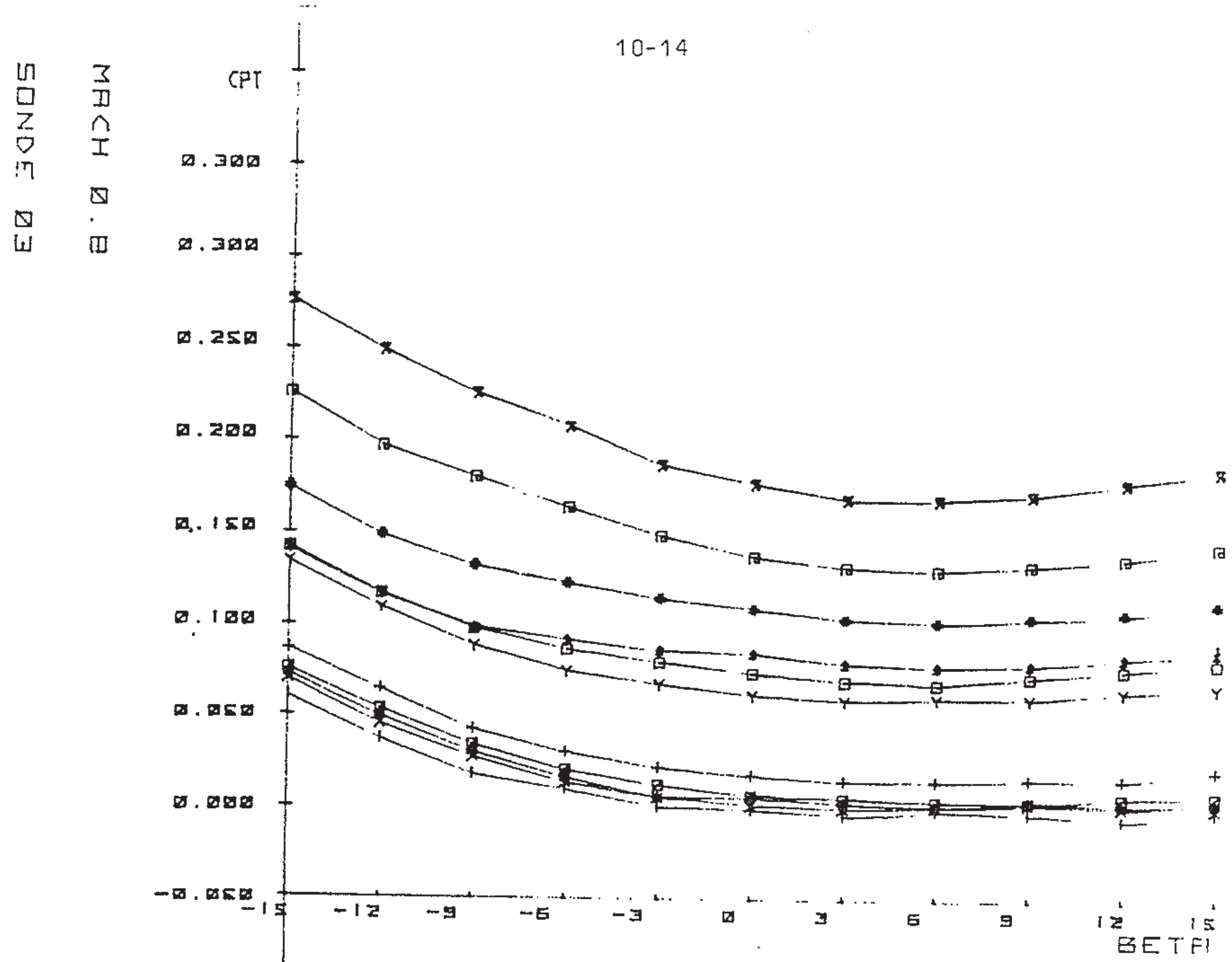

SONDE 03
MACH 0.2
CBETA
2.200
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA

