NASA-CR-202052

HIGH REYNOLDS NUMBER EFFECTS ON MULTI-HOLE PROBES AND HOT WIRE ANEMOMETERS

NAS8-38 75
IN-35-CR

N. Ramachandran+, A. Smith*, G. Gerry* and W. Kauffman*
+Universities Space Research Association
*NASA, Marshall Space Flight Center
Huntsville, Alabama 35812

ABSTRACT

The paper reports on the results from an experimental investigation of the response of multi-hole and hot wire probes at high flow Reynolds numbers (Re ~ 10^6). The limited results available in literature [1-3] for 5-hole probes are restricted to Re ~ 10^4. The experiment aims to investigate the probe response (in terms of dimensionless pressure ratios, characterizing pitch, and yaw angles and the total and static pressures) at high Re values and to gauge their effect on the calculated velocity vector. Hot wire calibrations were also undertaken with a parametric variation of the flow pressure, velocity and temperature. Different correction and calibration schemes are sought to be tested against the acquired data set. The data is in the analysis stage at the present time. The test provided good benchmark quality data that can be used to test future calibration and testing methods.

INTRODUCTION

Multi-hole probes like 3-hole and 5-hole probes are routinely used in air and water flow testing to determine flow angularity and velocity. The design of these probes stems from the classical pitot and pitot-static probes that are used to determine the local static and dynamic pressures, respectively. These probes are fairly rugged and can be easily put to use if there is enough flow velocity to generate measurable pressure differentials. A complete flow characterization in an experiment entails determining the velocity vector; the velocity magnitude and the flow pitch (α) and yaw (β) angles. A 3-hole probe can determine one of the flow angles, (usually β) and one of the flow components. The 5-hole probes on the other hand can determine the complete velocity vector. The afore-mentioned probes require calibrations that are usually provided by the manufacturer and some software to implement the calculations and derive the required results. The calibrations are valid over a certain range of pitch and yaw angles (typically ± 30°). The validity restrictions are due to flow separation on the probe surface at larger angles. Typical error estimates are ≈ 3° for flow angularity and 5% for velocity magnitude.

In the calibration of multi-hole probes, frequently dimensionless pressure ratios are used as opposed to the pressures themselves. The pressure ratios have been found to yield a more general calibration form that can be extrapolated to conditions other than the calibration conditions, without significant loss in accuracy of the results. To put it differently, this form of calibration affords its use at different flow Reynolds numbers. For example, it is fairly common practice to use air calibrated probes in water flows. Fig. 1 provides a summary of the available results from literature and the operational Reynolds numbers of some of MSFC's facilities.

There has been a long felt need at MSFC in particular and the research community in general, for a dedicated test to address the Reynolds number applicability range in subsonic air flows of the multi-hole probe calibrations. To this end, a specific test apparatus was designed and constructed. A series of test runs with 3-hole and 5-hole probes were conducted as part of this test. The experiment parameter envelope also proved ideal for carrying out hot wire anemometer calibrations to address its high Re response characteristics. This paper reports on the results from the investigation.

The final paper format will comprise of a detailed description of the setup and its performance validation followed by a description of a typical, routine (low Re) calibration of multi-hole and hot wire probes. This will be followed by results and comparisons from the high Re studies.

Some preliminary results are included in the next section.

TEST FACILITY AND PRELIMINARY RESULTS

A schematic representation of the spool piece used in the test is shown in Fig. 2 along with the flow envelope and test conditions. The spool piece was mounted in the inlet section of the NASA MSFC's Turbine Test Equipment (TTE). The blow down facility is capable of delivering precisely metered flow at any set temperature (ambient to 400°F) for a duration ranging from 30 s for very high flow rates to up to an hour at low flow rates. The test section (straight section of the spool piece) is 11" long with a diameter of 3". It is provided with 4 centrally (axial direction) located ports to house differeent calibration probes. Flow surveys in the spool piece were initially undertaken to measure the flow angularity (<1°), the extent of the central (uniform velocity) core region and wall boundary layers. The turbulence level in the core region was also measured. These tests were done in the facility validation stage to ensure the accuracy of the flow.

