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by

C. A. K. Irwin

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CHARACTERISTICS OF HIGH-SPEED WIND TUNNELS IN THE UNITED KINGDOM RELEVANT TO AEROELASTIC-MODEL TESTS

by

C. A. K. Irwin

SUMMARY

Operational and performance details are given of high-speed wind tunnels in the United Kingdom of working section sizes of about 6 inches × 6 inches or greater. The main objective is to provide the information needed to assess the suitability of these tunnels for investigations with aeroelastic models.

Replaces R.A.E. Tech. Report No.65147 A.R.C.27413

CONTENTS

1 INTRODUCTION

This document has been compiled at the request of the Ministry of Aviation Flutter and Vibration Committee. It is intended to provide sufficient of the operational and performance details of high subsonic, transonic, supersonic and hypersonic wind tunnels in the United Kingdom to enable the relative merits of the existing tunnels of suitable size to be assessed in the light of any particular requirement for aeroelastic tests. The minimum size has been taken as a working section of about 6 inches x 6 inches.

2 ARRANGEMENT OF DATA

The data were obtained by sending questionnaires to the tunnel operators. In presenting the information the tunnels have been divided into three groups as follows:-

(i) High-subsonic tunnels and transonic tunnels.
(ii) Supersonic tunnels.
(iii) Hypersonic tunnels.

Supersonic speeds have been taken arbitrarily as greater than M = 1·3 and less than M = 5. Hypersonic speeds are assumed to be at Mach numbers of 5 and over. Tunnels which operate over more than one of these ranges of speed are included in the first group into which their capabilities fall and are entered in the Index (Section 6) in all of the relevant groups. Many hypersonic tunnels have very short useful running times and only those with times greater than 0·01 sec have been included. For all intermittent tunnels the running times are given. The groups of high-subsonic tunnels and transonic tunnels, and supersonic tunnels have been sub-divided into continuously running and intermittent tunnels.

In each group or sub-division of a group the tunnels have been arranged in descending order of nominal working-section cross-sectional area; in some cases the actual dimensions vary with Mach number.

One page has been allotted to each tunnel. At the head are given the Mach numbers at which the tunnel can be operated.

Safety aspects are summarised by indicating whether the tunnel operators considered that the tunnel would suffer significant damage following the disintegration of high-speed aeroelastic models of conventional design; that is, having light alloy skins of thickness not greater than about 0·015 in with a light foam-plastic core and possibly some very light section metal spars.

Total pressures P_o, are quoted with any variation with Mach number. Where there is a variation it is illustrated by a graph. Controlled rates of change of total pressure with time dP_o/dt, are given where these are known. In general, where P_o is variable at a fixed Mach number, and provided that the running time is sufficient, it is possible to use the test procedure in which the run starts at a low value of P_o and the pressure is subsequently raised; it should be noted, however, that in some tunnels the required starting pressure is higher than $P_{o_{min}}$.

In the majority of tunnels the total temperature is nominally ambient temperature, but in a continuously running tunnel the temperature tends to rise with time, eventually reaching an equilibrium value dependent upon the cooling provided. In a blowdown tunnel the temperature tends to fall, although there may be a brief rise initially due to compression in the pipelines and settling chamber[1]. Where these details are known they are given under the heading T_o.

The methods of model mounting are self-explanatory. The incidence of the model can be changed during a run unless otherwise stated, and where sidewall, roof or floor mounting is available this is indicated under "wall mounting".

The times to commence a run and to shut down and gain access to the model give some indication of the additional tunnel time required if a test technique including frequent model modifications or substitutions is used. In assessing overall tunnel time additional time must be allowed in a blowdown or suckdown tunnel, particularly at the beginning of a series of tests, for the pumping of air into the high-pressure reservoir and/or out of the vacuum chamber. The pumping time is related to the stagnation pressure or pressure ratio required and the running time, and may increase very considerably for a small increase in any of these. Typical running times are given for the intermittent tunnels.

Any additional information which may be of use in assessing the suitability of a tunnel for testing aeroelastic models is included under the "Remarks" heading. Experience of dynamic response tests and flutter tests is mentioned, and, where this is known, an indication is given of the level of random model excitation of aerodynamic or mechanical origin. Although few detailed investigations of unwanted vibration appear to have been made it must be borne in mind that, in general, this lack of information implies that the effects of random excitation have not been significant in the type of work for which a tunnel has been used rather than that they are virtually non-existent. In some tunnels with slotted sections large wall interference effects have been found under oscillatory conditions for models that are relatively free from interference under steady conditions. The explanation for this interference has not yet been determined. Evidence of these effects has been found from measurements in N.P.L. tunnels[2], and a note that the effects have been investigated is made under "Remarks" for the tunnels concerned.

In assessing the suitability of a wind tunnel for a given task, and the model design requirements, two of the main tunnel characteristics to be considered are the kinetic pressure ($\frac{1}{2}\rho V^2$) of the tunnel flow and the stream density. For reference purposes, Fig.1 shows the tunnel total pressure required using a model with a structural stiffness scale of unity* for simulating flight at altitudes up to 60000 ft over the Mach number range M = 0 to M = 6 (based on the I.C.A.O. standard atmosphere); Fig.2 gives the variation with Mach number of the density in the working section (at total temperatures 300°K, 350°K and 400°K) for total pressures of 1 atmosphere absolute to 5 atmospheres absolute.

Section 6 contains an index of tunnels divided into groups and arranged in order of nominal working section size. An indication is given of whether slotted or perforated working section walls are provided for transonic running.

Finally, it should be noted that the inclusion in this survey of any particular tunnel does not imply that it will necessarily be made available for aeroelastic investigations.

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*A model that is geometrically similar in structure to an aircraft, and is built of the same materials, has unity stiffness scale.

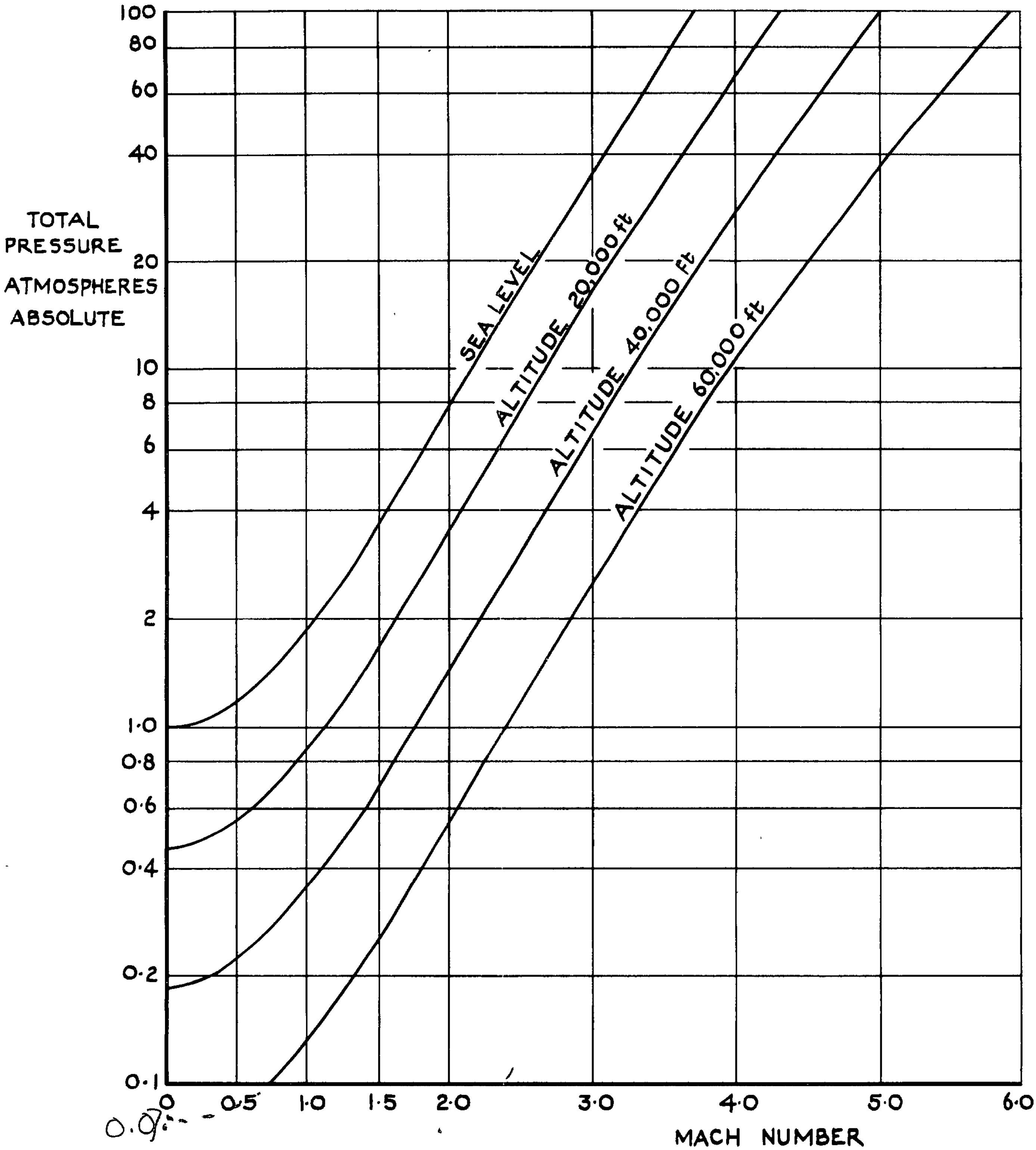
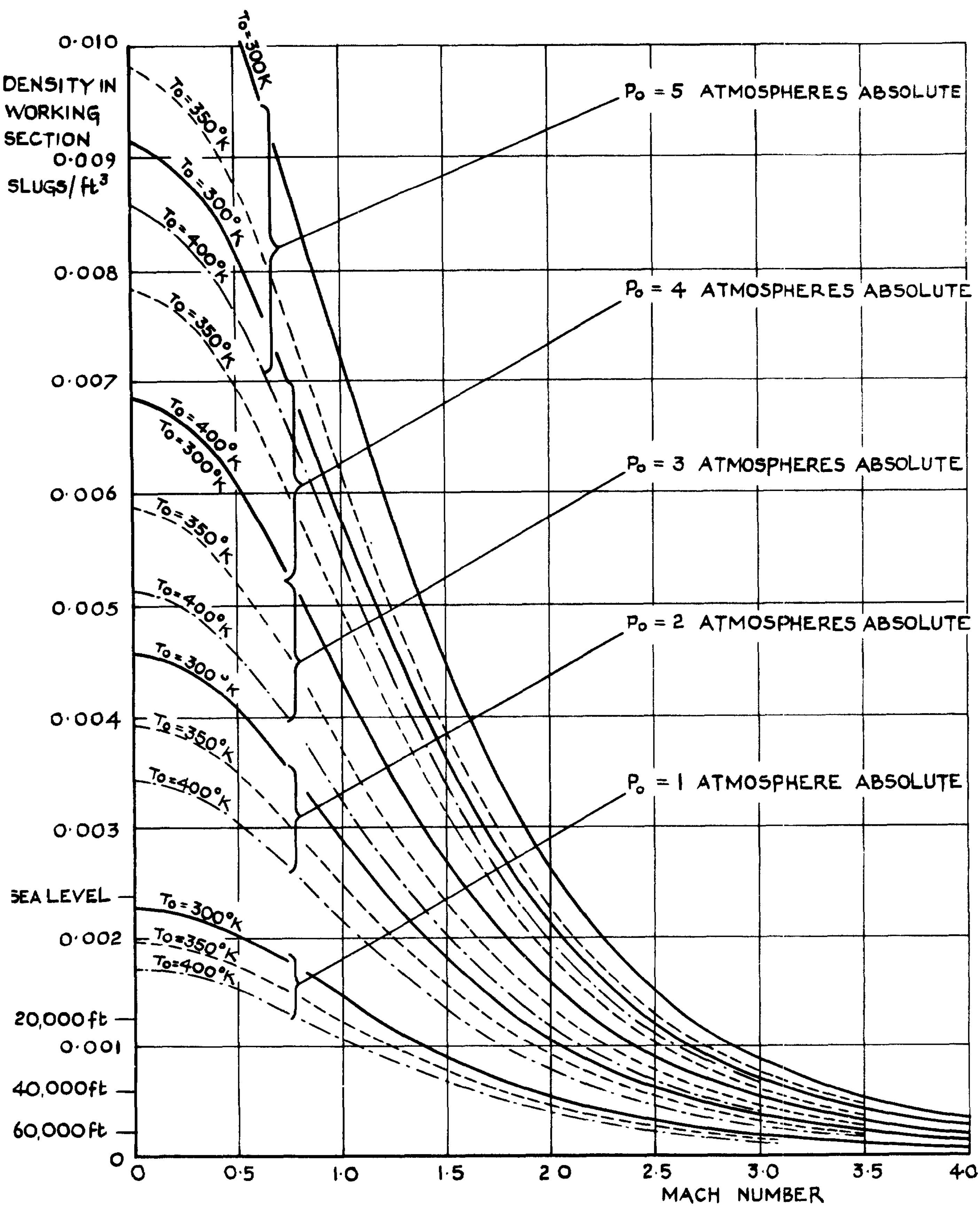


FIG.1 TOTAL PRESSURE REQUIRED FOR FLIGHT SIMULATION WITH A MODEL OF STRUCTURAL STIFFNESS SCALE UNITY



BASED ON N.A.C.A REPORT 1135 AND I.C.A.O. STANDARD ATMOSPHERE

FIG. 2 VARIATION OF DENSITY IN THE WORKING SECTION WITH MACH NUMBER FOR TOTAL PRESSURES OF 1 TO 5 ATMOSPHERES ABSOLUTE AND TOTAL TEMPERATURES 300°K, 350°K, 400° K

3 HIGH-SUBSONIC TUNNELS AND TRANSONIC TUNNELS

3.1 Continuously running tunnels

3.1.1 Tunnel: Transonic tunnel

Mach numbers: 0·2–1·45 (flexible nozzle with perforated working section)

Location: Aircraft Research Association Ltd., Bedford

Working section: 9 ft × 8 ft

Safety: Flutter tests acceptable (see Section 2)

P_o : 0·80 – 1·20 atm abs over the whole Mach number range (see Fig.3)

dP_o/dt : Time to increase from 0·8 atm abs to 1·0 atm abs, 10 min
Time to increase from 1·0 atm abs to 1·2 atm abs, 10 min
Time to decrease from 1·2 atm abs to 1·0 atm abs, 1 min
Time to decrease from 1·0 atm abs to 0·8 atm abs, 5 min

T_o : $T_{o_{max}}$, 316°K at M = 0·3 rising to 328°K at M = 0·49, then constant at 328°K at M = 0·49 – 1·45 (see Fig.3)

$T_{o_{min}}$, 294°K at M = 0·3 rising to 303°K at M = 1·0, and to 310°K at M = 1·45. Temperature can be controlled to within approximately ±2°C

Sting mounting: Yes with roll by remote control

Wall mounting: Yes, floor

Time to commence run: Approximately
5 min at M = 0·95,
8 min at M = 1·4

Time to shut down and open tunnel for access to model : Approximately 10 min

Remarks: Dynamic response and flutter tests have been made over the whole speed range of the tunnel. Models are subjected to random excitation, probably aerodynamic in origin, and this has been significant in some tests.

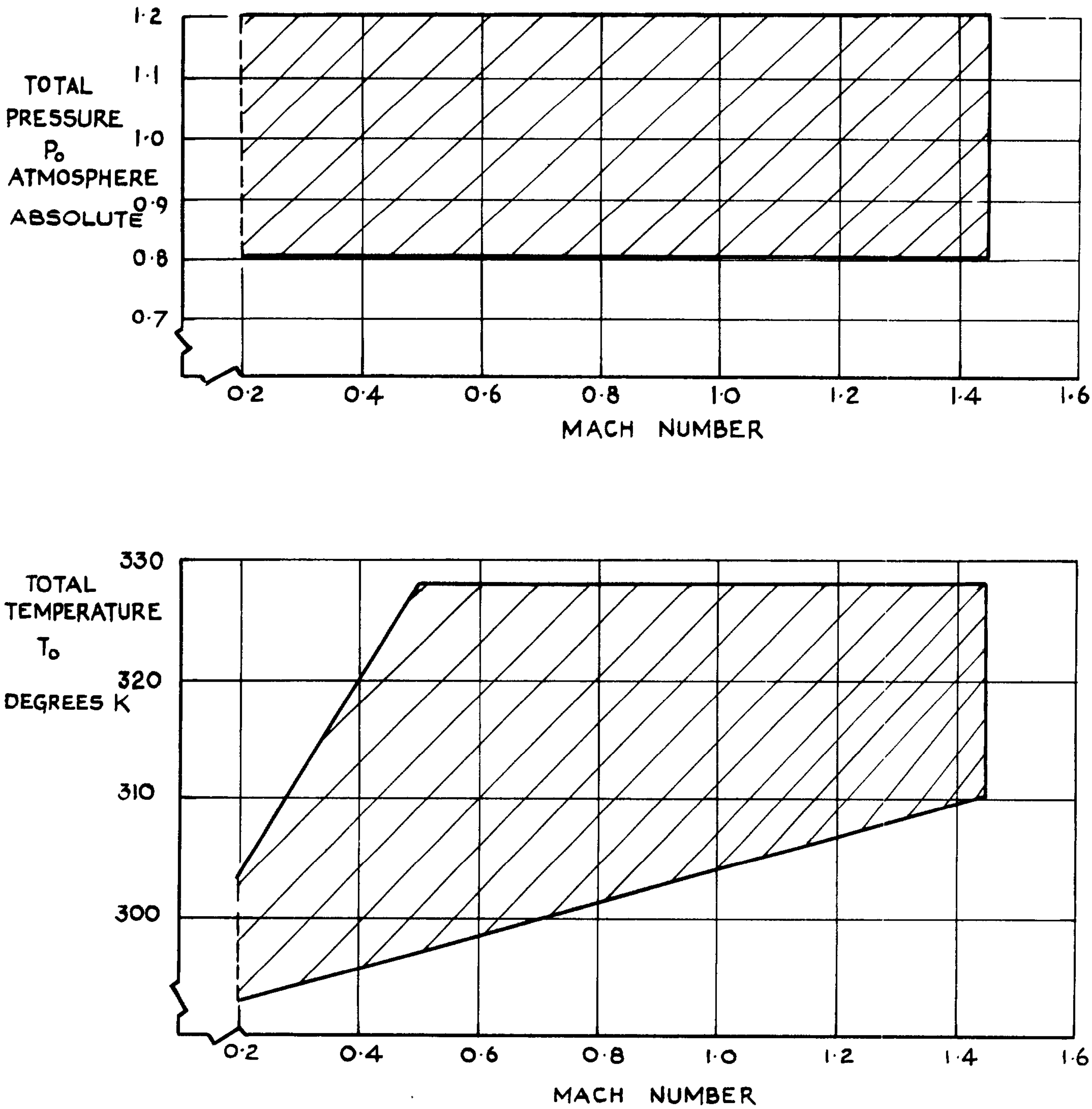


FIG. 3 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. AIRCRAFT RESEARCH ASSOCIATION LTD., 9ft x 8 ft

3.1.2 Tunnel: 8 ft

Mach numbers: 0-2·8, not transonic (flexible nozzle)

Location: R.A.E. (Bedford)

Working Section: 8 ft × 8 ft

Safety: Flutter model tests are not acceptable (see Section 2 and Remarks)

P_o: Range 0·1 atm abs to 4 atm abs for M = 0 to M = 0·5, range reducing to 0·1 atm abs to 0·8 atm abs at M = 2·8 (see Fig.4)

dP_o/dt: Maximum rate is approximately 1 atmosphere in 15 min.

T_o: Normally 313°K. Can be increased to about 318°K, or reduced to about 298°K dependent on tunnel pressure and weather conditions. Temperature can be controlled at a slow rate over this range.

Sting mounting: Yes, with remote control of roll.

Wall mounting: Yes

Time to commence a run: $\frac{3}{4}$ hour to start and reach steady conditions.

Time to shut down and open tunnel for access to model: about $\frac{1}{2}$ hour.

Remarks: The tunnel is driven by a 10-stage axial flow compressor which is vulnerable to model debris. Present H.T. steel safety net has 2 inch square mesh. Finer meshes of acceptably low drag have been found to have a short fatigue life.