FIGURE 7

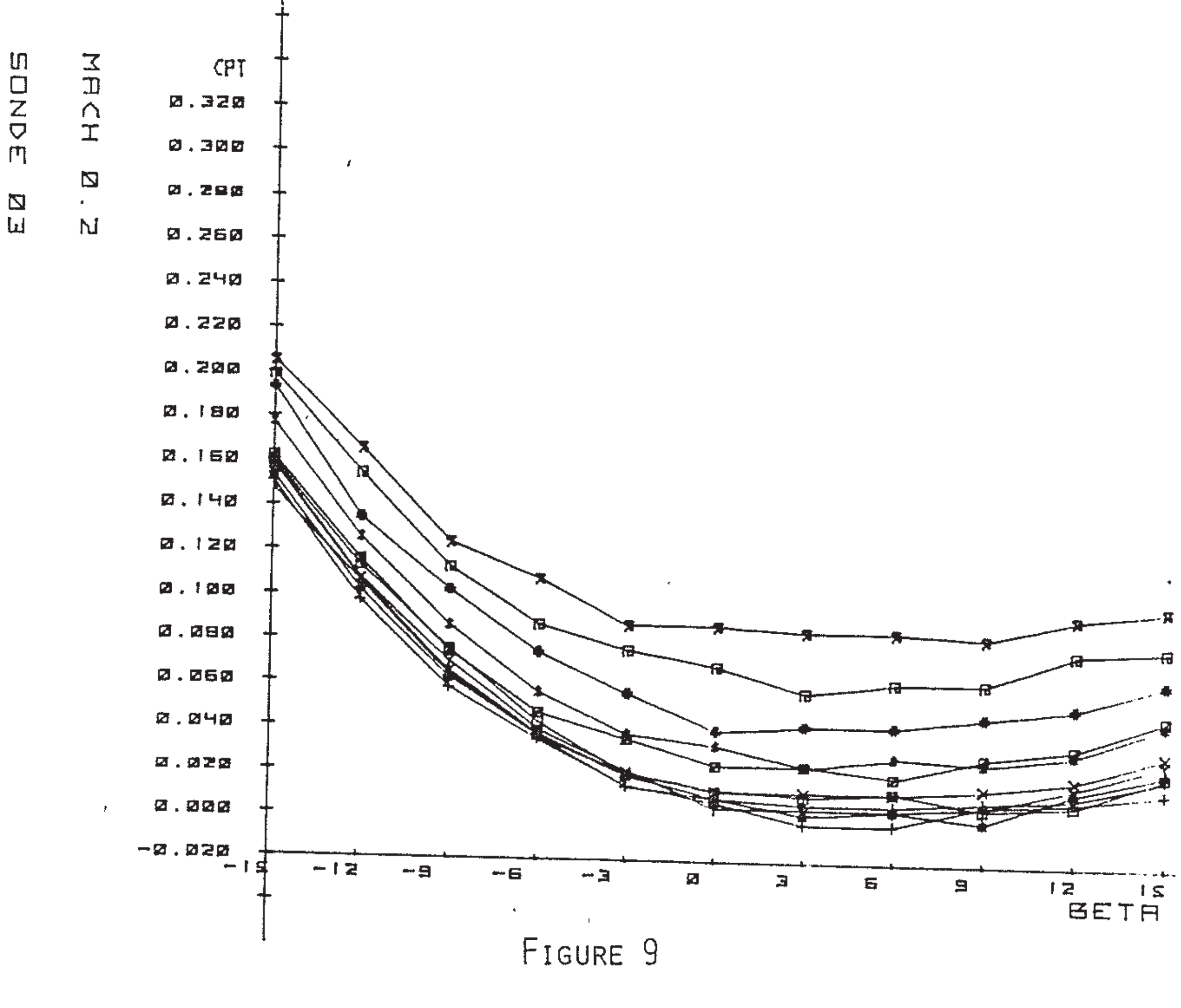


SONDE 03
MACH 0.8
CGAM
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
-0.200
-0.250
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA
SONDE 03
MACH 0.2
CGAM
-0.050
-0.100
-0.150
-0.200
-0.250
-0.300
-0.350
-0.400
-0.450
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA

