TRANSONIC FACILITIES OF D.I.ME.CA. FOR PROBE CALIBRATION AND CASCADE TESTING

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INTRODUCTION

The D.I.ME.CA. first began investigating problems inherent in high speed flow in the 70's with the construction of an open blowdown wind tunnel.

This tunnel, with open test section of 50 x 150 mm^2 and range of about 45 s at Mach = 1, was originally designed not only for the usual types of tests, but also for testing blade cascades. Initially however the tunnel was used more for studying calibration and use of high-speed aerodynamic probes, in view of the interest shown by firms operating in the turbomachinery field. Hence the tunnel was suitably adapted by reducing the test section to 50 x 50 mm^2 and incorporating apparata for automatic calibration.

Subsequently further changes were introduced: the test section was enlarged and air storage tank capacity increased.

More recently problems related to cascade testing have also been investigated, and the construction of a second wind tunnel for this purpose is nearing completion.

In the sequel the main operating and construction features of these two plants are illustrated and some remarks are made concerning the experience gained in the field of probe calibration.

WIND TUNNEL FOR PROBE CALIBRATION

As mentioned the wind tunnel is of the open blowdown type with air storage tank capacity of 25 m^3 at 1.8 MPa and an open test section measuring 70 x 70 mm^2.

For testing in the subsonic range a wooden symmetric nozzle is employed, whereas for supersonic tests three symmetric nozzles are available made of alluminum alloy using an electroerosion process, for Mach numbers 1.25, 1.50 and 1.70. The Reynolds number per unit length is about 3 x 10^7 at Mach = 1.00 with a turbulence level of roughly 1%. The capacity of the tanks together with the operating conditions applied allow to measure without refilling the tanks a number of points ranging from more than 50 at Mach = 0.4 to approximately 20 at Mach = 1.00.

The pressure in the settling chamber can be adjusted automatically but manual adjustment especially in the subsonic range proved more advantageous as far as reducing test times was concerned. For the same purpose supersonic tests are usually conducted with the nozzle in over-expanding conditions. In transonic regime, flow pattern in the test section was also controlled by means of a Schlieren system, carefully set up for visualization both in black and white and in colour.

The probes were placed by means of a traversing apparatus for pitch and yaw angle measuring (Fig.1) whereby the two rotations pitch and yaw can be accomplished without altering the position of the probe sensor.

Pressure signals are recorded by means of straingauge and variable capacitance differential pressure transducers and then the data automatically acquired and processed. Two systems are used for this purpose: the first is based on a mini computer Honeywell Level 6, fitted with two 16-channel modules for analog-to-digital conversion, the second on a Hewlett-Packard apparatus comprised of a multiprogrammer 6942A, and a computer of the series 200.

To calculate the dimensionless calibration coefficients $C_{p\ total}$ = DPO/Q, $C_{p\ static}$ = DPs/Q, $C_{p\ yaw}$ = DPlr/Q, $C_{p\ pitch}$ = DPud/Q, the static reference pressure was measured, in the supersonic range in a side wall pressure tap, whereas for subsonic flow atmospheric pressure was assumed. In both cases total pressure was taken as the static pressure observed in the settling chamber. These assumptions were introduced after a comprehensive experimental investigation, using reference probes (AGARD needle probes), in the calibration stage of the system.

The calibration procedure normally followed depends on the type of problem and operating conditions. As is well known the most exacting calibration is that using five-hole probes where usually calibration zeroing the yaw angle is required. Since zeroing the differential signal is a lengthy process, at the D.I.ME.CA. fixed position probes were employed and measurements were taken around zero, with a view to reducing the times involved. The data collected were interpolated to determine the corresponding typical quantities at DPlr = 0. Typical calibration curves are shown in Fig.2 which refers to a DC-125 United Sensor probe.

For some years now fixed position probe calibration has been carried out at the D.I.ME.CA. as with this technique measuring times in the operating stage can be considerably reduced. As is known this procedure involves measuring a vast number of points for the variables Mach, pitch and in addition yaw angle(*). For this reason the calibration curves can be variously represented, depending on the independent variable chosen. In Fig. 3, as an example, total (DPO/Q) and static

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(*) For instance, to calibrate a probe for Mach 0.4, 0.6, 0.8, 1.00, 1.25 with pitch angle ranging from +20° to -20° at 5° intervals and yaw angle ranging from +10° to -10° at 2° intervals, 495 calibration points are required.

(DPs/Q) pressure are plotted versus pitch, where the yaw angle is assumed as parameter: the differential signal curves (DPLr/Q and DPud/Q) are correlated assuming both pitch and yaw angles as parameters.

Calibrating probes used in two-dimensional flow is much simpler and in this case fixed position probes are preferable. As an example, Fig. 4 shows some calibration curves obtained for a combined two-dimensional cone probe for analysis at the transonic cascade exit. In any case, the graphical representation of the calibration functions no matter how it is done, can only effectively be used for an immediate check, in that three-dimensional probes, especially fixed-position ones, must always be backed up by an automatic data acquisition and elaboration system.

As already mentioned, data acquisition and processing during calibration is automatic and achieved by appropriate interactive calculation methods developed for this purpose. The flow chart is schematically shown in Fig.5. Similarly, Fig. 6 gives the flow chart of the procedures elaborated for the direct use in the computer of calibration curves which are also used as a statistic calibration control, in particular to check the congruence of discretization of the independent variables.

