using different guide vanes, which cause a different rpm for the same inlet angle. The problem of the blockage of the probe, which could happen investigating straight cascades, seems to be of less influence in the case of the rotating test wheel, because in the absolut system mainly subsonic velocities appear. Another problem, which could appear testing straight cascades, consists in getting uniform flow upstream of the cascade. This is easier to be achieved in the case of testing a rotating test wheel, because the flow is uniform to all blades.

The comparison of the results of both 2-D-wind tunnels is also quite good, mainly for the surface pressure measurements. Some differences may be explained by the different Reynoldsnumbers.

A detailed description of the experimental results is given in Ref. [2,3,4].

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Measurements of secondary flows in a transonic axial-flow compressor

by

G. Bois, F. Leboeuf, A. Comte and K.D. Papailiou

1. INTRODUCTION

Measurements were performed using two different probes (put at an angle of 90°) at one station upstream and two stations downstream of the rotating wheel of a transonic compressor. These measurements were performed in order to increase our knowledge about the behaviour of the viscous shear layers near the end walls of the compressor.

Special probes were conceived which permitted us to approach the stationary or rotating hub ("hub" probe) and the stationary tip ("tip" probe) and care was taken to ensure that for a certain radial distance, measurements were taken by both probes (overlapping region).

In the present paper the probes will be examined first and then their behaviour in a uniform stream (probe calibration). In the following the behaviour of the probes will be examined in the transsonic compressor environment as well as the quality of the measurements. Lastly some remarks will be made as far as the interpretation of the measurements is concerned.

2. THE PROBES AND THEIR CALIBRATION

Combined probes for total pressure, static pressure, one direction, and total temperature were conceived in order to diminish the measuring time in a costly installation.

Two probes were used (see photo (1)): a cylindrical-wedge-type probe ("tip" probe, figure (1)) which permitted us to approach the tip end