FIGURE 8

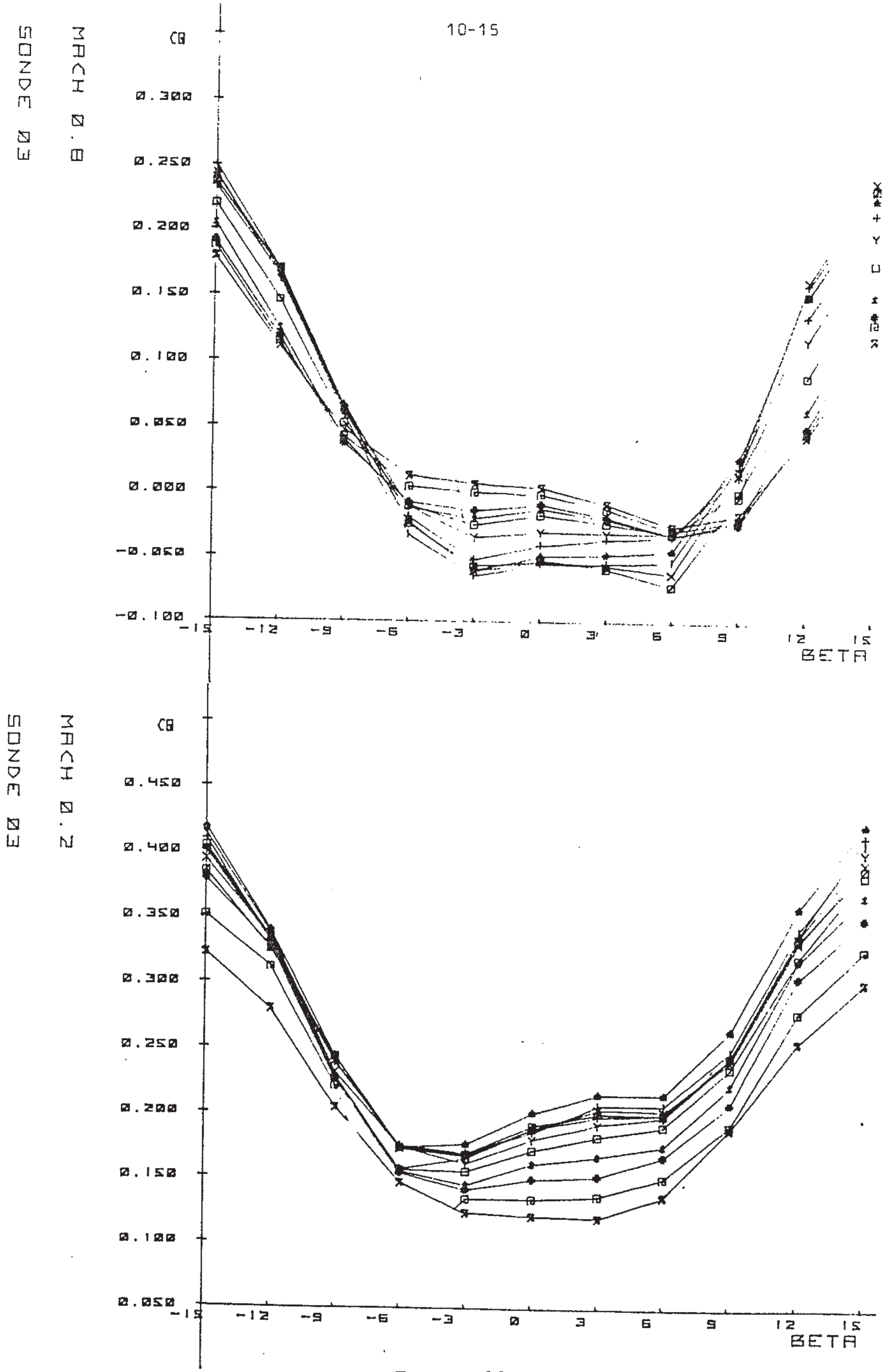


SONDE E0
MACH 0.8
CPT
0.300
0.300
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA



SONDE E0
MACH 0.2
CPT
0.320
0.300
0.280
0.260
0.240
0.220
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
-15 -12 -9 -6 -3 0 3 6 9 12 15
BETA

FIGURE 9



MACH 0.8
SONDE 03
CB
0.300
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA
MACH 0.2
SONDE 03
CB
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
-15
-12
-9
-6
-3
0
3
6
9
12
15
BETA

FIGURE 10

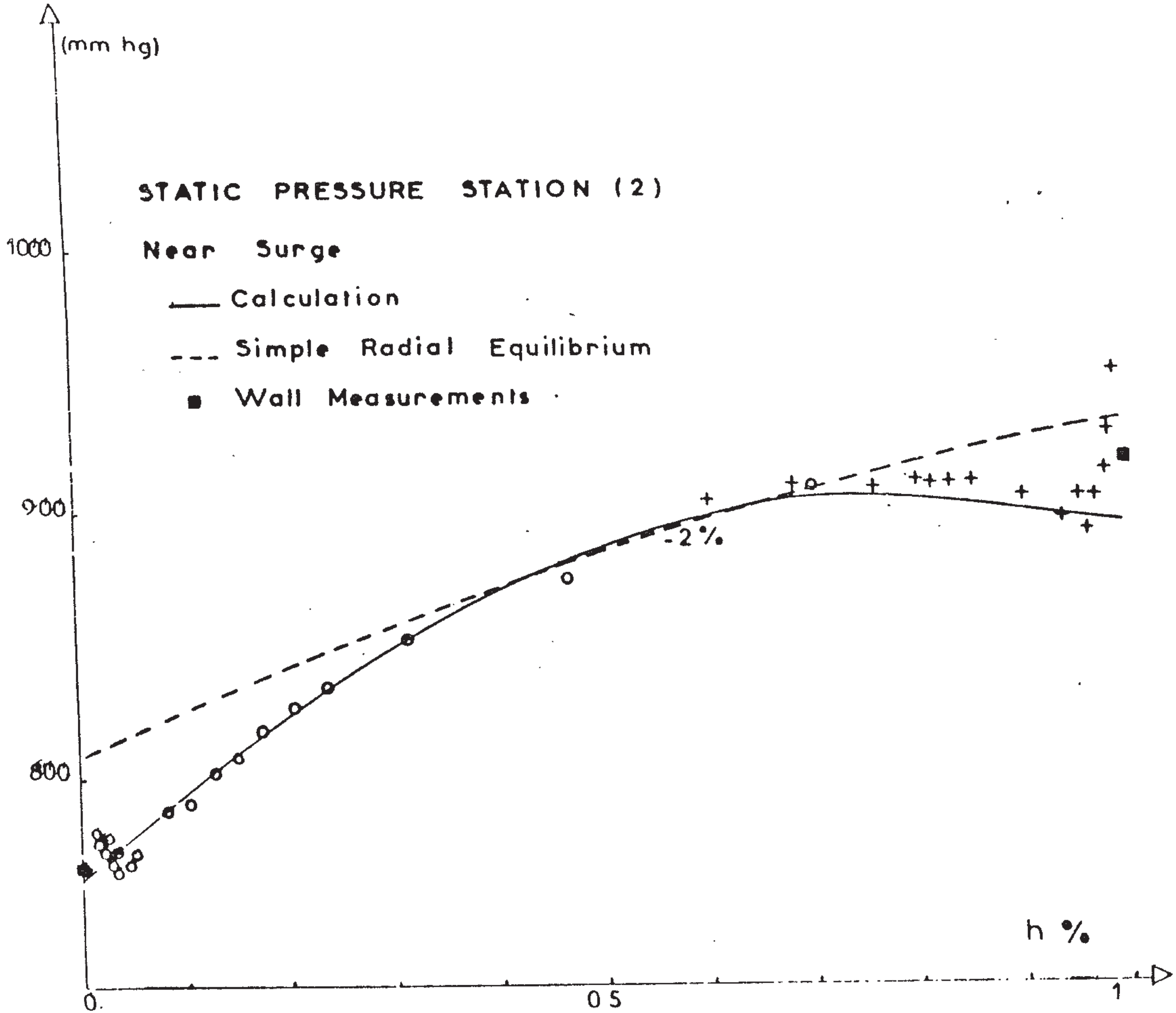

(mm hg)
1000
900
800
STATIC PRESSURE STATION (2)
Near Surge
Calculation
Simple Radial Equilibrium
Wall Measurements
-2%
0.
0 5
1
h %