WIND TUNNEL FOR CASCADE TESTING

In the ambit of the CNR Project "Progetto Finalizzato Energetica 2", the possibility of enlarging the system materialized, and a test section for bladed cascades of turbomachinery was built. A new wind tunnel was constructed alongside the existing one used for probe calibration, served by the same supply and regulation plant.

This tunnel (Fig.7) is equipped with a converging stiff wall nozzle having rectangular section with a width, similarly to the probe calibration tunnel, of 70mm and height variable between 80 and 230 mm. Height is adjusted through a mechanism which activates simultaneously the upper and lower walls without altering the nozzle axis. At maximum section and present air storage tank capacity (25 m^3 at 1.8 MPa) operating range at Mach = 1.00 is roughly 60 s.

The 'plenum' configuration incorporating the test section enables maximum flexibility for studying flow periodicity at the exit, working with low and high deflection blades. In addition the divergent conduits can be arranged upstream from the blades so that operation with supersonic flows at the inlet can be studied.

As the latter feature was taken into account in the choice of measuring apparata and data acquisition and elaboration systems, the new wind tunnel will not require any adaptation.

FINAL CONFIGURATION AND PERSPECTIVES

Fig.8 illustrates the plant with the new tunnel for cascade testing. The Schlieren visualization system was placed so as to enable alternate use in both tunnels.

With regards to investigations currently under way, in the probe calibration tunnel systematic tests are being carried out on three-dimensional probes at approximately Mach = 1.00. In the new tunnel a transonic high deflection cascade is being set up.

NOMENCLATURE

Cp total	total pressure coefficient
Cp static	static pressure coefficient
Cp yaw	yaw coefficient
Cp pitch	pitch coefficient

$DP_0 = P_{0ref} - P_{0p}$

$DP_s = P_{sref} - P_{sp}$

$DP_{lr} = P_{left} - P_{right}$

$DP_{ud} = P_{up} - P_{down}$

$Q = (P_0 - P_s)_{ref}$

Subscripts

0	total
p	probe
s	static

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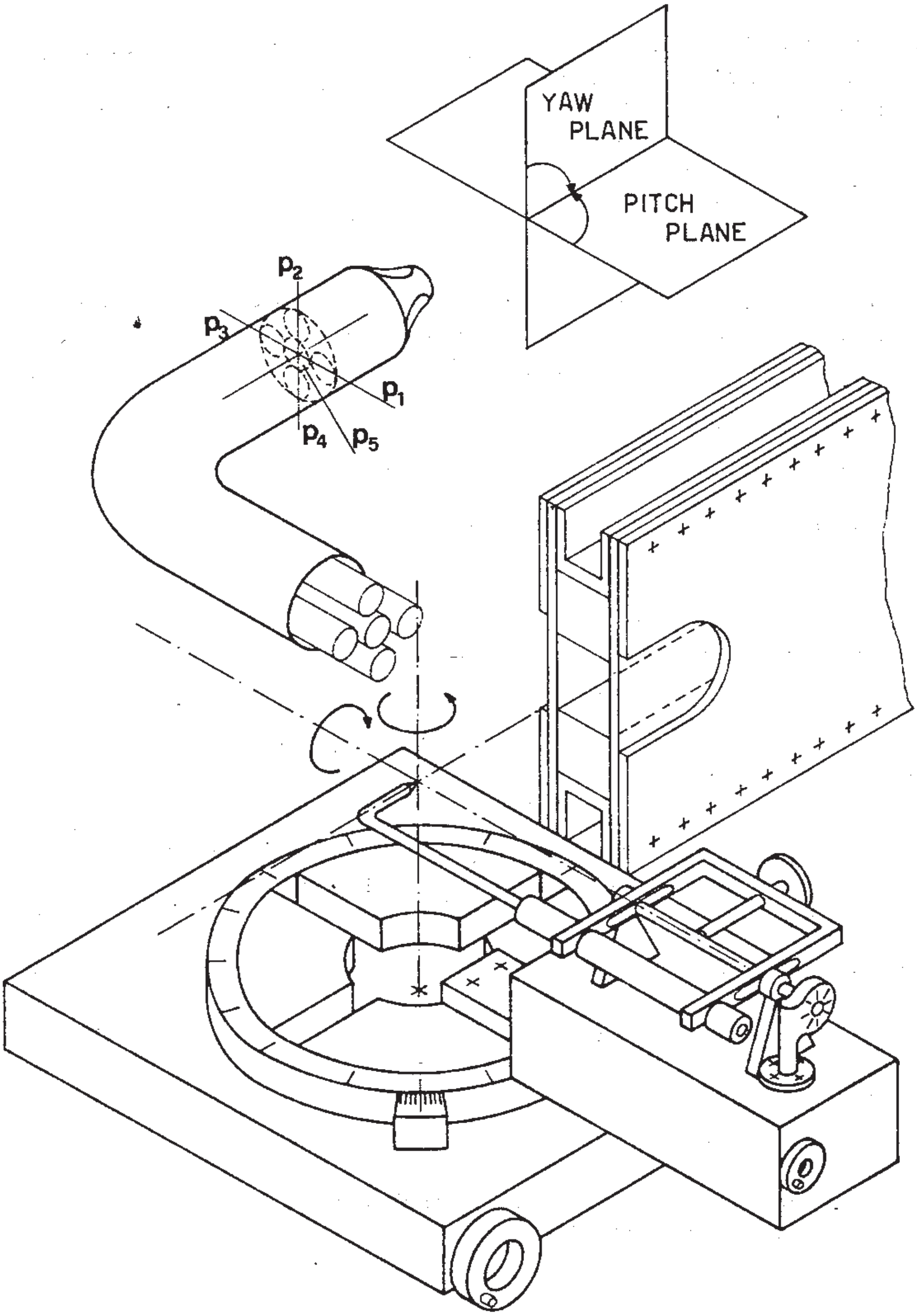