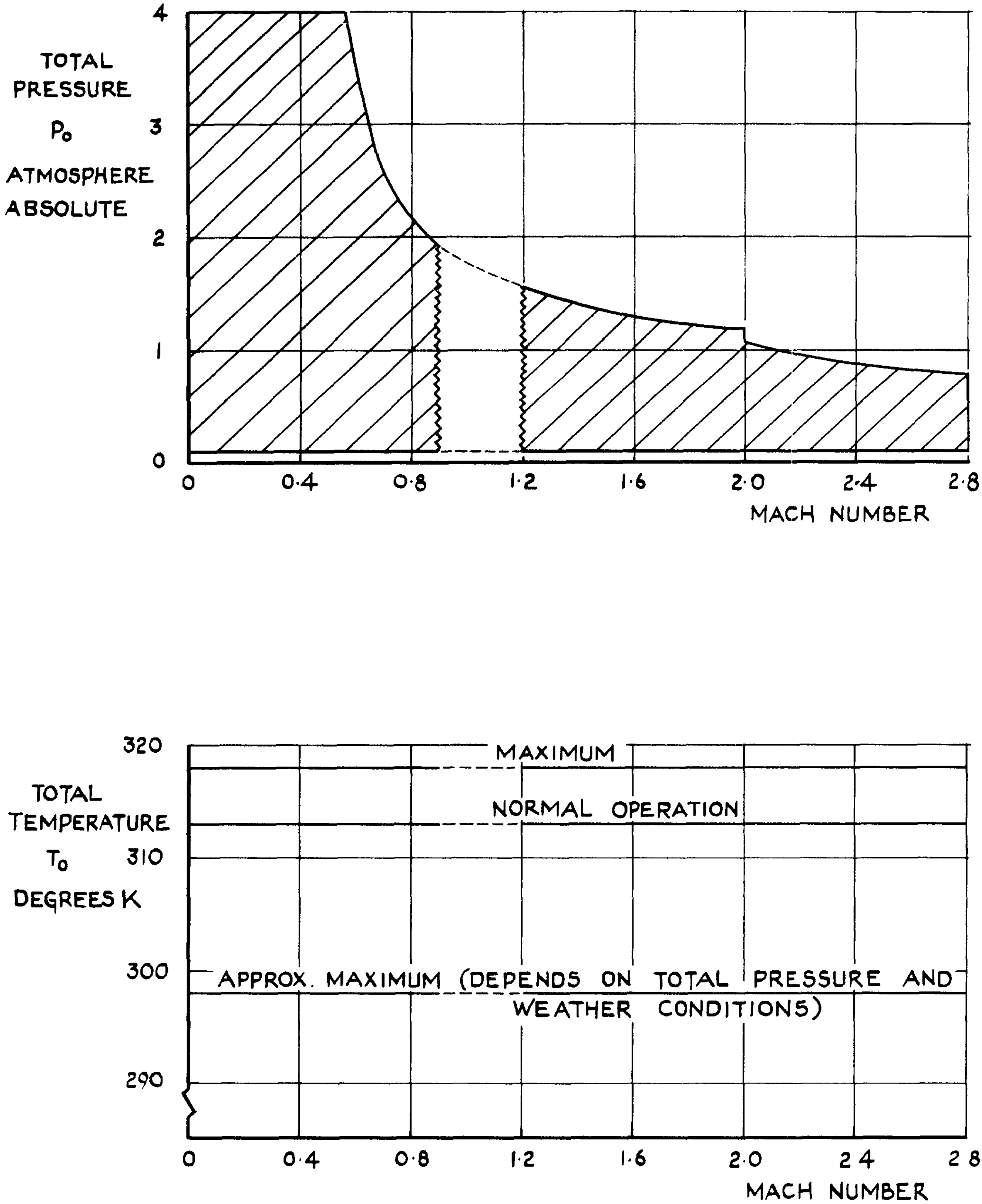


FIG. 4 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.E (BEDFORD) 8 ft x 8 ft

3.1.3 Tunnel: 8 ft × 6 ft

Mach numbers: 0-1.28 (slotted)

Location: R.A.E. (Farnborough)

Safety: Flutter tests not acceptable (see Section 2 and Remarks below)

Working Section: 8 ft × 6 ft

P_o: $P_{o_{max}}$ = 3·5 atm abs for M = 0 - 0·4, (See Fig.5)

$P_{o_{max}}$ = 0·87 atm abs at M = 1·28

$P_{o_{min}}$ = 0·10 atm abs at all M

At present, due to a temporary fairing round the model support, the total pressure is limited so that the kinetic pressure does not exceed 500 lb ft^{-2}.

dP_o/dt: Over most of the pressure range the maximum rate of pressure change is about 0·024 atmospheres per minute.

T_o: Normal operating temperatures are as follows:

$$M = 0\text{-}0{\cdot}4, \quad T_o = 292^\circ K - 298^\circ K \quad \text{(see Fig.5)}$$

$$M = 0{\cdot}8 \text{ and above}, \quad T_o = 323^\circ K$$

The maximum allowable total temperature is 328°K and at M ⩾ 0·8 almost the maximum circulation of coolant (brine) is required to keep T_o below this level. The temperature is, therefore, confined to a narrow range. At lower M some variation of temperature is possible through the coarse control provided by the circulation of the coolant.

Sting mounting: Yes, with remote control of roll, in the range -90° to +90°, and incidence, in the range -4° to +20°.

Wall mounting: Yes

Time to commence run: Evacuating or pressurising tunnel, up to 1 hour; starting and reaching speed 5 minutes.

Time to shut down and open tunnel for access to model: Shut down, 3 minutes; releasing vacuum or pressure and opening tunnel doors, up to 1 hour.

Remarks: The fan is immediately downstream of the working section and extremely difficult to protect. At all Mach numbers the model is subject to some random excitation depending upon the model configuration, etc. Periodic pressure fluctuations are present at the fan blade frequency up to M = 0·8.

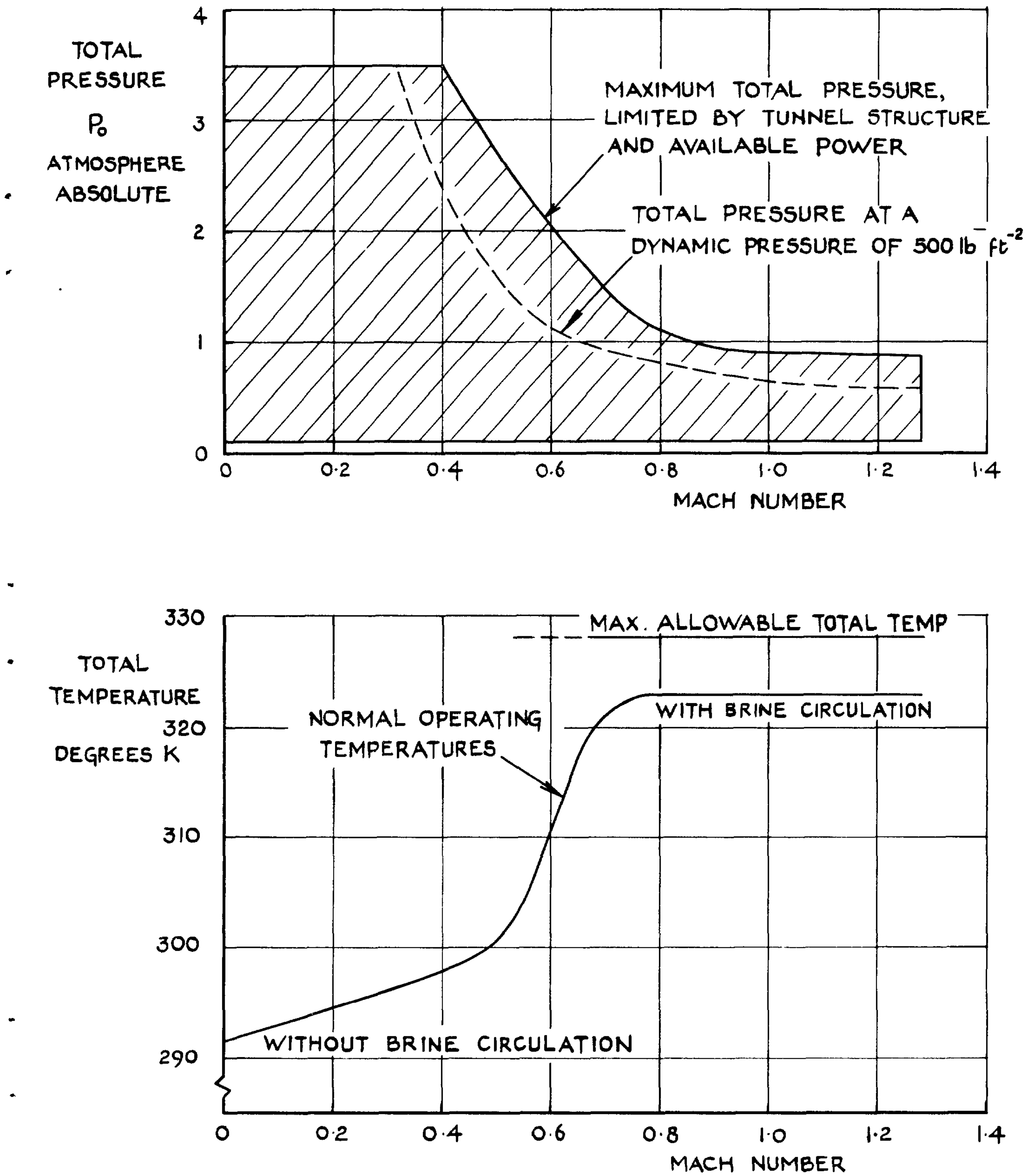


FIG. 5 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.E (FARNBOROUGH) 8 ft x 6 ft

3.1.4 Tunnel: High speed tunnel

Mach numbers: 0·2-1·0, empty tunnel (solid walls)

Location: Handley Page Ltd., Colney Street, St. Albans.

Working Section: 4 ft × 3 ft

Safety: Flutter tests acceptable (see Section 2 and Remarks below)

P_o: Atmospheric

dP_o/dt: No controlled variation possible; total pressure equals atmospheric pressure.

T_o: 288°K nominal. Control by valve giving a coarse pre-run adjustment for 328°K to 358°K approximately (independent of Mach number above M = 0·6). Temperature varies with time after a cold start, see Fig.6.

Sting mounting: Yes. Incidence and roll preset

Wall mounting: Underfloor mounting for half-models

Time to commence a run: 10-15 sec

Time to shut down and open tunnel for access to model: 30-45 sec.

Remarks: Speed control by manual variation of engine rpm for M = 0 - 0·6 and by second throat for M > 0·6.
Tunnel is of the induction type and part of the exhaust flow is recirculated to raise the total temperature. For flutter tests it would be desirable to fit a wire guard over the recirculation intake to prevent model debris lodging in the system.

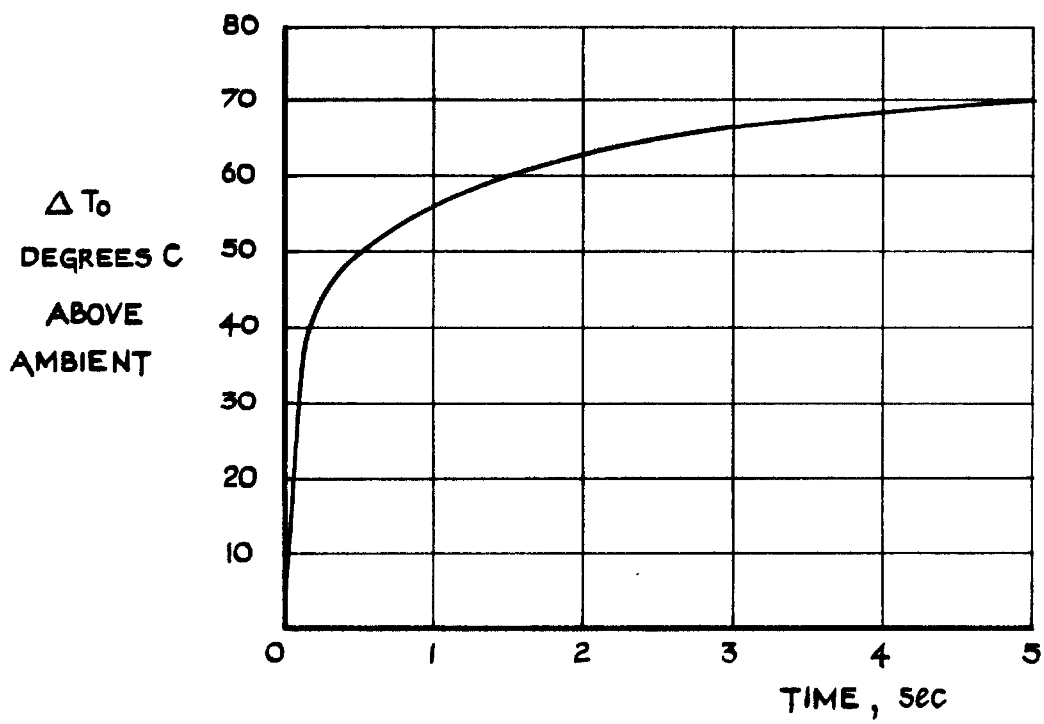


FIG. 6 VARIATION OF TOTAL TEMPERATURE WITH TIME AFTER A COLD START.
HANDLEY PAGE LTD., 4ft x 3ft H.S.T.

3.1.5 Tunnel: 3 ft

Mach numbers: 0·4 – 1·3 (slotted walls, see Remarks), then in 0·1M steps to M = 2·0 (fixed liners). Can also be run subsonically with solid walls.

Location: R.A.E. (Bedford)

Working Section: 3 ft × 3 ft

Safety: Flutter tests acceptable (see Section 2)

P_o: $P_{o_{max}}$ = 2 atm abs for M = 0 – 0·8, then falling linearly to 0·9 atm abs at M = 2·0

$P_{o_{min}}$ = 0·1 atm abs (see Fig.7)

dP_o/dt: Decrease pressure from 1 atm abs to 0·345 atm abs in 10 min
Decrease pressure from 0·345 atm abs to 0·1 atm abs in 10-15 min
Increase pressure from 1 atm abs to 2·0 atm abs in 10 min
(depends on motor load and air driers)

T_o: Nominal maximum 325°K. Coolers maintain the range 305°K – 325°K (see Fig.7)

Sting mounting: Yes. In some cases roll possible with tunnel running.

Wall mounting: Yes

Time to commence a run: 5 – 25 min depending on working conditions.

Time to shut down and open tunnel for access to model: 8 – 23 min depending on working conditions.

Remarks: With slotted walls vibration is intense above 150 c/s over the range M = 0·7 – 0·9; small at frequencies below 150 c/s. Noise can be reduced by using solid walls up to M = 0·8.

There are four separate working sections available:

(a) 36 inches × 36 inches (solid wall) for supersonic and subsonic running which can be used for either sting or sidewall mounted models.

(b) 36 inches × 35 inches (slotted wall) for transonic speeds up to M = 1·3, for sting mounted models only.

(c) and (d) Two sections 36 inches × 27 inches approximately (slotted wall) for sting or wall mounted models.

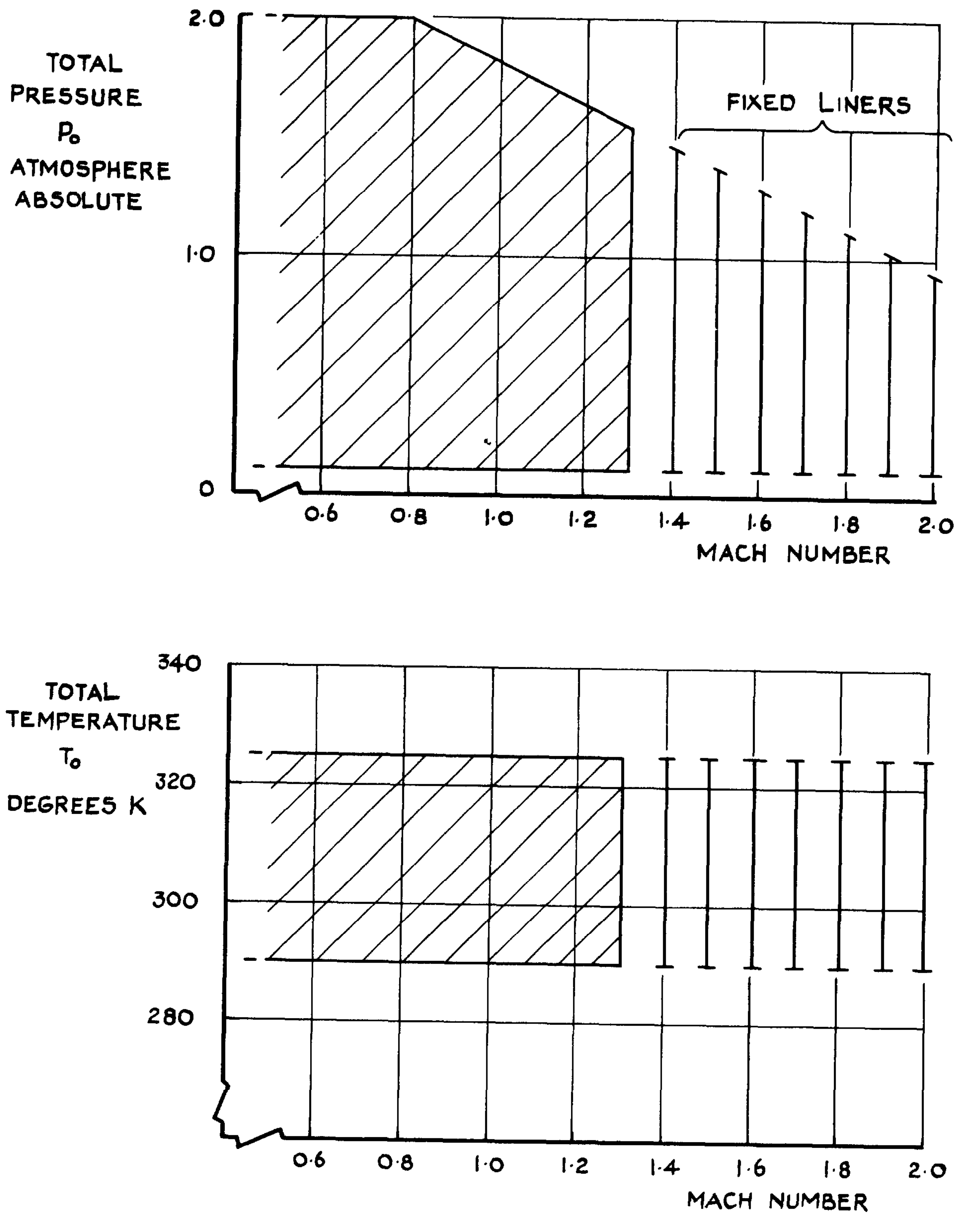


FIG. 7 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.E (BEDFORD), 3 ft x 3 ft

3.1.6 Tunnel: High speed wind tunnel

Mach numbers: 0·3–1·2 (slotted)

Location: Short Bros. and Harland, Queen's Island, Belfast.

Working Section: $2\frac{1}{2}$ ft × $2\frac{1}{2}$ ft

Safety: Flutter tests acceptable (see Section 2)

P_o: Atmospheric

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Temperature can be controlled between 288°K (nominal) and 378°K at any Mach number.

Sting mounting: Incidence, −5° to +20°
Roll, −90° through 0° to +90°
Both by remote control

Wall mounting: Yes

Time to commence run: 3 min

Time to shut down and open tunnel for access to model: 1 min.

Both of these times are the minima for M = 1·2. Slightly less for lower M.

Remarks: Models are subject to some excitation, which is almost certainly aerodynamic in origin. Frequencies have not been determined.

3.1.7 Tunnel: High speed tunnel

Mach numbers: 0·3-1·3 (slotted), 1·4, 1·6 (fixed liners, see Remarks)

Location: Hawker Siddeley Aviation Ltd. (de Havilland Div.)

Working Section: 2 ft × 2 ft

Safety: Flutter tests acceptable (see Section 2)

P_o: Atmospheric

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient to ambient +160°C approximately; the lower limit is determined by the requirement that condensation should not occur in the airstream (Fig.8). There is a coarse manual control.

Sting mounting: Yes, with remote roll control.

Wall mounting: Yes

Time to commence a run: 1-2 min if a steady temperature is not required within the model balance.

Time to shut down and open tunnel for access to model: Approximately 1 min.

Remarks: A range of ±0·05M can be obtained by tilting the supersonic liners. Turbulence levels measured during buffet tests were appreciably lower than those in the 3 ft × 3 ft tunnel at Bedford (see Section 3.1.5).