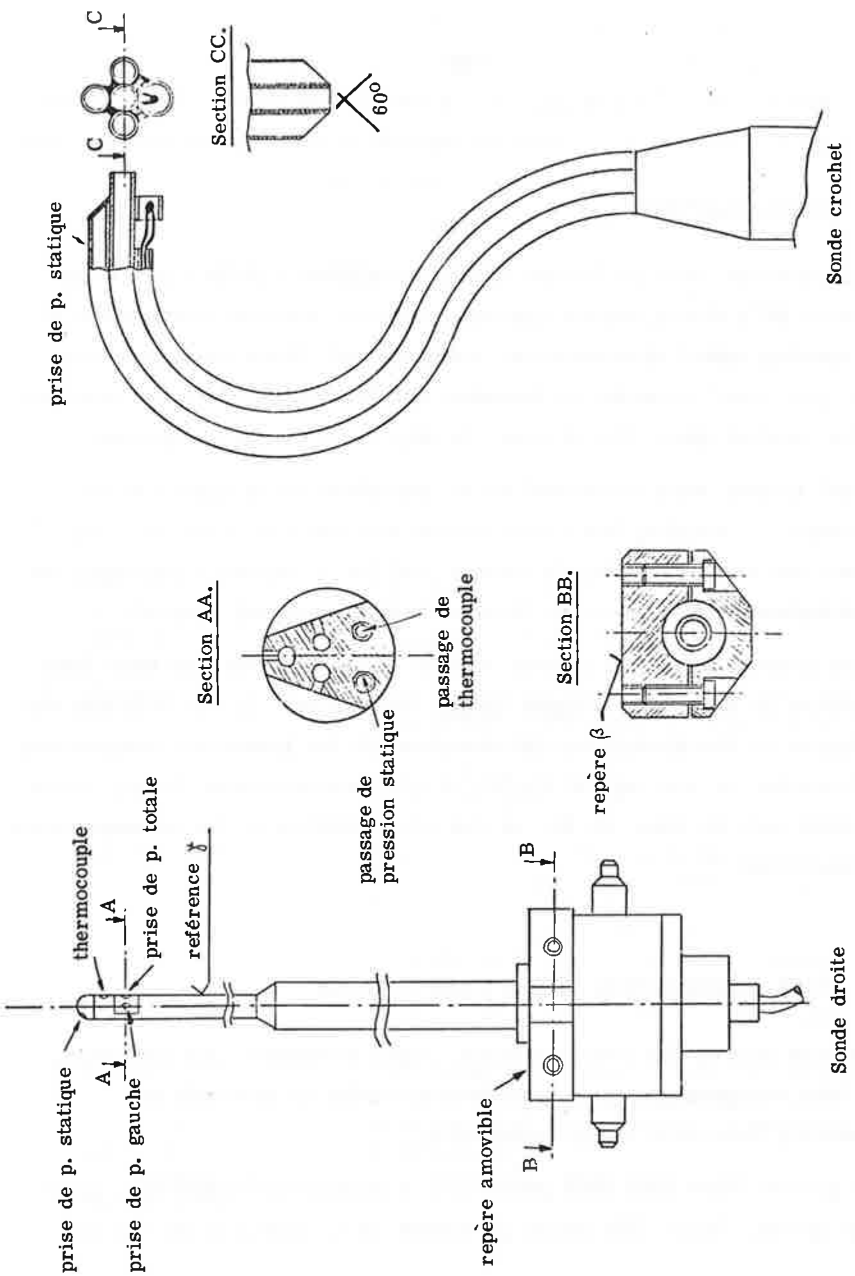

Fig. 2 Sonde crochet

Fig. 1 Sonde droite

wall of the compressor and a cobratype probe ("hub" probe, figure (2)) which permitted us to approach the hub end wall of the compressor. Small diameter tubes were used in order to diminish the probe dimensions as much as possible. Besides the directional holes, which were calibrated for static pressure measurements, one more possibility was added for the measurement of the static pressure:

(a) - For the "hub" probe a static hole was drilled on an extra tube under the probe stem (see figure (2))

(b) - For the "tip" probe a static hole was drilled on the ending hemisphere of the probe. Different backward positions of this hole were examined in order to find if one could obtain a stable response for the static pressure with varying pitch angle.

The probes were calibrated at the Von Karman Institute for different Mach numbers up to 0.8 and for varying pitch and yaw angles (pressure measurements) and at S. N. E. C. M. A. statically and dynamically for the temperature measurements.

The following remarks can be made as far as probe behaviour is concerned:

(a) - The static pressure measurements through the bottom hole for the "hub" probe are nearly independent of the pitch angle ($\pm 9^0$). However, the static pressure measurements through the directional holes depend strongly on the pitch angle.

(b) - The static pressure measurements through the bottom hole for the "tip" probe are strongly dependent on the pitch angle, whatever the position of the hole. The static pressure measurements through the directional holes are independant of the pitch angle.

(c) - The total pressure measurements for the "hub" probe are slightly but appreciably dependent on the pitch angle.

(d) - The total pressure measurements for the "tip" probe are practically independent of the pitch angle.

(e) - Good recovery coefficients were found for the total temperature measurements.

3. THE MEASUREMENTS UPSTREAM AND DOWNSTREAM OF A TRANSONIC COMPRESSOR ROTOR

Using the two probes, measurements were performed in a transonic compressor of S. N. E. C. M. A. Co. which is given schematically in figure (3). In the same figure, the three measuring stations are presented. Typical measurements of the total pressure, the static pressure, the yaw direction, the total temperature and resulting radial distribution of the meridional velocity are presented in figures (4) to (31).

The data reduction of these measurements was done using the calibration curves of the probes. It was found necessary to introduce the value of the pitch angle in order to obtain correct results. The value of the pitch angle (which was not measured) was taken equal to the one given by a theoretical through flow calculation in the meridional plane.

Although the probes present some geometrical imperfections that result into assymetric calibration curves, it seems that coherent results are obtained for every quantity measured, as can be seen from the presented experimental results in the overlapping region. It can also be seen that the static pressure measured from static pressure taps at the compressor end walls agrees with the static pressure measurements of the probes. Finally, the continuity equation is satisfied for the three stations within 0.25 %.

