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The Development of an Improved Diffuser for a 3 ft. x 3 ft. Wind Tunnel

By

J. B. Scott-Wilson, and D. I. T. P. Llewelyn-Davies

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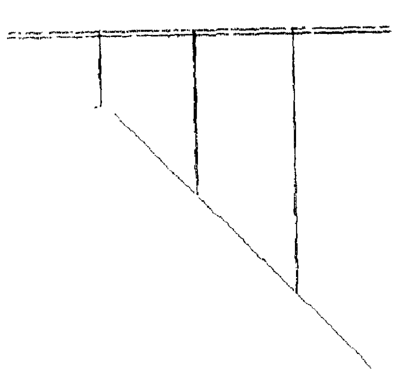

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ROYAL AIRCRAFT ESTABLISHMENT

The Development of an Improved Diffuser for a 3 ft × 3 ft Tunnel

by

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SUMMARY

A summary is given of the significant results of diffuser development tests made in a 4" × 4" supersonic tunnel at Mach numbers from 1.4 to 2.0. The application of these results to the design of an improved first diffuser stage for the 3 ft × 3 ft supersonic tunnel, is described. The design incorporates a long single wedge centrebody, which divides the diffuser into two approximately constant area passages. Using this improved diffuser, the pressure ratio needed to run the tunnel at its maximum Mach number of 2.0, is reduced from 2.04 to 1.76.

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1 Introduction

The 3 ft × 3 ft transonic and supersonic tunnel at R.A.E. is a closed circuit pressurized tunnel capable of operation at Mach numbers from about 0.7 to 2.0. A feature of the design of this tunnel is the use of two easily removable sections, the "balance section", containing the support gear for the model sting, and the "mobile diffuser", immediately downstream of the working section. The rigging of models is greatly simplified by this arrangement, and alternative balance sections can be used. The available length of the movable sections however imposes a limitation on the design of a diffuser for supersonic operation; it is not possible to install a simple adjustable flap system, for example. During the first four years that the tunnel was in service only one balance section, the one designed to hold the calibration gear for the tunnel[1], was available, and a temporary model support system was installed in this section. Recently a second balance section, with a quadrant type of model support system has been completed. The interior geometry of this section was designed as a result of model tests in a 4" × 4" tunnel, to give improved efficiency as a diffuser at supersonic speeds. In this note the significant results of the diffuser development tests in the 4" × 4" tunnel are presented, and the performance of the 3 ft × 3 ft tunnel with the second balance section is compared with its earlier performance to show the gain in efficiency achieved.

2 Description of the 3 ft × 3 ft Tunnel

Fig.1 shows the general arrangement of the tunnel, the driving plant and the auxiliary machinery. For supersonic operation the working section is 3 ft square, and the Mach number range is from 1.3 to 2.0. Single-sided fixed block nozzles are used to generate the flow; nozzles are available to give working section Mach numbers of 1.32, 1.42, 1.61, 1.82 and 2.00. The pressure in the tunnel circuit is variable from 1/20th atm. to 2 atm. absolute. The air is circulated by two double entry single stage centrifugal compressors, which are set in series with an intercooler. With the Mach number 2.0 nozzle the pressure ratio available at the maximum permissible speed of the driving plant is just over 2.0. An aftercooler, located in the settling chamber is used to control the stagnation temperature.

The balance section with the calibrating gear that was used for all the early running of the tunnel, is shown diagrammatically in Fig.2. The entry and exit areas of this section are fixed by the tunnel design, and give an overall expansion rate equivalent to that of a cone of semi-angle $2^\circ 22'$. The interior liners are, however, designed to maintain a constant area passage up to the end of the calibration saddle, and then to expand with an equivalent conical semi-angle of $3^\circ 13'$ to the exit section.

The design of the balance section with the quadrant is described in Section 4, after a summary of the diffuser tests in the 4" × 4" tunnel has been given.

3 Diffuser Tests in the 4" × 4" Tunnel

A brief summary is given here of the significant results of the diffuser development tests, which provided the basis of the design of the internal layout of the second balance section for the 3 ft tunnel. These tests were made in the 4" × 4" tunnel, which is one of two small supersonic tunnels powered by the 3 ft tunnel auxiliary plant. The settling chamber, nozzle and working section of this tunnel are 1/9th scale models of the larger tunnel. The first diffuser stage, which is removable, and to which modifications were made during these tests, is not to scale, and provides a rather more rapid expansion, the equivalent conical semi-angle being $2^{\circ}42'$, than the 3 ft tunnel balance section. This diffuser stage has a length of 18", and basically four straight diverging walls. The modifications made, for the results given here, were as follows:

(a) the fitting of two-dimensional centrebodies,

(b) the reduction of the angle between the walls for the first 14" of the diffuser.

In the first series of tests four centrebodies, with dimensions as shown in Fig.3, were fitted, each vertically spanning the diffuser. All the centrebodies were set with their leading edges 2.5" from the end of the working section. The wedge angle of $7^{\circ}42'$ was chosen by designing centrebody C so that the diffuser free area at its trailing edge was the same as that at its leading edge. Centrebody D was the longest centrebody that could be satisfactorily supported in the diffuser. The pressure ratios measured with the four centrebodies are shown in Fig.4. These measurements were made at a Reynolds number, based on tunnel height of about 2.0×10^6. These results show that large gains in performance can be achieved by using a long single wedge centrebody forming a roughly constant area passage in the diffuser. The addition of a tail wedge appears to have no large effect on the performance.

