NASA Contractor Report 159144

NASA-CR-159144
1980 0001991

CRYOGENIC WIND TUNNEL ACTIVITIES AT THE UNIVERSITY OF SOUTHAMPTON

M. J. Goodyer

THE UNIVERSITY OF SOUTHAMPTON
United Kingdom

NASA Grant NSG-7523
September 1979

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

CRYOGENIC WIND TUNNEL ACTIVITIES AT THE UNIVERSITY OF SOUTHAMPTON

by

M.J. Goodyer
Department of Aeronautics and Astronautics
University of Southampton
September 1979

1. Introduction

The University has been involved with the cryogenic wind tunnel since the earliest days of this type of tunnel, beginning in 1971/72 with an association with NASA Langley Research Center which led to an examination of the aerodynamic advantages and the difficulties of implementation of the notion. During the subsequent heady period when the tunnel began to be accepted as one deserving of full evaluation, the involvement continued, with modest inputs to the 0.3-m transonic cryogenic tunnel project.

More recently two types of cryogenic wind tunnel have been built at the University. This short paper summarises the researches on the latter tunnels, undertaken and, in some cases, satisfactorily completed in the period mid 1976 to date.

2. Low Speed Testing in a Fan Driven Tunnel

2.1 Performance

We built with some help from NASA a small continuous running tunnel[1] through late 1976 and early 1977. The test section is square and about 4 inches, 0.1m., across and the maximum Mach number at room temperature is about 0.17. Of course this is a very small tunnel, unsuitable on several counts for the testing of aircraft models. However, its behaviour does serve to highlight a little known but very advantageous characteristic of low speed cryogenic tunnels which has not before received attention simply because of our preoccupation with transonics. The characteristic is that of having an extraordinarily wide band of usable Reynolds number, without resort to pressurisation. To illustrate and quantify this, we can invoke the familiar avenues of analysis but adopt ground rules appropriate to the low speed atmospheric pressure tunnel, rules which can differ from those applicable to transonic tunnels. For example, sometimes it is only necessary for the Mach number to be low in a low speed tunnel, not constant.

The analysis summarised below is designed to highlight the feature of the wide Reynolds number band.

Firstly, the usual expression relating unit Reynolds number R to temperature is

$$R \;\alpha\; {}^{1}/_{T^{1.4}} \,,$$

N80-10231 #

Mach number constant. In lowering the tunnel temperature from 300K to 79K, R rises by the normally quoted factor of about 6.4. However, low speed tunnels are not Mach number limited. They may be power limited in which case the expression becomes

$$R \quad \alpha \quad {}^{1}/_{T^{1.53}} ,$$

drive power constant. R then increases by a factor of 7.7. Another possible limitation is fan speed. In this case

$$R \quad \alpha \quad {}^{1}/_{T^{1.9}} ,$$

fan speed constant, giving a Reynolds number factor of 12.5 which is about twice the increase usually quoted. The expressions are illustrated on Figure 1. Heating a tunnel, for example to 400K where Reynolds number is 64% of room temperature at constant fan speed, will spread further the useful band of Reynolds number.

The 0.1m. tunnel at Southampton happens to be fan speed limited, as may be the case in tunnel conversions to cryogenic operation, and therefore benefits from the factor of 12 or more in Reynolds number on running cold. Therefore the 4 inch test section effectively becomes something over 4 feet, no longer trivial. The fact that the Mach number is simultaneously 0.35 results in Reynolds numbers higher than in any other tunnel at the University including our largest (6 foot) low speed tunnel. The wide spread of attainable Reynolds number is already evident, but is broadened further by the two remaining measures, the usual one of changing fan speed, but also the less common one of increasing the tunnel temperature above room temperature. Our tunnel has a heater, and the materials of construction allow the tunnel to run at +105°C (378K), while the minimum usable Mach number (therefore dynamic pressure) is arbitrarily set at 0.04. The resultant operating envelope is shown on Figure 2 where the ratio of maximum to minimum Reynolds number is seen to be between 70:1 and 80:1. In our various tests during the past two years we have exploited the whole of this envelope.