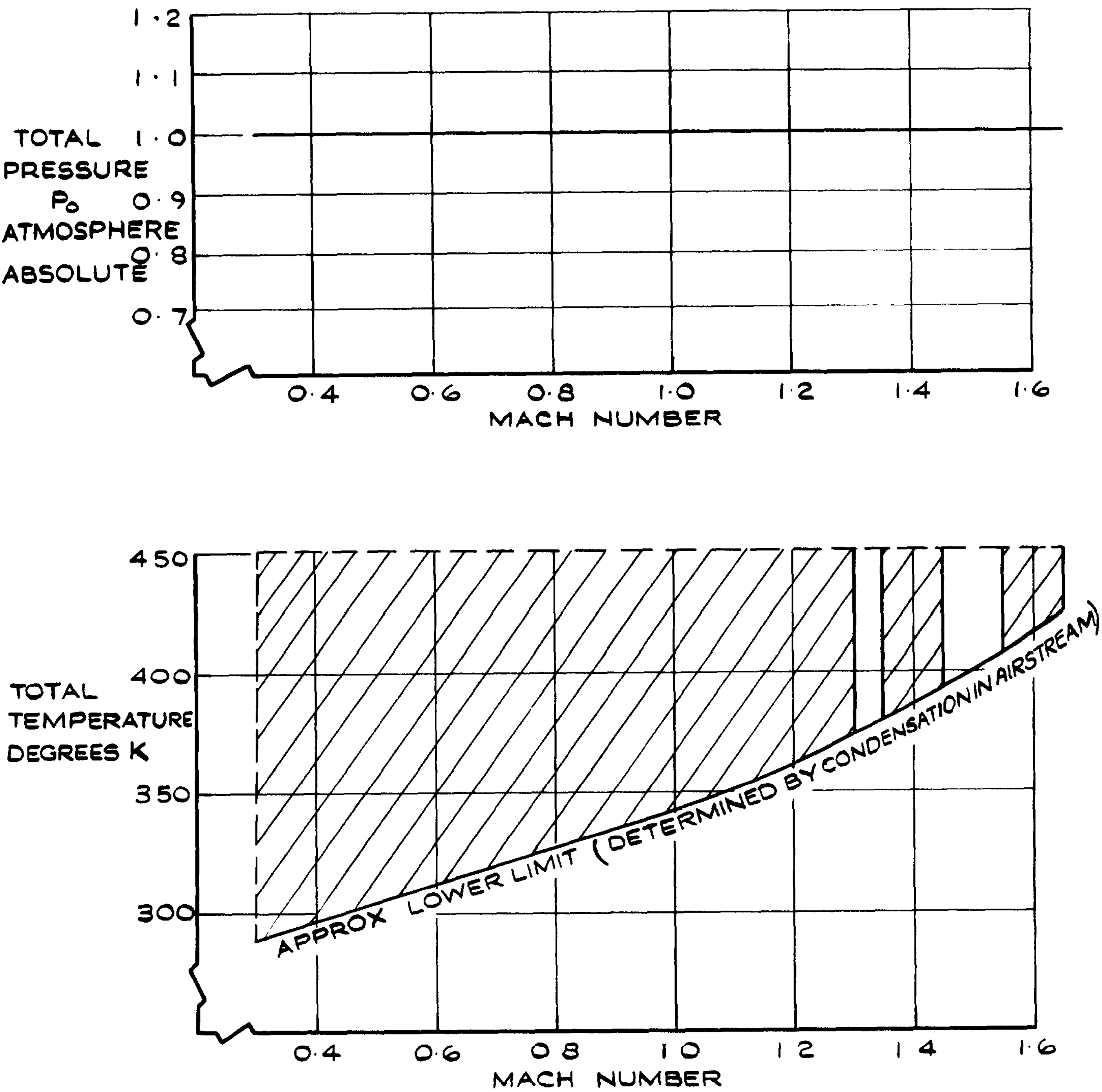


FIG. 8 TOTAL PRESSURE AND RANGE OF TOTAL TEMPERATURE OVER MACH NUMBER RANGE. HAWKER SIDDELEY AVIATION LTD. (de HAVILLAND DIV.), 2 ft x 2 ft H.S.T.

3.1.8 Tunnel: 10,000 HP continuous

Mach numbers: 0·3-1·3 (slotted), 1·4, 1·56, 1·90, 2·50, 2·96 (fixed liners)

Location: Hawker Siddeley Dynamics Ltd. (Coventry)

Working Section: 22 inches x 20 inches transonic, varying down to 16 inches x 14·5 inches at M = 3·0

Safety: Flutter tests acceptable (see Section 2)

P_o: Minimum, 0·25 atm abs.
Maximum depends on Mach number (see Fig.9)

dP_o/dt: Increasing P_o, 0·7 atmospheres/minute (maximum).
Decreasing P_o, 0·15 atmospheres/minute at atmospheric pressure.

T_o: Temperature can be controlled within the range 288°K - 313°K approximately, independent of Mach number.

Sting mounting: Yes

Wall mounting: Yes, floor.

Time to commence a run: 1 minute or longer depending upon operating conditions.

Time to shut down and open tunnel for access to model: 5 minutes or longer depending upon operating conditions.

Remarks:

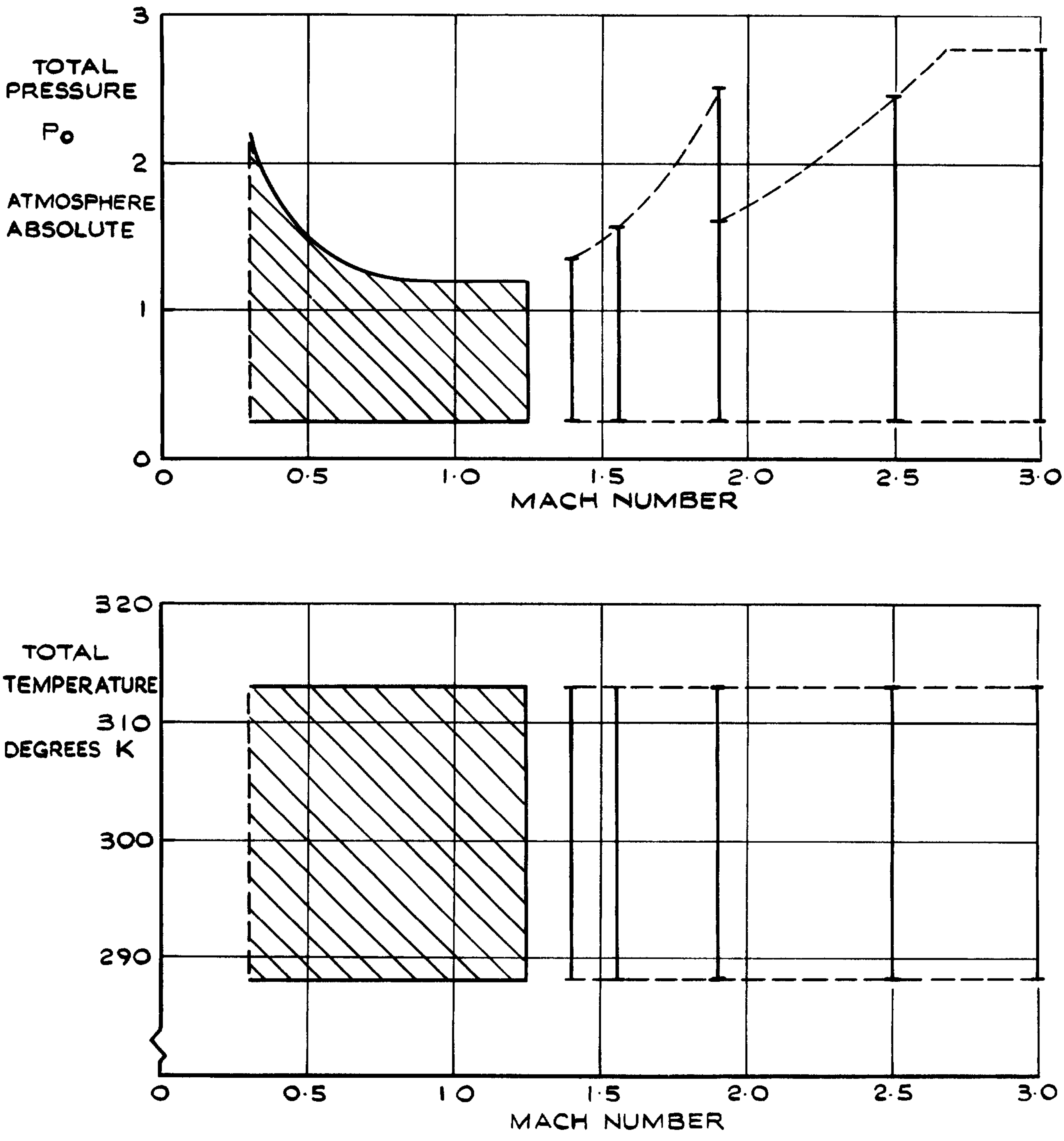


FIG.9 RANGES OF TOTAL PRESSURE AND TOTAL TEMPERATURE OVER MACH NUMBER RANGE. HAWKER SIDDELEY DYNAMICS LTD/ COVENTRY., 10,000 H.P. CONTINUOUS

3.1.9 Tunnel: By-pass tunnel

Mach numbers: 0·3–1·35 (solid or slotted sidewalls, slotted or perforated roof and floor)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 2 ft × 1½ ft

P_o: Minimum 0·2 atm abs. Maximum 0·9 atm abs at M = 0·4
0·67 atm abs at M = 0·8
0·5 atm abs at M = 1·3
(see Fig.10)

dP_o/dt: Typical rates are P_o decreased from 1·0 atm abs to 0·5 atm abs in 5 min approximately, and P_o increased from 0·5 atm abs to 1·0 atm abs in 4 min approximately.

T_o: From about ambient to 303°K over the range M = 0·8 to M = 1·35. The temperature increases slowly during a run and cannot be controlled.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes

Time to commence a run: 10 minutes.

Time to shut down and open tunnel for access to model: 10 minutes.

Remarks: This tunnel is driven by the same plant as the 8 ft × 6 ft transonic tunnel. Some acoustic excitation is present which becomes relatively more intense as speed is lowered from M = 0·7.

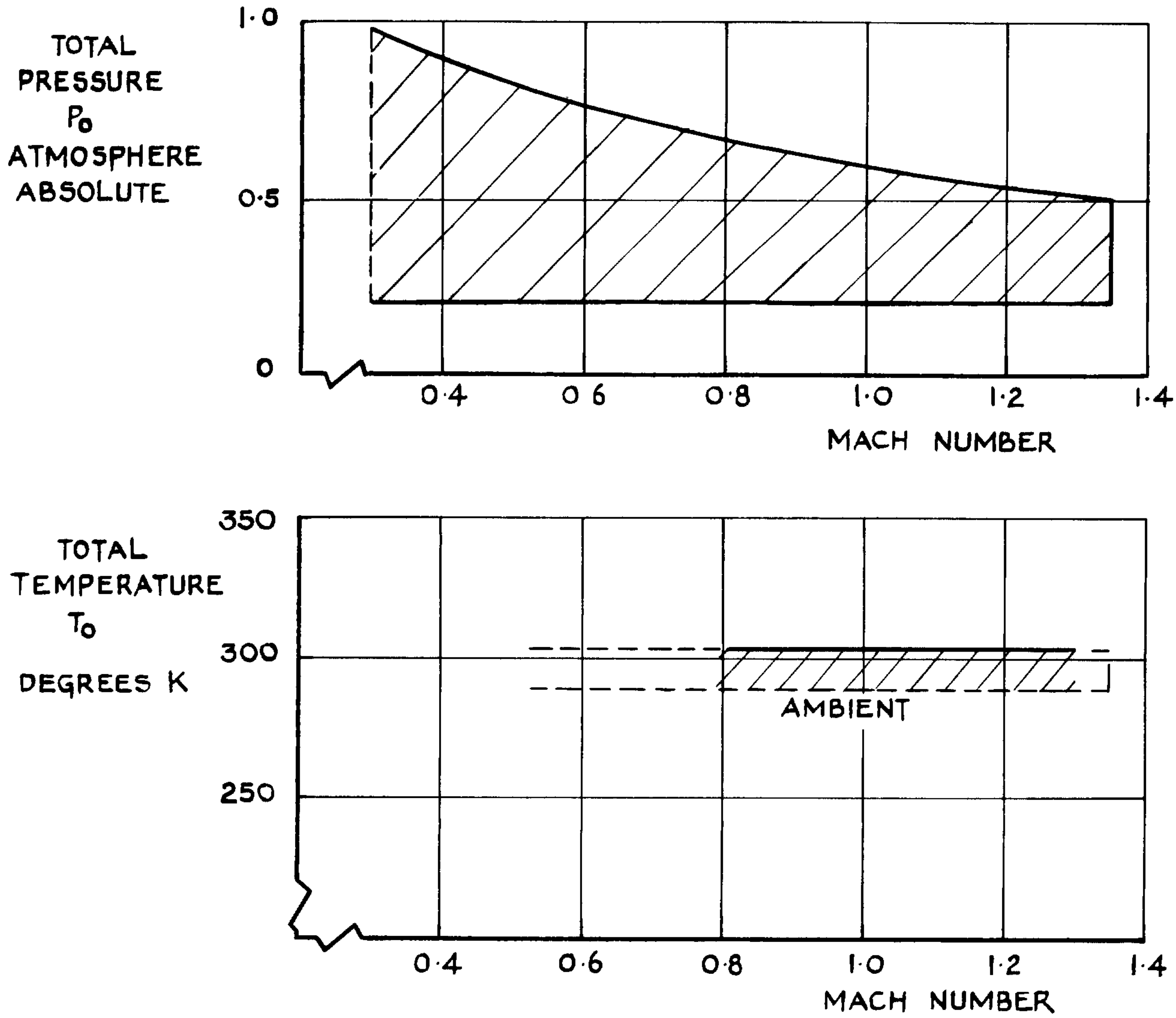


FIG. 10 RANGES OF TOTAL PRESSURE AND TOTAL TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (FARNBOROUGH), 2 ft x $1\frac{1}{2}$ ft BY-PASS TUNNEL

3.1.10 Tunnel: Transonic wind tunnel

Mach numbers: 0·6–1·15 (slotted), 1·3, 1·4, 1·5 (fixed liners)

Location: Hawker Siddeley Aviation Ltd. (Woodford Div.)

Working Section: 20 inches × 20 inches reducing to 20 inches × 14 inches at M = 1·5.

Safety: Flutter tests acceptable (see Section 2)

P_o:

M	$P_{o_{min}}$	$P_{o_{max}}$
0·6 to 1·15	1 atm abs	2·0 to 1·5 atm abs
1·3	1 atm abs	1·8 atm abs
1·4	1 atm abs	1·65 atm abs
1·5	1 atm abs	1·5 atm abs

The values of $P_{o_{max}}$ are estimated (see Remarks and Fig.11).

dP_o/dt: 1 atmosphere in 3 sec

T_o: Ambient temperature.

Sting mounting: Yes

Wall mounting: Yes

Time to commence a run: 3 sec for operation at 1 atm abs.

Time to shut down and open tunnel for access to model: 3 sec to shut down, 30 sec to open tunnel.

Remarks: This is an induced flow tunnel with adjustable vents to atmosphere in the closed return circuit. By adjusting the vents the stagnation pressure may be varied within the limits shown above. The tunnel has so far not been required to run at pressures above $P_{o_{min}}$.

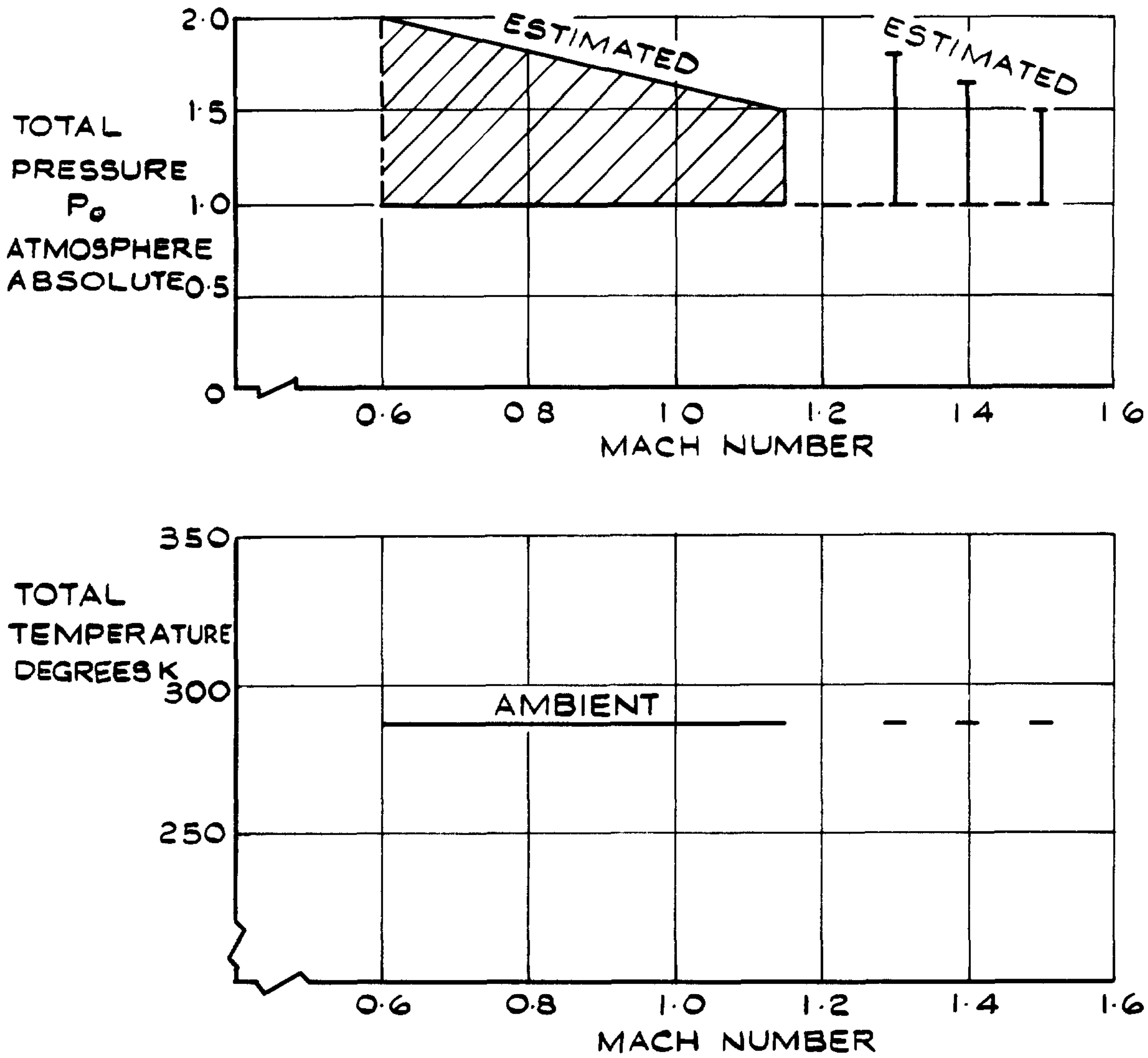


FIG.11 TOTAL PRESSURE RANGE AND TOTAL TEMPERATURE OVER MACH NUMBER RANGE. HAWKER SIDDELEY AVIATION LTD. (WOODFORD DIV), 20 in x 20 in TRANSONIC TUNNEL

3.1.11 Tunnel: 18 inches × 18 inches

Mach numbers: 0·5–1·15 (slotted) 1·4, 1·6 (fixed liners)

Location: British Aircraft Corporation (Operating) Ltd. (Preston Div), Warton.

Working Section: 18 inches × 18 inches.

Safety: Flutter tests acceptable (see Section 2)

P_o: Atmospheric

dP_o/dt: No controlled variation possible; total pressure equals atmospheric pressure.

T_o: At M = 0·6 $T_{o_{max}}$ = 340°K; at M = 1·15 $T_{o_{max}}$ = 386°K; at M = 1·6 $T_{o_{max}}$ = 400°K. The practical lower limit of temperature is determined by condensation in the airstream (see Fig.12). Temperature can be controlled to within ±5°C.

Sting mounting: Yes. Double-cranked sting to give yaw in 1° increments to ±5°. Fixed roll angles only.

Wall mounting: Yes, sidewall.

Time to commence run: To start engines and reach test Mach number, 3 min. To reach working temperature, up to 15 min longer.

Time to shut down and open tunnel for access to model: Less than 1 min.

Remarks: Experience indicates considerable random aerodynamic excitation; actual levels have not been measured. For a typical balance mounted model a dominant frequency is 1st order sting bending (20-30 c/s).