For the second series of tests the centrebody was removed and the angle between the walls was reduced over the first 14" of the diffuser. Diffusers were made with equivalent conical semi-angles of this entry length of 0°, $0^{\circ}28'$, $0^{\circ}56'$ and $1^{\circ}37'$. At the end of the entry length all the diffusers expanded to the same exit cross-section area as the basic diffuser. A fixed converging entry was not considered practical for a diffuser required to operate at low supersonic speeds because of the risk of choking. The effect of these modifications on the pressure ratio is shown in Fig.5. These measurements were also made at a Reynolds number of 2.0×10^6. It appears from these results that decreasing the expansion rate over the entry length improves the efficiency at Mach numbers of 1.8 and above, the maximum efficiency being achieved with a constant area entry. At lower Mach numbers there is an optimum expansion rate, dependent on Mach number, for minimum pressure ratio.

Comparing the results of these two series of tests, the long single wedge centrebody modification gives a slightly better performance at the higher Mach numbers than the best modification to the diffuser walls only, and also avoids the penalty of a loss in efficiency at low Mach numbers.

4 The Design of the Balance Section with Quadrant

The basic steel shell, and the model support quadrant for the second balance section had been designed and were being manufactured at the time when the 4" x 4" tunnel diffuser tests were made, but the design was such that plywood walls were to be fitted to the shell to form the interior faces of the diffuser. As a result of the 4" x 4" tunnel tests it was decided that this section should be fitted with a long single wedge centrebody with the quadrant forming its leading edge. To reduce the risk of a loss in efficiency at low Mach numbers due to choking, it was decided to provide a slightly expanding passage up to the quadrant. A diagrammatic layout of this balance section is shown in Fig.6. The top and bottom walls are straight, but the sidewalls are kinked out to make the ratio of the diffuser free area at the shoulder of the quadrant to the working section area 1.05, the equivalent conical semi-angle being $0^{\circ}43'$ for this part of the diffuser. The wedge fairing provides the same free area at the downstream end of the section as at the leading edge of the quadrant, dividing the diffuser into two approximately constant area passages.

5 Tunnel Performance Measurements

The tunnel performance has been measured with both balance sections, and the results are shown in Fig.7 as the variation of pressure ratio with Mach number. The measurements were made at a Reynolds number, based on tunnel height of about 12×10^6. The pressure ratio shown is the minimum pressure ratio required to achieve or maintain fully supersonic flow in the working section. The minimum pressure ratio has been determined both with increasing and decreasing pressure ratio, and no evidence of hysteresis found. The pressure ratios shown for the balance section with quadrant were obtained with a conical fairing as shown in Fig.6, in place of a model and sting. A brief check has shown that with a model and sting at zero incidence, the minimum pressure ratios are reduced by about 0.01.

The results in Fig.7 show that a reduction in pressure ratio of 0.28 has been achieved at a Mach number of 2.00 by the use of the balance section with quadrant. At the lowest Mach number, 1.42, at which both sections were tested, the balance section with quadrant required a pressure ratio 0.04 higher than the calibration section.

Some idea of the effective blockage caused by the quadrant and wedge was obtained by measuring the choking Mach number when the tunnel was run empty with the flat subsonic nozzle. Under these conditions choking occurred not in the diffuser, but upstream of the working section, presumably due to overcorrection of the nozzle blocks for boundary layer growth, and it was found possible to obtain a working section Mach number of 1.07.

6 Conclusions

From the results of tests in a 4" × 4" supersonic tunnel it has been found that the efficiency of a straight walled divergent diffuser, operating at Mach numbers in the range 1.4 to 2.0 can be greatly improved by fitting a long single wedge centrebody to form a roughly constant area passage along the first diffuser stage. Slightly smaller gains in efficiency were achieved by reducing the angle between the walls at the diffuser entry.

A "balance section" (first diffuser stage) fitted with a quadrant type of model support system, and a long single wedge centrebody, has been designed for the 3 ft × 3 ft supersonic tunnel. Using this improved diffuser the pressure ratio needed to run the tunnel at a Mach number of 2.0 is reduced from 2.04, with the earlier balance section with calibration gear, to 1.76.

REFERENCE

No.	Author	Title, etc.
1	Morris, D. E.	Calibration of the flow in the working section of the 3 ft × 3 ft tunnel. National Aeronautical Establishment. C.P. 261, September 1954.