2.2 Flow Visualisation

2.2.1 As a final year undergraduate project, Kell successfully devised[2] a surface flow visualisation technique using propane carrying a pigment onto the surface of the model. His equipment has since been modified in detail, but the propane still follows essentially the same cycle illustrated on Figure 3. It is stored under pressure at room temperature, A, but with the new plumbing illustrated on Figure 4 it is cooled under pressure directly via E to the tunnel temperature G (without the excursion to F). The evaporation of the propane into the nitrogen atmosphere, to H, leaves the pigment adhering quite effectively to the model, and incidentally to the tunnel walls as well. Two powders have been used: blue paint pigment, and fluoroscene.

2.2.2 Wool and cotton tufts have been fixed to models and to the tunnel walls from time-to-time. Five-minute epoxy is a reliable and convenient fixative, and most tufts remained flexible over the whole temperature range down to 78K. The only failure noted was an occasional breakage at the tuft root when subject to vigorous twirling under a vortex.

2.3 Thermal Turbulence

A search was attempted for this type of turbulence in our 0.1m. tunnel by Gray as a final year project[3]. Conventional fine-wire thermocouples were used, electronically compensated for a linear response to about 1KHz. While suggestions of thermal turbulence were found, with fairly definite evidence of droplet impacts on a thermocouple in the small end of the tunnel, we are forced to conclude that the search was indecisive.

2.4 Magnetic Suspension

The cryogenic wind tunnel was born as a result of research into the magnetic suspension of wind tunnel models, and therefore as we had a tunnel and a 6-component balance it seemed appropriate to link them. Colin Britcher undertook the modifications of the tunnel as a final year undergraduate project, and work has continued[4] more recently to refine the test technique. The refinements include the addition of automatic data acquisition equipment with on line reduction and real time reduced data displays for the operators. Figure 5 is an outline of the circuit showing the locations of the magnet system and some of the key features of the tunnel. The test procedure comprises launching the model by hand at room temperature using the hatch, closing up the tunnel, acquiring a good set of wind-off tunnel and balance data, then running the tunnel while cooling down. Wind-on data is acquired, reduced and displayed continuously, but data taken during speed or temperature changes is rejected. Typical data is shown on Figure 6, taken in the temperature band 100K to 360K. With more experience we would expect to reduce the scatter, but the work has already served to show that the combination of magnetic suspension with cryogenic wind tunnel does not raise insuperable technological problems. Further, here is one force balance which is relatively immune to the cryogenic environment.

2.5 Accumulated Experience

The total running time of the tunnel is just over 70 hours. Our running log includes notes of time run below 150K and below 110K. Respectively these are 1268 and 767 minutes.

2.6 Future Work

There may be more magnetic suspension work, partly with a view to investigating the effects of temperature on the magnetic properties of model core materials.

We will attempt to devise a thin-film technique for detecting boundary layer transition. This work will begin in October 1979 again as a final year undergraduate project.

3. A Free-Piston Tube Cryogenic Tunnel Drive

Another final year project undertaken by Hutt supervised by Dr. R.A. East[5] explored some of the features of the drive system proposed by Professor Stollery. A schematic of the equipment is shown on Figure 7. High pressure gas initially at room temperature to the right of the piston is expanded by leftward movement of the piston, creating lower pressure, low temperature gas to the right. This gas, the working fluid, is driven, by reversal of the piston motion, through what would be the test section off the right of the figure. Hutt measured mean working fluid temperature following expansion. Typical data is given on Figure 8 which shows that temperatures in the cryogenic range can be achieved in a short tube, even though the index of expansion n is less than 1.4. The pressure in the tube after expansion is sufficient to produce transonic speeds in a test section.

The project will be continued during the coming academic year, with emphasis on a detailed study of the mechanism responsible for the departure from isentropic expansion, and on a study of the uniformity of the reservoir conditions achieved.

4. References

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

2. Kell, D.M. A surface flow visualisation technique for use in cryogenic wind tunnels. The Aeronautical Journal, November 1978.

3. Gray, H.L. The development and use of a thermal turbulence probe for operation in a cryogenic wind tunnel. B.Sc. Honours Project Report, Southampton University, May 1978.

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

5. Hutt, G.R., East, R.A. Preliminary experimental studies of a free piston expander for an intermittent cryogenic wind tunnel. Paper 8, Proceedings of First International Symposium on Cryogenic Wind Tunnels, Southampton, April 1979.

