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ENGINEERING CHANGES TO THE 0.1m CRYOGENIC WIND TUNNEL AT SOUTHAMPTON UNIVERSITY

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ABS:   The more important changes to the 0.1 m cryogenic wind tunnel since its
       completion in 1977 are outlined. These include detailed improvements in
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       instrumentation, data logging, data reduction and tunnel controls were
       also improved and modernized. A tunnel performance summary is given.


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Contents

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Symbols

C_{po}	stagnation pressure coefficient
M_r	reference Mach number
P_o	calculated stagnation pressure
P_r	test section reference static pressure
ΔP	increase in static pressure
q_r	test section reference dynamic pressure
T_o	stagnation temperature

1. Introduction

The wind tunnel has been used for a variety of tasks since its commissioning in 1977, during which time there have been several significant changes and improvements. The tunnel is available for, among other applications, the 6-component magnetic suspension and balance system which is under development through Grant NSG-7523.

This report covers the more important changes which have taken place since the original report on the tunnel's construction[1], which drew attention to the need for some improvements. Other changes have been introduced to adapt it to the particular needs of magnetic suspension and to take advantage of new equipment which has become available. The work was made possible through support from the University mainly in the form of undergraduate projects, and support by NASA through loans of equipment under the above Grant. The tunnel has a closed circuit, is fan driven and operates at atmospheric pressure. The original test section which is still in use is 4" square with small corner fillets. The tunnel is cooled with sprayed liquid nitrogen (LN_2) in the usual way. Reference 1 contains more relevant design details.

2. Mechanical Changes

2.1 Adaptation for magnetic suspension

For this application the circuit was modified in two principal ways[2,3]. Both turns were cut and fitted with welded inserts in order to move the return leg further from the test section to clear the electro-magnets. A complete new test section leg comprising an expansion joint, contraction, octagonal test section and first diffuser, was constructed for the magnetic suspension system option. The equipment is shown schematically in this form on Figure 1. The circuit heater was installed in order to warm up the tunnel following cold runs.

2.2 Fan bearing

Originally this ball bearing was allowed to cool with the tunnel, but its life proved inadequate. The housing was modified by the addition of electrical cartridge heaters with a controlling thermocouple, and the application of a thin layer of thermal insulation. There are two heaters each of 250W which are arranged to hold a mean temperature of +60°C using automatic on-off control. At the lowest circuit temperature the heaters are on for about 50% of the time, and therefore have more than adequate power. A cross section is shown on Figure 2 where the insulation is seen almost surrounding the aluminium housing. The principal heat leakage path is to the driveshaft.

The bearing performs quite satisfactorily in this form.

2.3 Increase in fan speed

2.3.1 Fan stressing

Among the several actions necessary to allow a speed increase was a check on the rotor blade loads. A tensile test on a spare blade revealed a high usable stress, enough to allow speeds up to about 10,000 rpm in comparison with the usual maximum 6,000 rpm.

2.3.2 Drive shaft

In its original form the drive shaft appeared to be close to its whirl speed when running at 6,000 rpm and therefore a shorter, stiffer shaft has been made. One end is visible on Figure 2. The calculated whirl speed of this design is above 10,000 rpm.

2.3.3 Drive motor

A new variable frequency power supply on loan from NASA, coupled with a new 4kW a.c. motor, have provided the power necessary for an increase in speed. At the present time with this equipment the maximum fan speed has been set at approximately 7,200 rpm at a motor speed of 3,500 rpm, with a V-belt drive between the two. The variable frequency power supply (Dynamatic Dynahertz) has an output frequency range of 6 to 60 Hz., selected manually or automatically through an input signal in the band 0 to 10 volts d.c.

2.4 Circuit heaters and insulation

The use of an electrical circuit heater is mentioned in Section 2.1. The heater capacity is 3 x 1kW. A heater was installed originally to speed up the re-heating process following a cold run. They are used with the fan running and will raise the circuit temperature from 90K to 300K in about 20 minutes.

Other uses for the heaters have since arisen. They are used to run the tunnel at high temperature, broadening the band of available Reynolds number by extending the lower boundary downwards. When running hot the test gas is usually air, but nitrogen if the hot run immediately follows a cold run. The maximum circuit temperature is 380K, limited by materials of construction.

Another use is in the control of circuit temperature when running cold. The supply of LN_2 is under manual control and the heaters control temperature in the following way. The LN_2 flow is first adjusted to give a roughly constant temperature, then the flow is increased slightly. The subsequent fall in circuit temperature is checked by the heaters which are arranged to automatically cycle on and off.

Prior to the installation of heaters the thermal insulation on the tunnel was deliberately sparse in order to accelerate warmup. This is wasteful of LN_2 and now the circuit is 95% covered with about one inch of foam rubber insulation taped into position. The outside of the insulation remains free from condensation which indicates an adequate thickness, and the run time available from a given quantity of LN_2 is noticeably extended.

2.5 Operating envelope

This is shown on Figure 3 in the form of unit Reynolds number and Mach number as functions of temperature and fan speed. The whole area inside the limits has been explored and is available for testing. The maximum speed limit is that obtained with a large model in the test section.

3. Instrumentation

The test reference Mach number M_r is determined from the outputs of two pressure transducers (Druck) which read the settling chamber stagnation pressure, and the difference between this and the test section reference static pressure. The transducer outputs are fed through amplifiers to an A-D converter (CIL). Other pressures, usually related to the model under test, are similarly measured through a Scanivalve.

Circuit temperature, used in the calculation of Reynolds number and as a control signal for the circuit heaters, is measured with a copper-constantan thermocouple and meter (Comark), the meter feeding an analog output to the A-D.

A Commodore PET microcomputer is used for tunnel control and for data logging and reduction.

4. Systems and Controls

Figure 4 is a systems and interconnections block diagram. The tunnel circuit has the 4" square test section. Items already mentioned such as the LN_2 supply, instrumentation, motor and variable frequency power supply, bearing heater control loop and the circuit heaters are all shown. The power supply is interlocked to the circuit heaters by means of a relay which prevents the heaters being used if the motor is not running. Analog signals are routed through a 12 bit A-D to the comptuter which carries comprehensive software[4] for the control of the tunnel. The software has control modes which are userselectable, employing relay outputs to the circuit heaters or Scanivalve, and a 12 bit D-A in order to implement the options. The control options are

(i) hold a demanded Mach number. The output is through the D-A to the motor power supply.