FIGURE 11

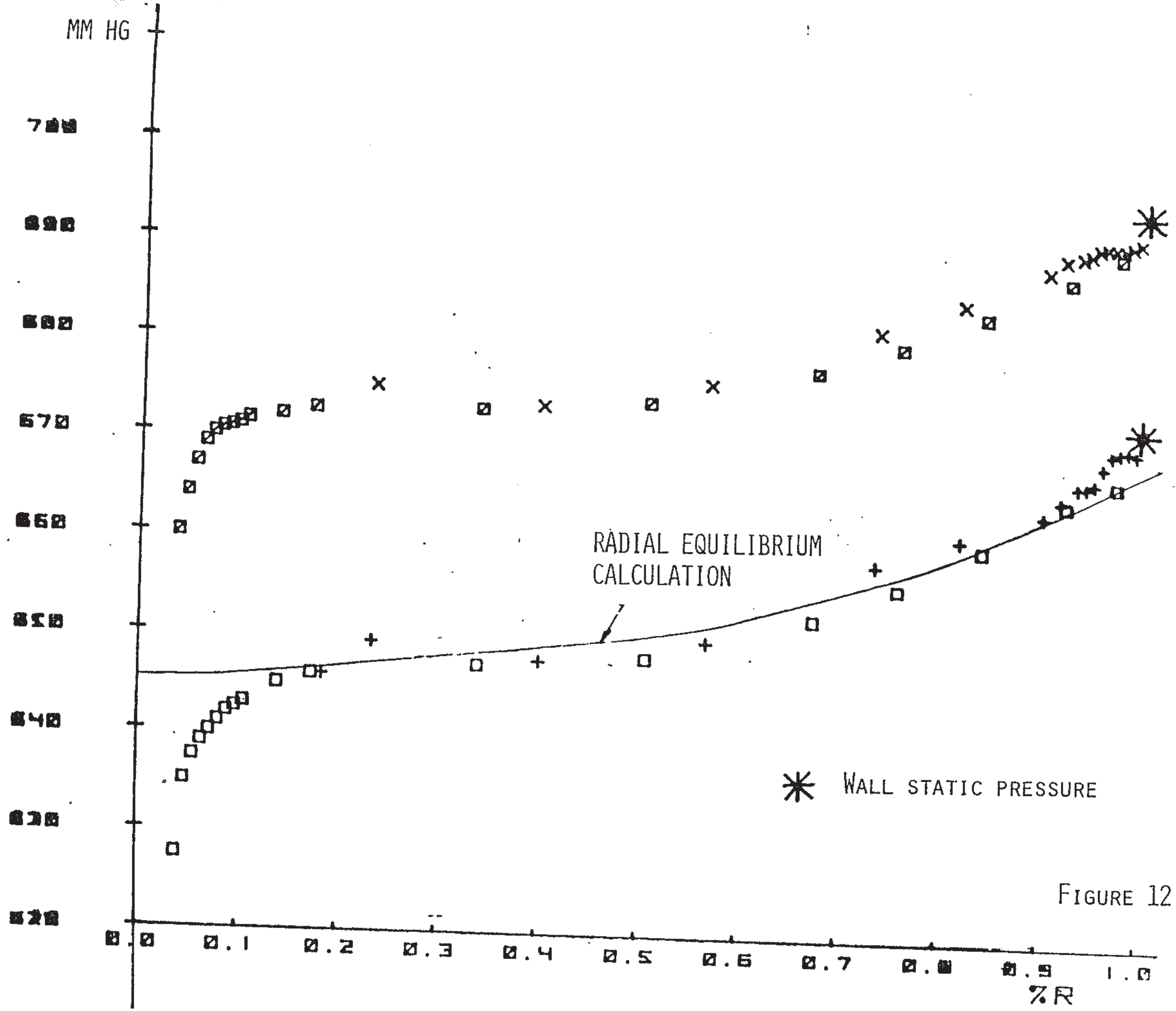

MM HG
700
690
680
670
660
650
640
630
620
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
%R
RADIAL EQUILIBRIUM
CALCULATION
WALL STATIC PRESSURE