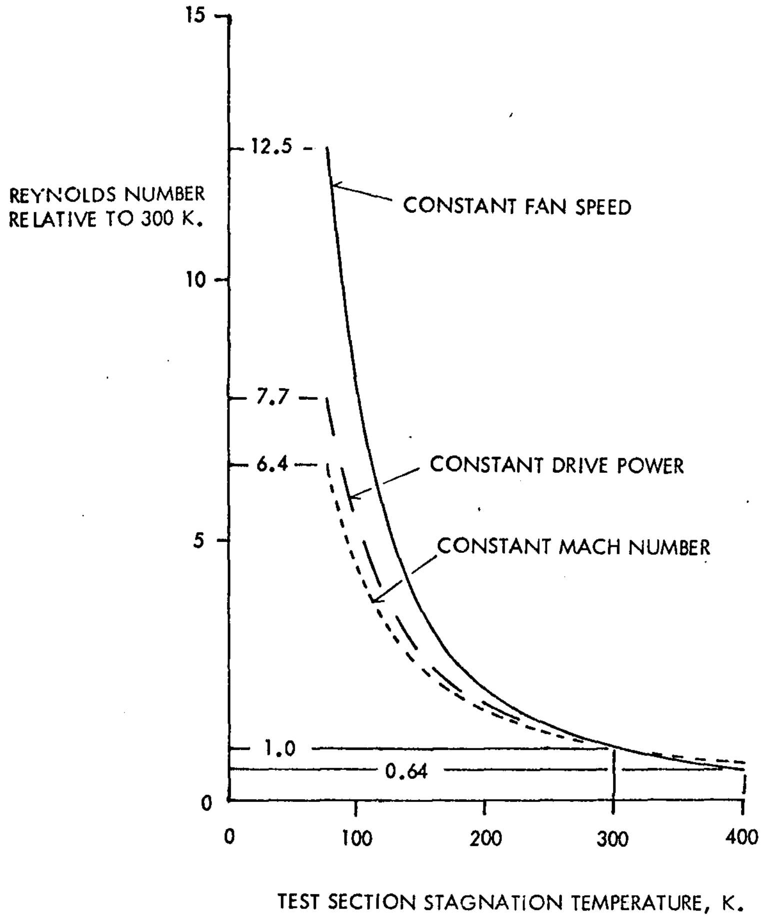

FIGURE 1. VARIATION OF TEST REYNOLDS NUMBER WITH TEMPERATURE.

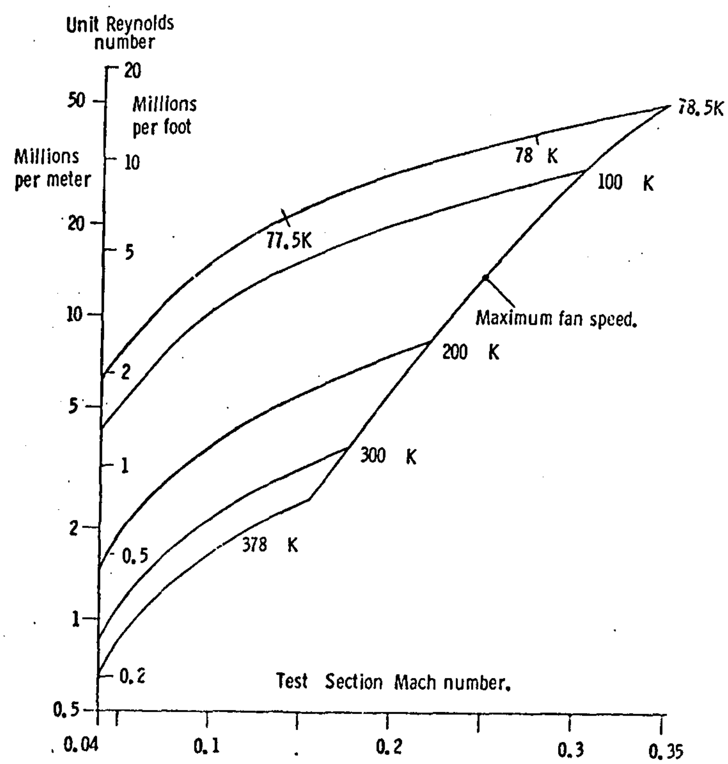

FIGURE 2. 0.1m CRYOGENIC TUNNEL OPERATING ENVELOPE.