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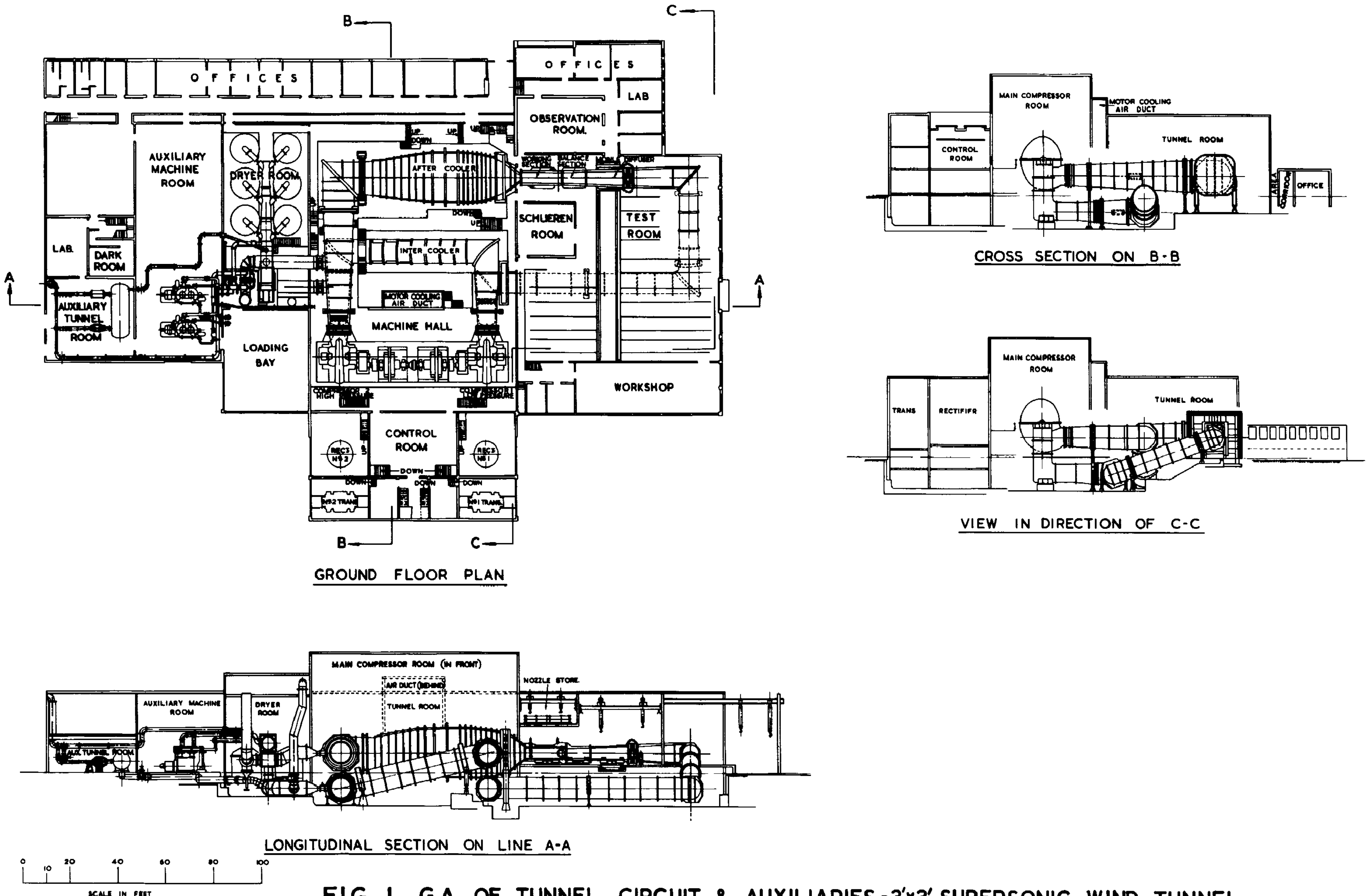


FIG. I. G.A. OF TUNNEL CIRCUIT & AUXILIARIES - 3'x3' SUPERSONIC WIND TUNNEL.