During the high Re testing phase, the test probe was oriented at precise angles to the flow and the probe pressures and test parameters were documented. The tests were repeated for different Mach numbers (Ma) keeping Re the same. Several sets of data corresponding to different Ma-Re combinations were recorded. For hot wire testing, temperature was an additional parameter included in the test matrix. The Mach number range is from 0.2 to 0.6 and Re range is from 10^4 to 10^6 based on the test section diameter.

The numbering convention and the pressure ratio definitions of a 5-hole prism probe are shown in Fig. 3 and a typical lab calibration for the probe is shown in Fig. 4. Results (preliminary at this stage) from the test are shown in Fig. 5. Data reduction at points 1, 2 and 3 noted on the figure using the lab calibration (Fig. 4) is presented in tables 1 and 2. The initial results tend to indicate that the conventional calibration method is fairly robust and applicable at the high Reynolds numbers tested.

A complete uncertainty estimation and results from the hot wire tests and complete data analysis will be presented in the final version of the paper.

References

1. Huffman, G.D. et al., Flow direction probes from a Theoretical and Experimental Point of View, Journal of Physics E, 13, 1980, pp. 751-760.

2. Treaster, A. L., and Yocum, A. M., The Calibration and Application of Five-Hole Probes, Penn. State University Applied Research Lab Report TM 78-10, 1978.

3. Krause, L. N., and Dudzinski, T. J., Flow Direction Measurement with Fixed position Probes in Subsonic Flow over a range of Reynolds numbers, NASA TMX-52576, 1969.

Table 1: Preliminary data analysis at a few selected points (see Fig. 5 for Point Ids.)

Re_d	Point Id.	$C_{p,pitch}$,	$C_{p,yaw}$	Calculated Pitch Angle	Calculated Yaw Angle	Actual Pitch Angle	Actual Yaw Angle
1.76×10^4	1	0.0711	-0.5403	2.529°	-0.172°	0	0
1.47×10^5	2	0.0955	-0.7003	3.258°	-7.815°	0	0
1.5×10^5	3*	0.4623	-2.612	8.170°	-16.01°	0	-20

* There appears to be sensor overanging for this run. This may explain the error in the predicted angles. This is under analysis.

Table 2: Velocity Analysis at a few selected points (see Fig. 5 for Point Ids.)

Re_d	Point Id.	Calculated Velocity	Actual Velocity	% Error
1.76×10^4	1	211.186	214.127	-1.370
1.47×10^5	2	217.510	216.107	0.065
1.5×10^5	3*	428.044	445.04	-3.819

* There appears to be sensor overanging for this run.