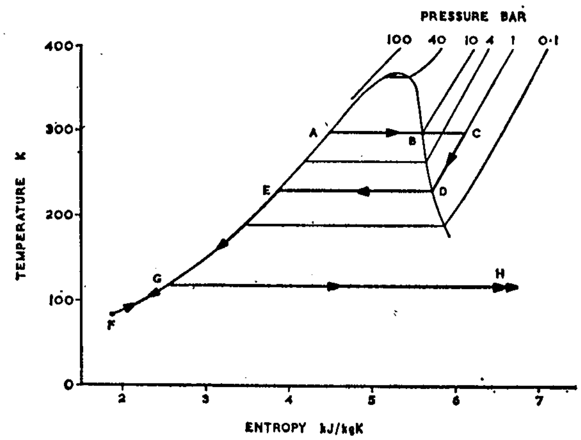

FIG.3. TEMPERATURE-ENTROPY DIAGRAM FOR PROPANE.

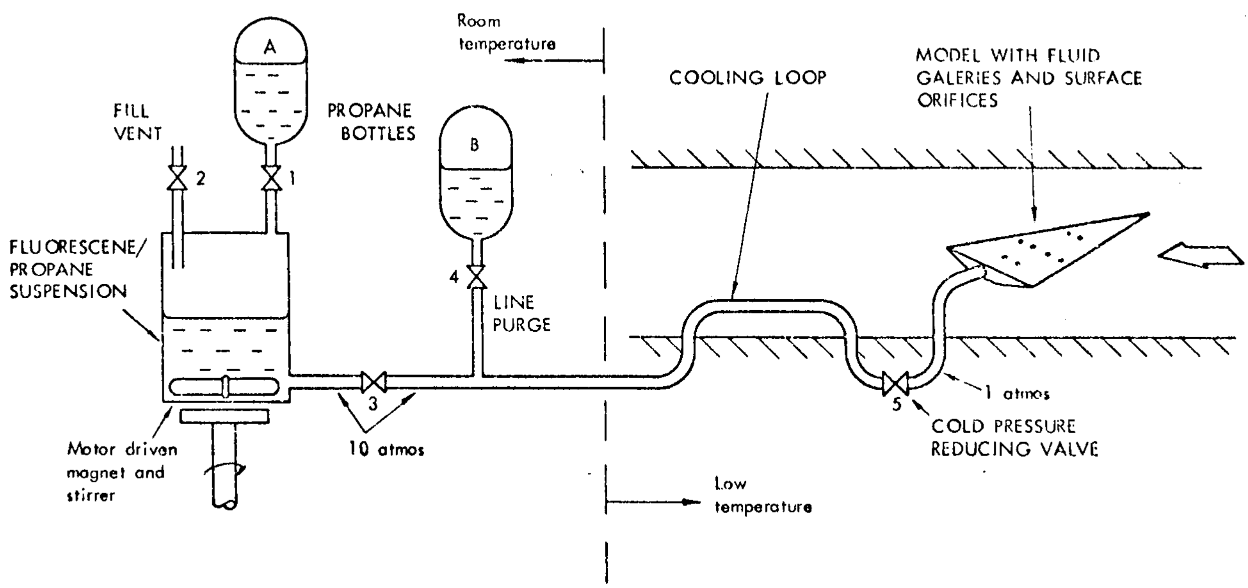

FIG. 4. PROPANE/PIGMENT SURFACE FLOW VISUALISATION EQUIPMENT FOR CRYOGENIC TUNNEL AT UNIVERSITY OF SOUTHAMPTON.

