Session 6 - Pressure Probes

AN INVESTIGATION INTO THE INFLUENCE OF THE DIFFERENT CALIBRATION COEFFICIENTS UPON MEASUREMENTS WITH AERODYNAMIC PRESSURE PROBES

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SUMMARY

The coefficients commonly employed in calibration make use of expressions which differ considerably especially as to the parameters to be rendered dimensionless, usually the dynamic pressure measured by the probe or reference dynamic pressure. A computer program has been developed by the D.I.ME.CA. for analysing the behaviour of a variety of dimensionless coefficients that may be used in calibration.

Experiments have shown that all the coefficients examined yielded good results when the probe within the calibration range and that the coefficients calculate with the reference pressure at and outside the limits of the range are more reliable.

INTRODUCTION

Different dimensionless factors have been proposed in the literature for calibration and use of aerodynamic probes for analysing two (2D) and three-dimensional (3D) flow.

The coefficients most widely used are rendered dimensionless with respect to dynamic pressure, employing both the pressure measured by the probe (Q) and the reference pressure (Qref). In both case the coefficient may differ in static pressure used when the probe is not fitted with a suitable static pressure tap. In fact, reference may be made, in these cases, to the measurements taken in a directional pressure tap (right or left) or to the average of these two (Pl+Pr)/2, or alternatively, for 5-hole probes, averaging over the four directional taps (Pl+Pr+Pu+Pd)/4.

The different types of coefficients require different modes of operation both in the calibration stage and when using the probe and sometimes lead to widely discrepant results.

In order to study the effect of the different calibration factors on the measurements, with special reference to the 5-hole probe, a series of experimental tests was undertaken using United Sensor type SDC 125-CD probes in fixed position (Fig. 1) and the coefficients listed in Table 1.

CALIBRATION CURVES.

Calibration was performed in the D.I.ME.CA.'s supersonic tunnel (blowdown wind tunnel with open test section of 70x70 mm^2 [1]) for three different Mach numbers, 0.3, 0.5, 0.7 and yaw and pitch angles variable from -40° to +40° in 5° steps.

Strain gauge differential pressure transducers (Schaewitz P 2100) were used for pressure up to 1100 mbar (standard deviation s=0.11% of bottom scale) and variable capacitance ones (Rosemount 1151 DP) for pressure up to 300 mbar (s=0.13% of bottom scale). Transducers were substituted in function of Mach number so as to always ensure operation in the mid calibration range of the transducers, thus minimizing standard deviation.

Some of the most significant curves are shown in Fig. 2 and 3 for the coefficients 1), 2) and 3), calculated with the reference dynamic pressure.

Generally speaking, the curves obtained displayed good directional sensitivity and only the curves for the static pressure coefficients showed a deterioration in sensitivity to the yaw angle for Ps=(Pl+Pr)/2 and also to pitch angle in the case of Ps=(Pl+Pr+Pu+Pd)/4

It should be remarked that for Ps=Pr for yaw angles smaller than a critical angle, typical of the probe type, the pressure measured by the probe will be negative (in the case at hand this happens for yaw less than -30°).

This usually means that these points have to be excluded when using the probe, thus limiting, sometimes considerably, its field of application [5]. However, as this is not due to irregular behaviour of the probe, these points can, in any case, be recovered by incorporating an appropriate algorithm into the data processing program.

On the other hand, when referring to the pressure measured by the probe, all the calibration coefficients vary with static pressure chosen (Fig. 4 and 5). In particular, it was found that none of the curves for Ps=Pr displayed a steady trend, owing to the change in sign of the dynamic pressure, which restricts the range of the probe (in our case to yaw angles of greater than -30°).

In the other two cases (Ps=(Pl+Pr)/2 and Ps=(Pl+Pr+Pu+Pd)/4) the probe may be used over the complete calibration range, even if at its limits the trend of the curves is not very steady.

As already seen for the coefficients 2 and 3, similarly for the coefficients 5) and 6), with Ps = Psm, the static pressure correction curves indicate a variation in sensitivity for the yaw angles, though not as pronounced.

The same trend was observed for the curves plotted for total pressure correction.