FIGURE 12

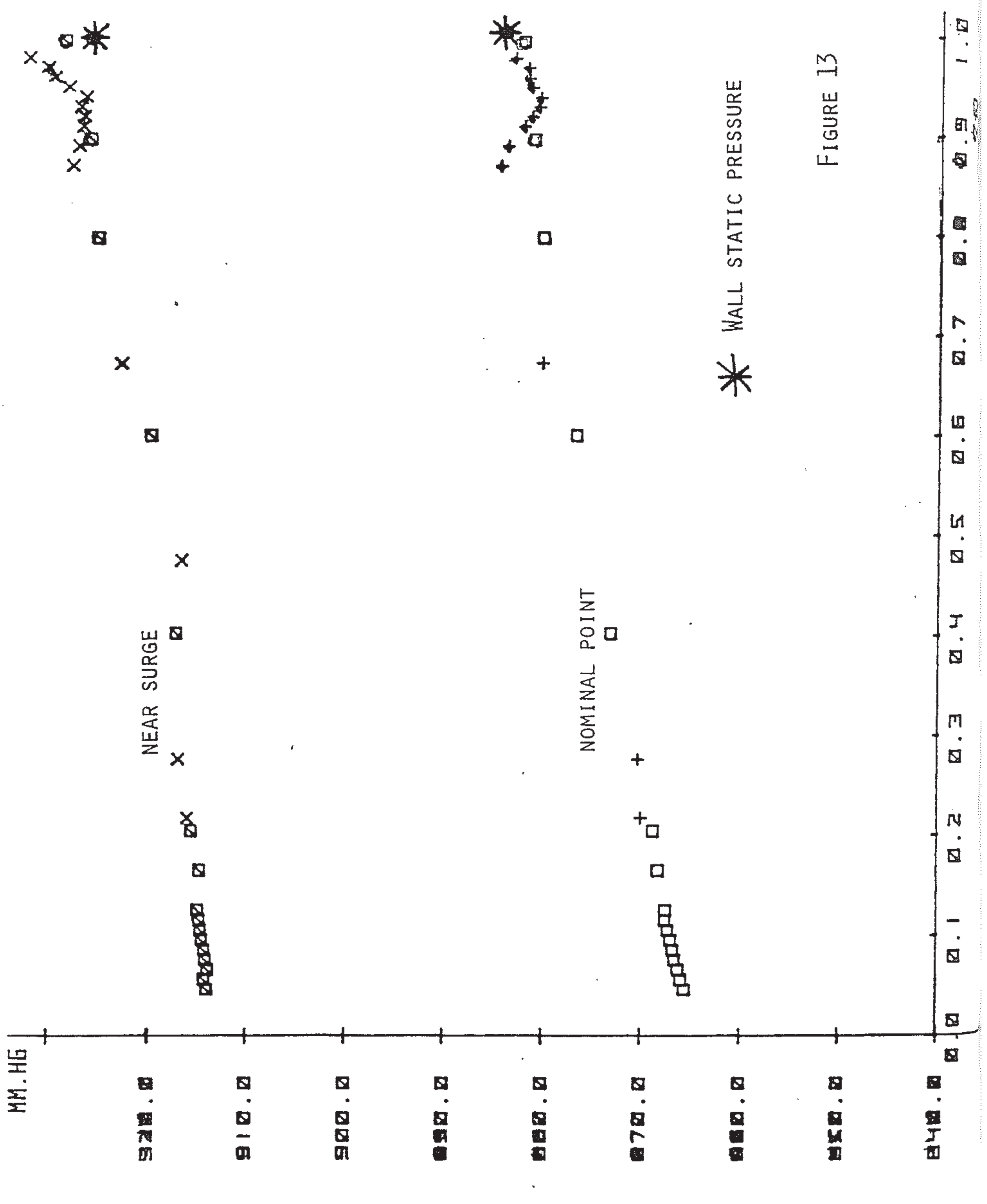


FIGURE 13

PS CF 31166

DEBIT CF 31144

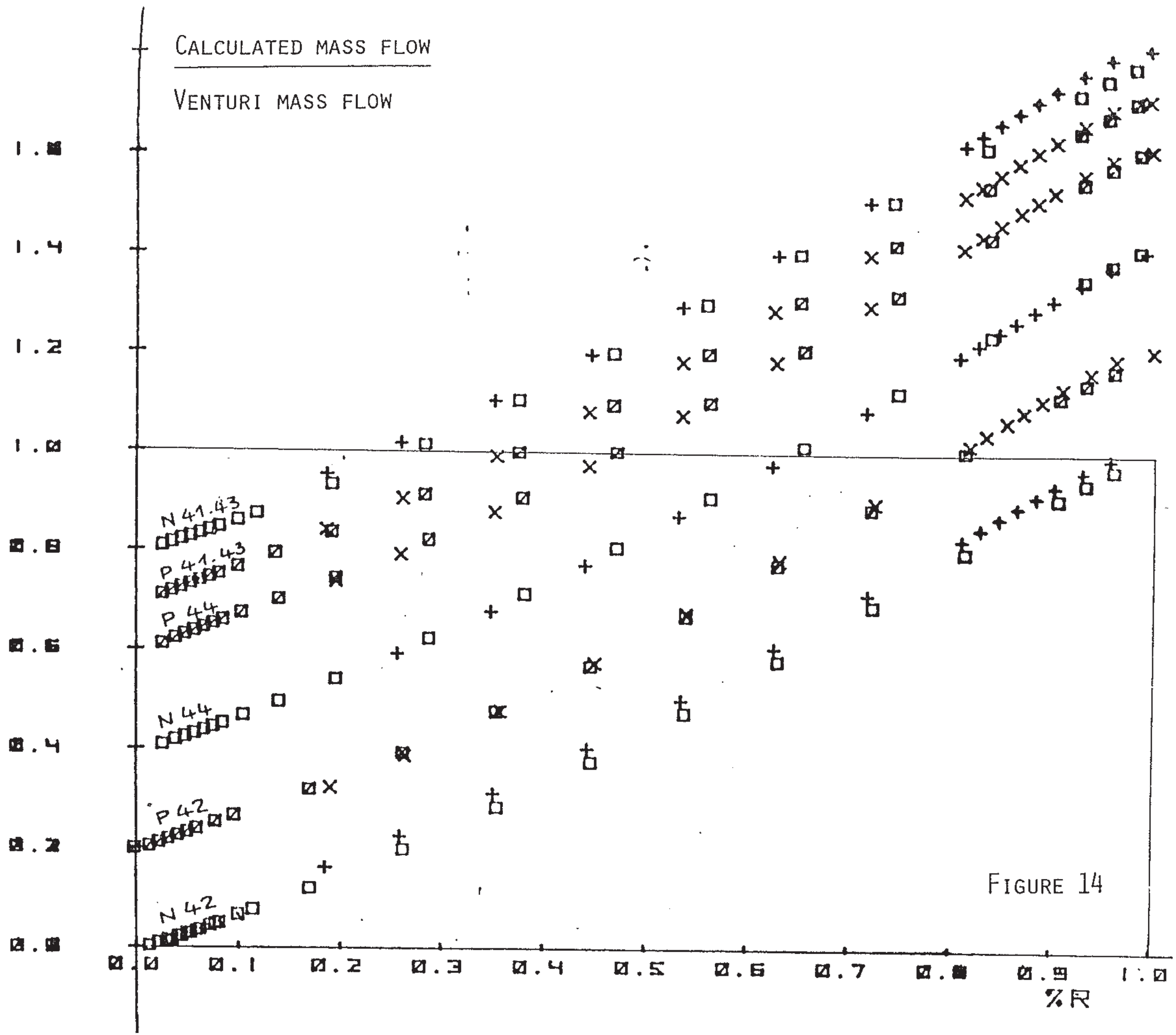


FIGURE 14