(ii) step Scanivalve, check the port number and acquire its pressure.

(iii) hold a demanded temperature. The output to the circuit heaters is through a relay giving on-off control. Options (i) and (iii) are available simultaneously.

(iv) hold a demanded Reynolds number. Control is by motor speed. Mach number will vary in response to change of circuit temperature.

During a run (typically of one hour duration) the test conditions are monitored continuously and the demanded and achieved conditions are redisplayed every few seconds. The achieved conditions are logged for subsequent analysis, along with model test data.

Comprehensive software packages have been developed to plot relevant tunnel data. Some plot examples are included here. Figure 5 shows temperature-time (upper line) and rpm-time (lower line) traces from one run. The corresponding Mach and Reynolds number histories are on Figure 6. The upper trace is Reynolds number. Following a rapid cooldown at Mach 0.15, reaching 100K in 7 minutes, the Mach number was raised to 0.2 and the temperature held constant for a further 6 minutes. Between minutes 20 and 32 the tunnel was allowed to warm up, first naturally and then with the heaters on, while holding Mach number constant. Between minutes 18 to 20, and again between minutes 40 to 50 following another cooldown, constant Reynolds numbers of 29 and 10 millions per meter respectively were held during warmups.

Also available is the locus of a run plotted over the operating envelope of Figure 3. It is shown for the same run on Figure 7a. The vertical and horizontal lines highlight the use of the constant Mach number and constant Reynolds number control modes.

When testing at low Reynolds numbers the form of Figure 7a is inconvenient and therefore the logarithmic plot of Figure 7b is employed to expand the low values. Evidence is again seen of control at constant Reynolds number (about 2.10^6 per meter) and several values of Mach number during this run which was in the temperature band 250K to 380K.

5. Circuit Performance

Some additional measurements have been made of the performance of components of the circuit since the original report[1]. Figure 8 shows the increase in static pressure ΔP across the first diffuser and fan, non-dimensionalised with respect to the test section reference dynamic pressure q_r, as a function of unit Reynolds number in the test section flow. The test section contained no model. It is seen that the performance of the diffuser improves somewhat with increase in Reynolds number. Due to this and similar improvements in other components, the pressure rise required of the fan falls significantly with increase in Reynolds number.

Static pressure measurements have been used to assess the variation of stagnation pressure around the circuit. A value for a local stagnation pressure was estimated from this measurement using the local flow area and an estimate of the mass flow rate. One-dimensional uniform compressible flow was assumed. For convenience the stagnation pressure is presented as a pressure coefficient C_{po} defined by

$$C_{po} = \frac{P_o - P_r}{q_r}$$

The variation of C_{po} around the circuit is shown on Figure 9, having the values of unity in the test section and approximately unity at the outlet of the screen. The largest losses in stagnation pressure are seen to occur in the first diffuser (which contains the liquid nitrogen spray bar) and through the screen. Some recovery in P_0 when calculated this way is evident after the fan.

6. Discussion

The tunnel has gradually been developed to the point where it is reliable, reasonably economical and simple to use. It is probably fair to say that while there will be improvements made, it is quite satisfactory for most purposes in its present form. When more experience has been gained at the present upper fan speed it might prove reasonable to raise speed, and hence the dynamic pressure, Reynolds and Mach numbers available for experiments.

A log has been kept of all cryogenic runs. For the record this tunnel has accumulated just over 34 hours of running in the cryogenic temperature range, that is below 150K.

7. References

1. M.J. Goodyer. The 0.1m subsonic cryogenic tunnel at the University of Southampton. NASA CR-145305, January 1978.

2. C.P. Britcher. The magnetic suspension and balance system in the cryogenic wind tunnel. B.Sc. Honours Project Report, University of Southampton, April 1978.

3. C.P. Britcher, M.J. Goodyer. The Southampton University magnetic suspension/cryogenic wind tunnel facility. Paper 10, Proceedings of First International Symposium on Cryogenic Wind Tunnels. April 1979.

4. D. Owen. Development of a Mach number control system for use in a cryogenic wind tunnel. Honours Project Report, University of Southampton, April 1984.