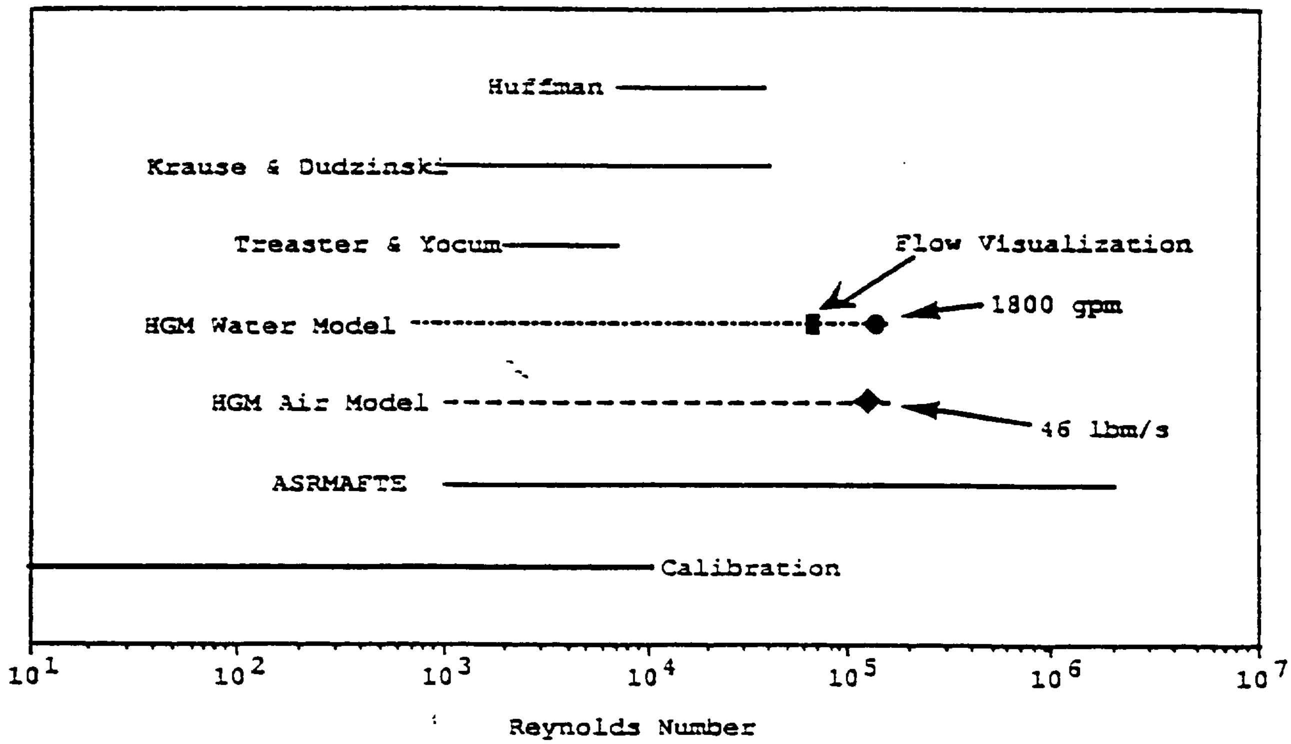


Fig. 1 Reynolds number ranges of experimental facilities and available results.

HGM: Hot Gas Manifold test

ASRMAFTE: Advanced Solid Rocket Motor Air Flow Test Equipment

Calibration refers to probe calibration in the MSFC calibration wind tunnel

References: Huffman [1]; Krause and Dudzinski [2] and Treaster and Yocum [3].

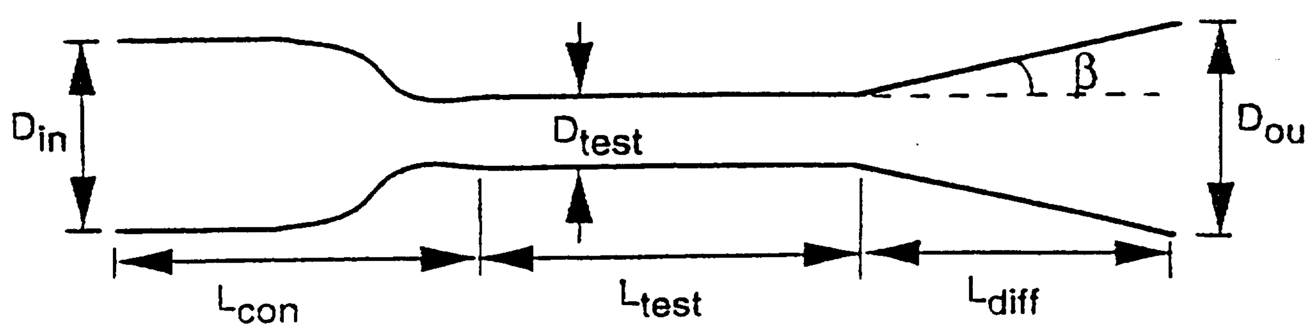


Fig. 2 Schematic of the Spool piece with the calibration test section.