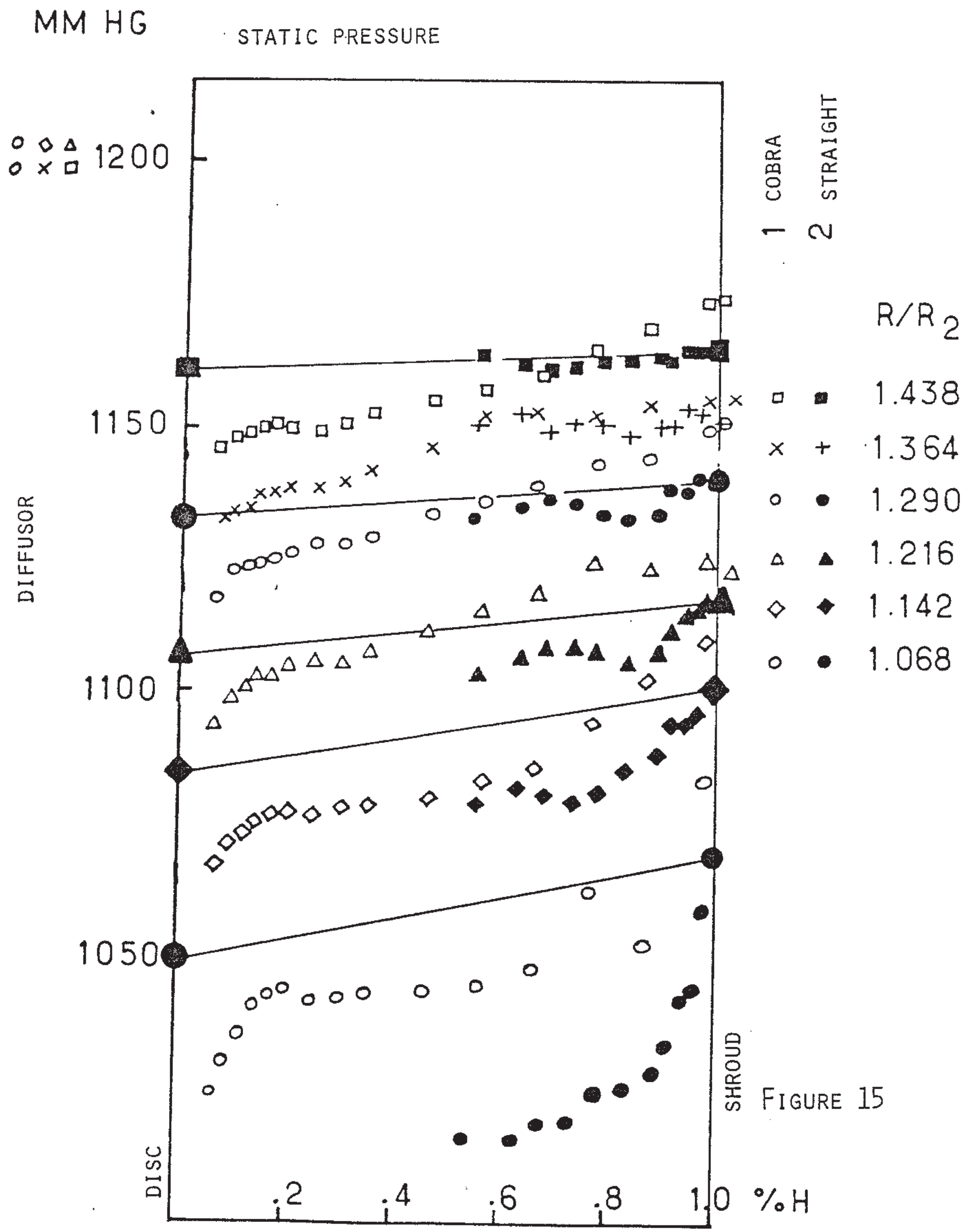

MM HG
STATIC PRESSURE
1200
1150
1100
1050
DIFFUSOR
DISC
SHROUD
.2
.4
.6
.8
1.0 %H
1 COBRA
2 STRAIGHT
R/R2
1.438
1.364
1.290
1.216
1.142
1.068