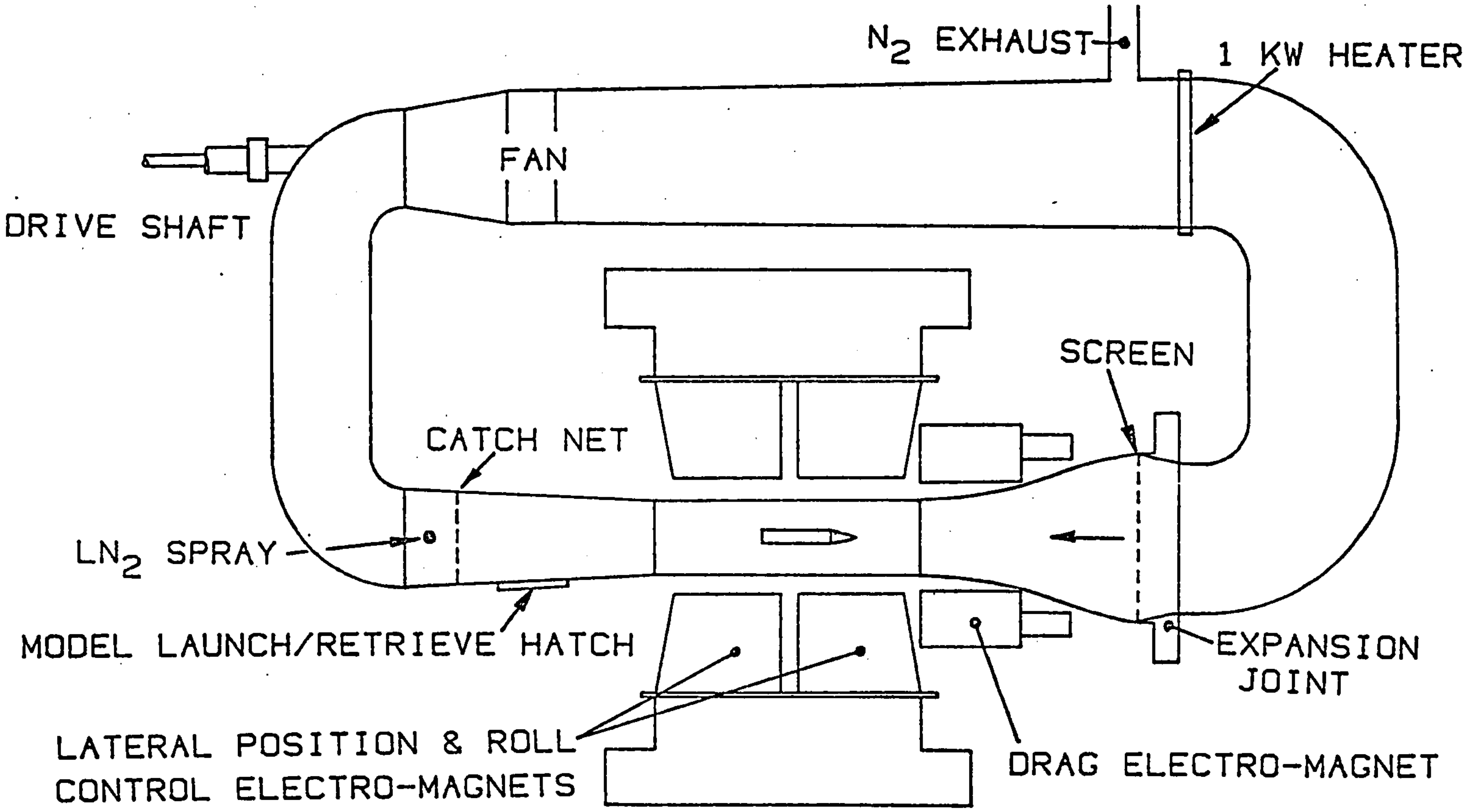


FIG. 1 MODIFICATIONS TO CRYOGENIC WIND TUNNEL FOR MAGNETIC SUSPENSION SYSTEM.

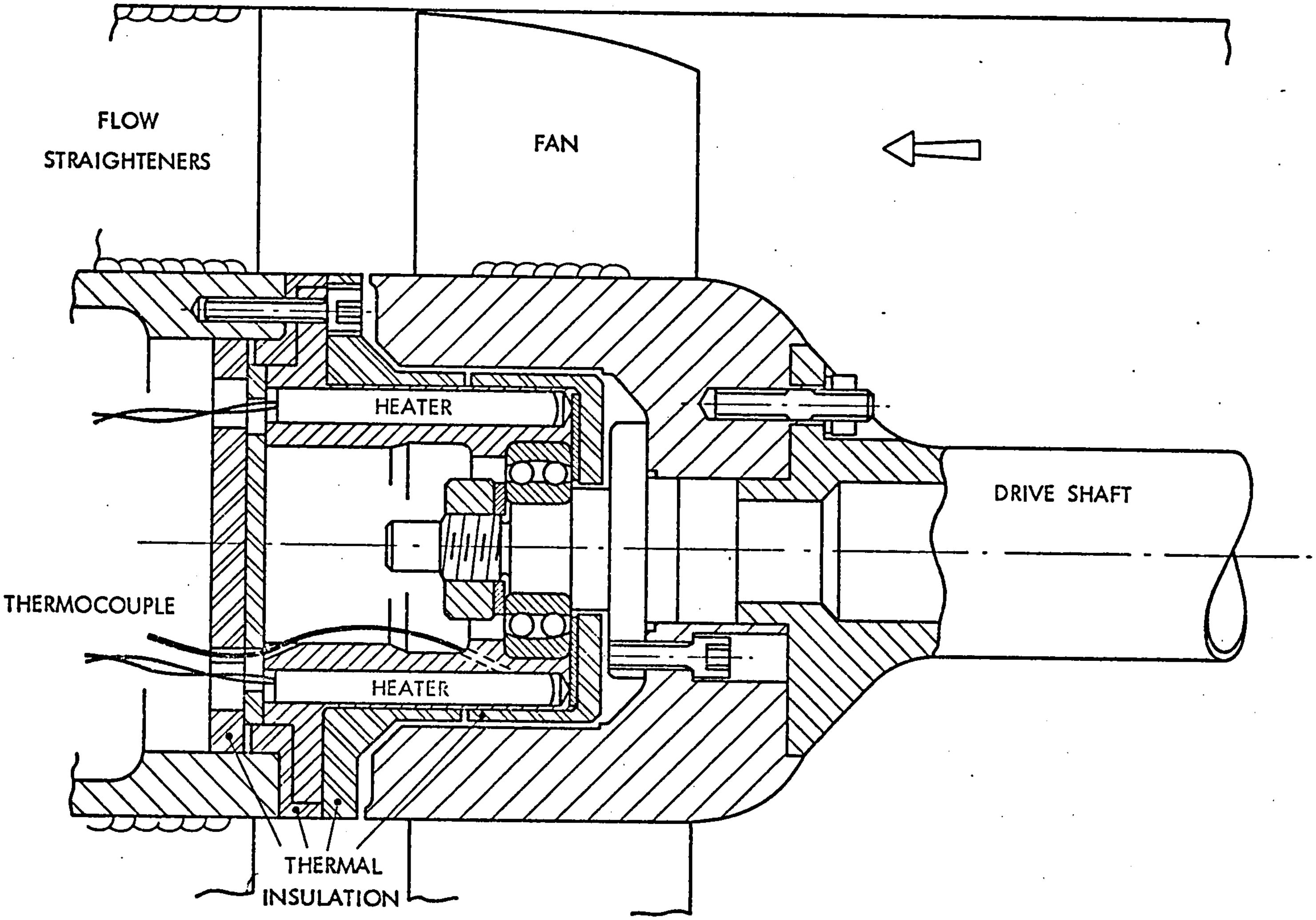


FIG. 2 FAN AND HEATED BEARING.