fig. 1

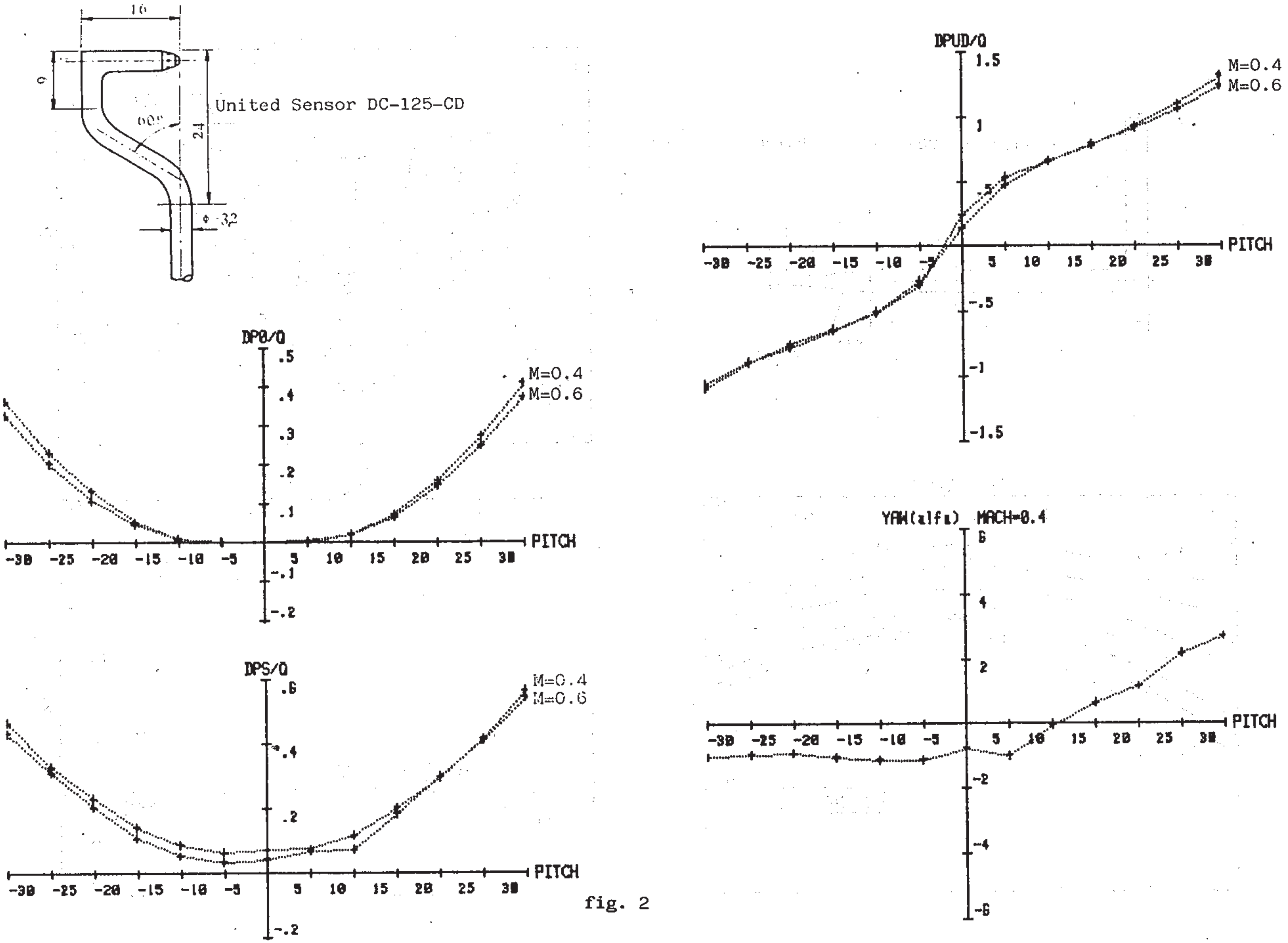

United Sensor DC-125-CD
16
9
24
60°
φ 3.2
DPUD/Q
1.5
1
.5
-.5
-1
-1.5
M=0.4
M=0.6
PITCH
-30 -25 -20 -15 -10 -5 5 10 15 20 25 30
DP0/Q
.5
.4
.3
.2
.1
-.1
-.2
M=0.4
M=0.6
PITCH
-30 -25 -20 -15 -10 -5 5 10 15 20 25 30
YAW(alfa) MACH=0.4
6
4
2
-2
-4
-6
PITCH
-30 -25 -20 -15 -10 -5 5 10 15 20 25 30
DPS/Q
.6
.4
.2
-.2
M=0.4
M=0.6
PITCH
-30 -25 -20 -15 -10 -5 5 10 15 20 25 30