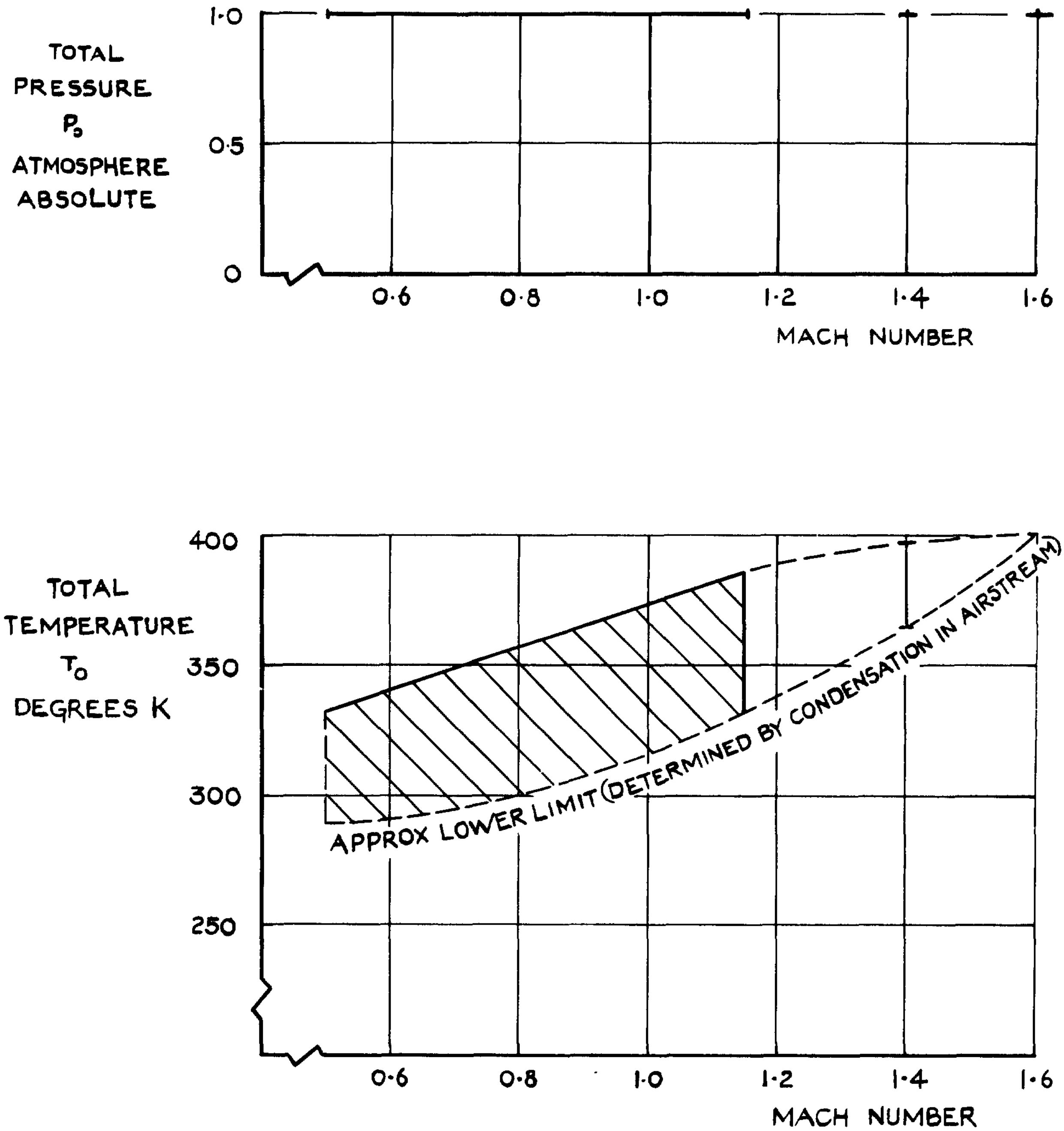


FIG. 12 TOTAL PRESSURE AND RANGE OF TOTAL TEMPERATURE WITH MACH NUMBER. BRITISH AIRCRAFT CORPORATION (OPERATING) LTD. (PRESTON DIV.), 18 in x 18 in

3.1.12 Tunnel: No.2 air intake rig

Mach numbers: 0-1·5, 0-1·8 (both slotted) fixed liners up to 5·2 (see Working Section).

Location: Bristol Siddeley Engines Ltd., Bristol

Safety: Flutter tests acceptable (see Section 2 and Remarks)

Working Section: Nozzles of the following exit dia:-

9 inch dia and 12 inch dia M = 0 to M = 1·5
3·75 inch dia M = 0 to M = 1·8

In the range 7·0 inch dia to 7·9 inch dia M = 1·5, 1·6, 1·7, 1·9, 2·0, 2·1, 2·25, 2·4, 2·5, 2·55, 2·7, 2·85, 3·0, 3·2

6·18 inch dia M = 3·6, 3·8, 4·0, 4·2, 4·4, 4·8, 5·2
12 inch dia M = 2·2, 2·4, 2·6
16·5 inch dia M = 2·2, 2·5

also 12·13 inch dia M = 1·51, 10·5 inch dia M = 1·6, 1·7, 1·8, 11·4 inch dia M = 20.

P_o: See Fig.13. At M > 3·2 high pressure nitrogen is added to the compressor output.

dP_o/dt: 1 -3 lb in^{-2} sec^{-1} for M = 1·5 to M = 3·2
10 lb in^{-2} sec^{-1} for M = 3·6 to M = 5·5.

T_o: Total temperature depends on the mass flow. For M ≤ 3·2, T_o lies within the range 320°K to 720°K and some control is available.

For M ≥ 3·6 the temperature cannot be controlled, and lies in the range 310°K to 420°K (see Fig.13).

Sting mounting: Yes, with preset incidence. No roll.

Wall mounting: Yes

Time to commence run: M ≤ 3·2, 3 minutes.
M ≥ 3·6, 10 seconds.

Time to shut down and open tunnel for access to model:
M ≤ 3·2, 1 minute,
M ≥ 3·6, 10 seconds.

Running time: The tunnel is continuously running at M ≤ 3·2; at M > 3·2 the running time varies between 1 min and 3 min depending on Mach number.

Remarks: This is a specialised free-jet tunnel for testing air intakes. The flow is generally not of interest behind the intake plane of the model and so the working section is short. At Mach numbers above about 2 annular diffusers are used to start the tunnel; it would probably not be possible to use this system in testing flutter models.

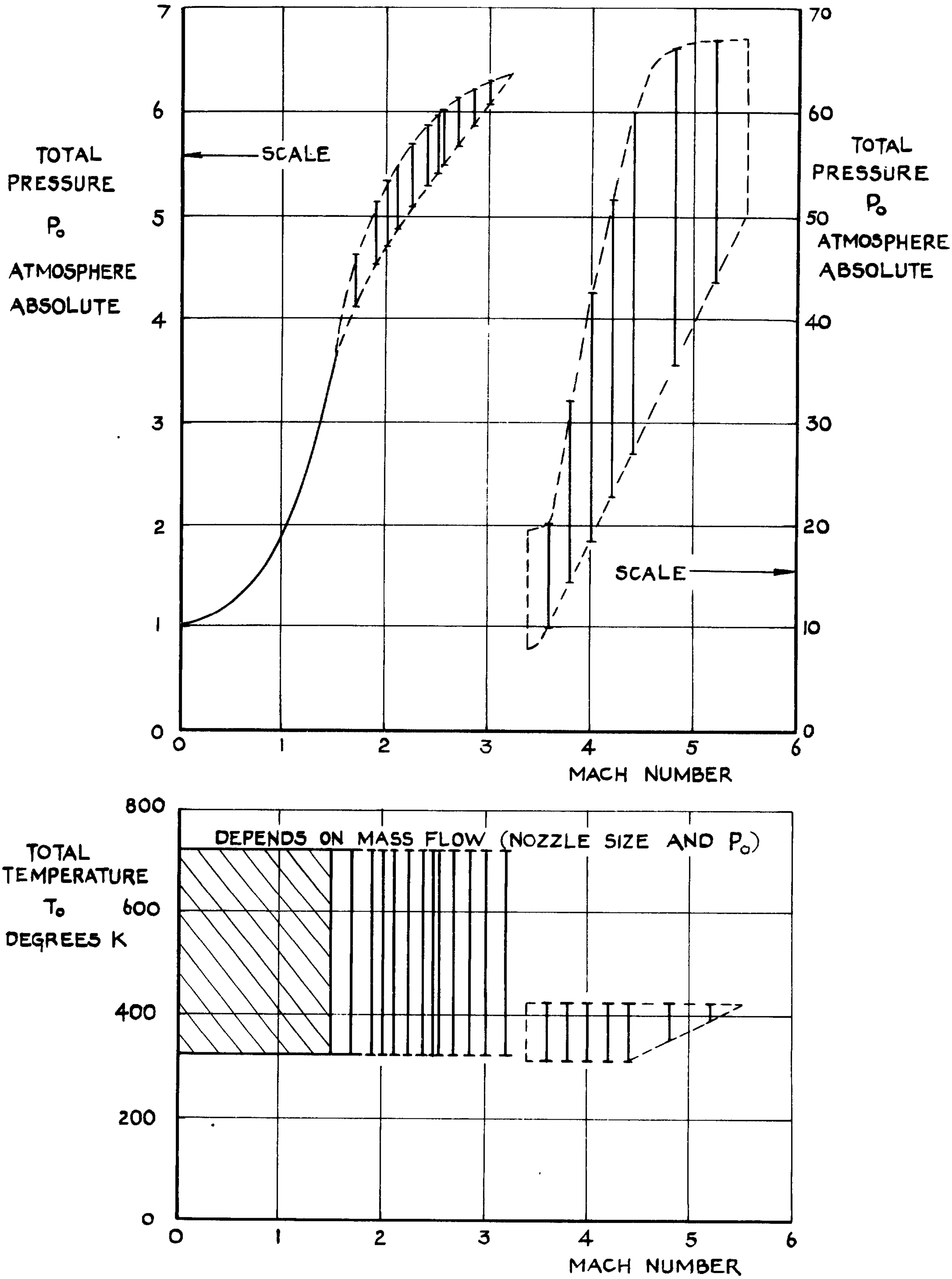


FIG.13 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. BRISTOL SIDDELEY ENGINES LTD. No.2 A.I.R.

3.1.13 Tunnel: 9 inches × 8 inches

Mach numbers: 0·4–0·8 then 1·6, 2·0, 2·5 (fixed liners)

Location: R.A.E. (Bedford)

Safety: Flutter tests acceptable (but see Remarks)

Working Section: 9 inches × 8 inches.

P_o: 0·25 atm abs to 1·7 atm abs, subsonic (see Fig.14)
0·25 atm abs to 2·3 atm abs, supersonic

dP_o/dt: 0·5 atm abs to 2·3 atm abs in 6 min. Tunnel is normally started at 0·5 atm abs for supersonic running.

T_o: 293°K ±3°C.

Sting mounting: A quadrant awaits assembly (see Remarks)

Wall mounting: Detachable window blank could be provided.

Time to commence a run: 5–10 min.

Time to shut down and open tunnel for access to model:
5 min to shut down. Access to model in about 10 min.

Remarks: A blow-off valve permits the total pressure to reach atmospheric pressure in 1 to 2 seconds if required. The supersonic liners can be changed in about 3 hours. The tunnel is used almost entirely for intake tests and a quadrant and sting have not been required. Consideration is being given to replacing the compressor to enable extension of the Mach number range to 3·0 and the maximum total pressure to 4 atmospheres absolute.

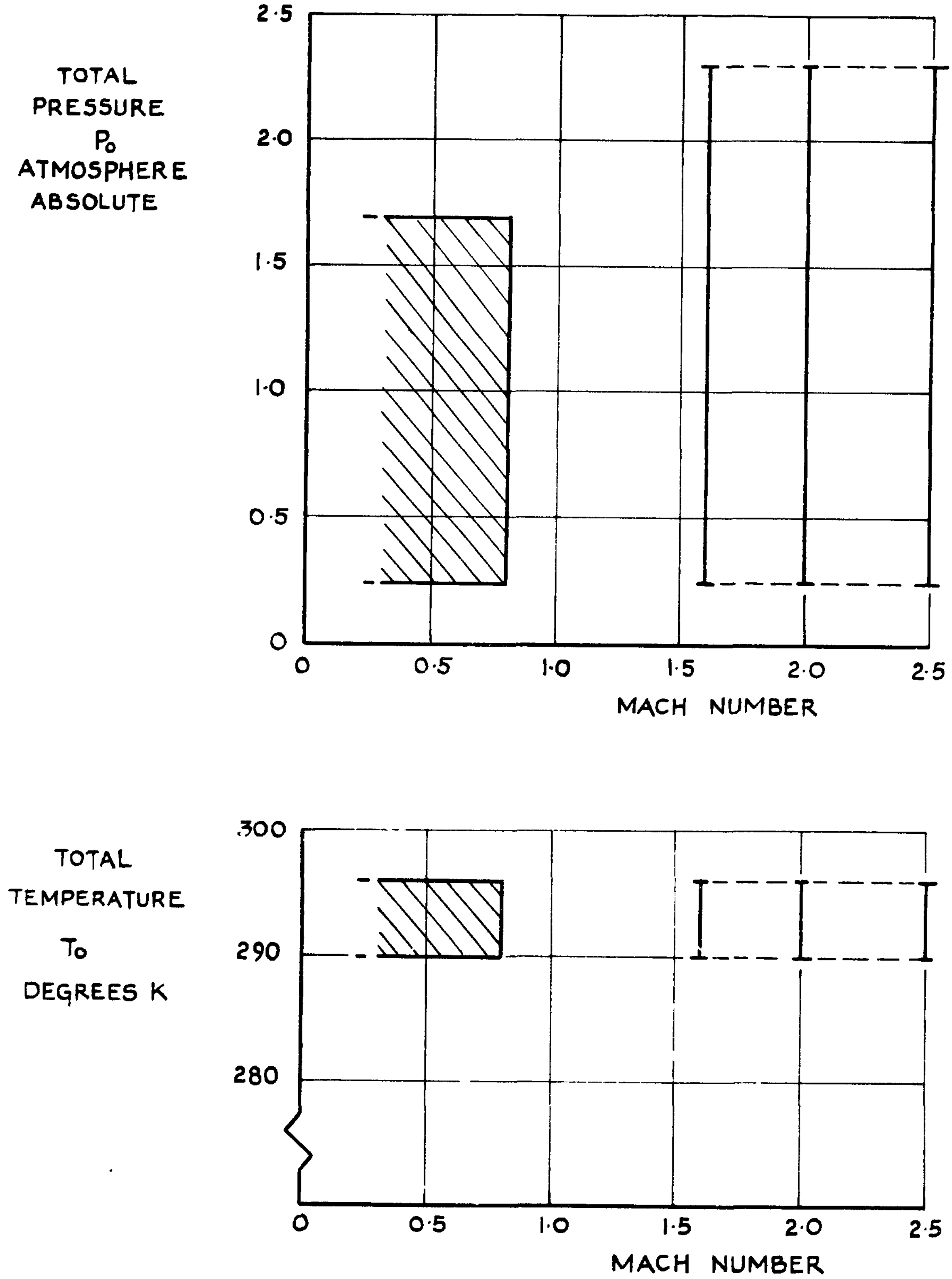


FIG. 14 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (BEDFORD), 9in x 8in

3.2 Intermittent tunnels

3.2.1 Tunnel: 4 ft high speed

Mach numbers: 0·4-1·4 (perforated), 1·4-4·0 (flexible nozzle)

Location: British Aircraft Corporation (Operating) Ltd. (Preston Division), Warton.

Working Section: 4 ft × 4 ft

Safety: Flutter tests acceptable (see Section 2)

P_o: See Fig.15. Note the minimum starting pressures.

dP_o/dt: Controlled pressure rise, $0 < dP_o/dt < 5$ lb in^{-2} sec^{-1}. Rates of pressure drop can be provided as required. Step changes can also be provided ($dP_o/dt \simeq 50$ lb in^{-2} sec^{-1} say).

T_o: Falls with time during a run but at M = 2 remains within the range (ambient -0°C) to (ambient -15°C). Less variation at M > 2, more variation at M < 2 with higher mass flows. For about 1/3 of running time $-1 < dT_o/dt < 0$°C/sec.

Sting mounting: Yes. Double cranked sting to give yaw in 1° increments to ±5°. Fixed roll angles only.

Wall mounting: Yes, floor-mounted for transonic working and may be arranged on window blank for supersonic working

Time to commence run: ½ hour to set the shape of the flexible nozzle. Time to recharge air storage depends on P_o and running time at each M. A typical time is 1 hr after a 10-15 sec run. Time to establish flow 1-3 sec

Time to shut down and open tunnel for access to model: 2 min.

Running time: For running times see Fig.15

Remarks: Considerable model excitation at transonic speeds. It is thought to be of both aerodynamic and structural origins. No difficulties at M > 1·4.

The contours of the flexible nozzle are normally set for certain standard values of Mach number but interpolations can be made.

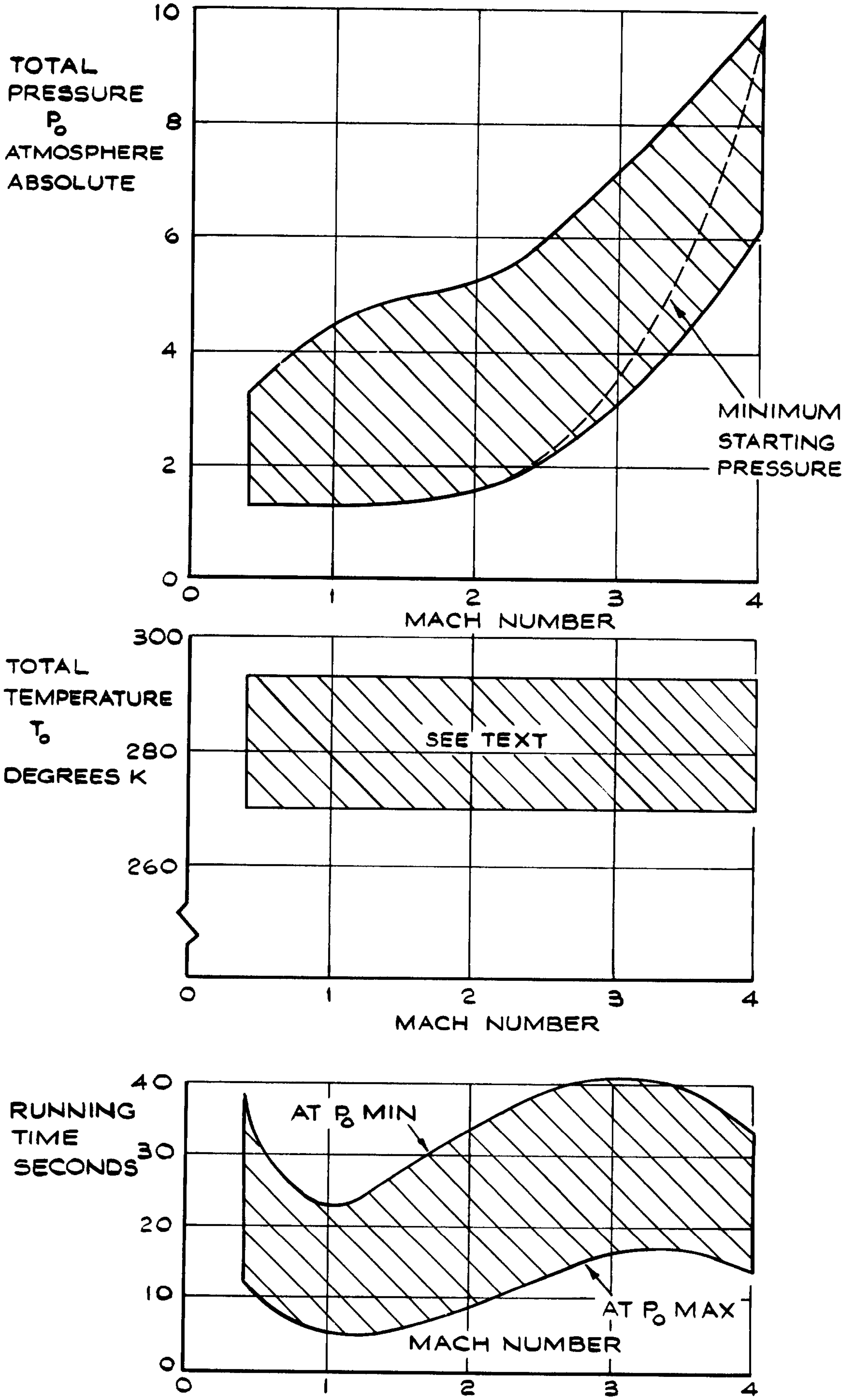


FIG.15 RANGES OF TOTAL PRESSURE, TOTAL TEMPERATURE AND RUNNING TIME OVER THE MACH NUMBER RANGE.
B.A.C.(OPERATING) LTD. (PRESTON DIV.),4ft HIGH SPEED TUNNEL

3.2.2 Tunnel: 27 inches × 27 inches high speed.

Mach numbers: 0·45–1·30 (perforated), 1·6, 2·0 (fixed liners, additional liners can readily be made up to M = 3·5)

Location: Hawker Siddeley Aviation Ltd. (Hawker-Blackburn Div.), Brough

Working Section: 27 inches × 27 inches

Safety: Flutter tests acceptable (see Section 2)

P_o: Maximum 4·0 atm abs; Minimum 1·3 atm abs — $0{\cdot}45 \leqslant M \leqslant 1{\cdot}30$ (see Fig.16)

Maximum 6·0 atm abs; Minimum, starting pressure — $1{\cdot}4 \leqslant M \leqslant 3{\cdot}5$

dP_o/dt: Increase pressure at 2·5 lb in^{-2} sec^{-1}
Decrease pressure at 2·5 lb in^{-2} sec^{-1}

T_o: Nominally ambient but this is a blow-down tunnel and after an initial small rise the total temperature drops 5°C to 15°C during a run, depending on conditions.