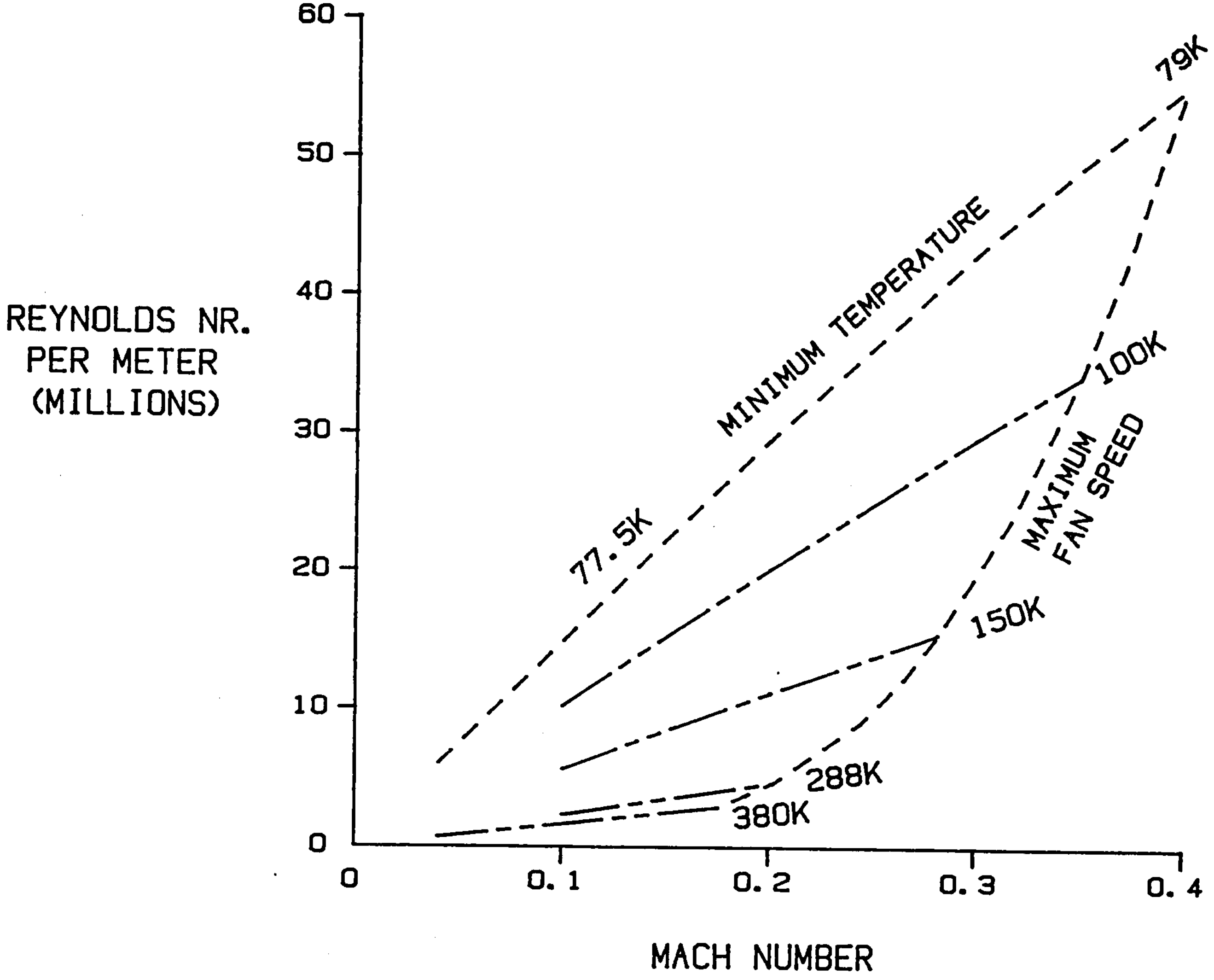


FIG. 3 0.1 m CRYOGENIC WIND TUNNEL - CURRENT OPERATING ENVELOPE.