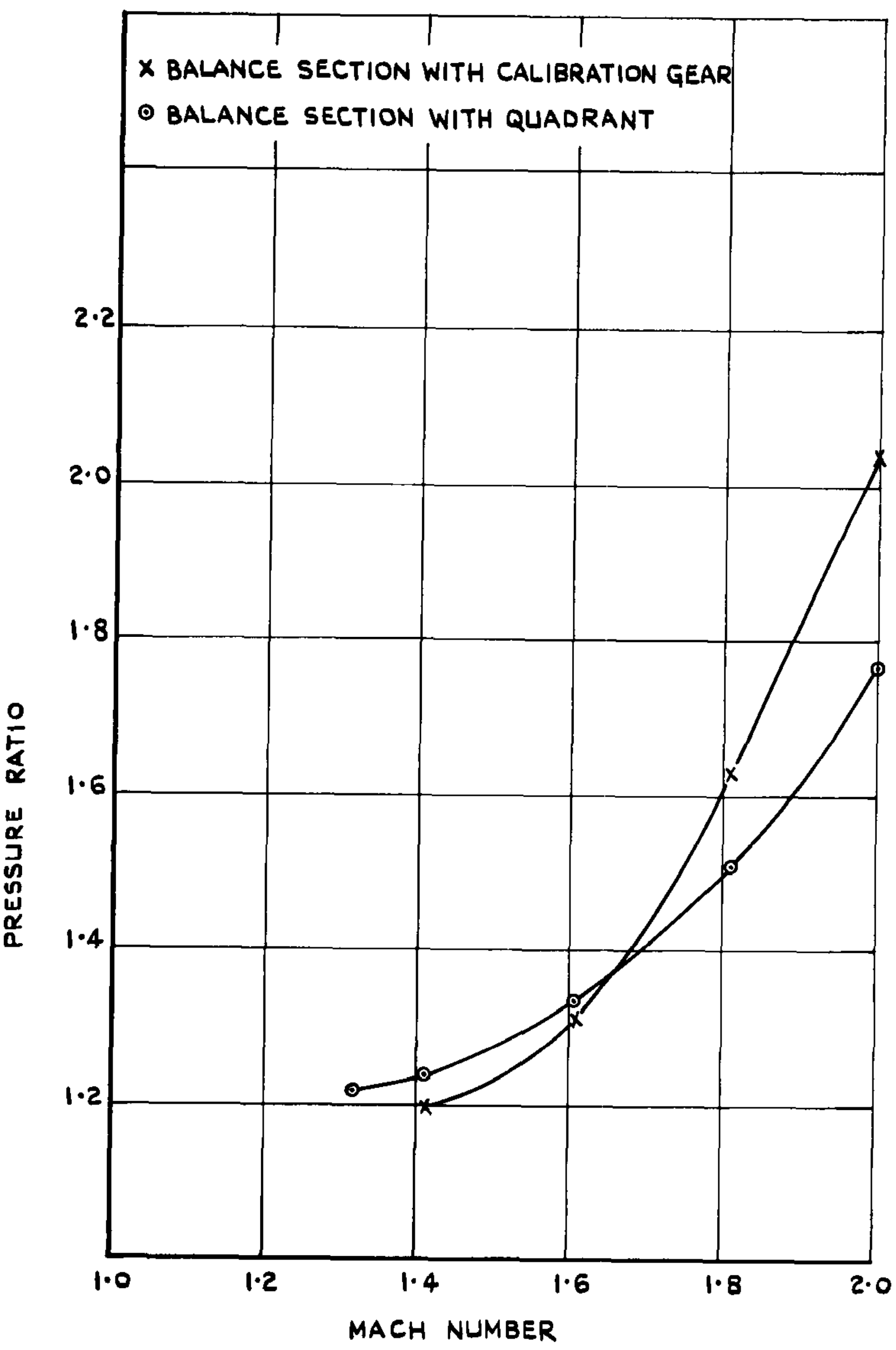


FIG. 7. TUNNEL PERFORMANCE MEASUREMENTS.
3 FT. X 3 FT. TUNNEL.

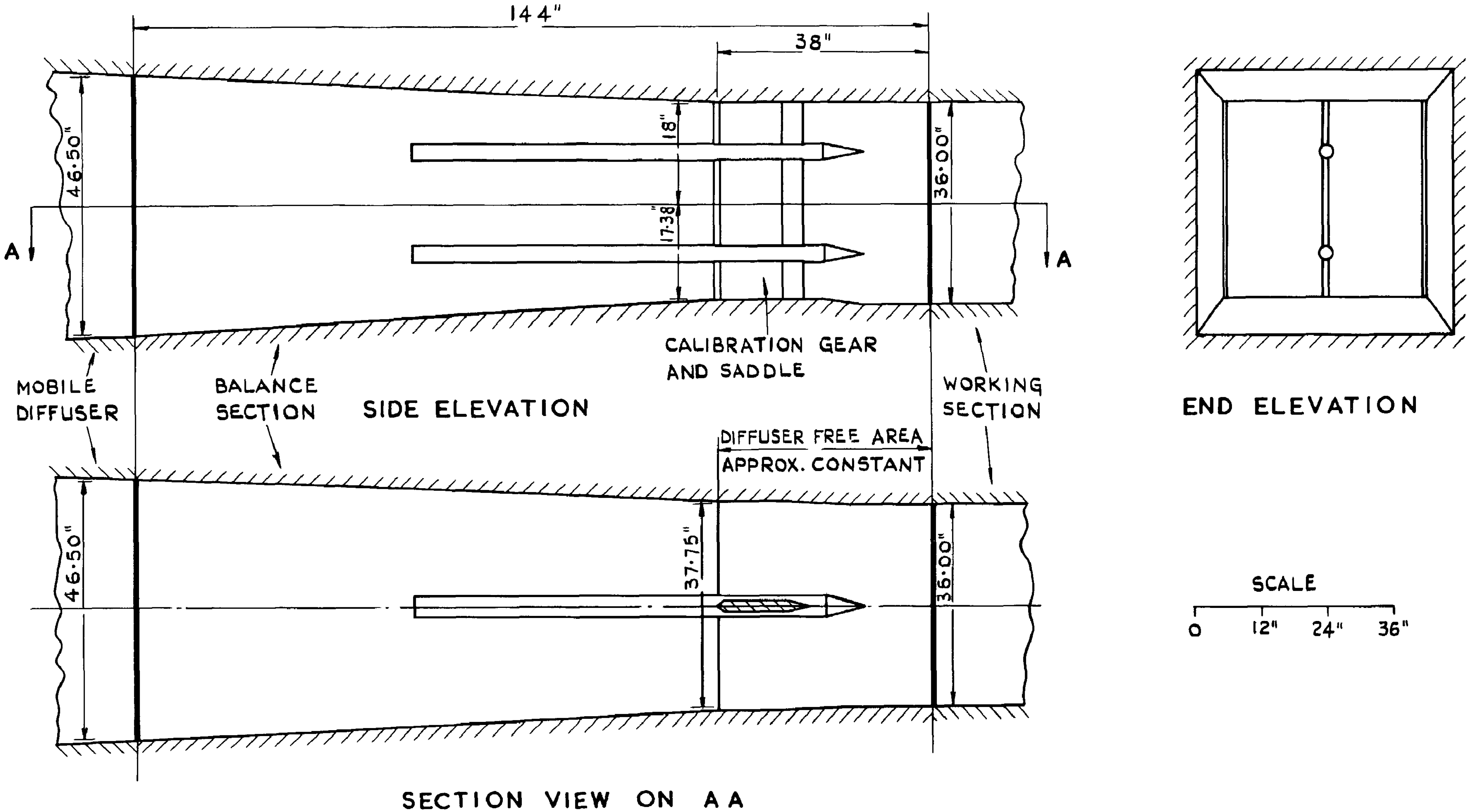


FIG. 2. DIAGRAMMATIC LAYOUT OF BALANCE SECTION WITH CALIBRATION GEAR.