Sting mounting: Yes. No roll (see Remarks)

Wall mounting: Half-model balance, model plates on floor.

Time to commence run: Pressure in dry air reservoir raised at a rate of 7 atm/hr. Time to establish flow 3–4 sec.

Time to shut down and open tunnel for access to model: 5–10 min.

Running time: In the transonic range running times vary between 20 sec at M = 0·45 with P_o = 1·3 atm abs and 4 sec at M = 1·30 with P_o = 4·0 atm abs.

Depending on the total pressure required the running time is up to 37 sec at M = 1·6 and up to 45 sec at M = 3·5.

Remarks: Flutter models have been mounted on the floor of the working section and on a pole extending from the settling chamber through the working section to the second throat. A significant level of excitation is present which is thought to arise from both aerodynamic turbulence and transmitted vibration.

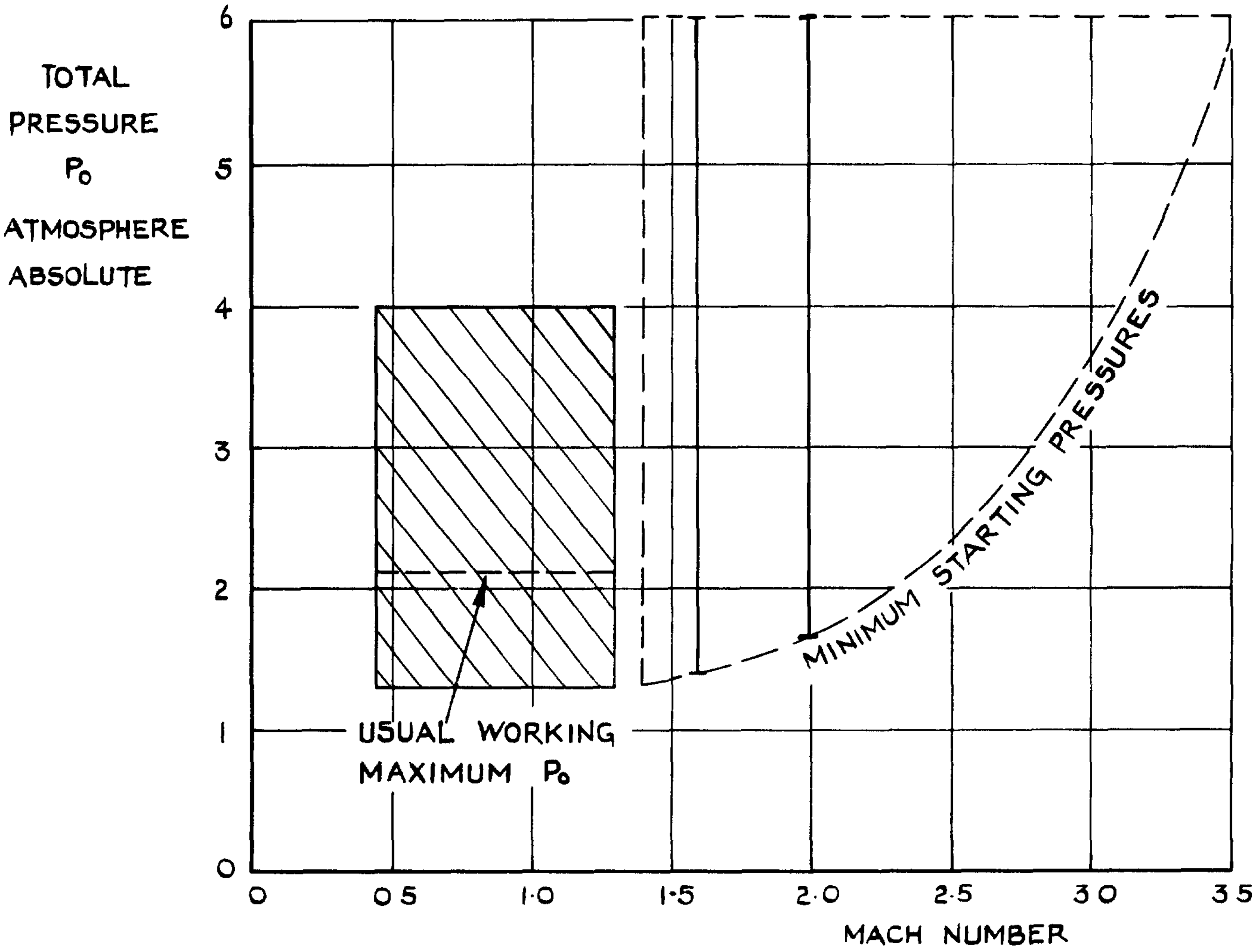


FIG. 16 RANGE OF TOTAL PRESSURE OVER MACH NUMBER RANGE. HAWKER SIDDELEY AVIATION LTD. (HAWKER BLACKBURN DIVISION), BROUGH, 27 in x 27 in HIGH SPEED TUNNEL

3.2.3 Tunnel: 36 inches × 14 inches.

Mach numbers: 0·4–1·15 (slotted), 1·4 and 1·6 (fixed liners)

Location: N.P.L. Teddington.

Safety: Flutter tests acceptable (see Section 2)

Working Section: 31 inches × 14 inches transonic, 36 inches × 14 inches supersonic.

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Approximately ambient but there is probably a fall of several degrees C per minute.

Sting mounting: No.

Wall mounting: Yes.

Time to commence run: 30 sec.

Time to shut down and open tunnel for access to model: 1 min.

Running time: About 20 min at M = 0·7, decreasing to 4 min at M = 1·15. At M = 1·4 and 1·6 the running time is slightly less than 4 min.

Remarks: The slotted liners for transonic running are at top and bottom walls only. Models have not been subjected to significant levels of random excitation.

An investigation of unsteady interference effects has been made in this tunnel and some results are given in Ref.2.

3.2.4 Tunnel: 25 inches × 20 inches

Mach numbers: 0·4–1·5 (flexible nozzle with perforated working section)

Location: N.P.L. Teddington

Safety: Flutter tests acceptable (see Section 2)

Working Section: 21 inches × 20 inches.

P_o: Atmospheric.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Approximately ambient temperature. Temperature cannot be controlled.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes.

Time to commence run: 30 sec

Time to shut down and open tunnel for access to model: 1 min.

Running time: Running times decrease with increasing Mach number from about 20 min at M = 0·7 to about 4 min at M = 1·5.

Remarks: An investigation of unsteady interference effects has been made in this tunnel (in its earlier slotted form) and some results are given in Ref.2.

3.2.5 Tunnel: 18 inches × 14 inches

Mach numbers: 0·4–1·15 (slotted), 1·2, 1·4, 1·6, 2·0, 2·5 (fixed liners)

Location: N.P.L. Teddington

Working Section: 17 inches × 14 inches, $M \leqslant 1 \cdot 15$
21 inches × 14 inches, $M > 1 \cdot 15$

Safety: Flutter tests acceptable (see Section 2)

P_o: (see Fig.17)

M	$P_{o_{min}}$ atm abs	$P_{o_{max}}$ atm abs
0·5	1·0	3·0
1·0	1·0	3·0
1·6	1·0	3·0
2·0	1·6	3·0
2·5	2·3	3·0
also, if a liner were made,		
3·0	3·0	3·0

dP_o/dt: Pressure cannot be altered readily during a run.

T_o: Nominally ambient but falls progressively during a run. Temperature cannot be controlled.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes.

Time to commence run: 10 sec at P_o = 1 atm abs
60 sec at P_o = 3 atm abs

Time to shut down and open tunnel for access to model:
Shut down, 5 sec.
Access to model, 5 min.

Running time:

M	Time at $P_{o_{min}}$ minutes	Time at $P_{o_{max}}$ minutes
0·5	20	6
1·0	10	3
1·6	4	1
2·0	4	2
2·5	4	3

Remarks: At high values of P_o it is difficult successfully to vary M in the transonic range during a run. The transonic working section is slotted in the top and bottom walls only. The tunnel has been used for flutter tests. Measurements of dynamic response indicate that models in this tunnel may be subject to a significant level of wall interference in unsteady flow (see Section 2).

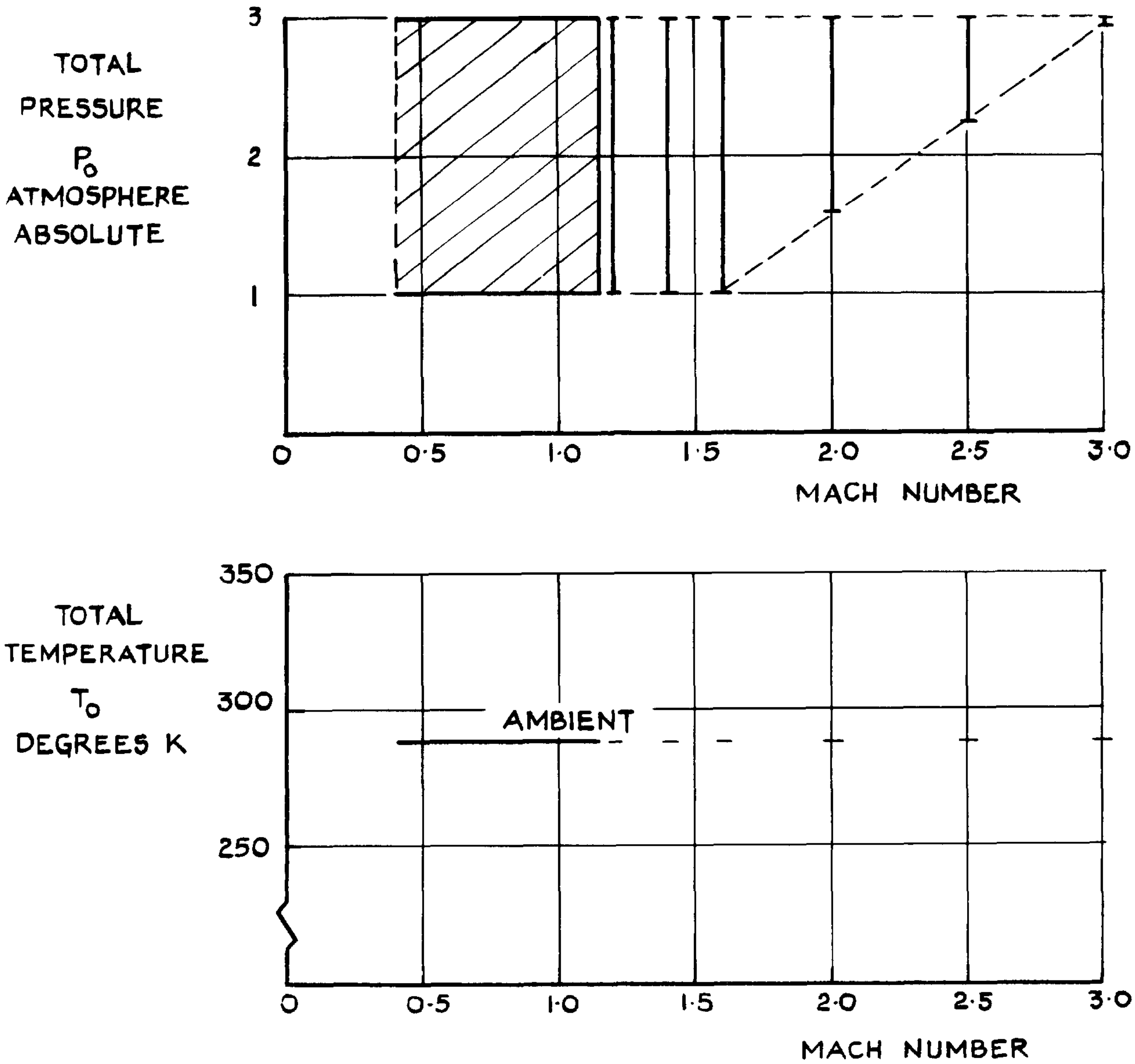


FIG. 17 TOTAL PRESSURE RANGE AND TOTAL TEMPERATURE OVER MACH NUMBER RANGE. N.P.L., 18 in x 14 in

3.2.6 Tunnel: 20 inches × 8 inches

Mach numbers: 0·4–1·1 (slotted) 1·3, 1·6 (fixed liners)

Location: N.P.L. Teddington

Working Section: 17 inches × 8 inches.

Safety: Flutter tests acceptable (see Section 2)

P_o: Atmospheric

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: No.

Wall mounting: Yes

Time to commence run: 30 sec.

Time to shut down and open tunnel for access to model: 5 sec.

Running time: Typical times are 30 min at low M, 5 min at high M.

Remarks: The slotted section has slots in the top and bottom walls only. The tunnel is used almost entirely for two-dimensional aerofoil tests.

3.2.7 Tunnel: 12 inches x 12 inches.

Mach numbers: 0-0·8 approx., 1·4, 1·8 (solid half-liners)

Location: Imperial College, University of London.

Working Section: 12 inches x 12 inches.

Safety: Flutter tests acceptable (see Section 2 and Remarks below).

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Nominally ambient temperature but tends to fall with increasing run time. Maximum fall is about 15°C.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes.

Time to commence run: Time to raise compressed air storage pressure from atmospheric pressure, ½ day; time to raise pressure after previous run, 2 hours; time to start tunnel and reach speed, 5-10 sec.

Time to shut down and open tunnel for access to model: 2 hours approximately.

Running time: This is an induced flow tunnel driven by compressed air. Using the compressed air storage plus the compressor flow the maximum run time is approximately 4 min. Using the storage alone run time at M = 1·8 is ½-1 min and slightly longer at M = 1·4.

Remarks: The first set of turning vanes is thought to be vulnerable to damage from model debris. A safety net could be fitted to protect it.

3.2.8 Tunnel: $9\frac{1}{2}$ inches × $9\frac{1}{2}$ inches. Mach numbers: 0·4-1·1 (slotted), 1·2,1·4,1·6 (fixed liners)

Location: N.P.L. Teddington

Safety: Flutter tests acceptable (see Section 2)

Working Section: $9\frac{1}{2}$ inches × $7\frac{1}{2}$ inches (transonic)
$9\frac{1}{2}$ inches × $9\frac{1}{2}$ inches (supersonic)

P_o: Atmospheric.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: No.

Wall mounting: Yes.

Time to commence run: A few seconds to establish flow.

Time to shut down and open tunnel for access to model: a few seconds to shut down, about 5 min to gain access.

Running time: This is an induced flow tunnel driven from compressed air storage but the pumping facilities are sufficient to give almost continuous running.

Remarks: Some mechanical and aerodynamic excitation present but no known dominant frequencies. An investigation of unsteady interference effects has been made in this tunnel and some results are given in Ref.2.

3.2.9 Tunnel: 10 inches x 8 inches. Mach numbers: 0·4–1·2 (slotted), 1·55, 1·8 (fixed liners).

Location: Lanchester College of Technology, Coventry. Safety: Flutter tests acceptable (see Remarks and Section 2)

Working Section: 10 inches x 8 inches.

P_o: Approximately atmosphere pressure.

dP_o/dt: No controlled variation; total pressure approximately equals atmospheric pressure.

T_o: Ambient temperature with slight drop during run. Drop not yet determined.

Sting mounting: Yes. No remote roll facilities. Wall mounting: Directly to wall, no balance.

Time to commence run: To charge compressed air reservoir 2 hours except for first run; to establish flow 10 sec. Time to shut down and open tunnel for access to model: 2 min.

Running time: Maximum times are as follows:

Mach number	0·4	0·6	0·8	1·0	1·2	1·55	1·8
Time (min)	12	$7\frac{1}{2}$	4	3	2	$1\frac{1}{2}$	1

Remarks: This is an induction tunnel with return circuit. It may be necessary to fit safety nets to protect the return circuit from damage by model debris.

Unsteady interference effects are being investigated in this tunnel.

3.2.10 Tunnel: Intermittent induction

Mach numbers: 0·2-1·20 (slotted), 1·55 (fixed liner)

Location: Hawker Siddeley Dynamics Ltd. (Coventry)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 10 inches × 8 inches.

P_o: Atmospheric.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Approximately ambient temperature. Falls slightly during a run, depending on mass flow. No control.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes, floor.

Time to commence run: A few seconds. Time to charge compressed air reservoir depends upon required M and running time. A typical time is 12 min for 15 sec run at M = 1·55.

Time to shut down and open tunnel for access to model: 1 min to open window.

Running time:

Mach number	Maximum running time sec
0·50	145
0·80	58
1·00	38
1·10	20
1·55	42

Remarks: The level of random excitation has not been found significant for static measurements.

3.2.11 Tunnel: Z.4

Mach numbers: 0·3-1·3 (flexible nozzle followed by perforated section. Nozzle setting varied for M = 1·1 to 1·3)

Location: Aircraft Research Association Ltd., Bedford.

Safety: Flutter tests acceptable (see Section 2 and Remarks, below)

Working Section: 9 inches × 8 inches.

P_o: Atmospheric.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature. No significant variation with time.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes, floor.

Time to commence run: About 40 min pumping required prior to a 90 sec run, at all M. A short time to reset flexible nozzle. 5 sec to bring tunnel to speed.

Time to shut down and open tunnel for access to model: 2 min.

Running time: 90 sec at all Mach numbers.

Remarks: Light gauge metal corner vanes would have to be protected by a net. Some random excitation present due to turbulence but frequencies are not known.

3.2.12 Tunnel: 9 inch x 6 inch boundary layer.

Mach numbers: 0·4-0·85, then 1·2, 1·4, 1·5, 1·8 (fixed liners)

Location: University of Southampton.

Working Section: 9 inches x 6 inches.

Safety: Flutter tests acceptable (see Section 2)

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: No.

Wall mounting: No.

Time to commence run: $2\frac{1}{2}$ hr for initial storage of compressed air (see Remarks), 5 sec to bring tunnel up to speed.

Time to shut down and open tunnel for access to model: 3 sec to shut down, 4 min for access.

Running time: This tunnel can be run either as an induced flow tunnel or as a straight-through tunnel. At supersonic speeds the maximum running times are 20 sec to 1 min, depending upon M, using the induction arrangement, and up to 2 min using the straight-through arrangement. At subsonic speeds running times up to 15 min can be achieved.

Running times are limited by the compressed air storage capacity (3000 ft^3 at 350 lb/in^2) combined with the pumping rate (2 lb/sec). The pump capacity is to be increased to give a rate of 4 lb/sec.

Remarks: This tunnel has been used mainly for boundary layer research.

4 SUPERSONIC TUNNELS

4.1 Continuously running tunnels

4.1.1 Tunnel: High supersonic speed tunnel.

Mach numbers: 4·0 (fixed liners; to be replaced by M = 2·5-5·0 flexible nozzle, see Remarks)

Location: R.A.E. (Bedford)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 4 ft × 3 ft

P_o: $\frac{1}{2}$ atm abs to $7\frac{1}{4}$ atm abs with present M = 4 liners. With the flexible nozzle the estimated range of total pressure will be $\frac{1}{2}$ atm abs to 4 atm abs at M = 2·5, $\frac{1}{2}$ atm abs to 12 atm abs at M = 5·0.

dP_o/dt: 1 atmosphere per minute.

T_o: Ambient +15°C to 313°K with present M = 4 liners. Maximum temperature with flexible nozzle will be about 420°K, depending on the mass flow, while the minimum temperature will be unchanged.

Sting mounting: Yes (see Remarks). Remote roll control.

Wall mounting: No (see Remarks)

Time to commence run: For $\frac{1}{2}$ atm abs total pressure, 20 min.

Time to shut down and open tunnel for access to model: From $\frac{1}{2}$ atm abs, 15 min.

Remarks: The tunnel is fitted with M = 4 liners but it is expected that these will be replaced by a flexible nozzle during May, 1965. Four test sections, with incidence quadrants, are available in which models can be pre-rigged. A wall mounting is planned.

4.1.3 Tunnel: No.19 supersonic

Mach numbers: 1·4, 1·6, 2·0, 2·2 (fixed liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2 and Remarks below)

Working Section: 18 inches x 18 inches.

P_o: Maximum P_o is approximately 2·4 atm abs at M = 1·4,
and 2·0 atm abs at M = 2·2.
Minimum P_o is 0·1 atm abs at all Mach numbers (see Fig.19).

For short period ($1\frac{1}{2}$ hours) 25% power overload is allowed giving maximum P_o of 2·8 atm abs at M = 1·4, and 2·5 atm abs at M = 2·2.

dP_o/dt: Pressure may be varied slowly.

T_o: 5°C to 25°C above ambient temperature, with some control at higher values of P_o. At $P_o < \frac{1}{2}$ atm abs control is difficult and depends upon the cooling water temperature.

Sting mounting: Yes. With remote roll control.