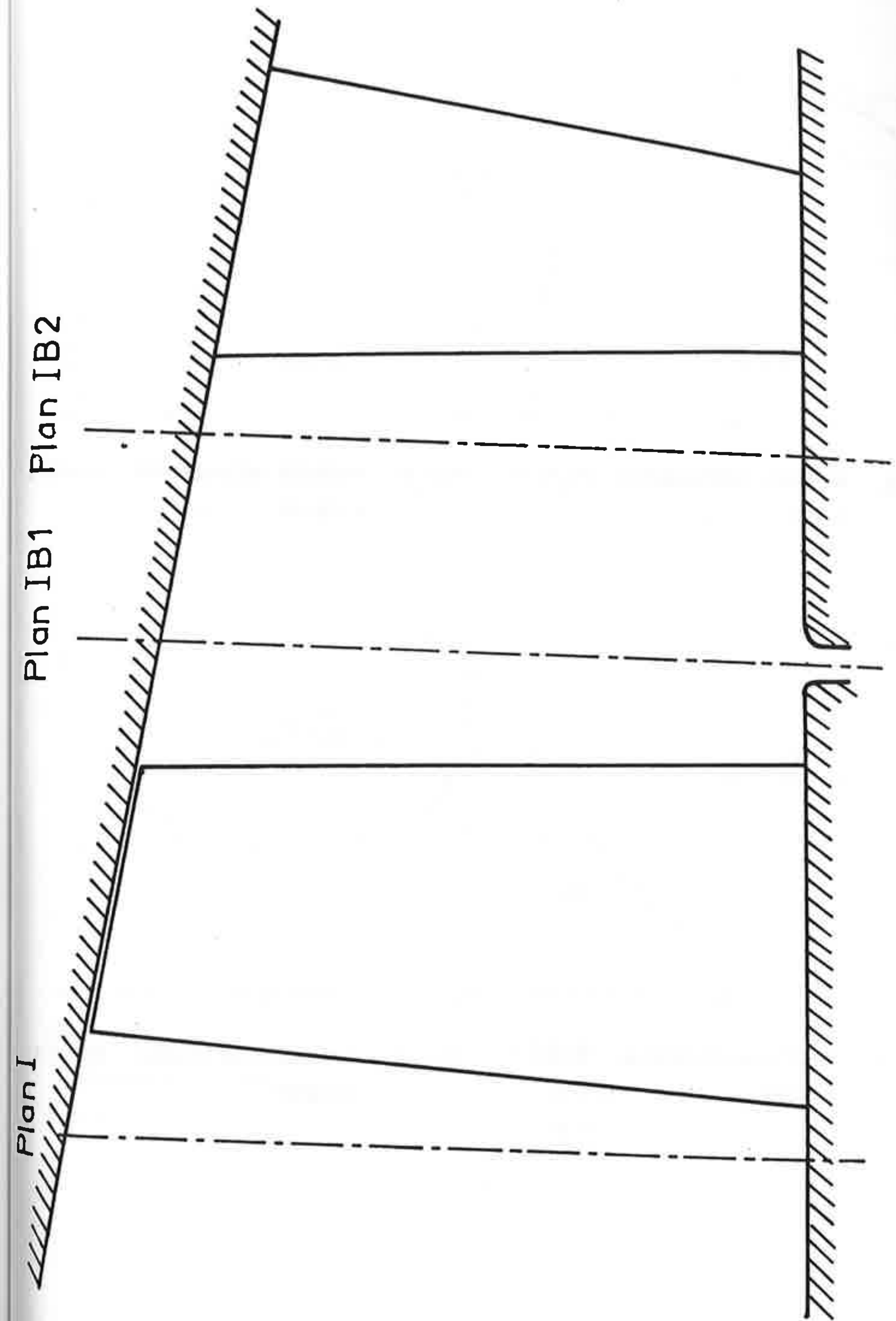

Fig. 3 Compresseur Expérimental SNECMA

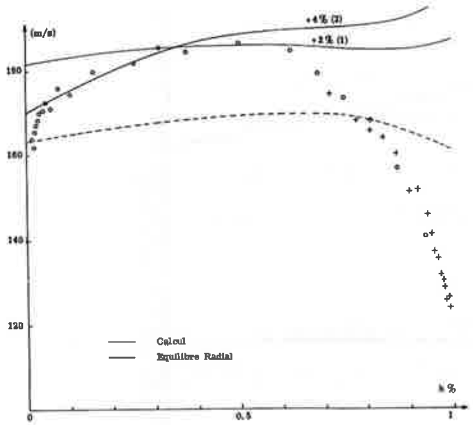

Fig. 4 VITESSE MERIDIENNE PLAN I
nominal

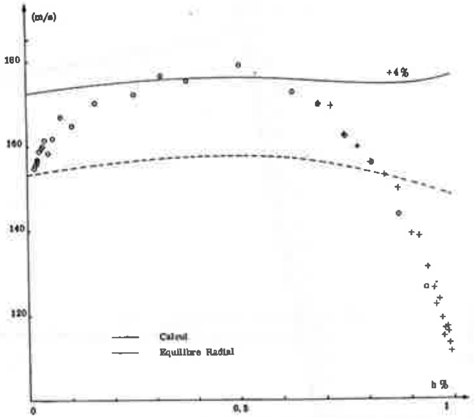

Fig. 5 VITESSE MERIDIENNE PLAN I
pompage

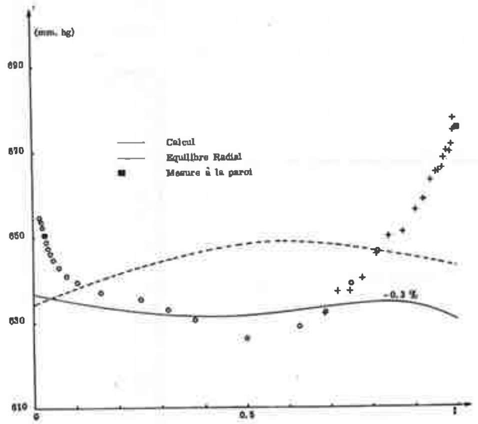

Fig. 6 PRESSION STATIQUE PLAN I
nominal

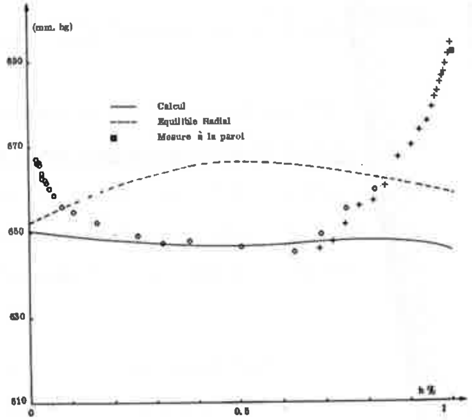

Fig. 7 PRESSION STATIQUE PLAN I
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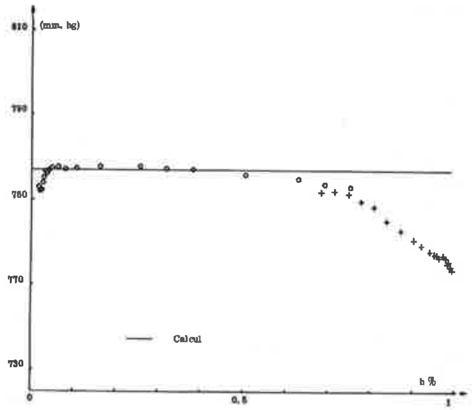