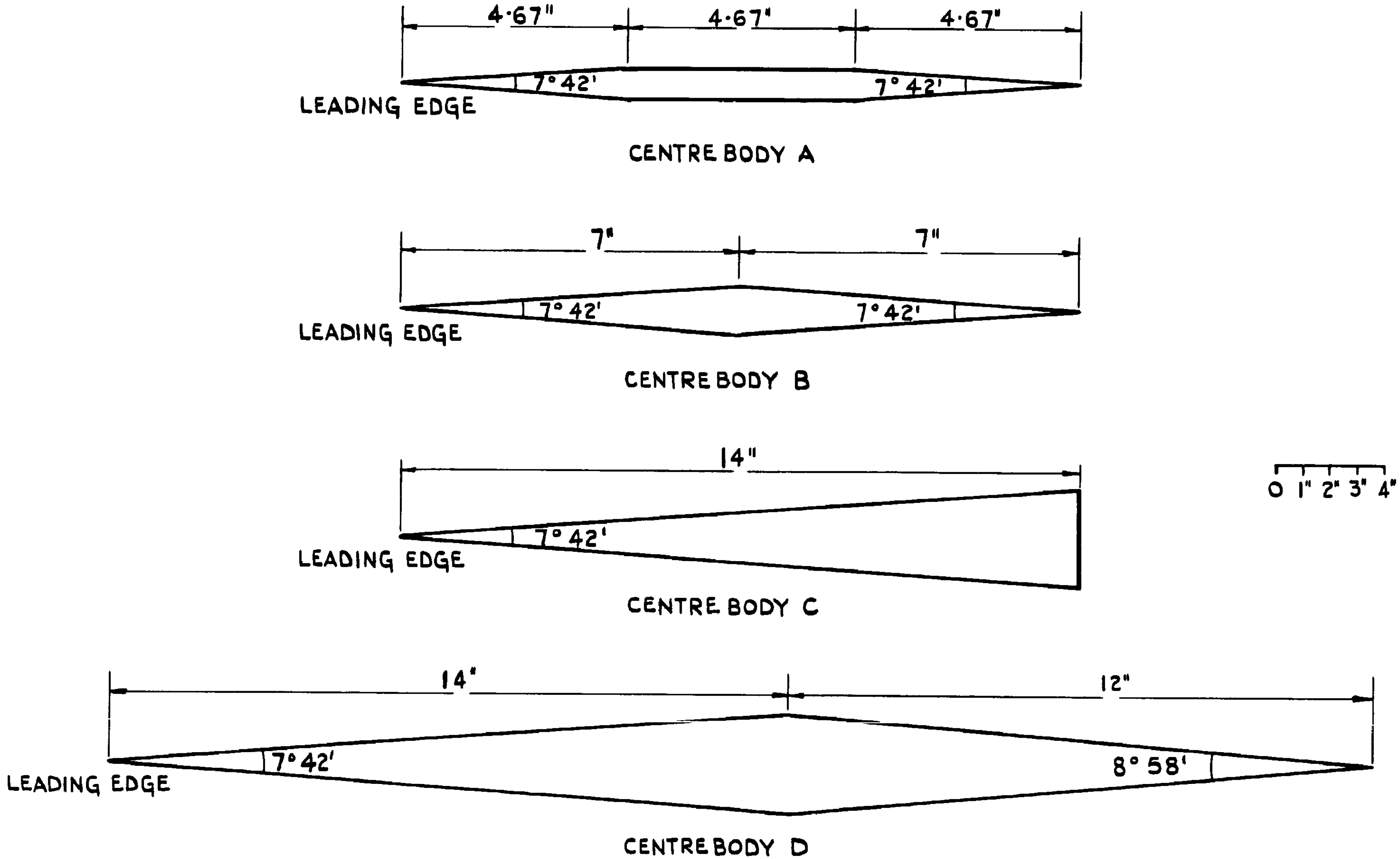
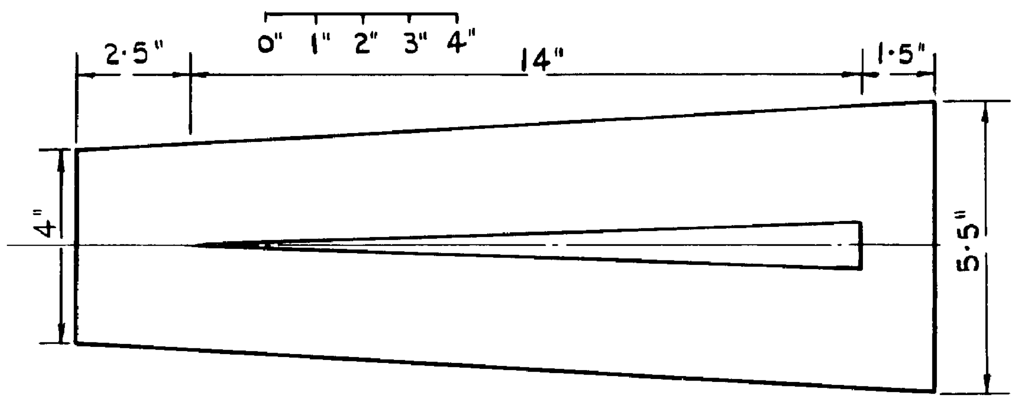


FIG. 3. DETAILS OF CENTRE BODIES USED FOR TESTS IN 4" X 4" TUNNEL.