Wall mounting: Yes

Time to commence run: Varies with operating pressure. Approximately 20 min to reduce pressure to 0·17 atm abs. 2-3 min for runs without decompressing.

Time to shut down and open tunnel for access to model: 12 min, less if no further running required.

Remarks: The number of test runs is limited to about 4 per day due to armature heating during starting.

The compressor blades are vulnerable to metal parts from a broken model but have in the past digested foam plastic which was collected as a powder on an oiled muslin screen. The following guards are fitted; (i) a screen of spring curtain wire (ii) two sets of cascades (iii) a piano wire screen and (iv) a 2 inch honeycomb (2 inches deep).

Random excitation of models has not been apparent but no detailed measurements have been made.

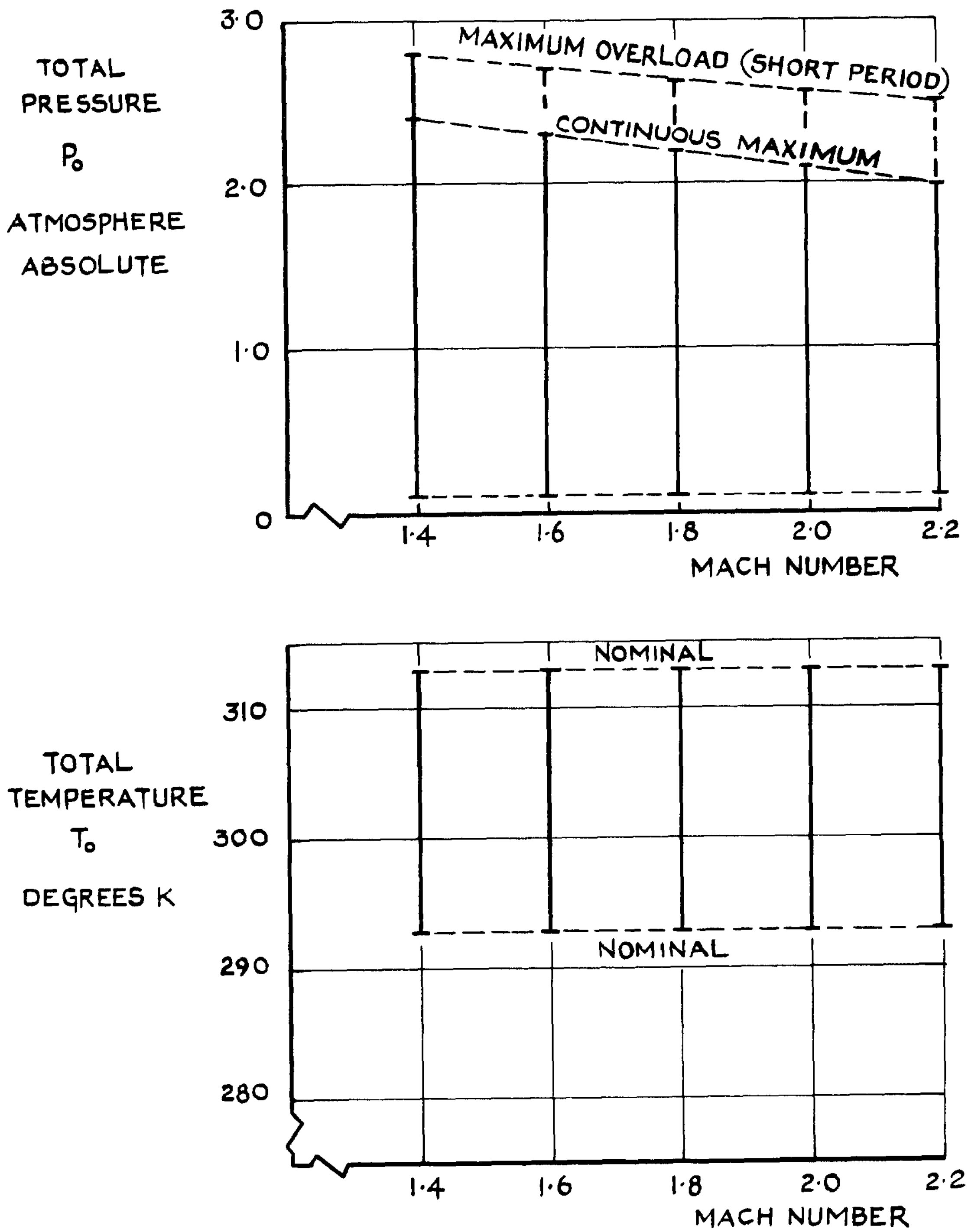


FIG. 19 RANGES OF TOTAL PRESSURE AND TOTAL TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (FARNBOROUGH), N°19 SUPERSONIC, 18 in x 18 in

4.1.4 Tunnel: 13 inches

Mach numbers: 1·3-2·8 (flexible nozzle)

Location: R.A.E. (Bedford)

Safety: Flutter tests not acceptable (see Section 2 and Remarks below)

Working Section: $13^1/3$ inches x $13^1/3$ inches.

P_o: Atmospheric.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Nominally ambient.

Sting mounting: Yes. Preset roll position.

Wall mounting: Yes, window blank may be provided.

Time to commence run: 10-15 min.

Time to shut down and open tunnel for access to model: 5 min.

Remarks: This tunnel is driven by the Sysholm evacuator which is part of the 8 ft x 8 ft tunnel plant. The small lobe clearances in the evacuator make it vulnerable to damage from parts of broken models.

The tunnel is a 1 : 7·2 scale model of the 8 ft x 8 ft tunnel and has been used to determine diffuser settings and shut down loads.

4.1.5 Tunnel: 11 inch.

Mach numbers: 1·4, 1·6, 1·8, 2·0, 2·2, 2·5 (fixed liners)

Location: N.P.L. Teddington

Safety: Flutter tests not acceptable (see Section 2 and Remarks below)

Working Section: 13 inches × 11 inches.

P_o: 0·4 atm abs to 1 atm abs (see Fig.20).

dP_o/dt: 0·4 atm abs to 1 atm abs in a few minutes.

T_o: Depending on conditions, the coolers limit the temperature rise during a run to 15°C to 25°C above ambient temperature.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes

Time to commence run: 5 min.

Time to shut down and open tunnel for access to model: 5 min.

Remarks: The axial flow compressor is vulnerable to damage from the parts of broken flutter models and it would not be possible to fit safety nets. Derivative measurements on oscillating wings have been made. There has been no significant random excitation of models but compressor vibration at 100 c/s has been observed.

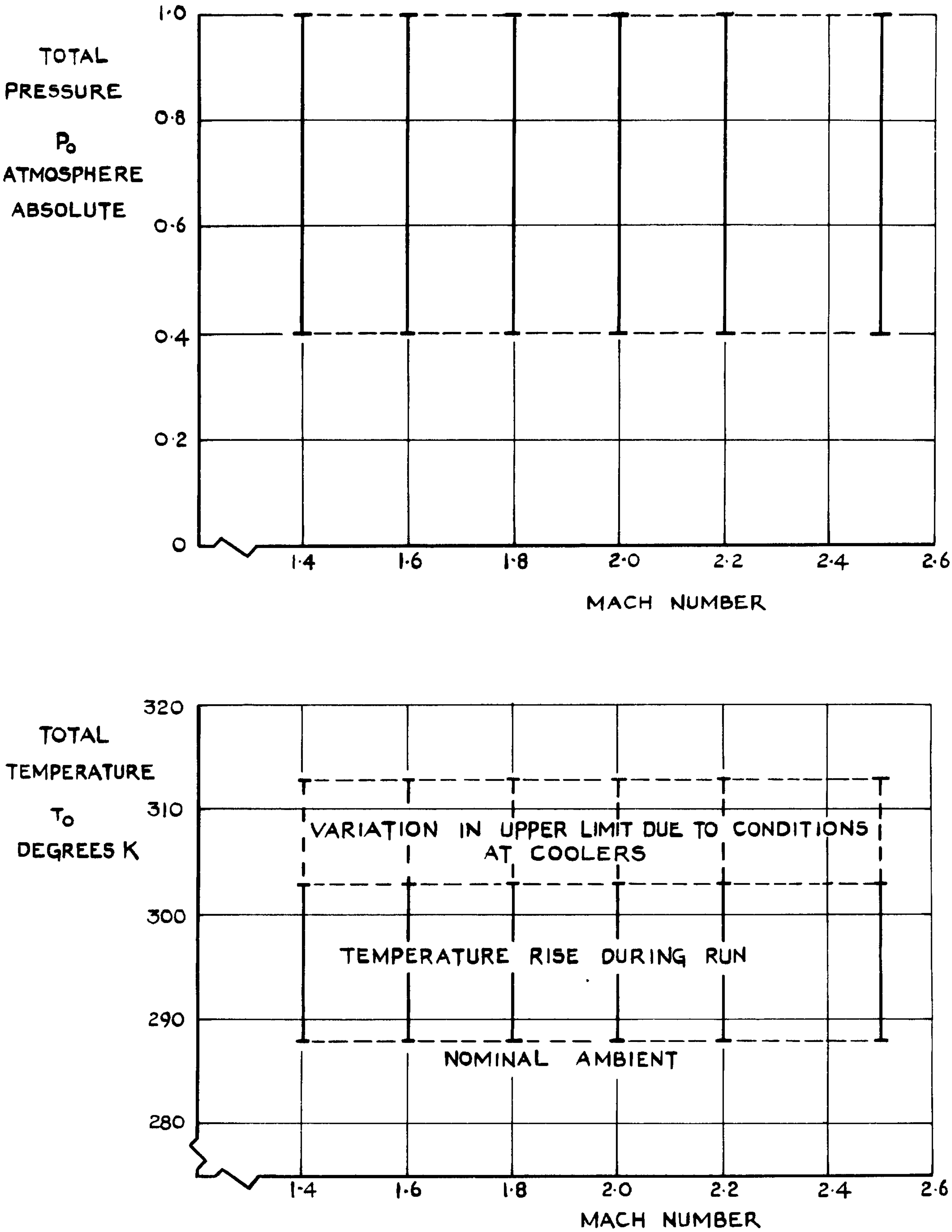


FIG. 20 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. N.P.L., 11 in TUNNEL

4.1.6 Tunnel: 10 inch × 10 inch supersonic

Mach numbers: 1·5, 1·8, 2·5, 3·0, 3·5 (fixed liners)

Location: R.A.R.D.E., Section B3, Fort Halstead.

Safety: Flutter tests acceptable (see Section 2)

Working Section: 10 inches × 10 inches.

P_o:

M	P_o atm abs
1·5	0·67
1·8	0·77
2·5	0·97
3·0	1·23
3·5	1·47

(see Fig.21)

Pressures can be changed by ±5% at all available M during a run.

dP_o/dt: ±5% of P_o in a few minutes.

T_o: Normally controlled to within the range 293°K – 323°K but can be raised to 523°K. For temperatures outside the normal range special nozzles are required.

Sting mounting: Yes. No remote roll control.

Wall mounting: No, but would be provided.

Time to commence run: 15 min.

Time to shut down and open tunnel for access to model: 10 min.

Remarks: Models are not subjected to significant levels of random excitation.

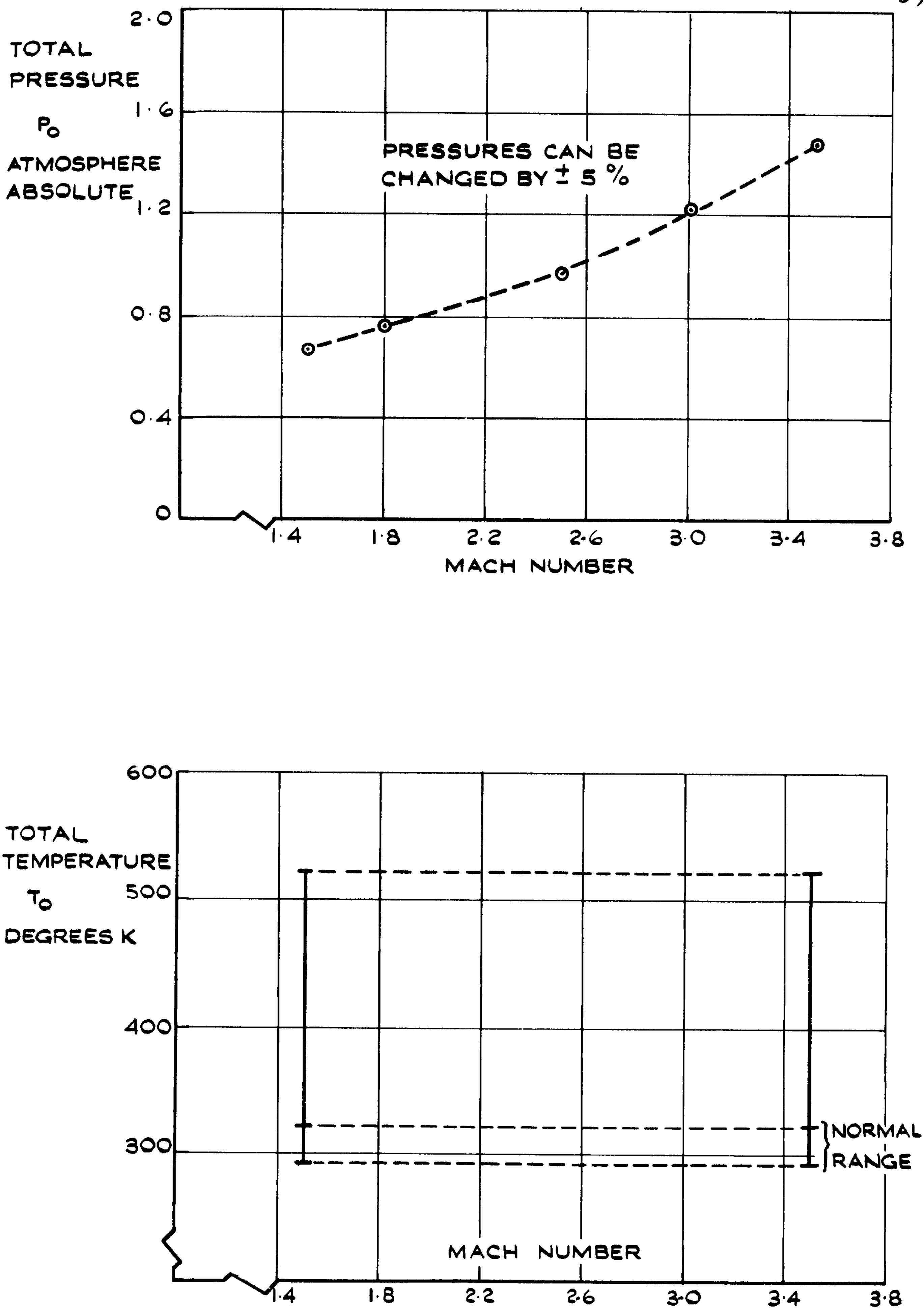


FIG. 21 TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.R.D.E., 10 in x 10 in

4.1.7 Tunnel: No.16 jet tunnel

Mach number: 2·0 (fixed nozzle)

Location: R.A.E. (Farnborough).

Safety: Flutter tests acceptable (see Section 2)

Working Section: 11 inch diameter nozzle, open working section in plenum chamber.

P_o: Maximum = 1 atmosphere absolute.
Minimum = $\frac{1}{2}$ atmosphere absolute.

dP_o/dt: Full range of pressure can be covered in approximately 5 min.

T_o: Ambient temperature.

Sting mounting: Centreline sting from upstream. No roll control.

Wall mounting: No.

Time to commence run: 5 min.

Time to shut down and open tunnel for access to model: 5 min.

Remarks: This is an annular tunnel with provision for independent "blowing" of the inner core. Operating time is rationed as the power plant is shared with other users. Used for nozzle and ejector research.

4.1.8 Tunnel: No.8 Supersonic

Mach numbers: 1·5, 1·87, 2·47, 4·30, 4·50 (fixed liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 9 inches × 9 inches.

P_o: At M = 1·5, 1·87 P_o = 1 atm abs (see Fig.22)
At M = 2·47, 4·3, 4·5 minimum P_o = 1 atm abs,
and maximum P_o = 2·5 atm abs.

dP_o/dt: Pressures may be changed from one value to another at a rate of about 1 atmosphere per minute. Also, all pressures may be reduced to 1 atmosphere absolute in about 1 minute.

T_o: Upper limit 323°K, lower limit normally ambient temperature. Temperature can be controlled except at M = 4·3, 4·5 when P_o is close to 1 atmosphere absolute.

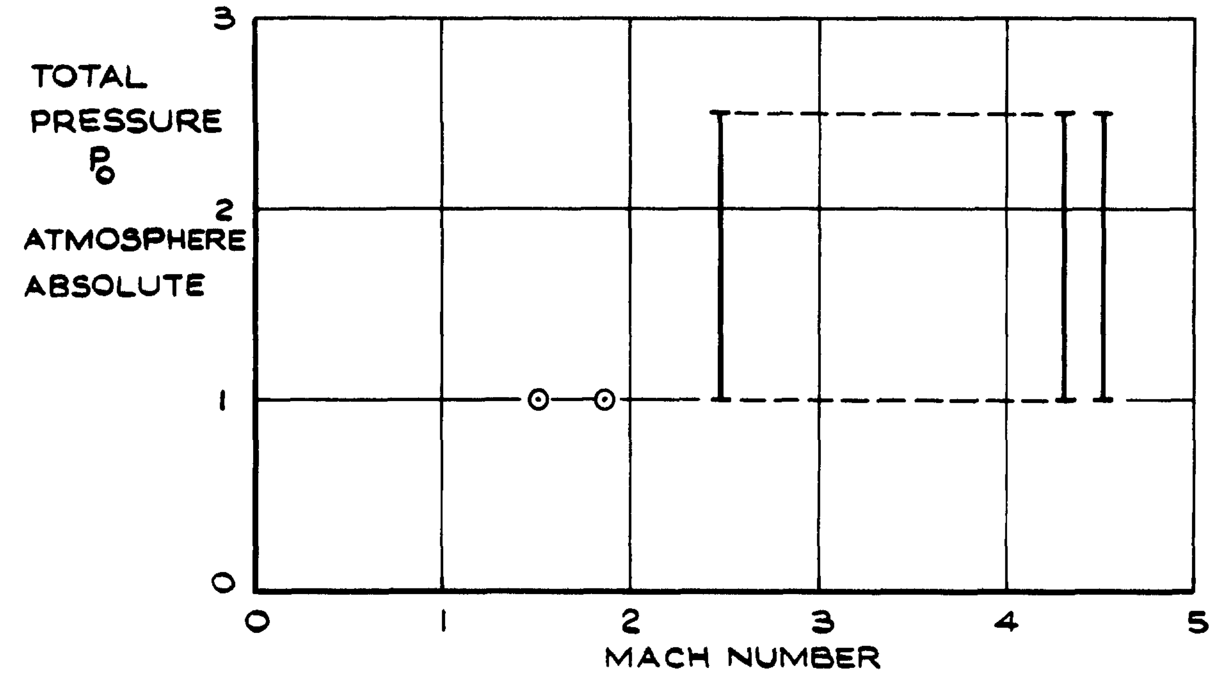
Sting mounting: Yes. A double-cranked sting is available to give roll or yaw without roll.

Wall mounting: No, but a reflector plate could readily be made.

Time to commence run: 2 min.

Time to shut down and open tunnel for access to model: 2 min to shut down, 2 min to open window.

Remarks: Operating time is rationed as the power plant is shared with other users.



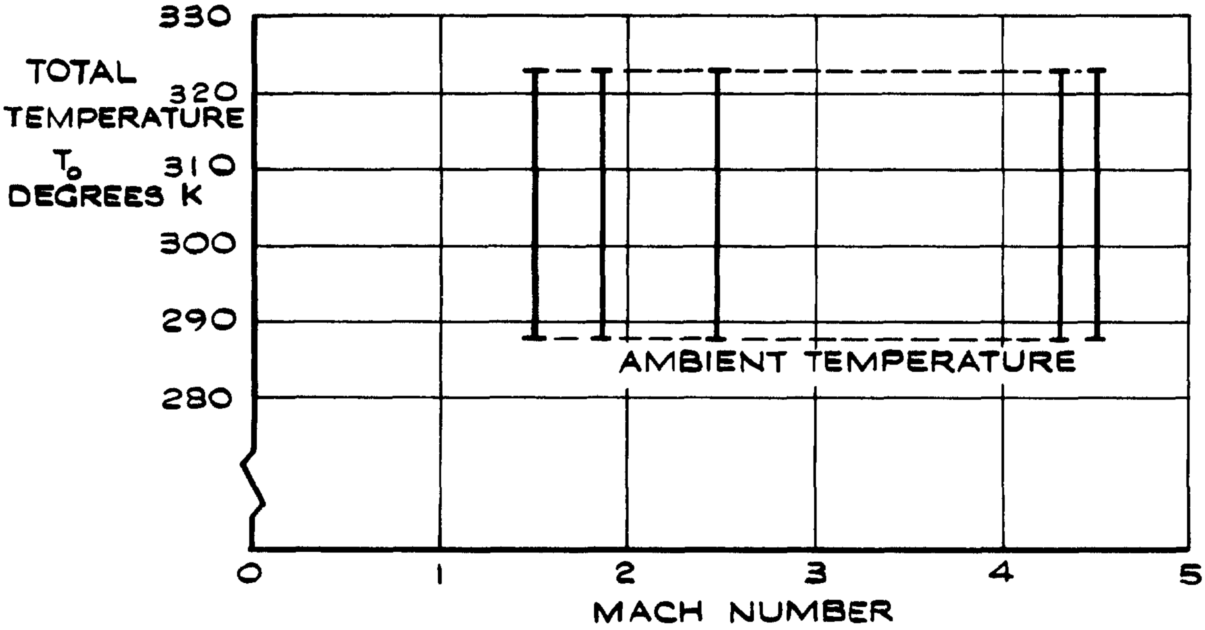


FIG.22 RANGES OF TOTAL PRESSURE & TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (FARNBOROUGH), No 8 SUPERSONIC, 9 in x 9 in

4.1.9 Tunnel: No.18 Supersonic

Mach numbers: 1·3-2·0 in steps of 0·1M (fixed liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptabl (see Section 2)

Working Section: 9 inches × 9 inches.