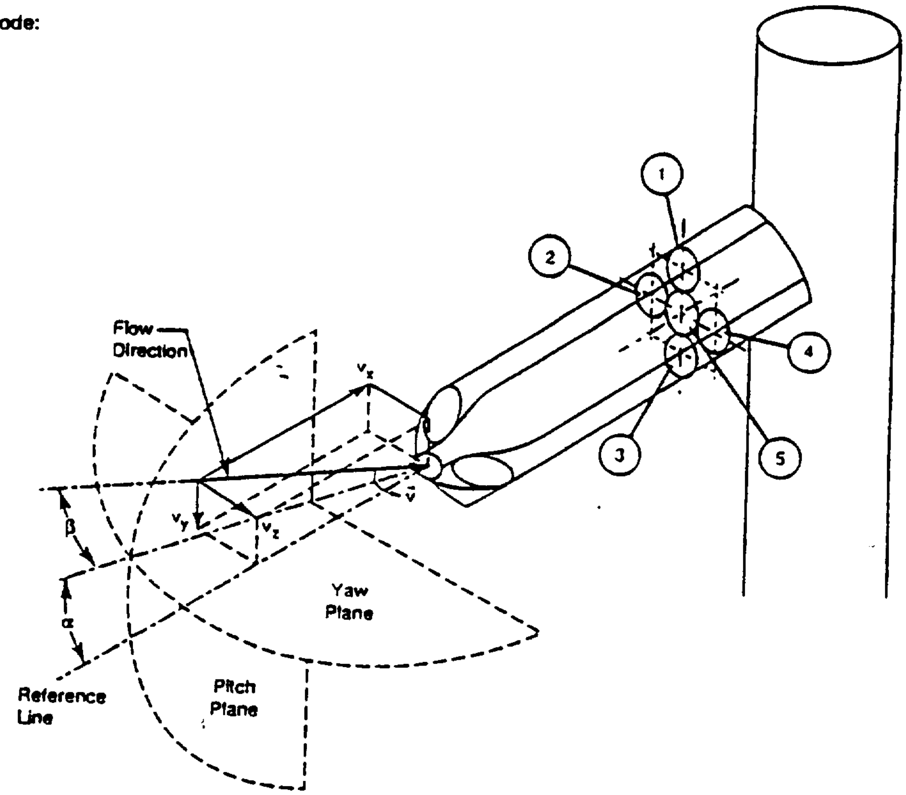
5-Hole Probe Velocity Components (Yaw-Pitch Calibration)

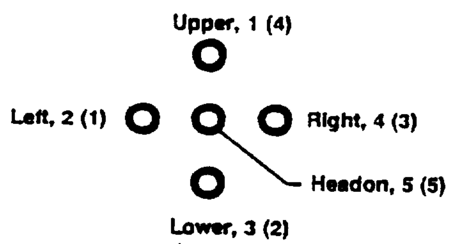
Calibration in the Yaw-Pitch mode:

$$V_x = \overline{V}\cos\beta\ \cos\alpha$$

$$V_y = \overline{V}\cos\beta\ \sin\alpha$$

$$V_z = \overline{V}\sin\beta$$





Probe Nomenclature

$$C_{p,pitch} = \frac{(P_3 - P_1)}{(P_5 - \overline{P})} \quad (1)$$

$$C_{p,yaw} = \frac{(P_4 - P_2)}{(P_5 - \overline{P})} \quad (2)$$

$$C_{p,total} = \frac{(P_5 - P_{total})}{(P_5 - \overline{P})} \quad (3)$$

$$C_{p,static} = \frac{(\overline{P} - P_{static})}{(P_5 - \overline{P})} \quad (4)$$

$$\overline{P} = \frac{(P_1 + P_2 + P_3 + P_4)}{4} \quad (5)$$

Fig. 3 Numbering Convection for 5-hole prism probes and the definition of pressure ratios.