Fig. 8 PRESSION TOTALE PLAN I
nominal

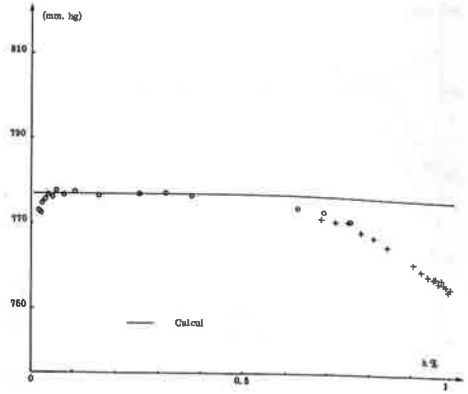

Fig. 9 PRESSION TOTALE PLAN I
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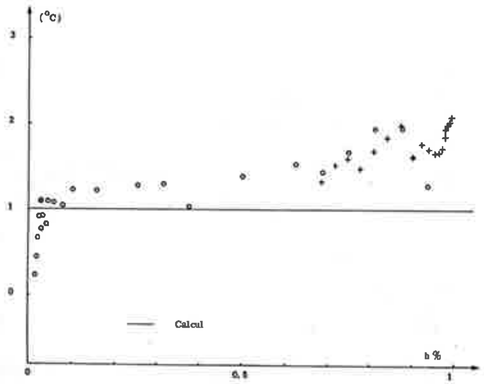