USE OF CALIBRATION CURVES AND RESULTS.

The probe data processing program is part of a general computer code developed at D.I.ME.CA for: a) calibration, b) plotting the relative curves and c) use, for any type of aerodynamic probe in analysing both sub- and supersonic flows.

This program allows to use twelve different types of calibration factors which can be obtained through different combinations of reference and measured pressures. The code employs directly the data pertaining to the calibration points, performing linear interpolations between them and extrapolating the calibration range of a interval to be assigned, which will depend on probe type.

The program is also designed to process those data that lead, when using the probe, to negative dynamic pressure values, which, as previously mentioned, may arise when calibration factors of type 1) are used.

As regards extrapolation, this is employied both for measurements at and outside the limits of calibration range, and because, when using coefficients with the reference dynamic pressure, the values of the first run of the input data (coefficients calculated with values measured with the probe) fall outside calibration range already from yaw angles outside the range +- 15°.

In addition, the program is capable of distinguishing, without possibilities of error, profoundly diverse situations both as to Mach number and flow angles, which, in many cases, can result in apparently similar measurements (for instance very low pressures may be attributable either to a particularly slow flow or to the probe being strongly misaligned).

At first the computer code was tested over the complete calibration range using the same calibration points, and for all the coefficients the results were remarkably accurate. Generally, appreciable variations in pressures (in mbar abs.) and flow angles were only found on the second decimal digit whereas for Mach numbers differences were observed on the fifth decimal digit.

The next test was run for points different from the calibration points and extended to beyond the calibration range both viz angles and Mach number. Importantly, in the case of totally unknown flow, with points outside the calibration range, the program does not yield results inside the range, and hence only apparently satisfactory, but even if the final result is not acceptable, it must in any case be clear that the measurement pertains to points outside the calibration range. The above tests showed that it is possible to extrapolate the Mach number with all coefficients, down to very low values (Ma<0.1). No tests run for Mach>0.8.

Extrapolation of flow angles yielded reliable results with the three coefficients 1), 2) and 3), calculated with the reference dynamic pressure and for dynamic pressure measured with the probe, only for Ps=Pr, coefficient 4). In the other two cases results were patently incorrect, but at least one of the angles found indicated that we were operating outside the calibration range.

With all coefficients, accuracy was of the same order of magnitude and slightly better results were observed for Ps=Pr and with the reference dynamic pressure, especially at the limits of the calibration range.

The number of iterations was always higher with the first three coefficients (from 5 to over 30 compared to between 2 and 10 for dynamic pressure measured with the probe) and increased slightly going from Ps=Pr to the averaged static pressure.

Tests conducted immediately after calibration showed variations, compared to true values, on the first decimal digit for pressures (in mbar) and angles, and on the fourth for Mach number. Another series of tests carried out after prolonged use of the probe indicated a slight deterioration of the results with errors of a greater order of magnitude.

CONCLUSIONS.

The experiments provided evidence that with a suitably structured data processing program all the coefficients examined can be employied, at least for not very broad fields of application.

The marked variations observed in the dynamic pressure measured with the probe can, however, give rise to some problems, especially for larger flow angles. The use of average static pressure may even, in certain cases yield poorer results.

Overall smaller uncertanty and better reliability were obtained with the coefficients calculated using reference dynamic pressure, especially with static pressure measured with only one tap.

In this case computation times are slightly longer, but the three coefficients 1), 2), and 3) all permit, when using the probe, to reliably extrapolate the calibration range by 5°. Beyond this range, the accuracy of results gradually declines.