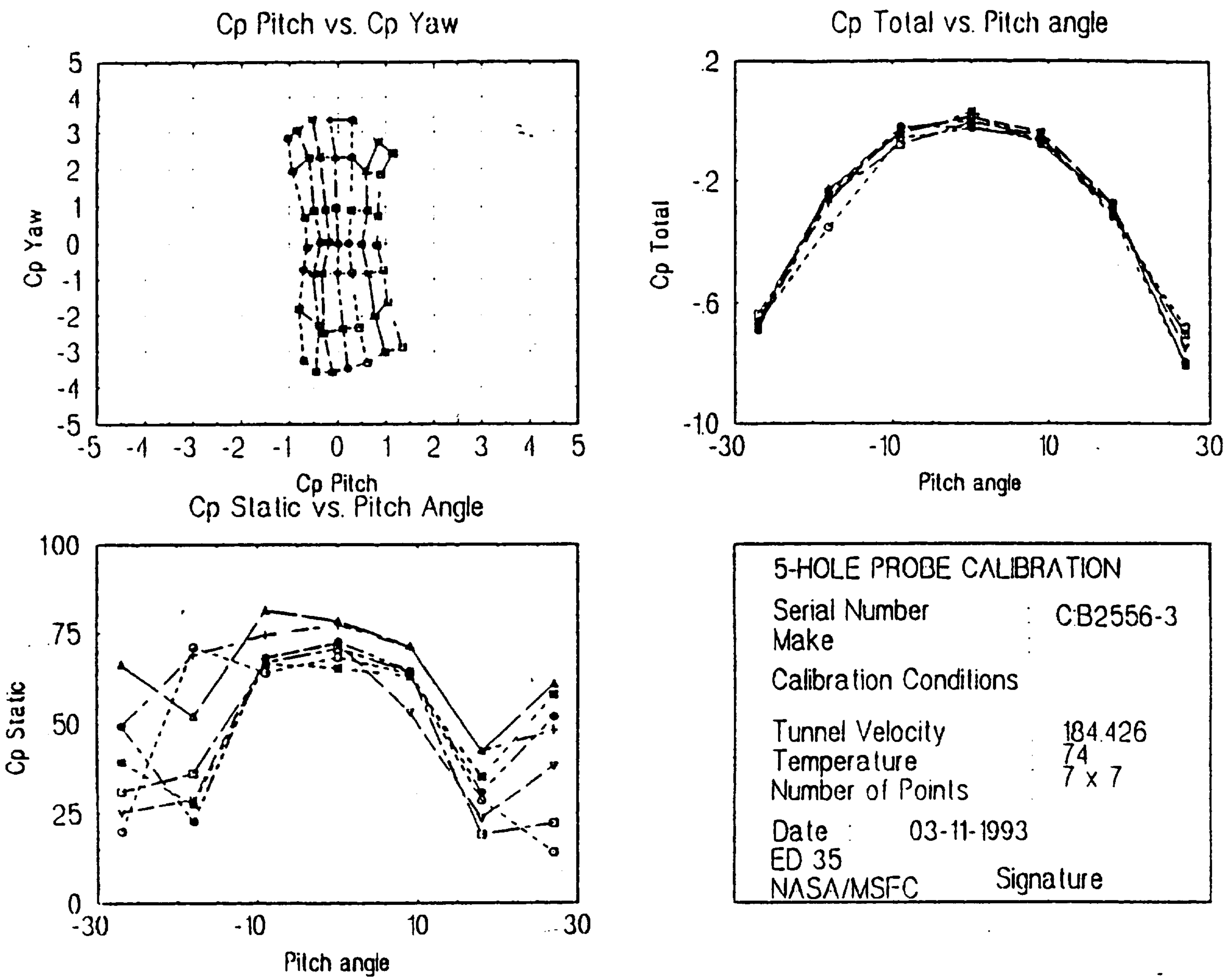
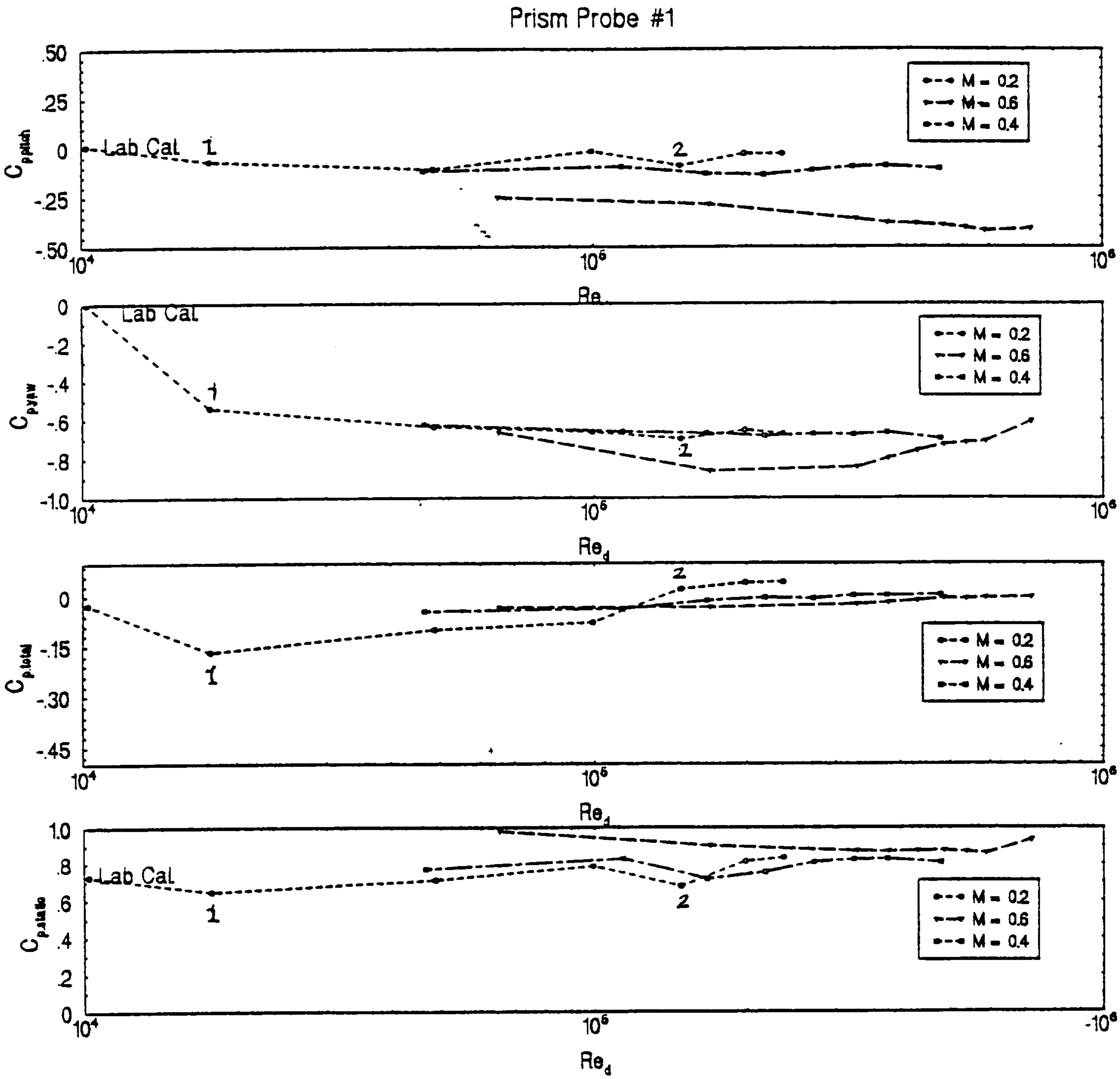


Fig. 4 Typical Calibration curves for a 5-hole Prism probe.



NOTE: These results are for probe settings : 0 deg Yaw and 0 deg. pitch.

Points 1 and 2 are as shown in the figure. Point 3 is for Pitch = 0 & yaw = -20 deg and hence is not shown in this figure.

Fig. 5 Preliminary results from high Re testing of a 5-hole prism probe.