Fig. 10

TEMPERATURE TOTALE PLAN I
nominal

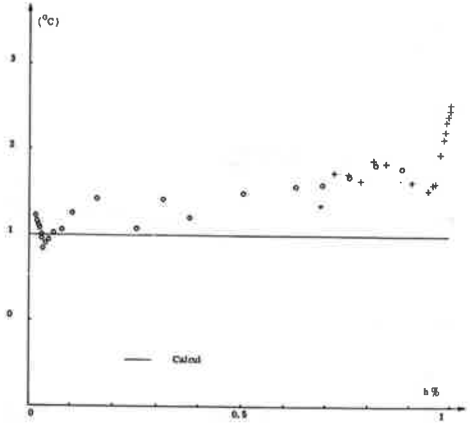

Fig. 11

TEMPERATURE TOTALE PLAN I
pompage

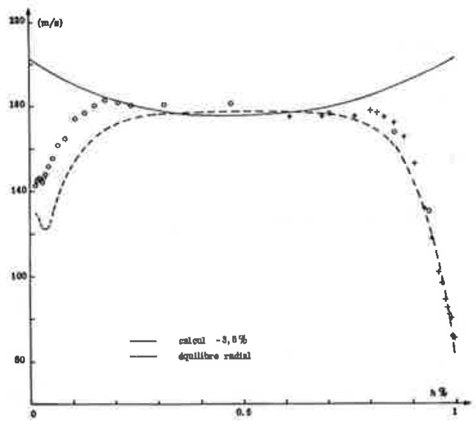

Fig. 12

VITESSE MERIDIENNE PLAN IB1
nominal

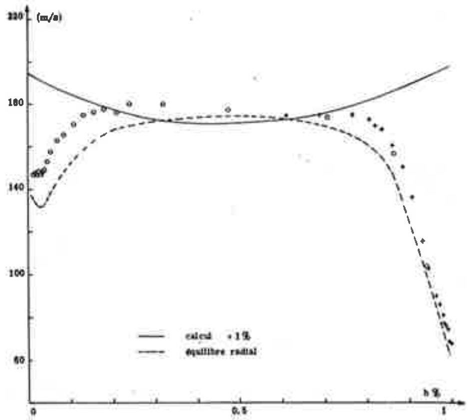

Fig. 13

VITESSE MERIDIENNE PLAN IB1
pompage

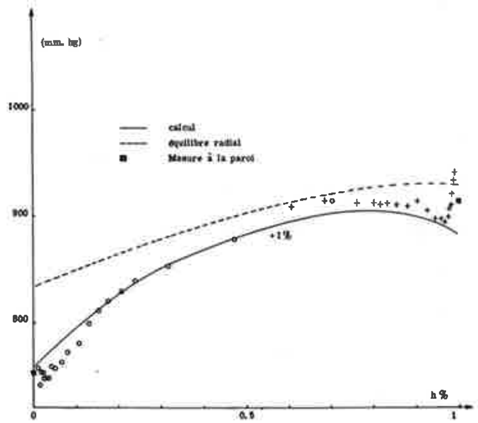

Fig. 14

PRESSION STATIQUE PLAN I^b_1
nominal

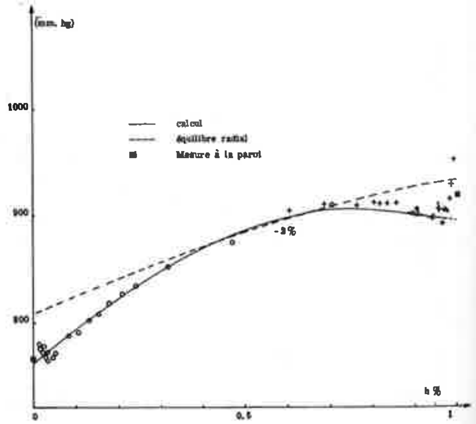

Fig. 15

PRESSION STATIQUE PLAN I^b_1
pompage

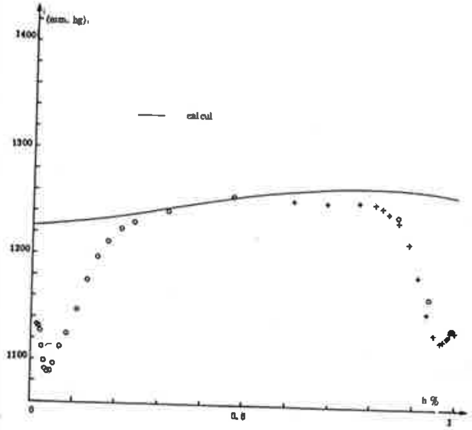

Fig. 16 **PRESSION TOTALE PLAN IB1**
nominal

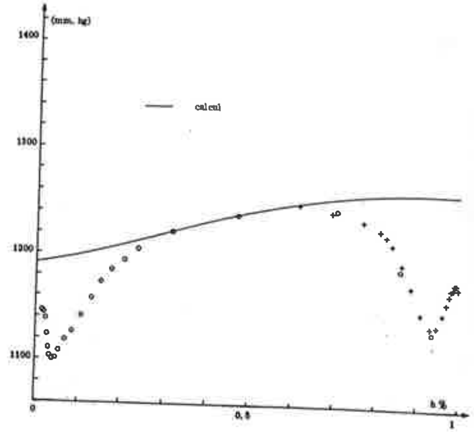

Fig. 17 **PRESSION TOTALE PLAN IB1**
pompage

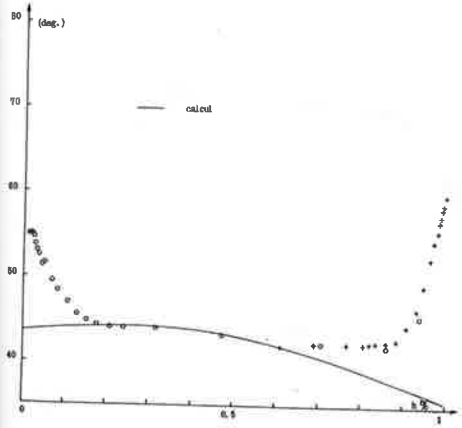

Fig. 18 **ANGLE ALPHA PLAN IB1**
nominal