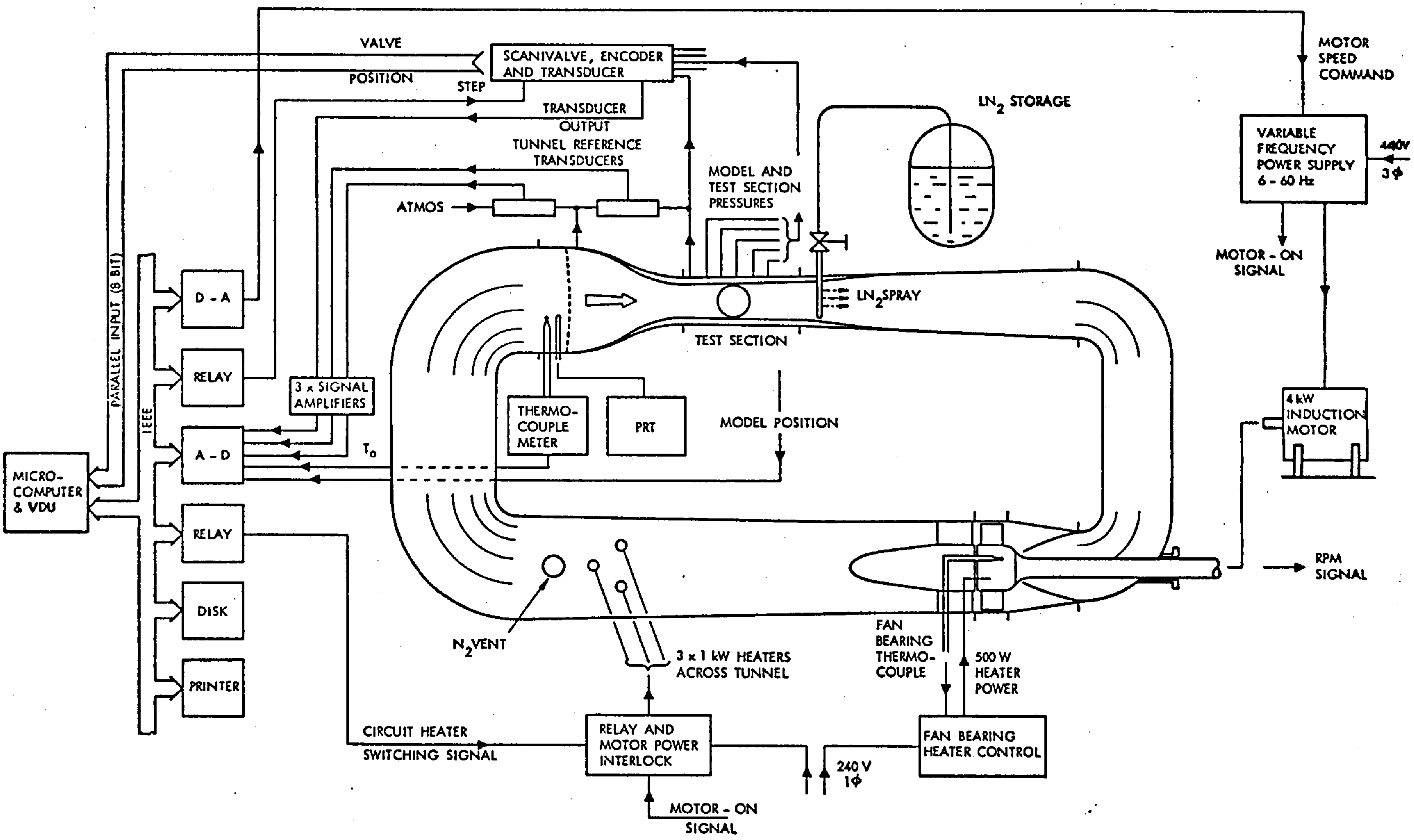
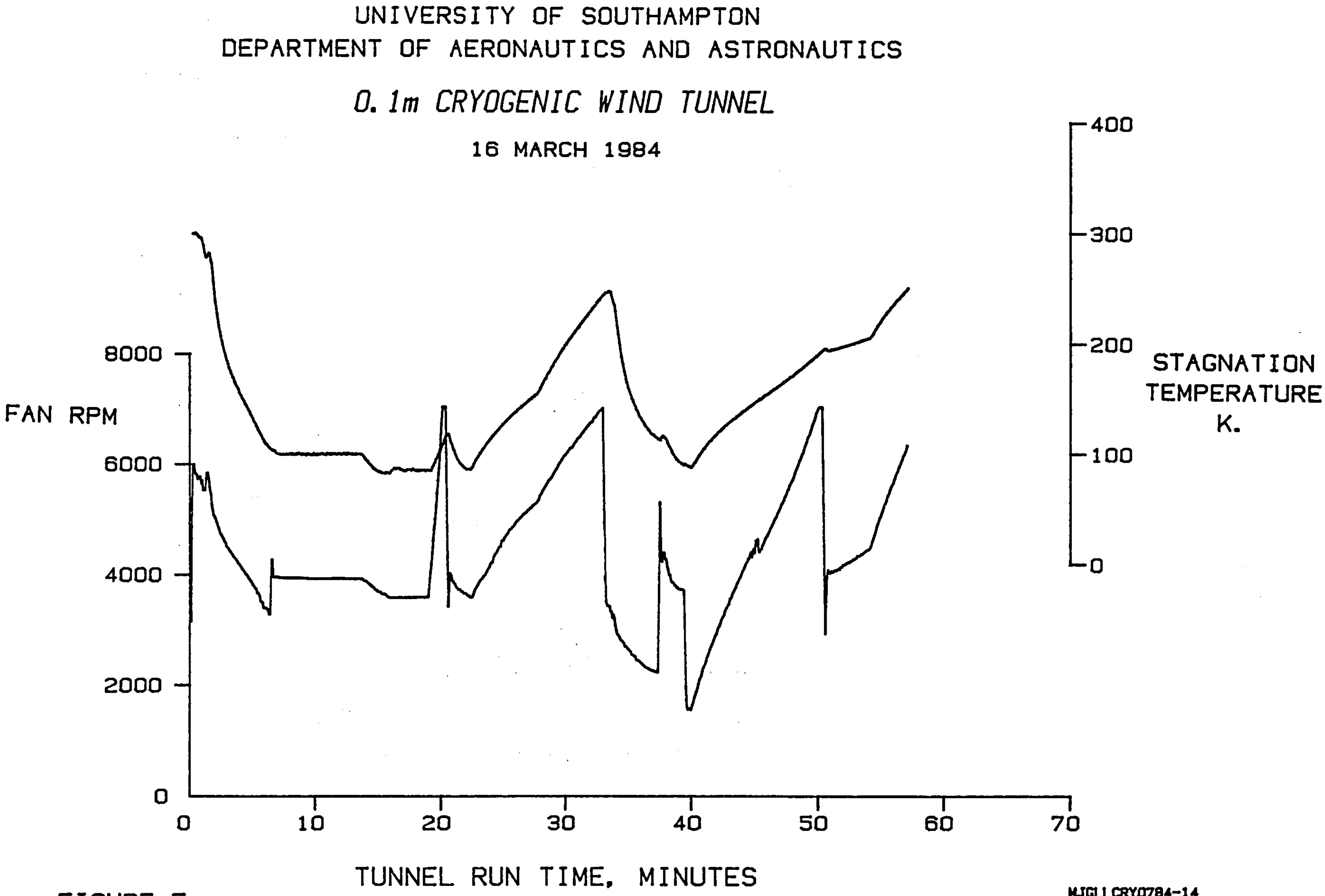