fig. 2

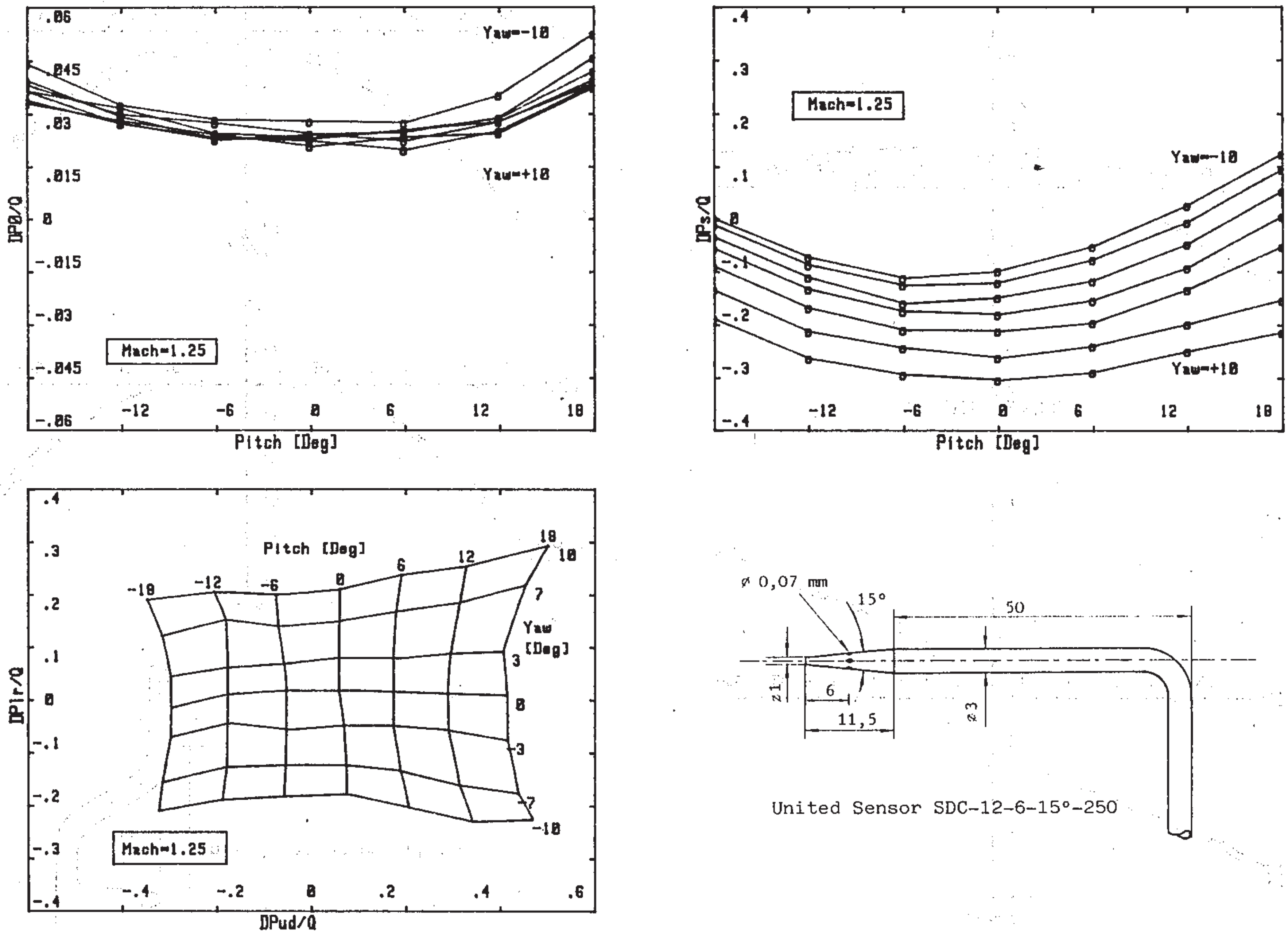
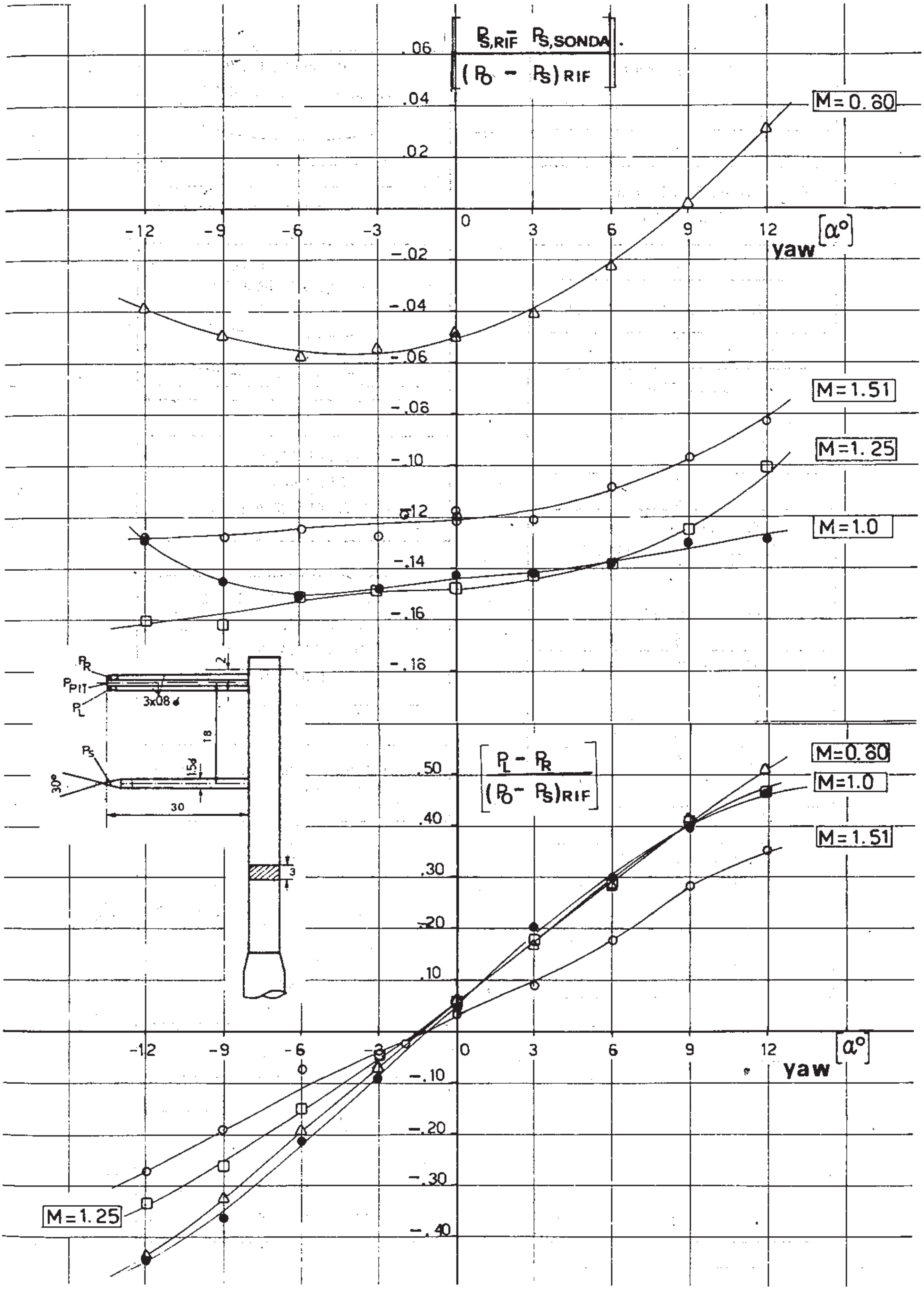