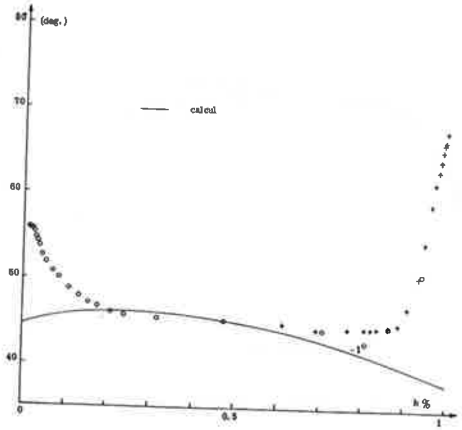

Fig. 19 **ANGLE ALPHA PLAN IB1**
pompage

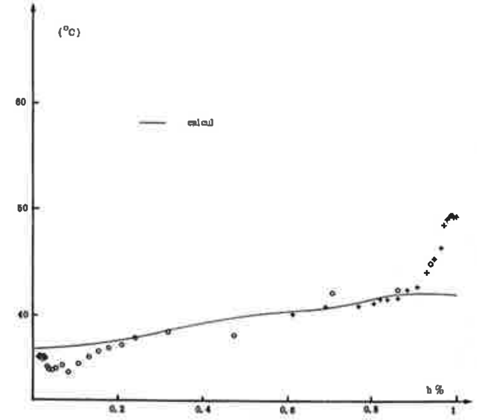

Fig. 20

TEMPERATURE TOTALE PLAN IBI
nominal

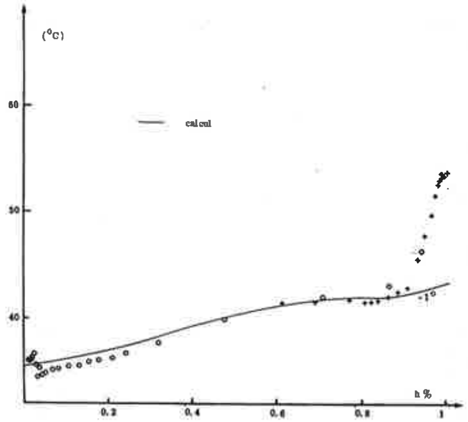

Fig. 21

TEMPERATURE TOTALE PLAN IBI
pompage

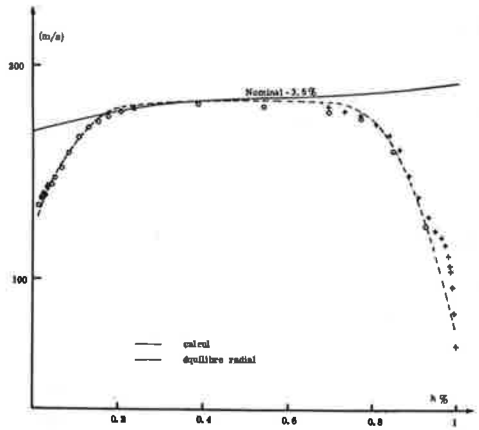

Fig. 22

VITESSE MERIDIENNE PLAN IB2
nominal

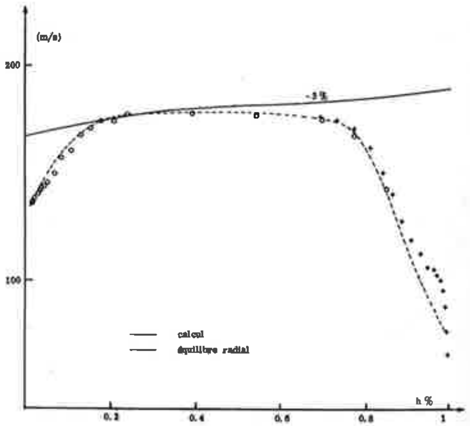

Fig. 23

VITESSE MERIDIENNE PLAN IB2
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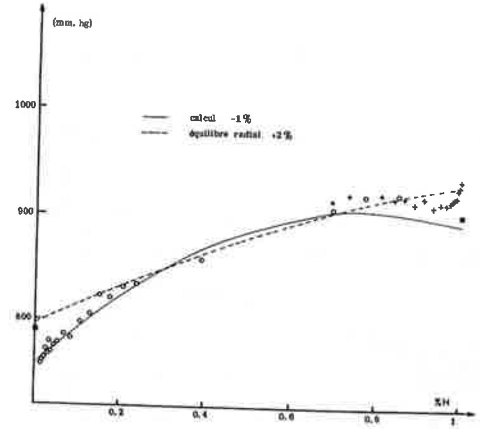

Fig. 24

PRESSION STATIQUE PLAN IB2
nominal

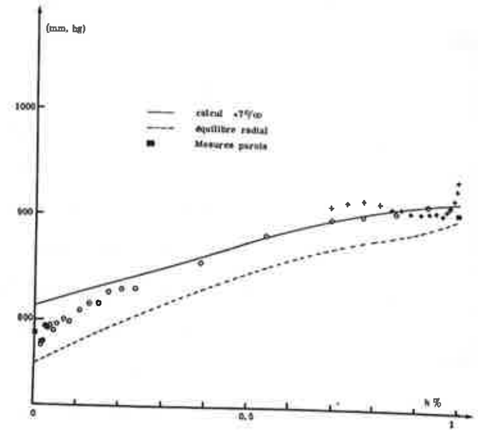

Fig. 25

PRESSION STATIQUE PLAN IB2
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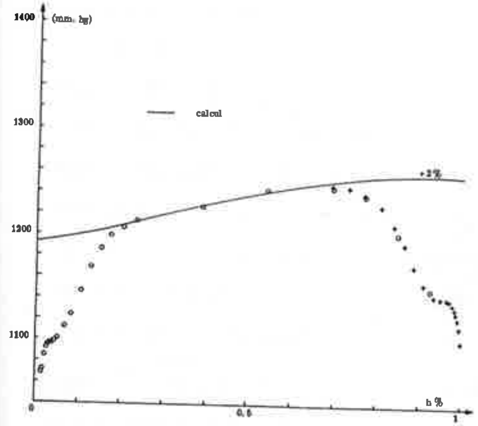