NOMENCLATURE

Ma	Mach number
P_d	Measured down pressure
P_l	Measured left pressure
Pr	Measured right pressure
Ps	Static pressure
Psm	Mean static pressure
Ps_{ref}	Reference static pressure
P_t	Measured total pressure
Pt_{ref}	Reference total pressure
P_u	Measured upper pressure
Q	Measured dynamic pressure
Q_{ref}	Reference dynamic pressure

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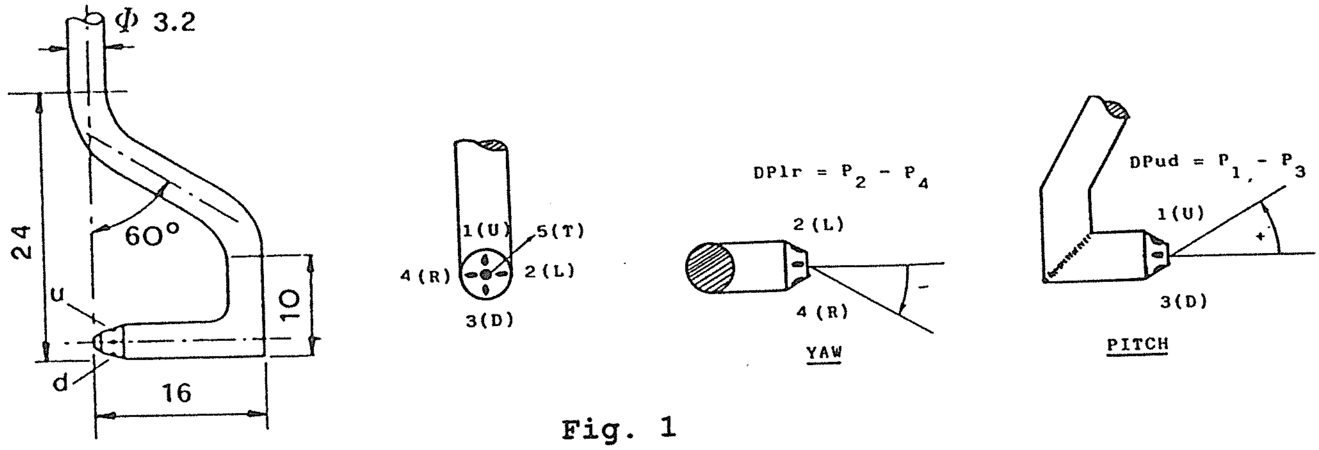

Fig. 1

CALIBRATION FACTORS

$\frac{DPt}{Q_{ref}} = \frac{Pt_{ref} - Pt}{Pt_{ref} - Ps_{ref}}$	$\frac{DPt}{Q} = \frac{Pt_{ref} - Pt}{Pt - Ps}$
$\frac{DPs}{Q_{ref}} = \frac{Ps_{ref} - Ps}{Pt_{ref} - Ps_{ref}}$	$\frac{DPs}{Q} = \frac{Psref - Ps}{Pt - Ps}$
$\frac{DPlr}{Q_{ref}} = \frac{Pl - Pr}{Pt_{ref} - Ps_{ref}}$	$\frac{DPlr}{Q} = \frac{Pl - Pr}{Pt - Ps}$
$\frac{DPud}{Q_{ref}} = \frac{Pu - Pd}{Pt_{ref} - Ps_{ref}}$	$\frac{DPud}{Q} = \frac{Pu - Pd}{Pt - Ps}$
Coeff. 1) $Ps = Pr$	Coeff. 4) $Ps = Pr$
Coeff. 2) $Ps = \frac{Pl + Pr}{2}$	Coeff. 5) $Ps = \frac{Pl + Pr}{2}$
Coeff. 3) $Ps = \frac{Pl+Pr+Pu+Pd}{4}$	Coeff. 6) $Ps = \frac{Pl+Pr+Pu+Pd}{4}$