PLAN VIEW OF DIFFUSER WITH CENTRE BODY C

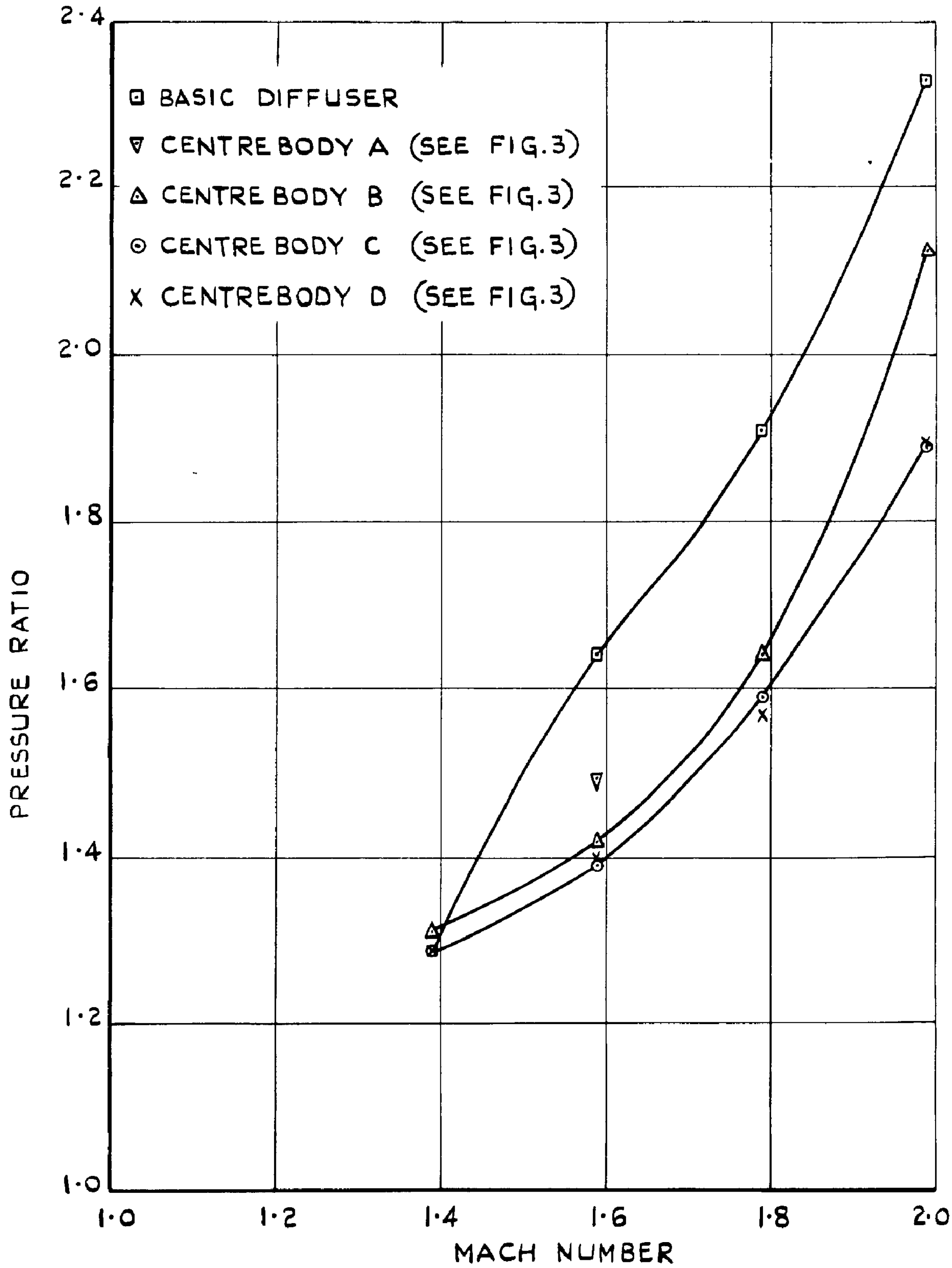
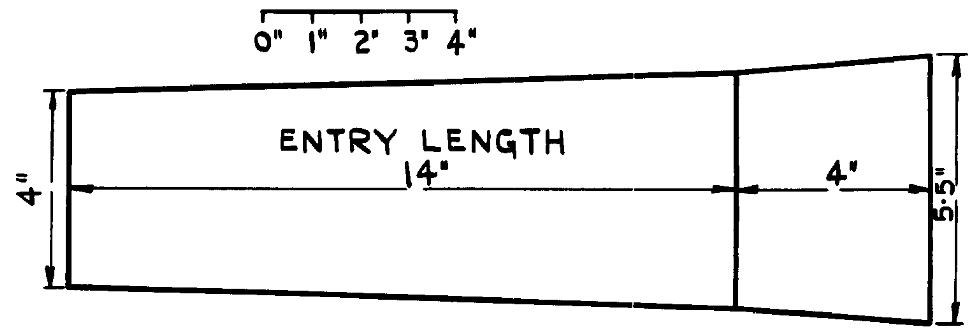


FIG.4. EFFECT OF CENTREBODIES ON DIFFUSER PERFORMANCE 4" x 4" TUNNEL.