FIGURE 15

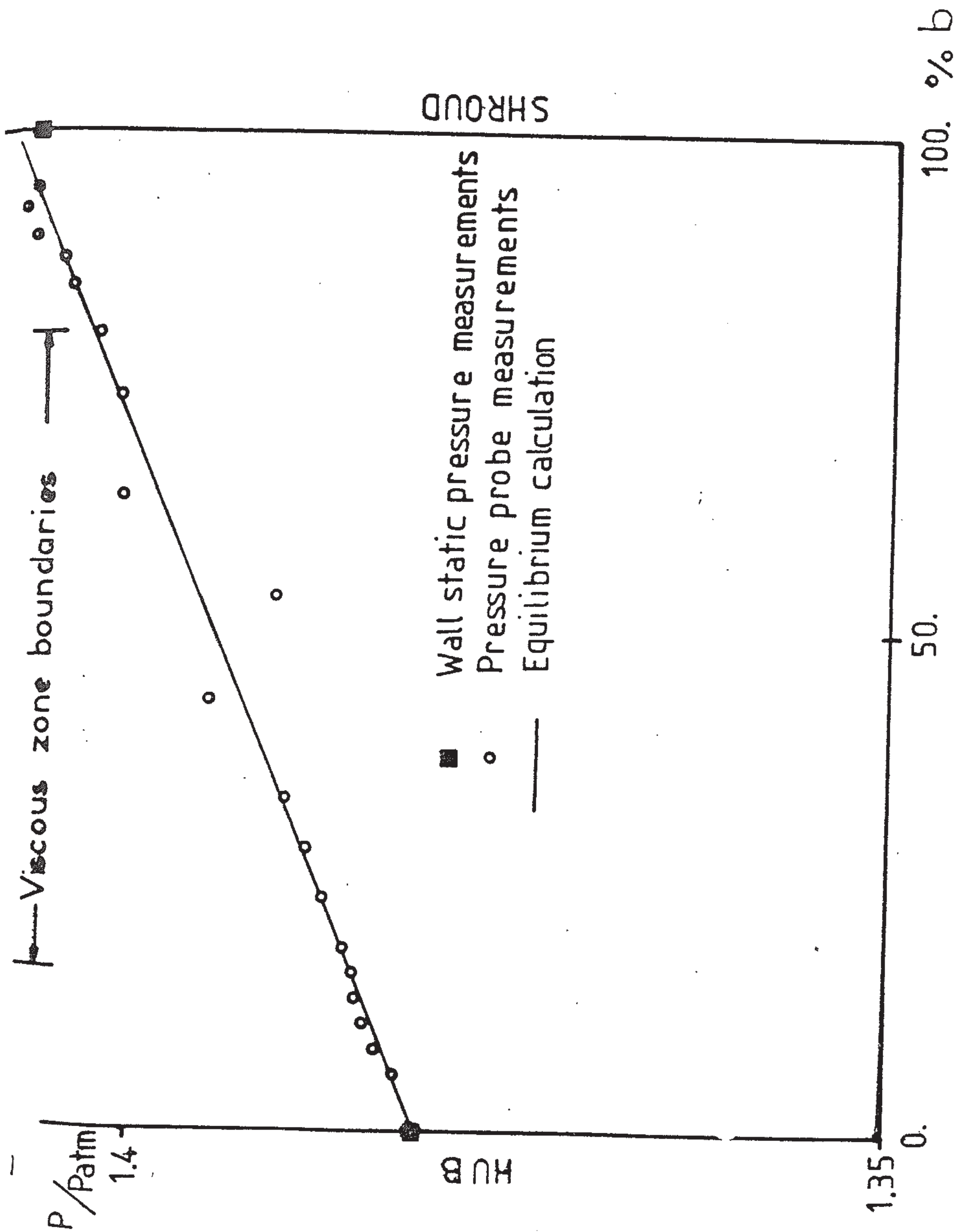


Figure 16 - Static pressure ratios distribution downstream of the shrouded radial compressor impeller.