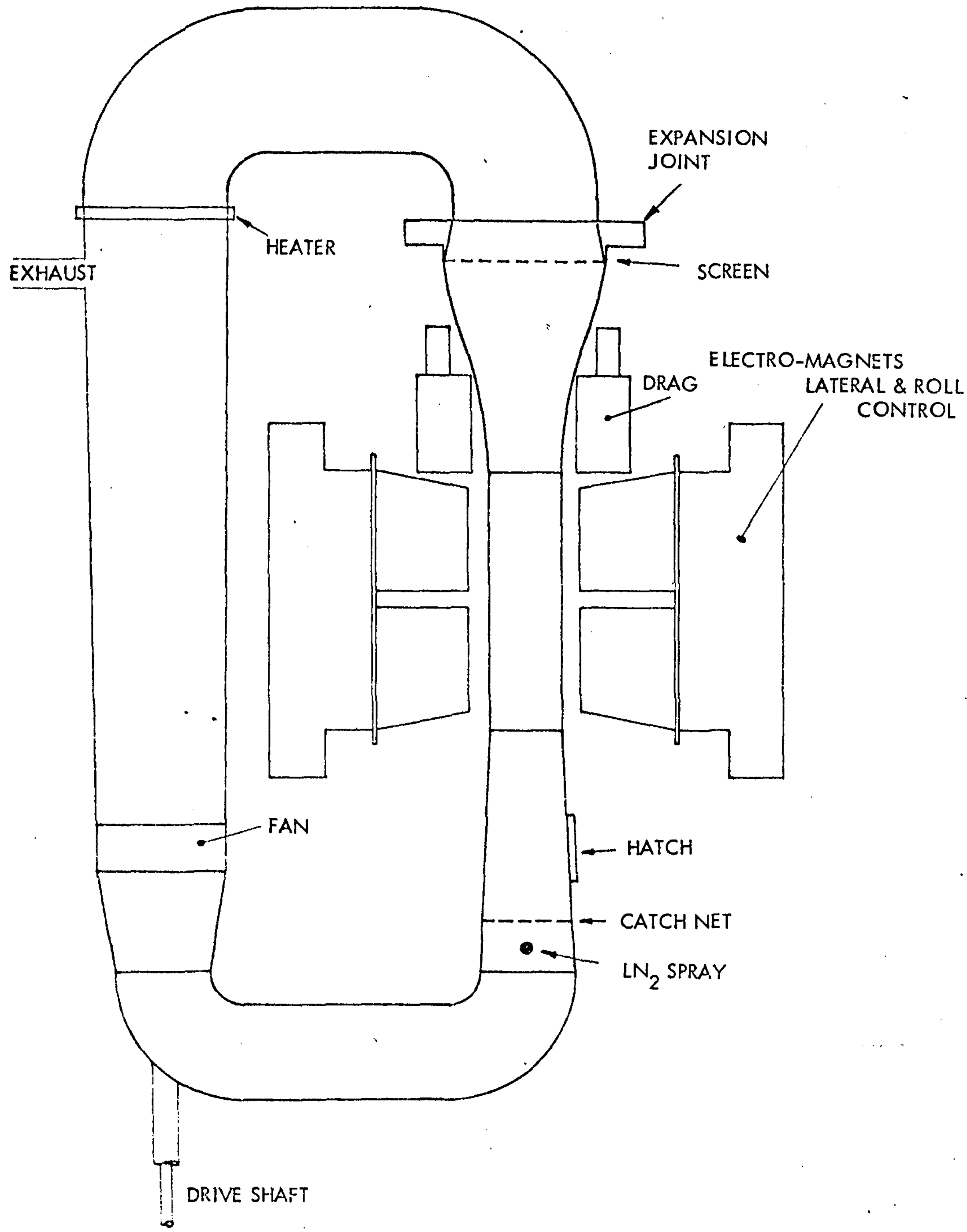

FIG. 5. THE 0.1m CRYOGENIC LOW SPEED WIND TUNNEL AND SIX COMPONENT MAGNETIC SUSPENSION & BALANCE SYSTEM.