PLAN VIEW OF DIFFUSER WITH 1° 37' ENTRY ANGLE

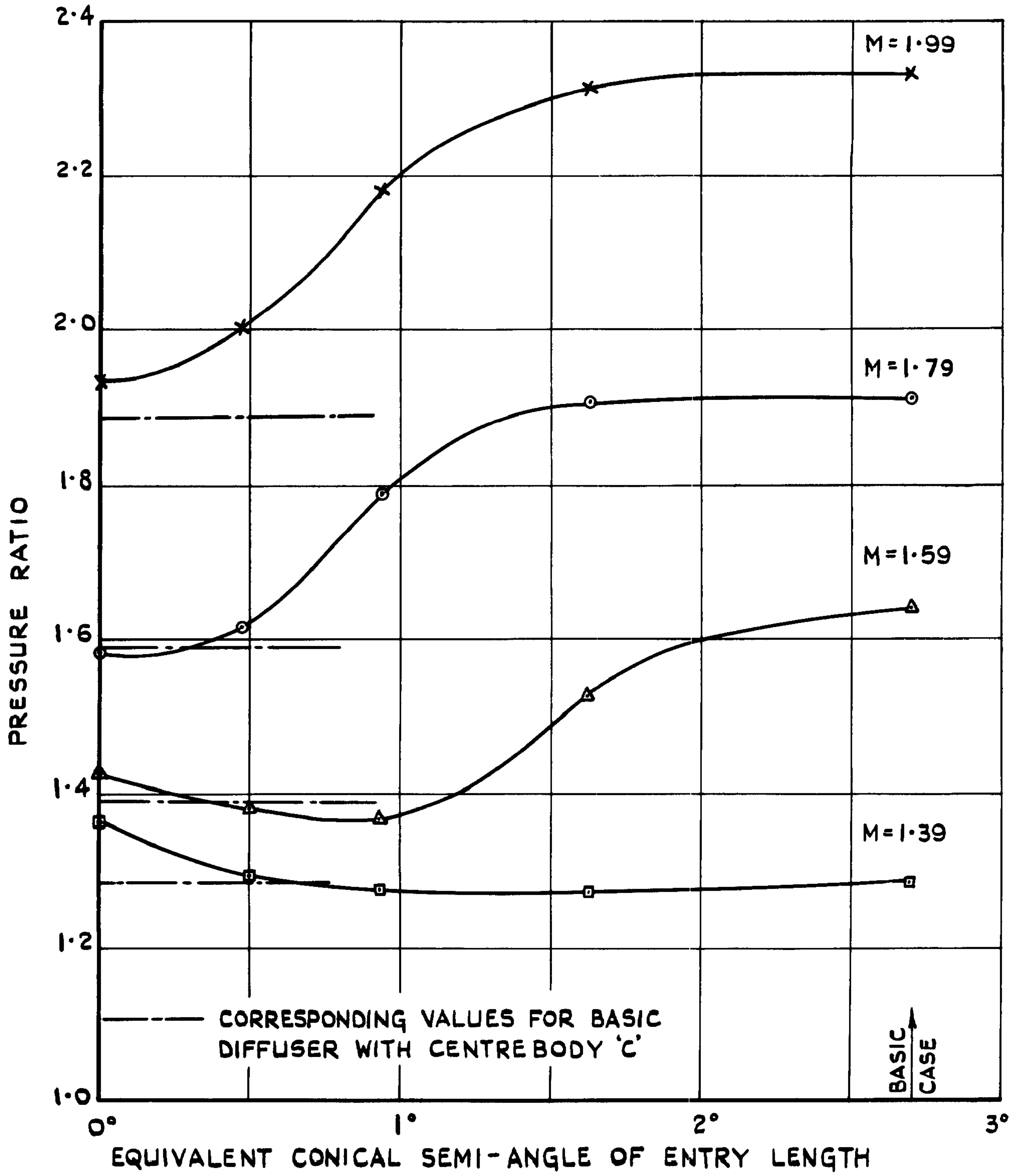


FIG. 5. EFFECT OF EQUIVALENT CONICAL SEMI-ANGLE ON DIFFUSER PERFORMANCE 4" X 4" TUNNEL.