Fig. 26 PRESSION TOTALE PLAN IB2
nominal

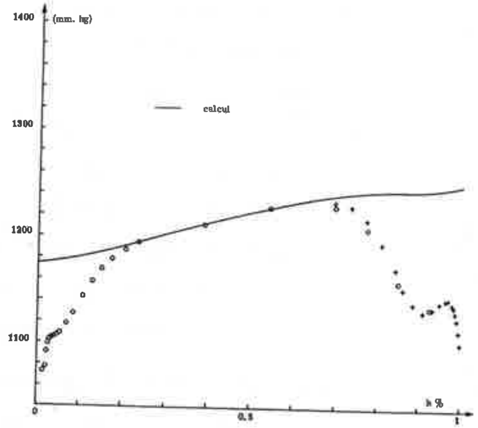

Fig. 27 PRESSION TOTALE PLAN IB2
pompage

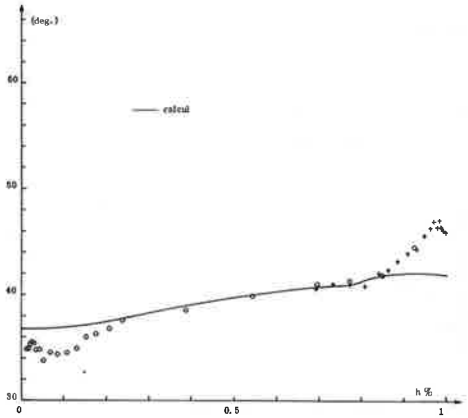

Fig. 28

TEMPERATURE TOTALE PLAN IB2
nominal

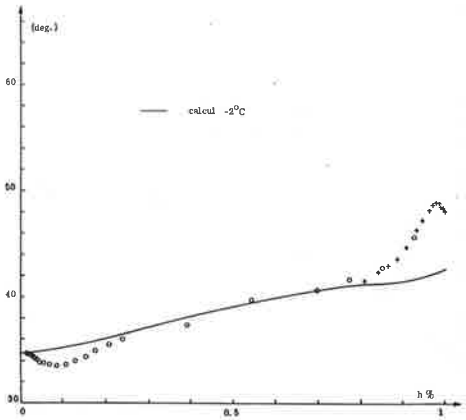

Fig. 29

TEMPERATURE TOTALE PLAN IB2
pompage

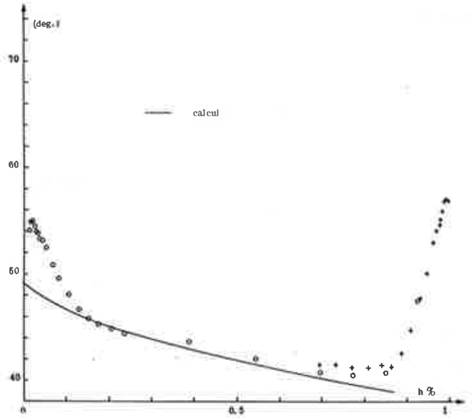

Fig. 30 ANGLE ALPHA PLAN IB2
nominal

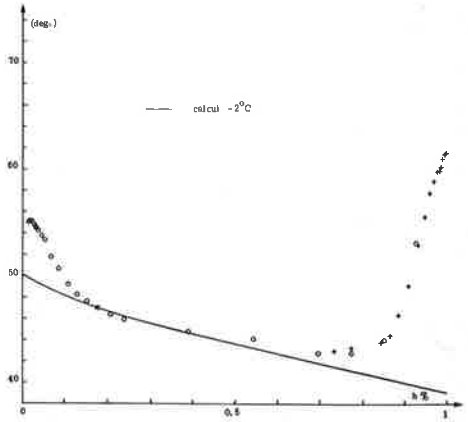

Fig. 31 ANGLE ALPHA PLAN IB2
pompage

A first general remark that one can make concerning the flow is that, as it can be seen from the measurements, a different kind of radial equilibrium is established in the viscous end wall regions. We shall examine this situation focusing our attention to the static pressure measurements. In fact, many investigators, not believing in the static pressure measurements given by probes, often use the values of the wall statics and interpolate in between. From the results presented here it seems that this may be dangerous. On the other hand another method to avoid static pressure measurements is to use the continuity equation and the simple radial equilibrium equations (the curvature curves neglected). In this case the experimental total pressure, total temperature and yaw angle distributions are used. Such a data reduction was performed and the results are compared with the experimental static pressure and meridional velocity distributions. It can be seen that only fair agreement can be obtained.

The results of the through flow calculation at our disposal, which combines a modified version [1] of the matrix method solution of DAVIS [2] for the meridional plane and a modified version [3] of MELLOR's theory [4] for the wall boundary layer calculation are given on the cited figures. It can be easily seen that the predicted static pressure distribution comes closer to the measured one. It seems then, that taking into account of the streamline curvature effects in a data reduction program using as input the total pressure, the total temperature and the yaw angle distributions, could result in a good approximation of the static pressure distribution.

The calculation of the flow at the compressor inlet plane presents some difficulties. It was found that the calculation results for the upstream of the rotor plane were greatly influenced by the values of the different parameters downstream of the rotor (especially loss distribution and curvature). However, no valid explanation was found for the differences present between measurements (which seem to be coherent) and different ways of data reduction or calculations.

A question, which comes up frequently, concerns the response of a probe which is introduced in a non-stationary environment as is the case for the measurement we have at hand behind the rotor. A typical comparison of total pressure measurements for the stations $Ibis_1$ and $Ibis_2$ (which is located more than a chord behind the rotor) are given in figure (32). Noting that the measurements were not done simultaneously and that they are only referred to the same operating point, it can be deduced that the differences of the order of 1 % present, can be considered to be within the error of measurements.