P_o: Minimum = 0·133 atmospheres absolute (see Fig.23)
Maximum = 1·0 atmospheres absolute at M = 1·3,
1·5 atmospheres absolute at M = 2·0.

dP_o/dt: The full range in 5 min.

T_o: Nominally ambient temperature. Temperature rises slowly in warm weather to 303°K, throughout the speed range. There is a coarse temperature control.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes, sidewall.

Time to commence run: 5 min.

Time to shut down and open tunnel for access to model: 5 min.

Remarks: Two $1\frac{1}{2}$ inch mesh catch nets and 3 sets of turning vanes are already fitted but a fine mesh screen could be incorporated if necessary. The frequency spectrum of the random turbulence is not known but the levels have not been significant. Model natural frequencies of 40-60 c/s have been excited by the tunnel.

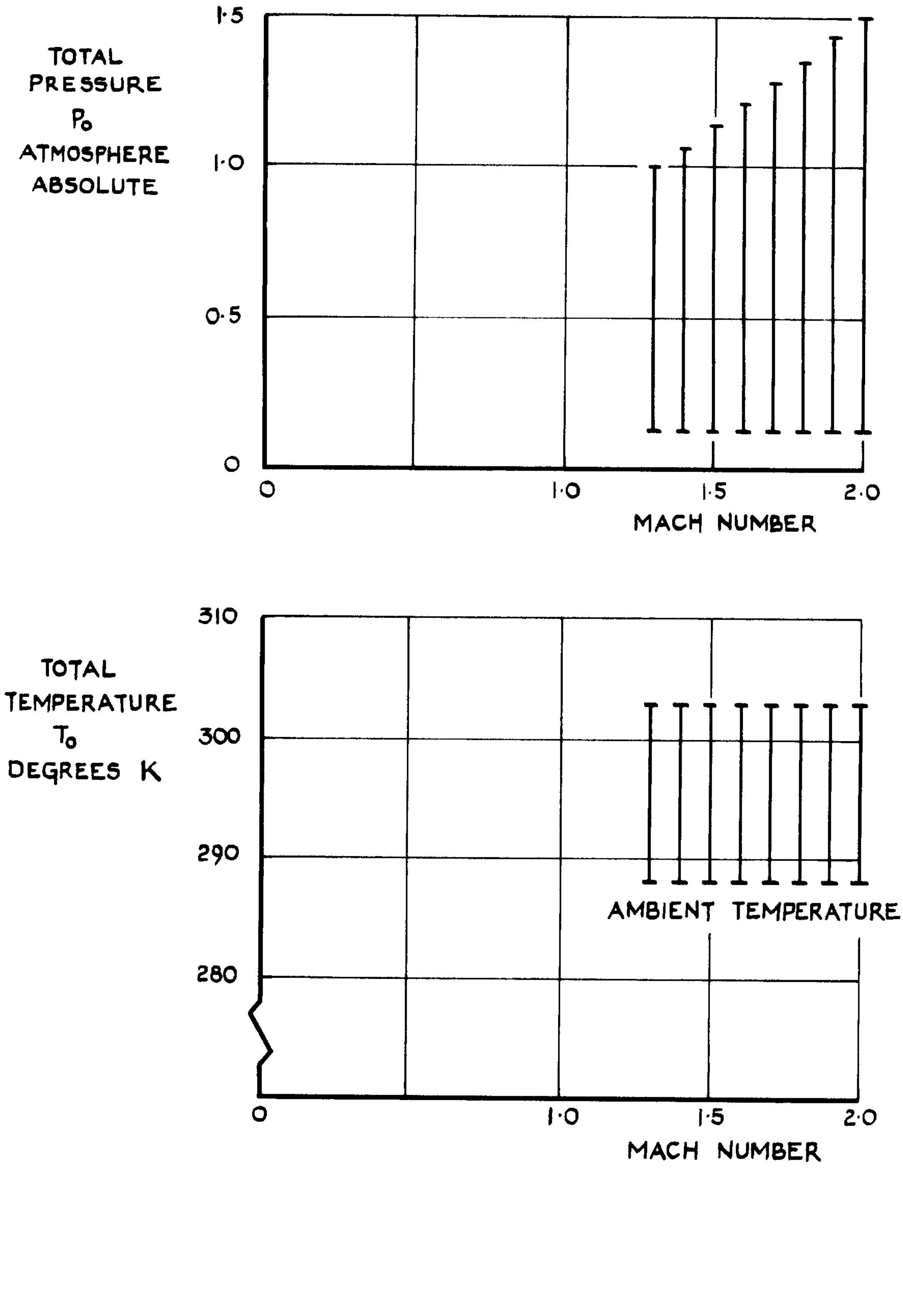


FIG.23 TOTAL PRESSURE AND TEMPERATURE RANGES OVER MACH NUMBER RANGE. R.A.E.(FARNBOROUGH), No.18 SUPERSONIC, 9 in x 9 in

4.1.10 Tunnel: No.14 Supersonic

Mach number: 1·5, 2·0, 2·5, 3·0 (fixed liners)

Location: College of Aeronautics, Cranfield.

Safety, Flutter tests acceptable (see Section 2 and Remarks, below)

Working Section: 9 inches × 9 inches

P_o: Maximum pressure = 1 atm abs at M = 2, falling to 0·44 atm abs at M = 3·0 (see Fig.24)
Minimum pressure = 0·1 atm abs at all M.

dP_o/dt: Full pressure range in 2-3 min.

T_o: T_o can be controlled within range 293°K - 313°K.

Sting mounting: Yes, several stings available. Roll angles generally preset

Wall mounting: Reflector plate could be made to replace window (see Remarks)

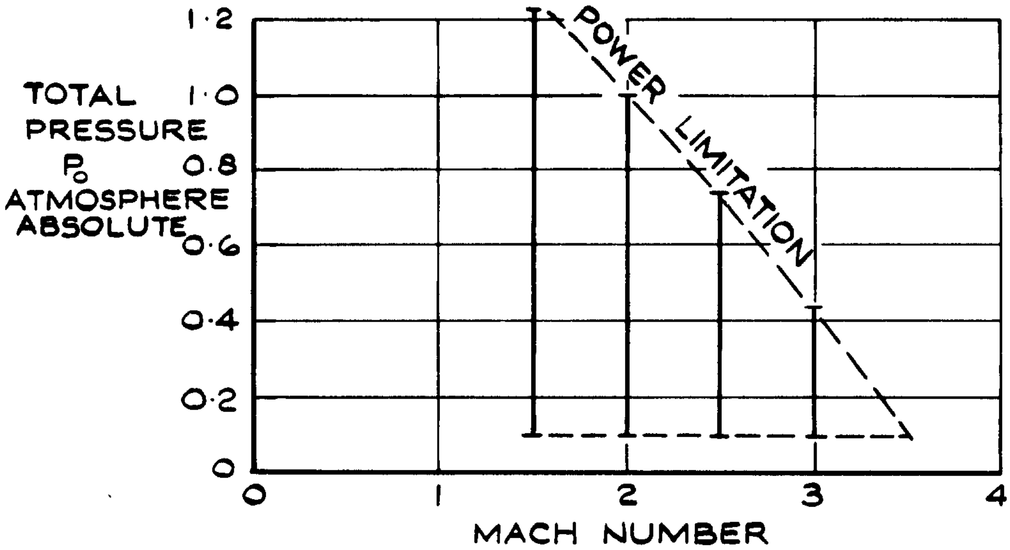
Time to commence run: At start of day ½ hr, between runs 12 min.

Time to shut down and open tunnel for access to model: a few min.

Remarks: The tunnel is provided with a model catchment screen and automatic tunnel stop.

Tests have been made on panels fitted into a special sidewall.

No significant random excitation has been observed on missile configurations under test.



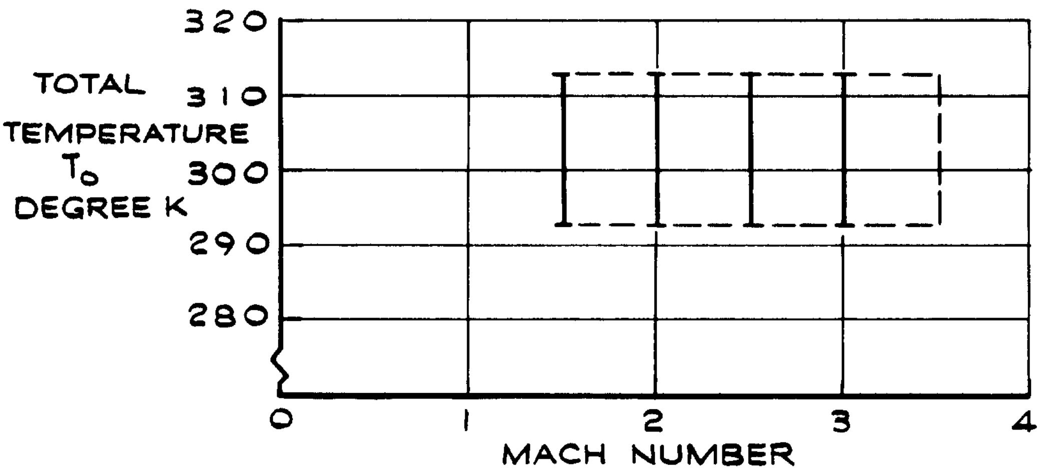


FIG.24 RANGES OF TOTAL PRESSURE & TEMPERATURE OVER MACH NUMBER RANGE. COLLEGE OF AERONAUTICS, CRANFIELD, No 14. 9 in x 9 in

4.1.11 Tunnel: No.6 Supersonic

Mach numbers: 1·56, 1·86, 2·46, 3·25, 4·30, 4·84 (fixed liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2 and Remarks below)

Working Section: 11 inches × 6 inches.

P_o: At M = 1·56, $P_{o_{max}}$ = 1 atm abs, $P_{o_{min}}$ = 1 atm abs,

M	$P_{o_{max}}$	$P_{o_{min}}$
1·56,	1 atm abs,	1 atm abs,
1·86,	1·4 " "	1 " "
2·46,	2·5 " "	1 " "
3·25,	2·5 " "	1 " "
4·30,	5·0 " "	1 " "
4·84,	5·0 " "	3 " "

(see Fig.25)

dP_o/dt: One atmosphere per minute. Also, all pressures above atmospheric may be removed in about one minute.

T_o: Upper limit 323°K; lower limit normally ambient temperature. Limited control is available, except at M = 3·25 and M = 4·30 when P_o = 1 atm abs where the temperature control is too coarse (see Remarks).

Sting mounting: Yes.

Wall mounting: No, but a reflector plate could be made.

Time to commence run: 2 min.

Time to shut down and open tunnel for access to model: 3 min.

Remarks: A screen is provided downstream of the working section which consists of a 1 inch thick plate with holes 5/8 inch diameter. A new heater is planned which will give total temperatures up to 373°K and control within 1°C, in steps. The power plant for this tunnel is shared with other equipment and running time is severely rationed.

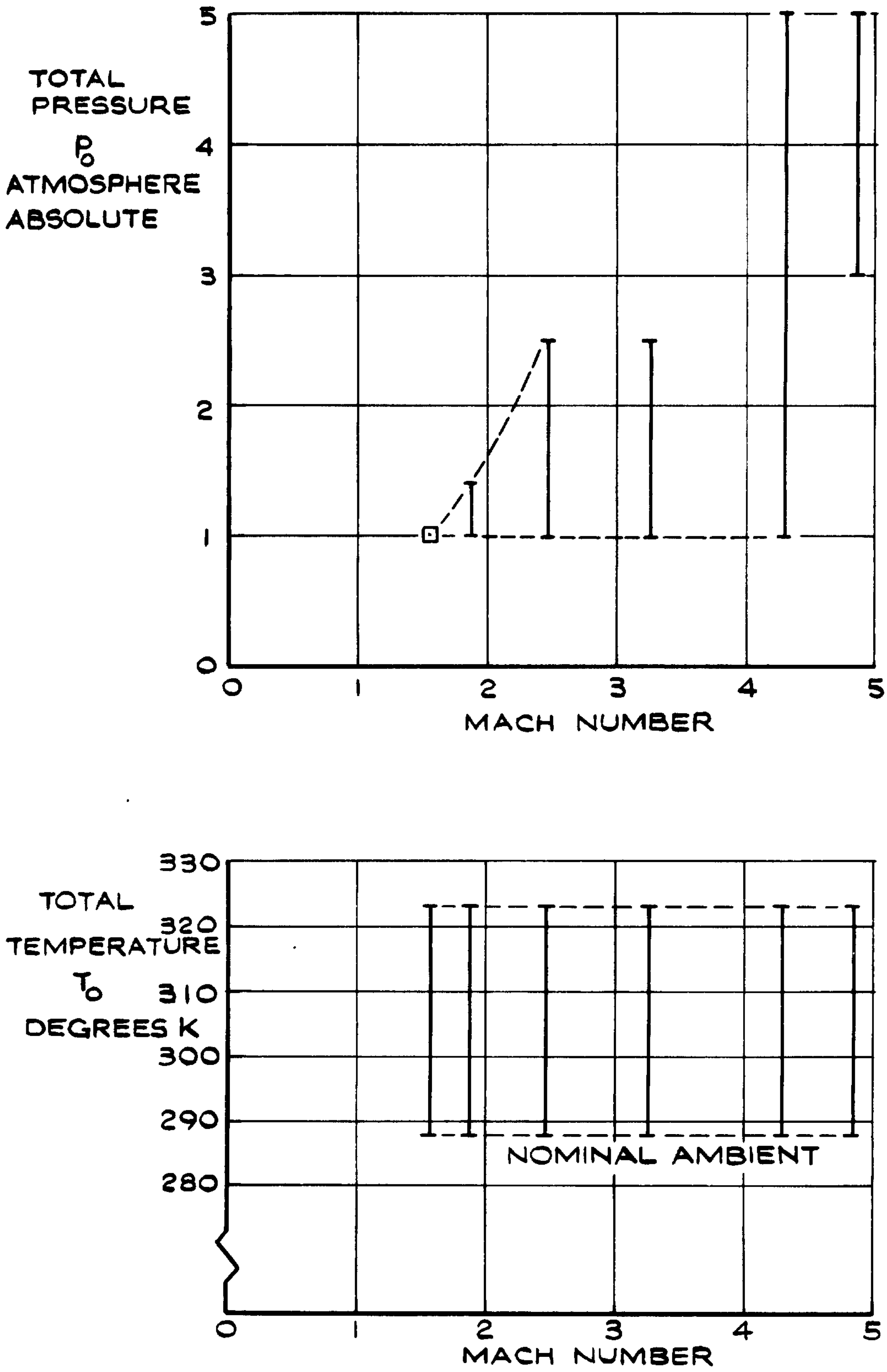


FIG.25 RANGES OF TOTAL PRESSURE & TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (FARNBOROUGH), No 6, 11 in x 6 in

4.1.12 Tunnel: Heat Transfer Tunnel

Mach numbers: 2,3,5 (fixed liners) and see below

Location: N.P.L. Teddington

Safety: Flutter tests acceptable (see Section 2)

Working Section: 6 inches × 6 inches nominal.

P_o: M = 2 $P_{o_{max}}$ = 3·5 atm abs, $P_{o_{min}}$ = 0·2 atm abs

M = 2	$P_{o_{max}}$ = 3·5 atm abs	$P_{o_{min}}$ = 0·2 atm abs
3	= 7·9 " "	= 0·4 " "
5	= 25 " "	= 1·0 " "

These are estimated values (see Remarks and Fig.26).

dP_o/dt: Not yet known.

T_o: $T_{o_{max}}$ = 720°K, $T_{o_{min}}$ = 290°K.

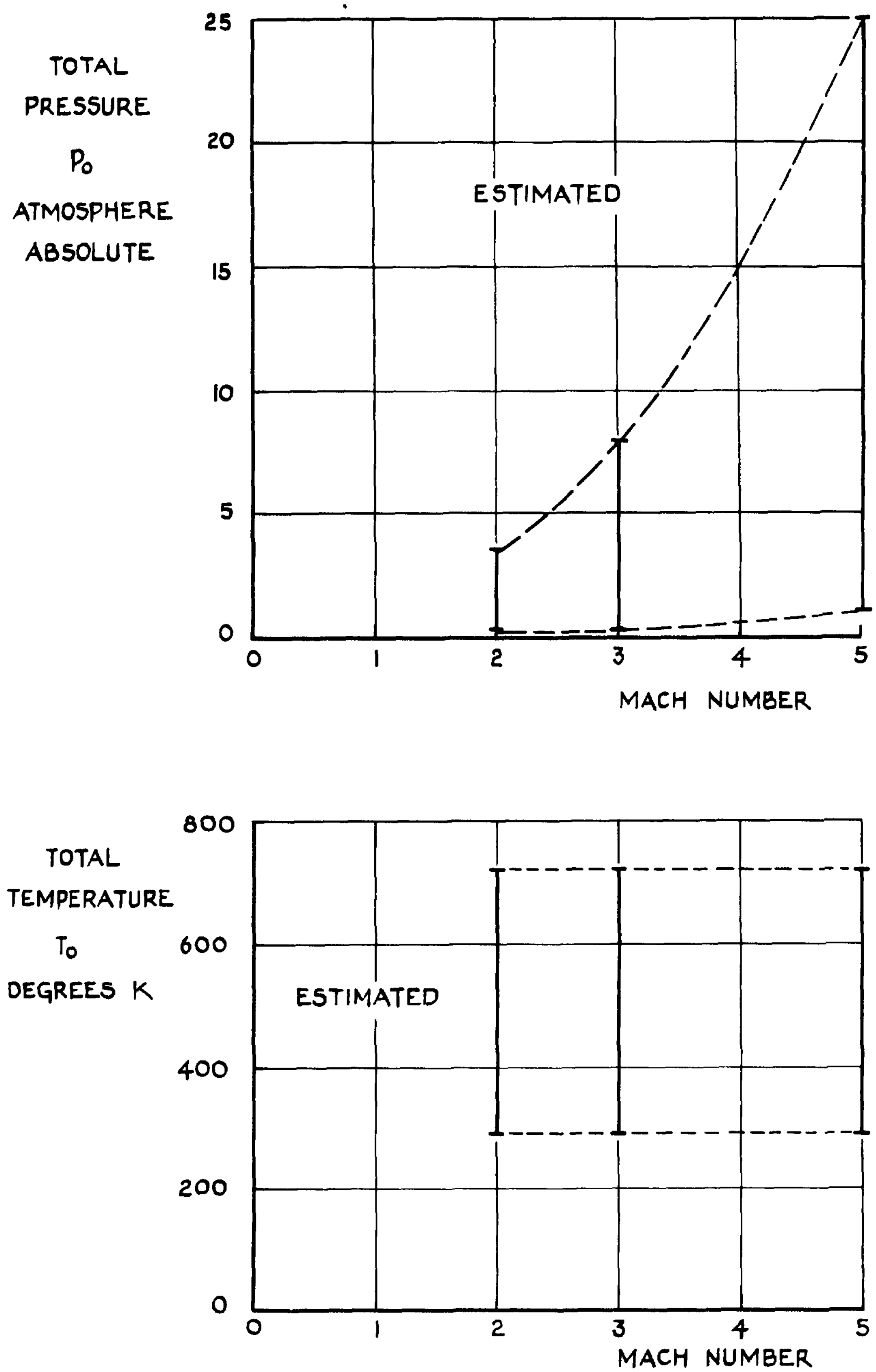
Sting mounting: Yes. No remote roll control.

Wall mounting: No.

Time to commence run: Not yet known. About 4-5 sec between runs, using the by-pass circuit.

Time to shut down and open tunnel for access to model: Approximately 10 min is expected.