FIG. 4 SYSTEMS BLOCK DIAGRAM FOR CRYOGENIC WIND TUNNEL.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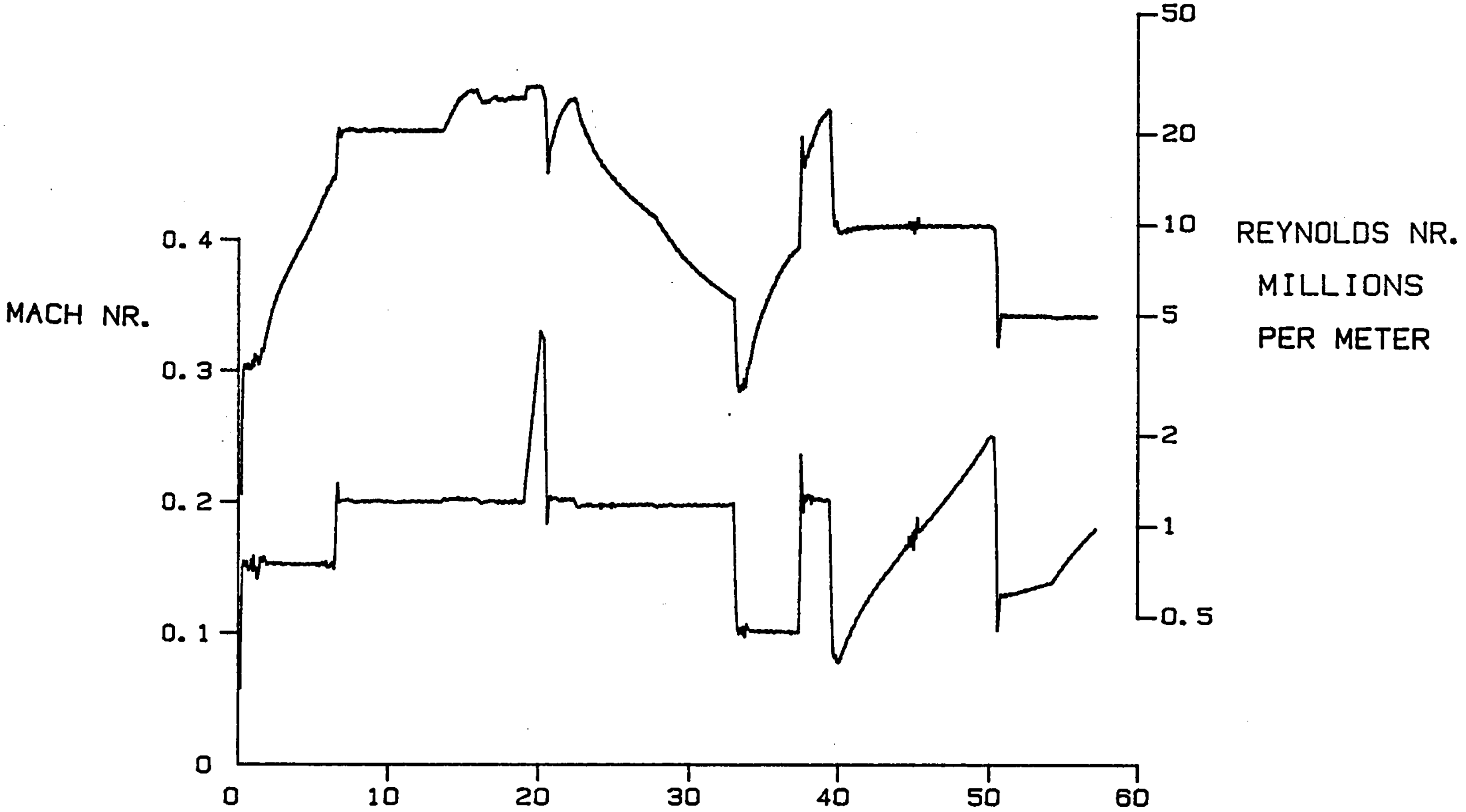
0.1m CRYOGENIC WIND TUNNEL
16 MARCH 1984
FAN RPM
0
2000
4000
6000
8000
STAGNATION TEMPERATURE K.
0
100
200
300
400
0
10
20
30
40
50
60
70
TUNNEL RUN TIME, MINUTES
MJGI I CRY0784-14

FIGURE 5.



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0. 1m CRYOGENIC WIND TUNNEL

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FIGURE 6.

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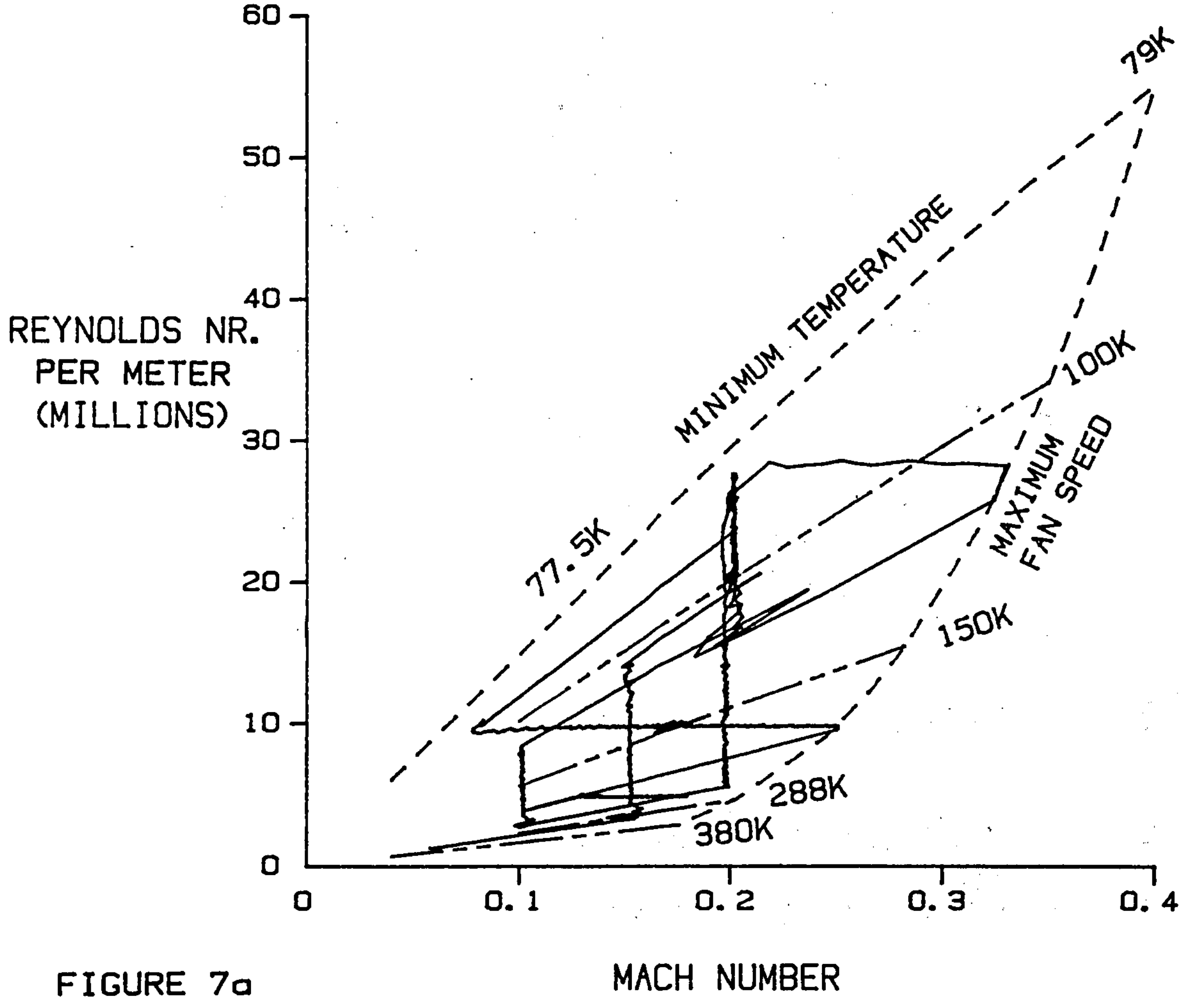
0.1m CRYOGENIC WIND TUNNEL