It seems, so that for our case there is little influence of the non-stationary field on the probe response. This fact is confirmed by the already mentionned continuity considerations between upstream and downstream of the rotor measuring stations. In our opinion this result must be attributed to the small size of the probe tube diameters used.

4. CONCLUSIONS

Measurements of two combined probes were examined in a uniform stream and in the flow created by the rotating wheel of a transonic compressor.

It can be deduced that, provided that a detailed calibration of the probes is done, coherent and accurate measurements can be obtained, the measurement of the static pressure included.

Concerning the static pressure measurements, it was shown that although wall statics are accurate, they cannot provide the whole static pressure distribution inside the channel and if static pressure is to be deduced, then the complete radial equilibrium equations (including the curvature terms) must be used.

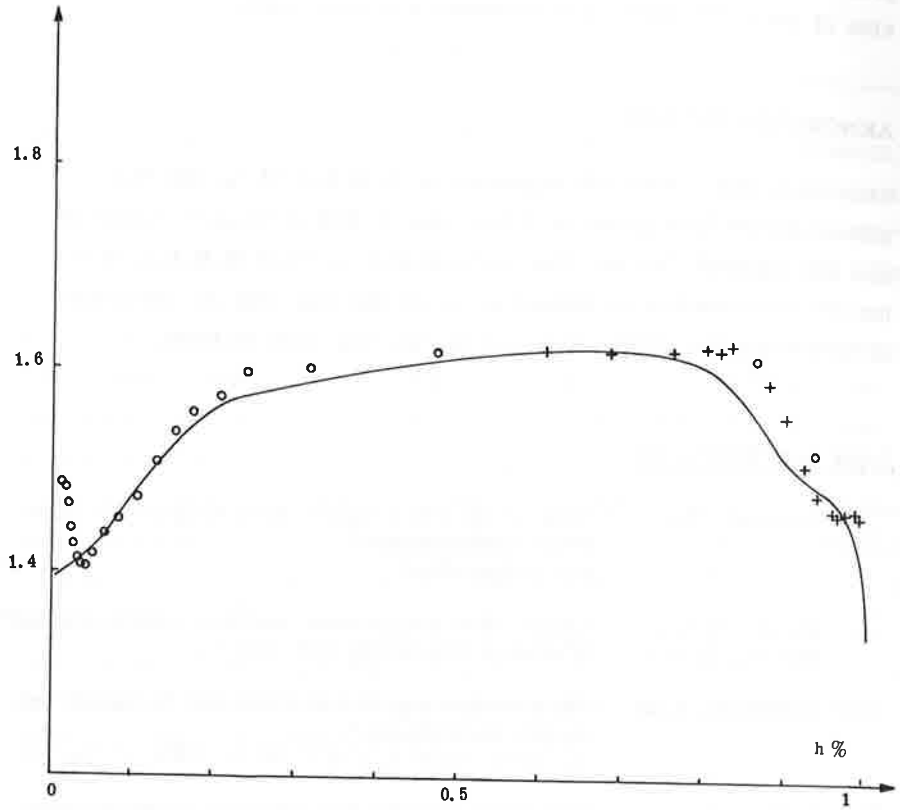

Fig. 32 TAUX DE PRESSION PLAN $I^{b}{}_1$
nominal

—— plan $I^{b}{}_2$

Finally, although one cannot deny that nonstationary flow has an effect on the probe behaviour concerning the measurement of the total pressure, it seems that in our case, probably because of the small size of the tubes used, this influence was very small.

AKNOWLEDGEMENTS

This work was financially supported by S. N. E. C. M. A. and the measurements took place at Villaroche, S. N. E. C. M. A.'s Research and Development Center. The authors wish to thank S. N. E. C. M. A. for the authorization to publish some of the data and the personnel of Villaroche for all the help and advise that gave to them.

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Analysis of the unsteady flow in a turbine stage with different methods

by

K. Einsfeld

On the turbine stage at the "Institut für Aerodynamik und Gasdynamik, Universität Stuttgart" there were at first made spatial and/or temporal integrating pressure measurements and high-speed Schlieren and interference measurements[1)] with high spatial and temporal resolution. The essential result was: the Schlieren and interference pictures show a highly complicated unsteady flow; the consequence is, the conventional integrating pressure measurements cannot describe satisfactorily the universal flow behaviour. Therefore other more informative time resolving measuring techniques were applied; techniques with less expense than by the optical measurements and more expense than by the pressure measurements. Integral forces effected on the profile were determined with semi-conductor strain-gages[2)] and velocity distributions with a hot-wire anemometer[3)].

The aim of all investigations is to analyse the unsteady flow through a turbine stage in detail and to study what is the consequence, if the highly complicated unsteady flow is treated as a simpler one.

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3) This investigation is within the "Sonderforschungsbereich 85 Thermodynamische und strömungsmechanische Probleme der Luft- und Raumfahrtantriebe", sponsored by the Deutsche Forschungsgemeinschaft.