.06
.045
.03
.015
0
-.015
-.03
-.045
-.06
DP0/Q
Yaw=-10
Yaw=+10
Mach=1.25
-12
-6
0
6
12
18
Pitch [Deg]
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
DPs/Q
Mach=1.25
Yaw=-10
Yaw=+10
-12
-6
0
6
12
18
Pitch [Deg]
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
DPlr/Q
Pitch [Deg]
-18
-12
-6
0
6
12
18
10
7
Yaw
[Deg]
3
0
-3
-7
-10
Mach=1.25
-.4
-.2
0
.2
.4
.6
DPud/Q
ø 0,07 mm
15°
50
z1
6
11,5
ø3
United Sensor SDC-12-6-15°-250

fig. 3



$\left[\frac{P_{S,RIF} - P_{S,SONDA}}{(P_O - P_S)_{RIF}}\right]$
.06
.04
.02
-.02
-.04
-.06
-.08
-.10
-.12
-.14
-.16
-.18
-12
-9
-6
-3
0
3
6
9
12
yaw [α°]
M=0.80
M=1.51
M=1.25
M=1.0
P_R
P_{PIT}
P_L
3x0.8 ⌀
2
18
P_S
30°
1.5d
30
3
$\left[\frac{P_L - P_R}{(P_O - P_S)_{RIF}}\right]$
.50
.40
.30
.20
.10
-.10
-.20
-.30
-.40
M=0.80
M=1.0
M=1.51
M=1.25