Table 1

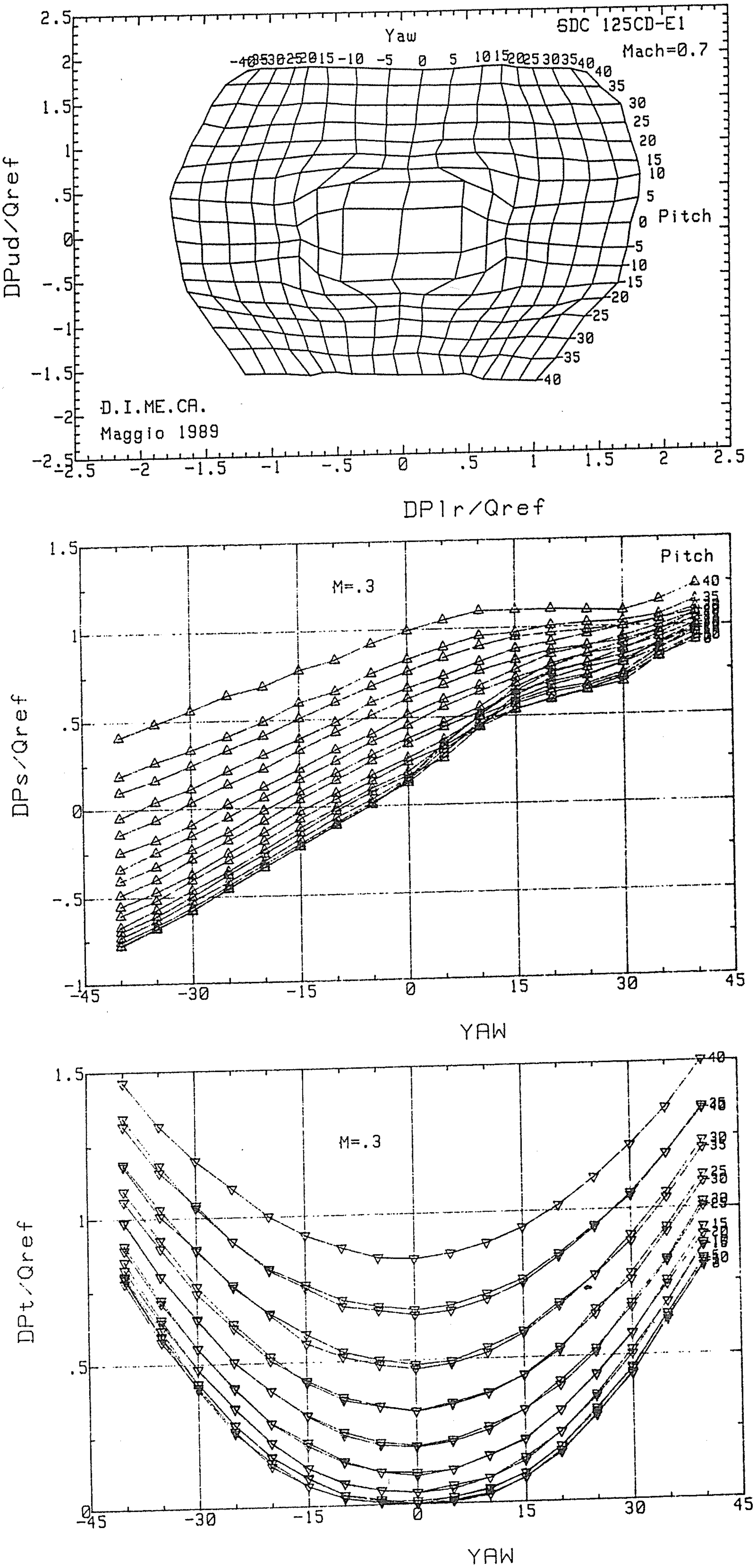
Yaw
SDC 125CD-E1
Mach=0.7
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40
40 35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35 -40
Pitch
DPud/Qref
2.5 2 1.5 1 .5 0 -.5 -1 -1.5 -2 -2.5
-2.5 -2 -1.5 -1 -.5 0 .5 1 1.5 2 2.5
D.I.ME.CA.
Maggio 1989
DPlr/Qref
Pitch
M=.3
40 35
DPs/Qref
1.5 1 .5 0 -.5 -1
-45 -30 -15 0 15 30 45
YAW
M=.3
40 35 30 25 20 15 10 5 0
DPt/Qref
1.5 1 .5 0
-45 -30 -15 0 15 30 45
YAW