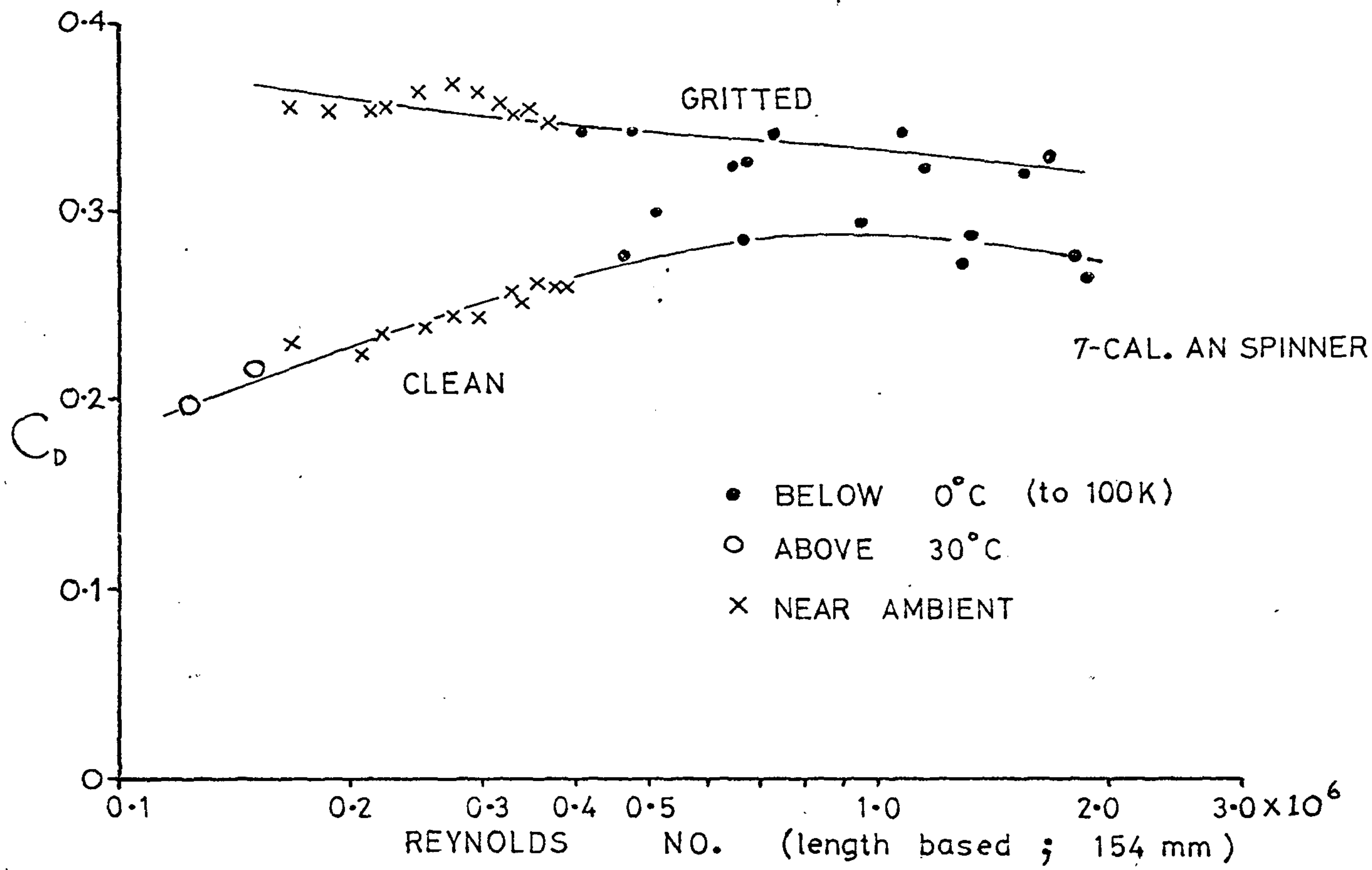

FIG. 6. LOW SPEED DRAG MEASUREMENTS ON 7-cal. A-N SPINNER MAGNETICALLY SUSPENDED IN 0.1m CRYOTUNNEL HOT AND COLD.