LOCUS OF TEST

OF 16 MARCH 1984

FIGURE 7a

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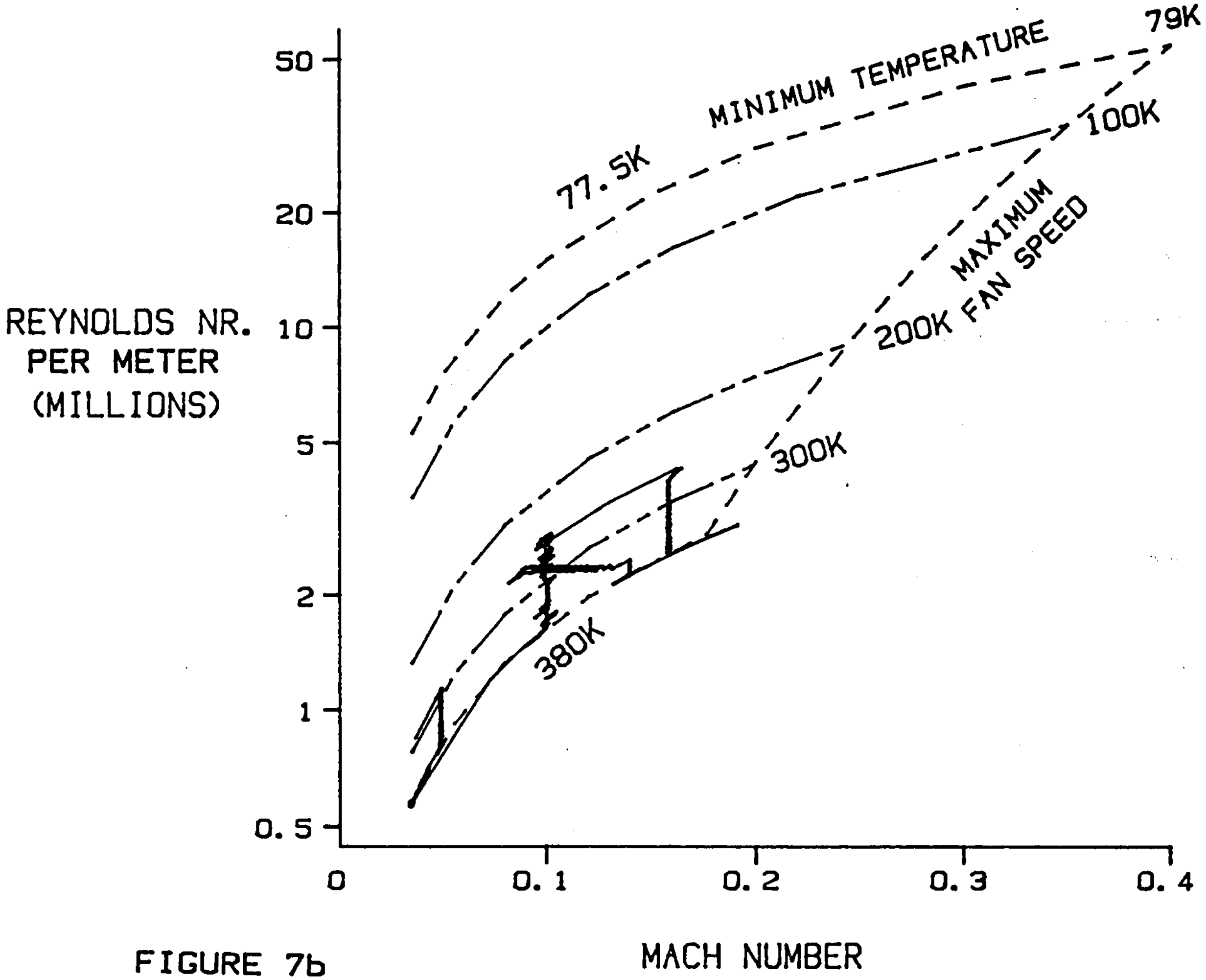
0.1m CRYOGENIC WIND TUNNEL



LOCUS OF TEST

OF 6 APRIL 1984

FIGURE 7b

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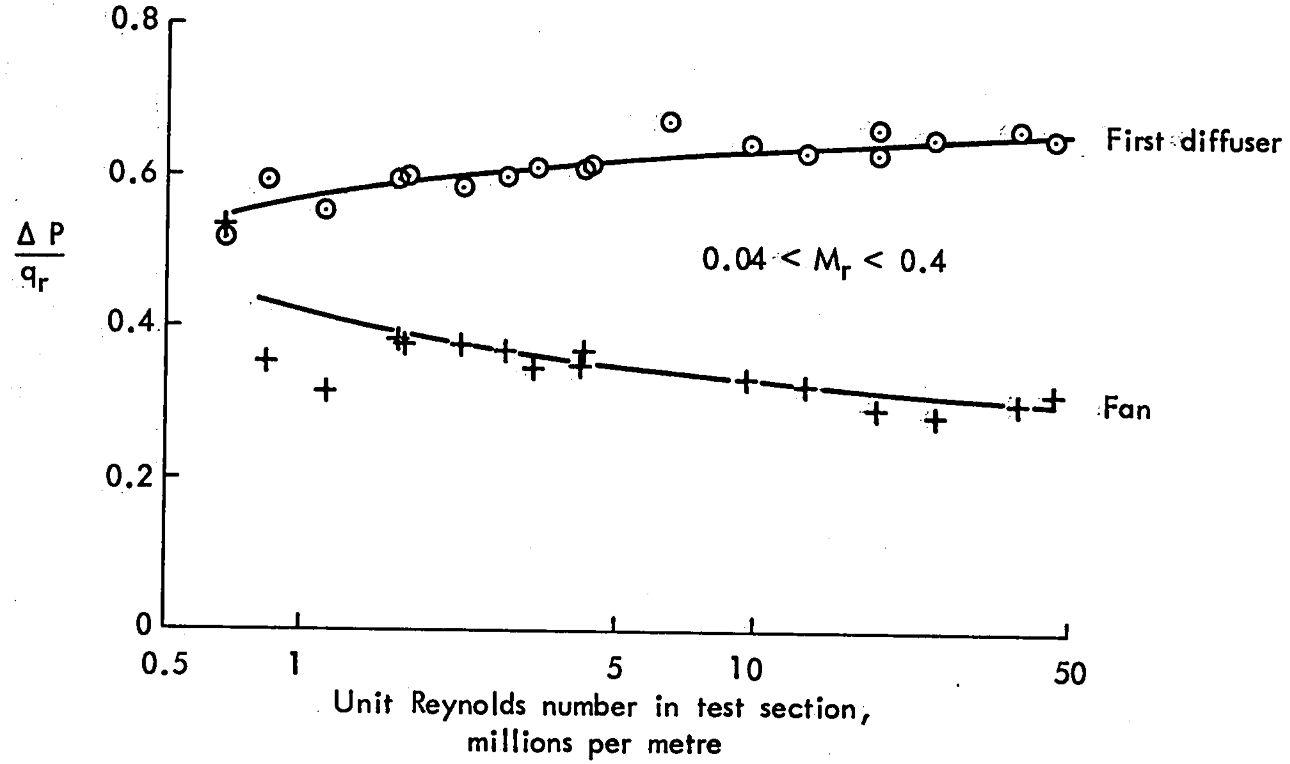