Fig. 2

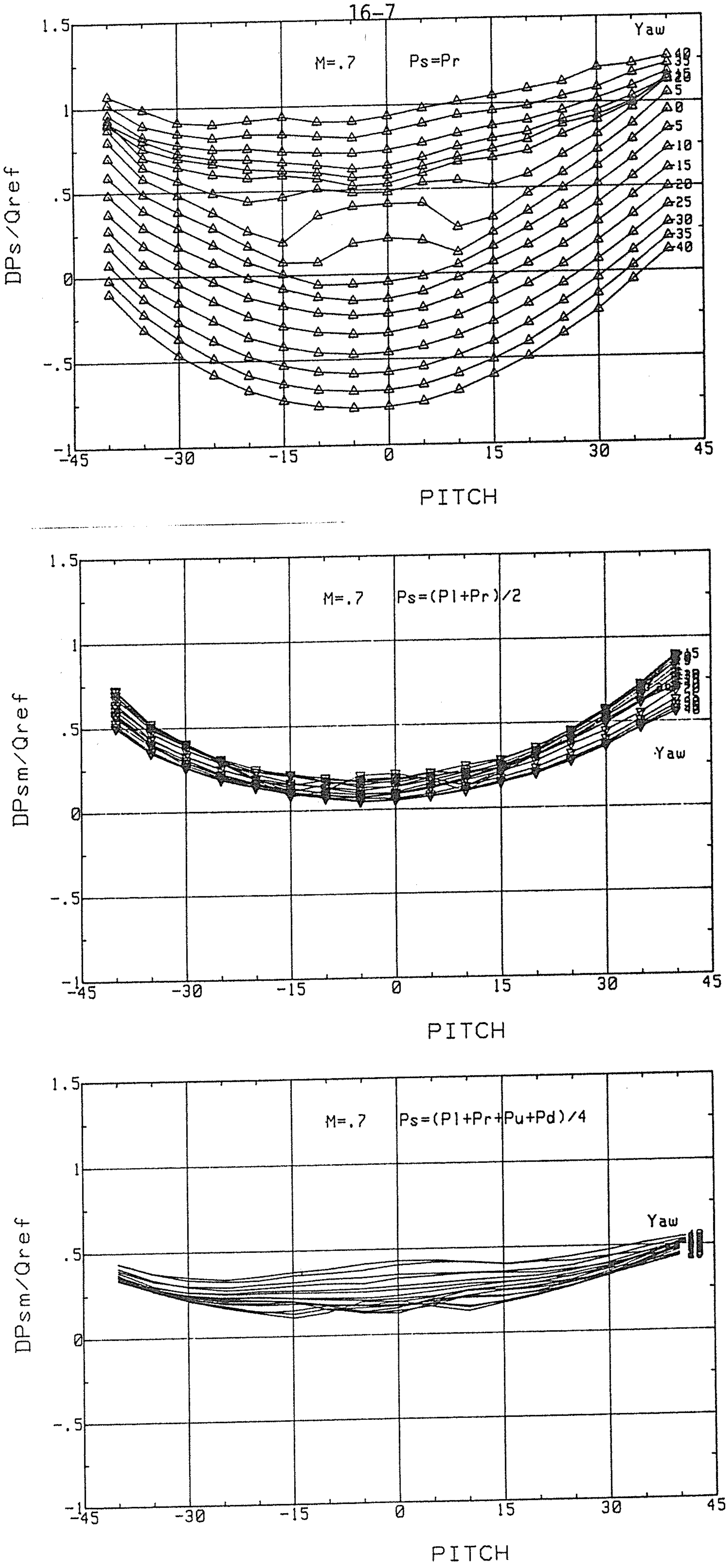
M=.7
Ps=Pr
Yaw
40
35
15
20
5
0
5
10
15
20
25
30
35
40
DPs/Qref
1.5
1
.5
0
-.5
-1
-45
-30
-15
0
15
30
45
PITCH
M=.7
Ps=(Pl+Pr)/2
Yaw
DPsm/Qref
1.5
1
.5
0
-.5
-1
-45
-30
-15
0
15
30
45
PITCH
M=.7
Ps=(Pl+Pr+Pu+Pd)/4
Yaw
DPsm/Qref
1.5
1
.5
0
-.5
-1
-45
-30
-15
0
15
30
45
PITCH