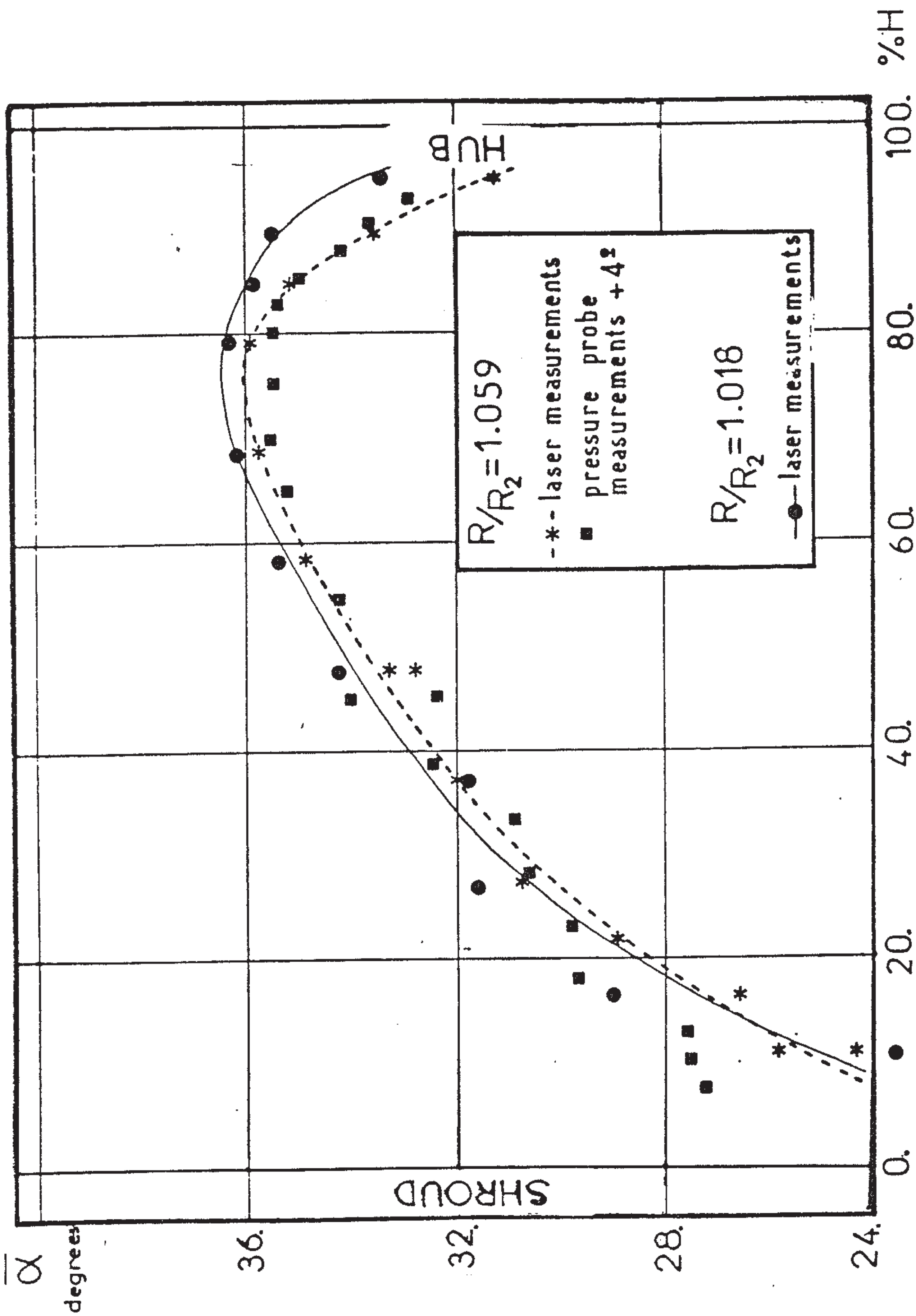


Figure 17 - Laser measurements downstream of the radial compressor impeller: absolute flow angles.

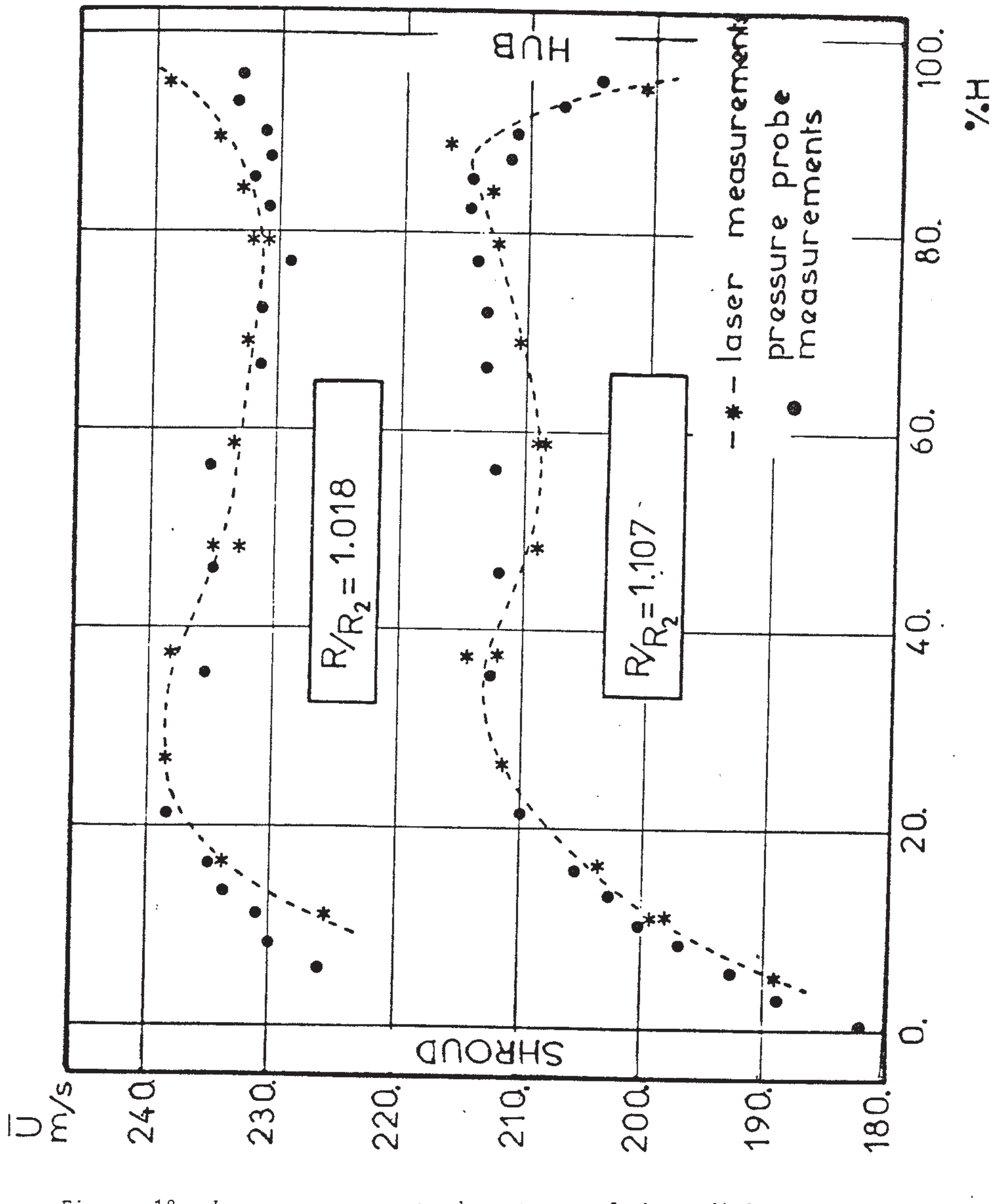


Figure 18 - Laser measurements downstream of the radial compressor impeller : absolute velocities.