fig. 4

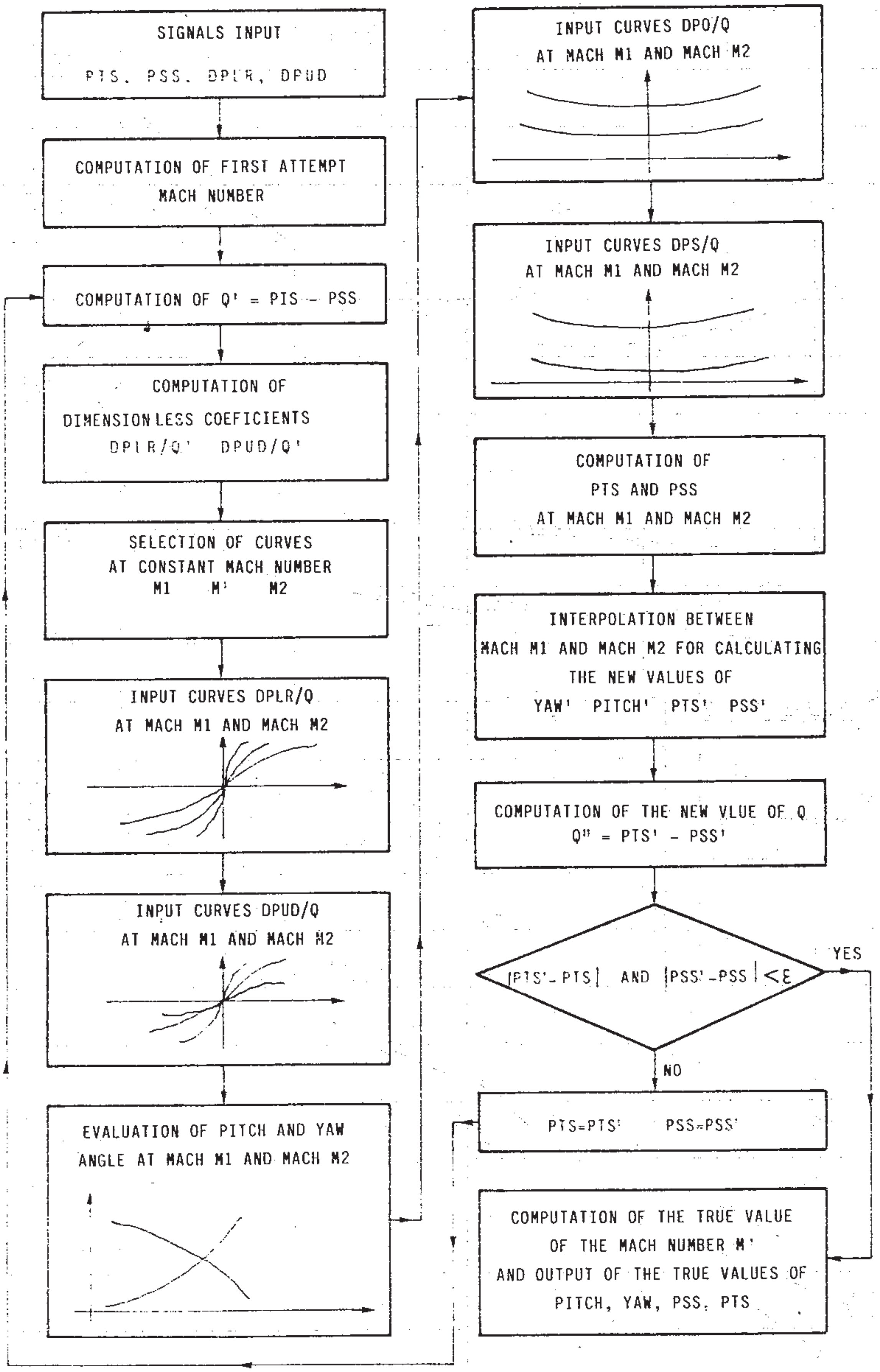

SIGNALS INPUT
PTS, PSS, DPLR, DPUD
COMPUTATION OF FIRST ATTEMPT MACH NUMBER
COMPUTATION OF Q' = PIS - PSS
COMPUTATION OF DIMENSIONLESS COEFICIENTS
DPLR/Q' DPUD/Q'
SELECTION OF CURVES AT CONSTANT MACH NUMBER
M1 M' M2
INPUT CURVES DPLR/Q AT MACH M1 AND MACH M2
INPUT CURVES DPUD/Q AT MACH M1 AND MACH M2
EVALUATION OF PITCH AND YAW ANGLE AT MACH M1 AND MACH M2
INPUT CURVES DPO/Q AT MACH M1 AND MACH M2
INPUT CURVES DPS/Q AT MACH M1 AND MACH M2
COMPUTATION OF PTS AND PSS AT MACH M1 AND MACH M2
INTERPOLATION BETWEEN MACH M1 AND MACH M2 FOR CALCULATING THE NEW VALUES OF
YAW' PITCH' PTS' PSS'
COMPUTATION OF THE NEW VLUE OF Q
Q" = PTS' - PSS'
|PTS'-PTS| AND |PSS'-PSS| < ε
YES
NO
PTS=PTS' PSS=PSS'
COMPUTATION OF THE TRUE VALUE OF THE MACH NUMBER M' AND OUTPUT OF THE TRUE VALUES OF PITCH, YAW, PSS, PTS