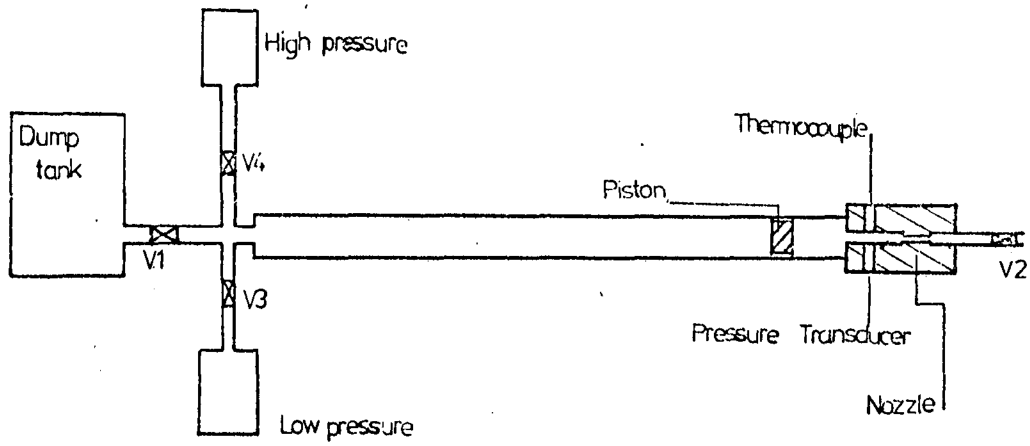

FIG. 7. FREE PISTON EXPANSION TUBE.

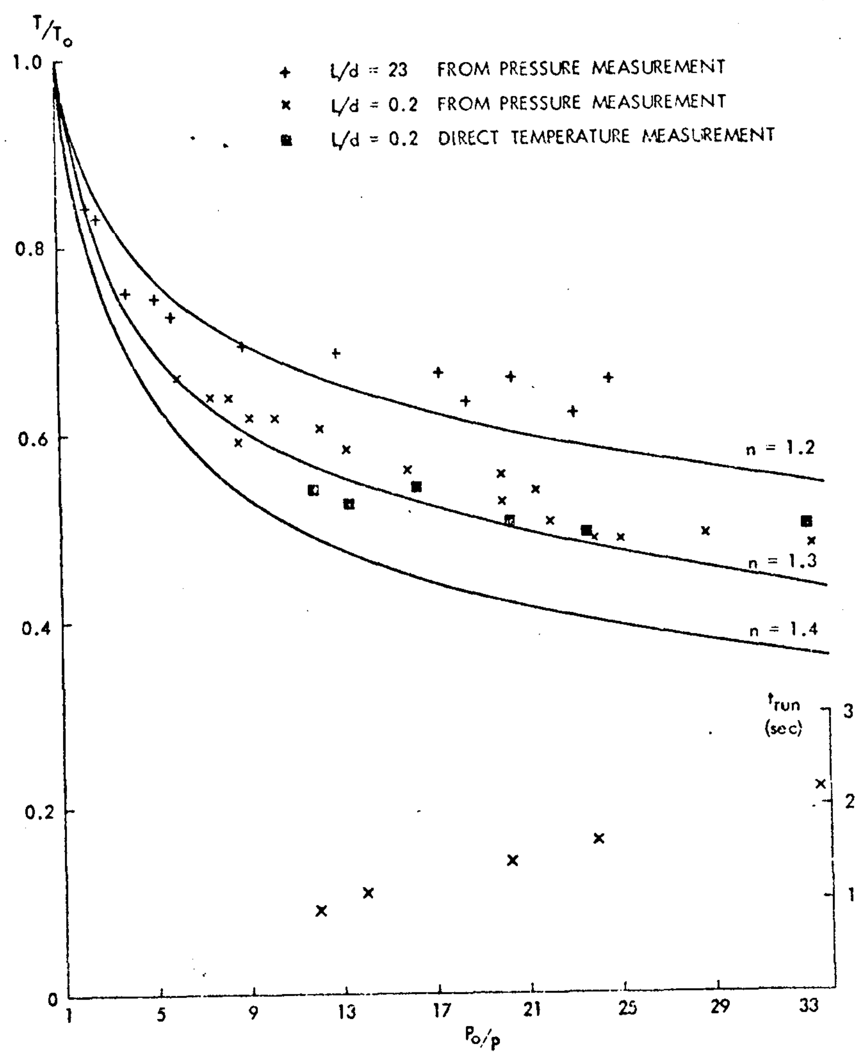

FIG. 8. PRESSURE-TEMPERATURE HISTORIES IN TWO EXPANSION TUBES COMPARED WITH AN ISENTROPIC EXPANSION.