Fig. 3

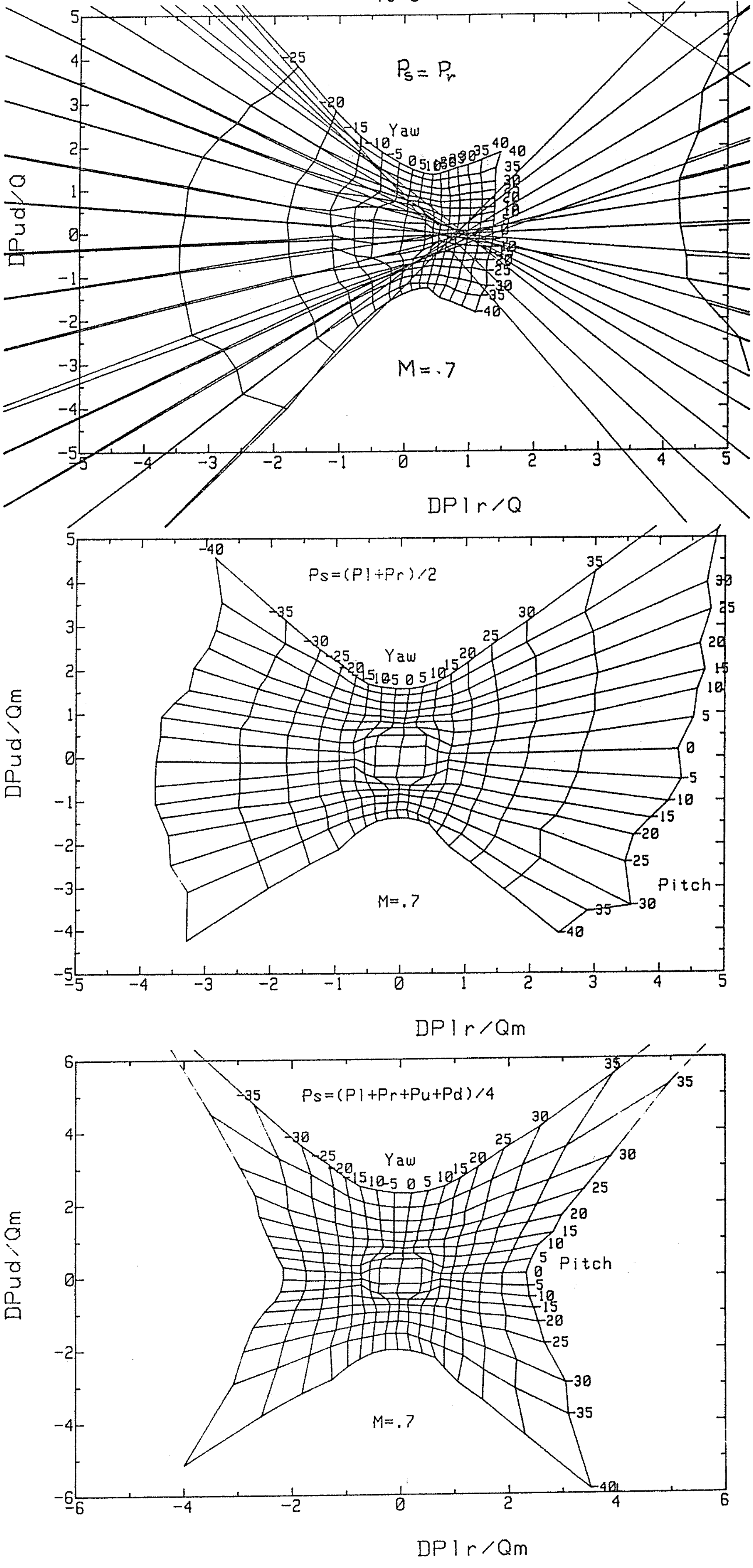
Ps = Pr
Yaw
M=.7
DPud/Q
DPlr/Q
Ps=(Pl+Pr)/2
Yaw
Pitch
M=.7
DPud/Qm
DPlr/Qm
Ps=(Pl+Pr+Pu+Pd)/4
Yaw
Pitch
M=.7
DPud/Qm
DPlr/Qm
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40