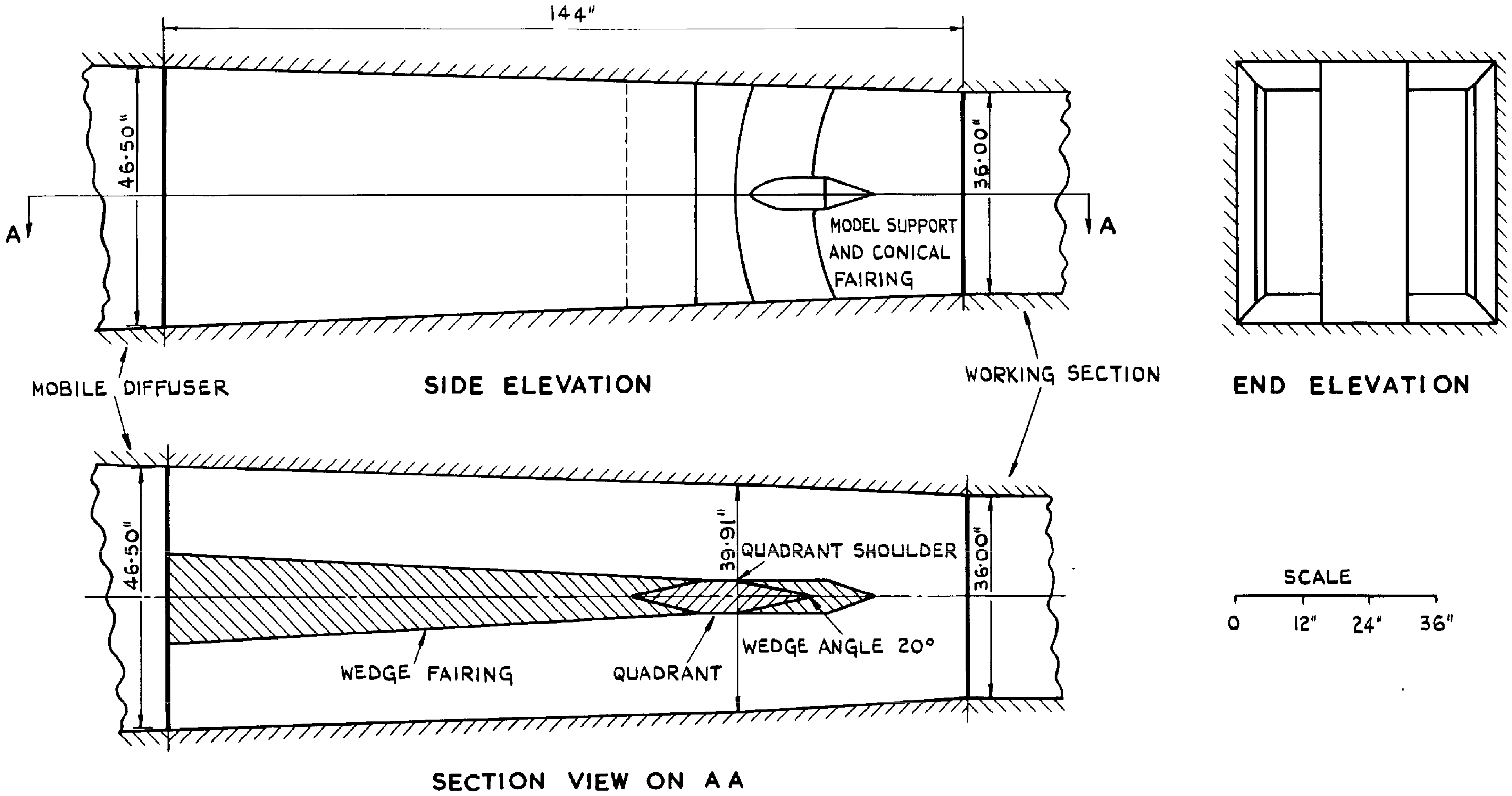


FIG.6. DIAGRAMMATIC LAYOUT OF BALANCE SECTION WITH QUADRANT.

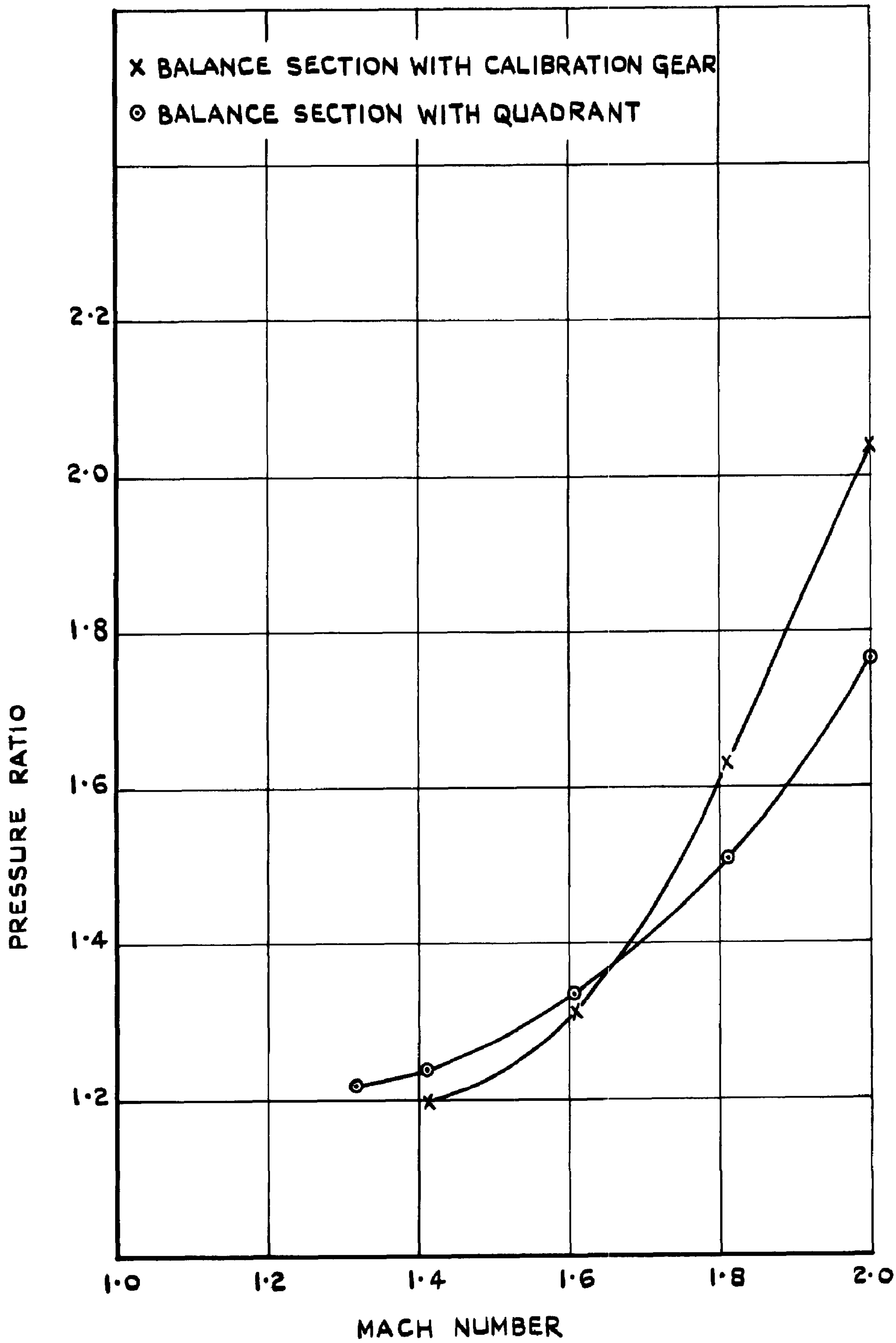


FIG. 7. TUNNEL PERFORMANCE MEASUREMENTS.
3 FT. X 3 FT. TUNNEL.

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