fig. 6

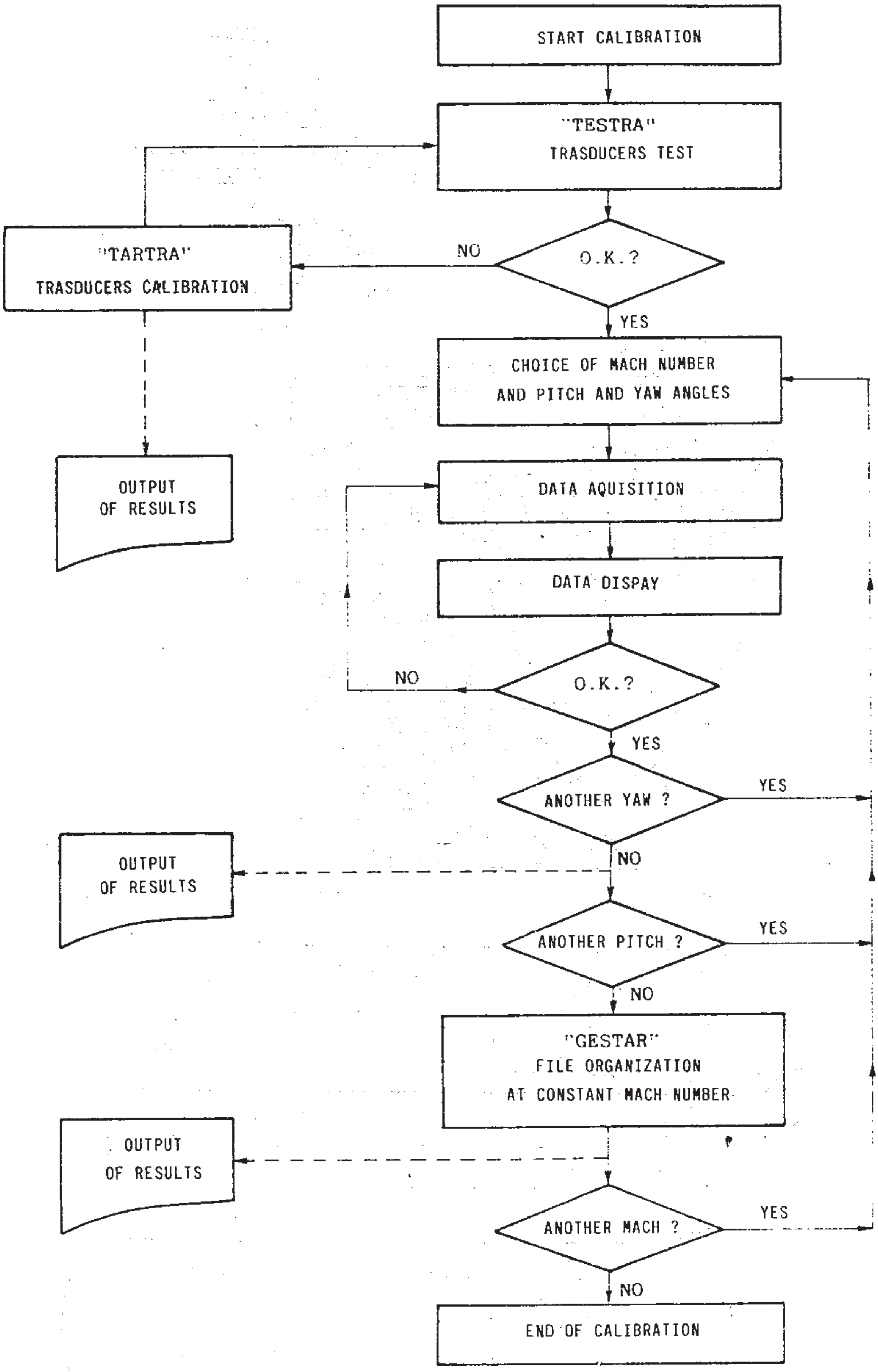

START CALIBRATION
"TESTRA"
TRASDUCERS TEST
"TARTRA"
TRASDUCERS CALIBRATION
NO
O.K.?
YES
CHOICE OF MACH NUMBER
AND PITCH AND YAW ANGLES
OUTPUT
OF RESULTS
DATA AQUISITION
DATA DISPAY
NO
O.K.?
YES
ANOTHER YAW ?
YES
NO
OUTPUT
OF RESULTS
ANOTHER PITCH ?
YES
NO
"GESTAR"
FILE ORGANIZATION
AT CONSTANT MACH NUMBER
OUTPUT
OF RESULTS
ANOTHER MACH ?
YES
NO
END OF CALIBRATION