Fig. 4

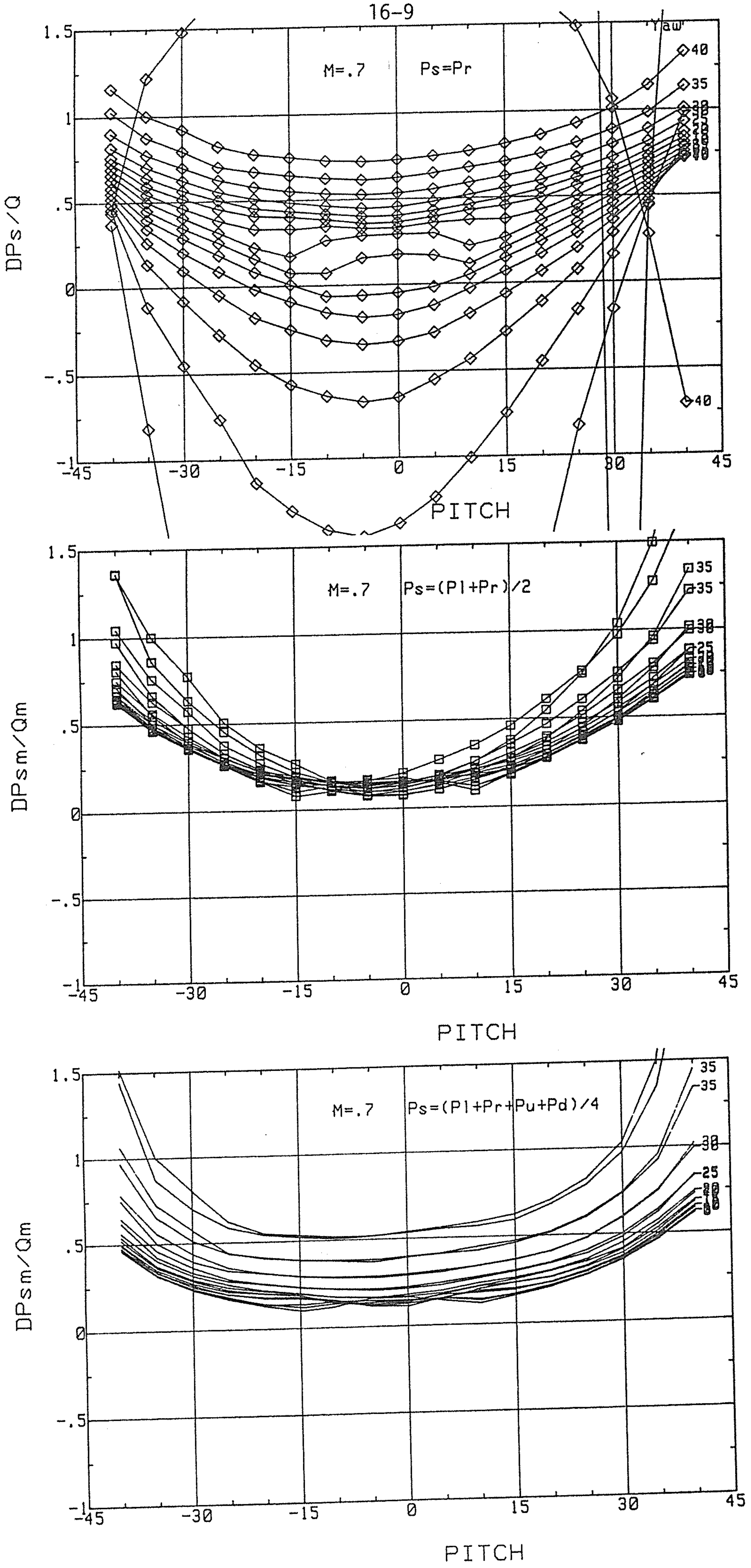
M=.7
Ps=Pr
Yaw
DPs/Q
PITCH
40
35
30
40
M=.7
Ps=(Pl+Pr)/2
DPsm/Qm
PITCH
35
35
30
25
M=.7
Ps=(Pl+Pr+Pu+Pd)/4
DPsm/Qm
PITCH
35
35
30
25
1.5
1
.5
0
-.5
-1
-45
-30
-15
0
15
30
45

Fig. 5