FIG. 8 PERFORMANCE OF FIRST DIFFUSER AND FAN : DIMENSIONLESS INCREASE IN STATIC PRESSURE AS A FUNCTION OF REYNOLDS NUMBER.

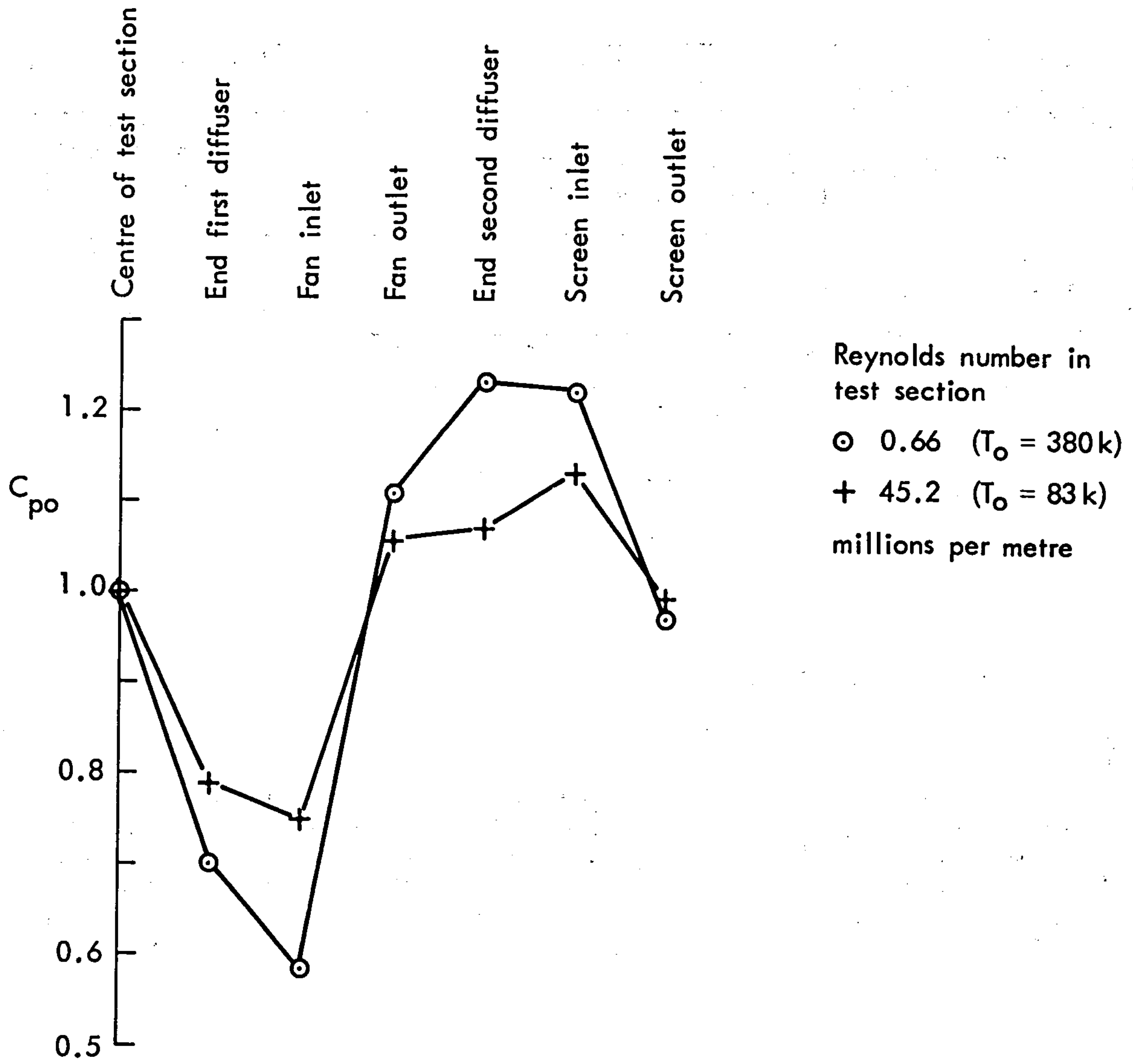

FIG. 9 VARIATION OF A LOCAL STAGNATION PRESSURE COEFFICIENT AT POINTS IN THE CIRCUIT AS INFLUENCED BY REYNOLDS NUMBER.

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15. Supplementary Notes

Langley Technical Monitor: Charles L. Ladson

16. Abstract

This report outlines the more important changes to the tunnel since its completion in 1977. These include detailed improvements in the fan drive to allow higher speeds, and the provision of a test section leg suitable for use with a magnetic suspension and balance system. The instrumentation, data logging, data reduction and tunnel controls have also been improved and modernized. The report concludes with a tunnel performance summary.

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