fig. 5

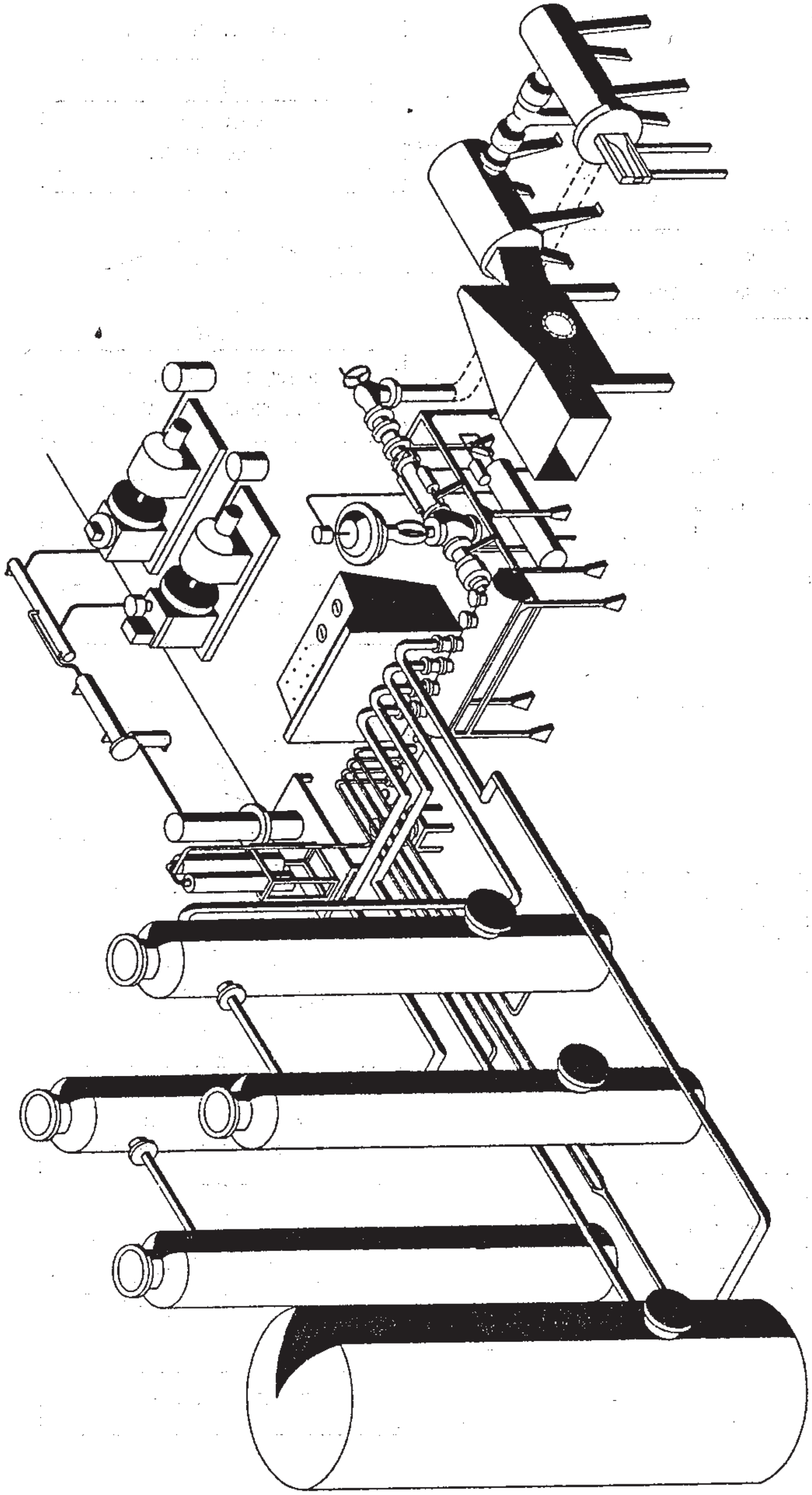


fig. 8

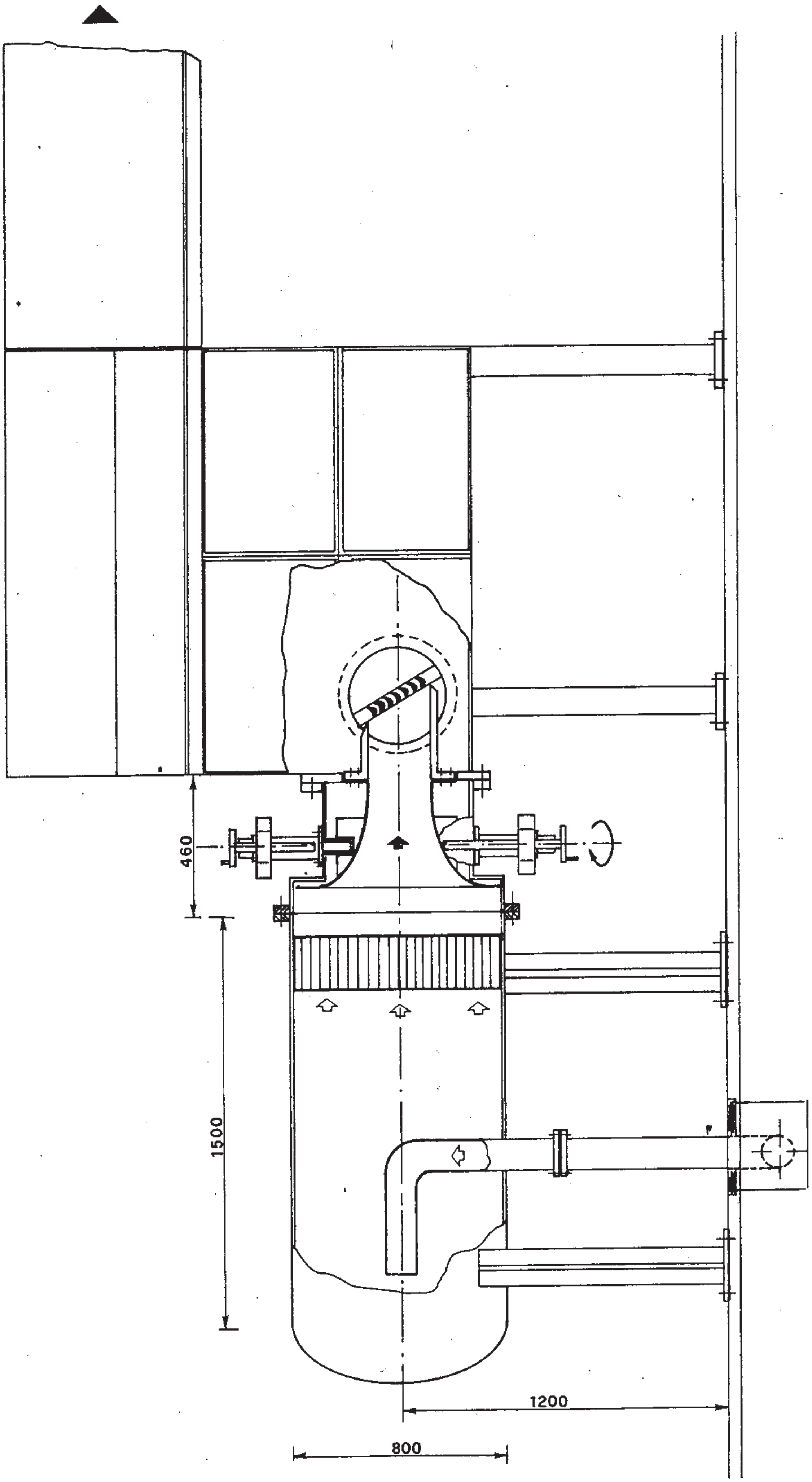


fig. 7