Remarks: This tunnel is designed for tests in the presence of large heat transfers and a specialised working section has been provided. The commissioning of the tunnel is in progress.



'IG. 26 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. N.P.L., HEAT TRANSFER TUNNEL, 6 in x 6 in

4.2 Intermittent tunnels

4.2.1 Tunnel: Supersonic

Mach numbers: 1·6, 2·0, 2·5, 3·0, 3·5 (fixed liners)

Location: Hawker Siddeley Aviation Ltd., (Woodford Div.)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 30 inches × 27 inches.

P_o: (Fig.27)

M	$P_{o_{min}}$	$P_{o_{max}}$
1·6	2·2 atm abs	4·3 atm abs
2·0	2·1 " "	5·4 " "
2·5	2·7 " "	6·3 " "
3·0	4·0 " "	7·0 " "
3·5	6·1 " "	7·0 " "

dP_o/dt: 1 atmosphere in 2 sec at M = 1·6
1 atmosphere in 0·5 sec at M = 3·5

T_o: Ambient temperature ±10°C, except for starting and stopping transients. No temperature control. At low pressure ratios and $M \leqslant 2·5$ the transients are small, of the order 10°C, but for other conditions the transients can be large, up to 70°C (see Fig.27 and Ref.1).

Sting mounting: Yes. No remote roll control (see Remarks)

Wall mounting: Yes (see Remarks)

Time to commence a run: 2 sec approximately.

Time to shut down and open tunnel for access to model: 2 sec shut down, ½ min to open tunnel.

Running time: Depends on Mach number and total pressure. For $1·6 \leqslant M \leqslant 3·0$ running times up to 30 sec can be achieved but times are considerably less for M = 3·5.

Remarks: A pressure higher than the minimum running pressure is required for starting at M > 2 (see Fig.27). As this is a blowdown tunnel the starting loads can be high. The ram-operated sting incidence gear has the ability to raise the model into the stream after the start. The sting can also be used to support a wall-mounted model during starting.

There is a significant level of random excitation. Aerodynamic turbulence at about 300 c/s has been measured.

The arrangement of the tunnel is such that it is invulnerable to damage from broken models. The tunnel can be modified for use as a supersonic blower tunnel (i.e. discharging into the open air direct).

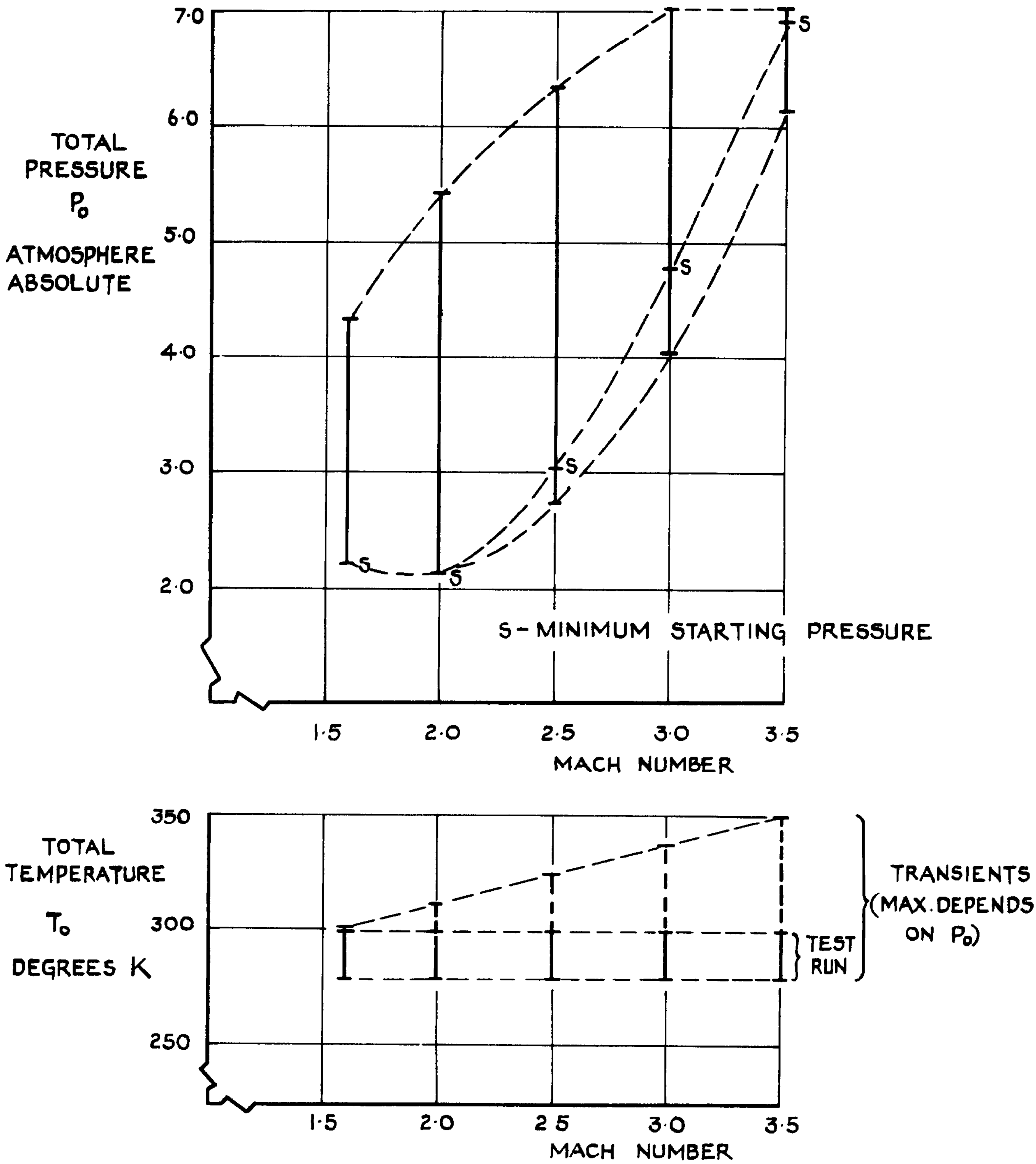


FIG. 27 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. HAWKER SIDDELEY AVIATION LTD. (WOODFORD DIV.), SUPERSONIC, 30 in x 27 in

4.2.2 Tunnel: Intermittent Supersonic

Mach numbers: 1·4, 1·6, 1·8, 2·0 then in steps of 0·25 to 3·50 (fixed liners)

Location: British Aircraft Corporation (Operating) Ltd. (Weybridge Division)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 20 inches × 20 inches.

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: Yes. Incidence $-5°$ to $+45°$. Sting roll, $1°$/sec.

Wall mounting. Yes.

Time to commence a run: 20 min to lower pressure in air receiver, 1·5 sec to settle flow.

Time to shut down and open tunnel for access to model: 30 sec.

Running time: Useful time about 10 sec at $M = 1{\cdot}4$, 25 sec at $M = 3{\cdot}5$.

Remarks: The number of test runs is limited to about sixteen per day by the capacity of the air driers. No significant random excitation is present but the starting and stopping loads can give rise to initial vibrations (1-1·5 sec).

4.2.3 Tunnel: G.W. Tunnel

Mach numbers: 1·5-6·0 (flexible nozzle, see Remarks)

Location: British Aircraft Corporation (Operating) Ltd., (G.W. Division), Warton.

Safety: Flutter tests acceptable (see Section 2)

Working Section: 18 inches × 18 inches.

P_o: The air storage pressure can be up to 40 atm abs but practical maxima of P_o are lower, see Fig.28. Minimum starting pressures, using an ejector at $M > 3{\cdot}0$, and minimum running pressures are also illustrated in Fig.28.

dP_o/dt: Manual control is used. Rates not determined.

T_o: Capacity heater is arranged to give ambient temperature for $M \nless 3{\cdot}75$, and an approximately linear rise with Mach number in the values of the total temperature up to 460°K at $M = 6$ (see Fig.28). The temperature is within ±2% over all runs.

It may be possible to give higher temperatures at lower Mach numbers by pre-heating but the length of run for a reasonably constant temperature is then reduced.

Sting mounting: Yes. Roll at constant velocity only, no incremental drive.

Wall mounting: A sidewall mounting could be made if required.

Time to commence a run: Time to recharge air storage depends on P_o and running time at each M. A typical time is 1 hr after a 3-4 min run. To establish flow 2-10 sec.

Time to shut down and open the tunnel for access to model: 5 min.

Running times: Approximately 10 sec at practical $P_{o_{max}}$ for all Mach numbers and up to 6 min at minimum running pressure, dependent on Mach number.

Remarks: The flexible nozzle was designed to work down to $M = 1{\cdot}5$ but blockage at the model cart caused difficulties. Modifications have been made but not retested at $M = 1{\cdot}5$. Conditions are satisfactory at $M = 1{\cdot}75 - 5{\cdot}0$. The tunnel has not yet been run with the ejector at $M = 6{\cdot}0$.

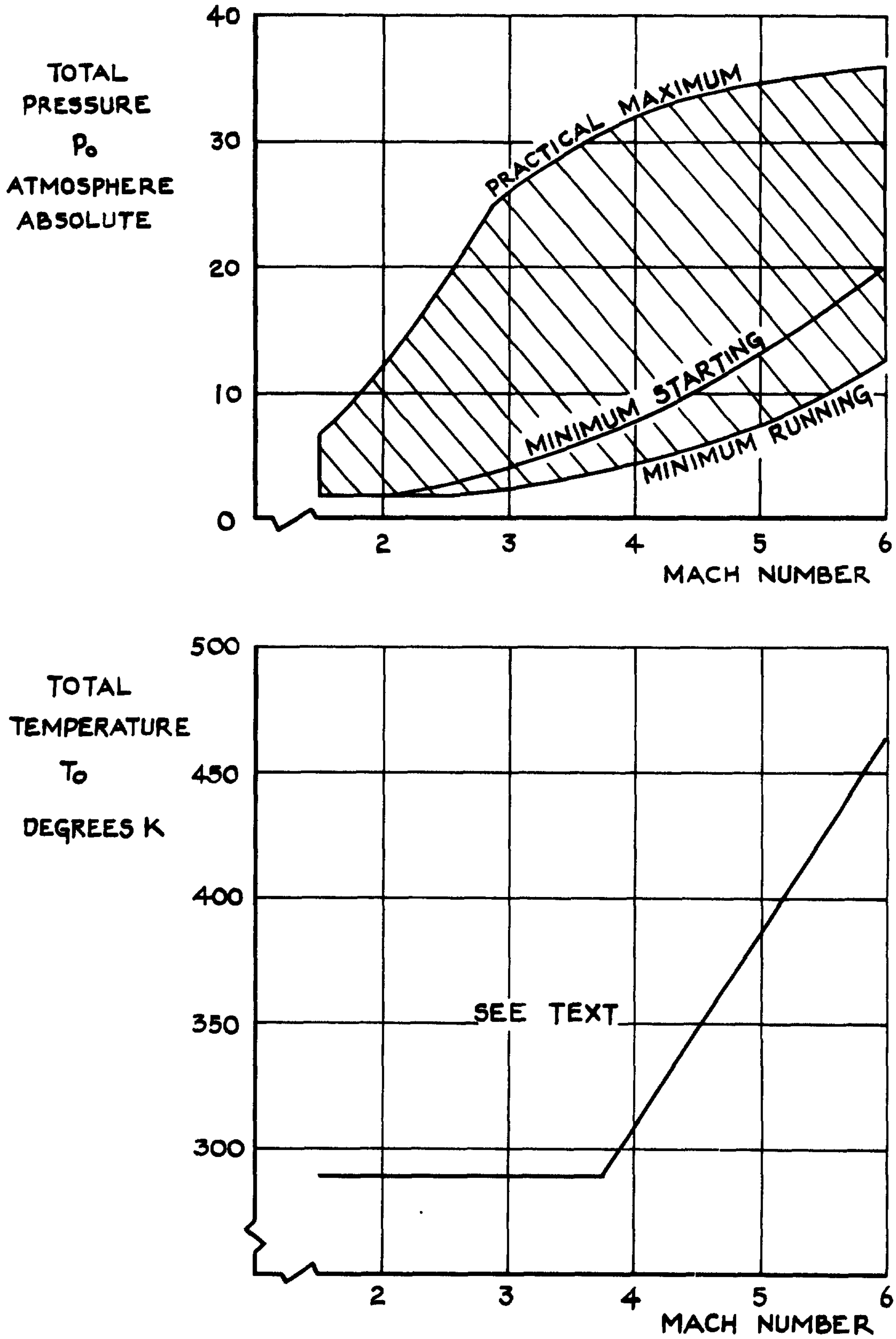


FIG. 28 RANGE OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. BRITISH AIRCRAFT CORPORATION (OPERATING) LTD. (G.W. DIVISION), 18 in X 18 in

4.2.4 Tunnel: No.15 Supersonic

Mach numbers: 1·6, 1·8, 2·0, 2·25, 2·50, 3·0, 3·5, 4·0 (fixed liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 16 inches × 15 inches.

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation; total pressure equals atmospheric pressure.

T_o: Ambient temperature. No control.

Sting mounting: Model support with incidence changing system but no sting. Roll position preset.

Wall mounting: No.

Time to commence run: 5 min between runs, according to M. Approximately 10-15 min for the initial decompression.

Time to shut down and open tunnel for access to model: 2-3 min.

Running time: Times depend on the initial pressure in the low pressure reservoir. Typical times are 20 sec at M = 2·5, 10 sec at M = 4·5.

Remarks:

4.2.5 Tunnel: Hypersonic Tunnel

Mach numbers: 4,5,6,7,8 (fixed liners)

Location: Aircraft Research Association Ltd., Bedford

Safety: Flutter tests acceptable (see Section 2)

Working Section: 16 inches × 12 inches, M = 4 and 5
12 inch dia, M = 6,7 and 8

P_o:

M	$P_{o_{max}}$ atm abs	$P_{o_{min}}$ atm abs	
4	12	8	
5	27	17	
6	100	40	estimated
7	175	70	estimated
8	200	150	estimated

(see Fig.29)

dP_o/dt: Full range in 1 sec.

T_o:

M	$T_{o_{max}}$ °K	$T_{o_{min}}$ °K	
4	400	330	
5	400	350	
6	840	470	estimated
7	840	650	estimated
8	840	800	estimated

(see Fig.29)

The temperature cannot be controlled during a run but the variation should not exceed 10°C.

Sting mounting: Yes. No remote roll control.

Wall mounting: Plate could replace window.

Time to commence run: 1 hr to raise storage pressure for 10 sec run at M = 4 or 5. 2 sec to bring tunnel up to speed.

Time to shut down and open the tunnel for access to model: 2 min.

Running time: (see Fig.29)

M	at $P_{o_{max}}$ sec	at $P_{o_{min}}$ sec	
4	23	35	
5	27	40	
6	24	100	estimated
7	30	96	estimated
8	24	55	estimated

It has been found that for steady aerodynamic tests run times of about 10 sec are generally sufficient.

Remarks: The tunnel has been run at M = 4 and M = 5 but the construction of the M = 6,7 and 8 sections is not yet complete.

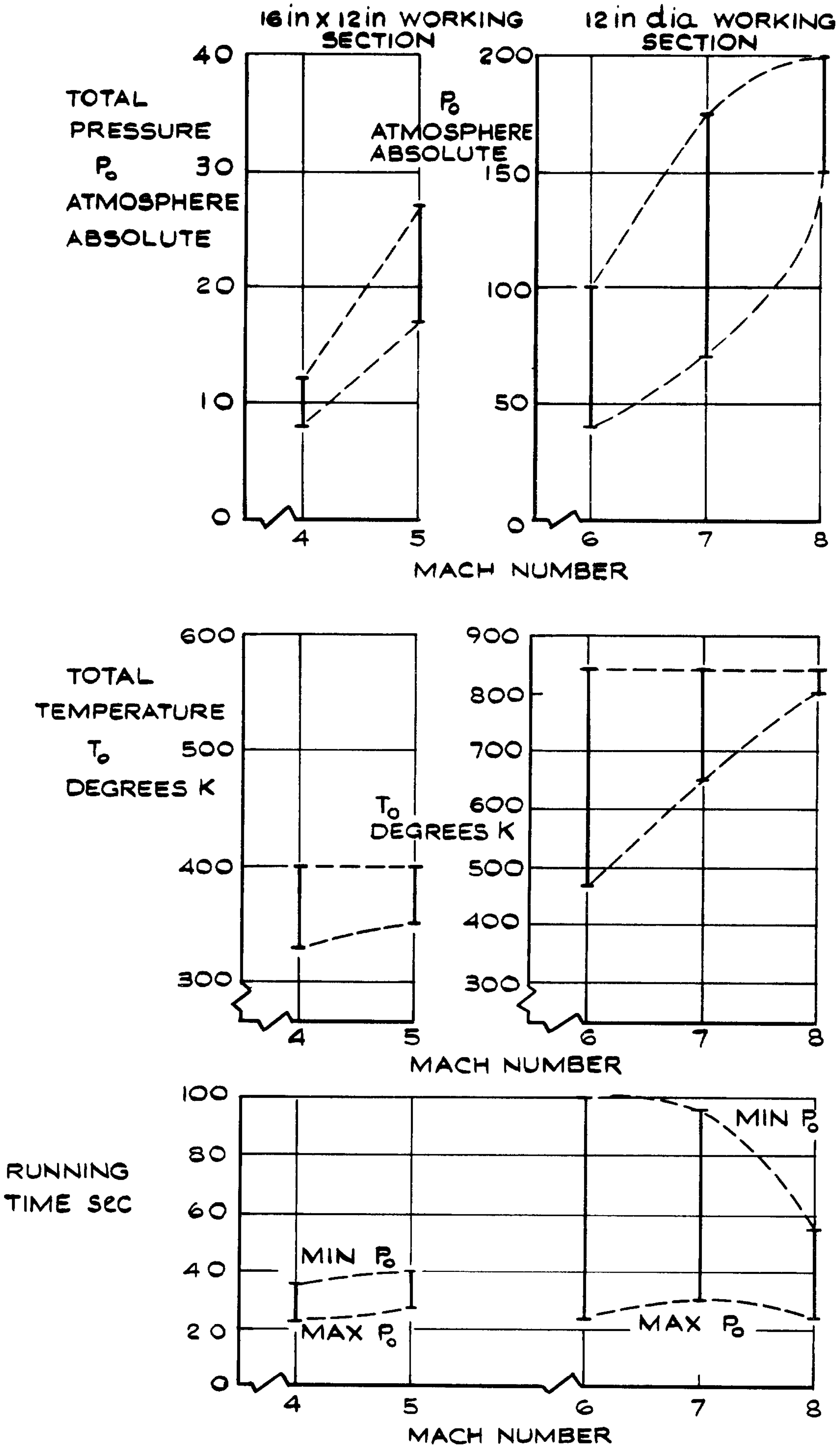


FIG. 29 RANGES OF TOTAL PRESSURE, TEMPERATURE AND RUNNING TIME OVER MACH NUMBER RANGE. AIRCRAFT RESEARCH ASSOCIATION LTD., HYPERSONIC TUNNEL

4.2.6 Tunnel: 15 inch x 10 inch Supersonic. Mach numbers: 2,3,5,7 (fixed liners), also 4, see below

Location: N.P.L. Teddington

Safety: Flutter tests acceptable (see Section 2 and Remarks)

P_o: $P_{o_{min}}$ varies from 0·6 atm abs at M = 2 to 6 atm abs at M = 7
$P_{o_{max}}$ depends on T_o. For $T_o < T'_o$ (see below), $P_{o_{max}}$ = 6·5 atm abs at M = 2 and 15 atm abs at M $\geqslant$ 3 (see Fig.30).

dP_o/dt: Pressure can be doubled in 10 sec and halved in about the same time.

T_o: Tunnel is designed for standard operation such that at M = 2,3 and 4 ambient recovery temperature will be achieved and at M = 5 and 7 condensation avoided: T'_o is the total temperature corresponding to the standard operating conditions.

The present working sections at M = 2 and 3 are limited to a temperature $T_o \not> 373^\circ$K. Temperature is controlled by adjusting the mixture of hot and cold air to give a constant temperature during a run. The maximum possible temperature is $T_o = 623^\circ$K (see Fig.30).

Sting mounting: Yes, but no roll.

Wall mounting: Yes

Time to commence run: The capacity of the pumps limits the number of test runs to 4 or 5 per day. 7 sec is required to bring the tunnel up to speed. The heater bed requires 2 hr to reach the highest operating temperatures at the start of the day and then requires little re-heating.

Time to shut down and open the tunnel for access to the model: 5 sec to shut down. A few min to open tunnel.

Running time: Useful time not less than 30 sec except at M = 7 and low P_o when the maximum duration may be only a few sec. For $T_o < T'_o$ run times may be as long as 120 sec in some cases.

Remarks: Requirements for flutter testing were considered during the design of this tunnel. A M = 4 nozzle is being prepared.

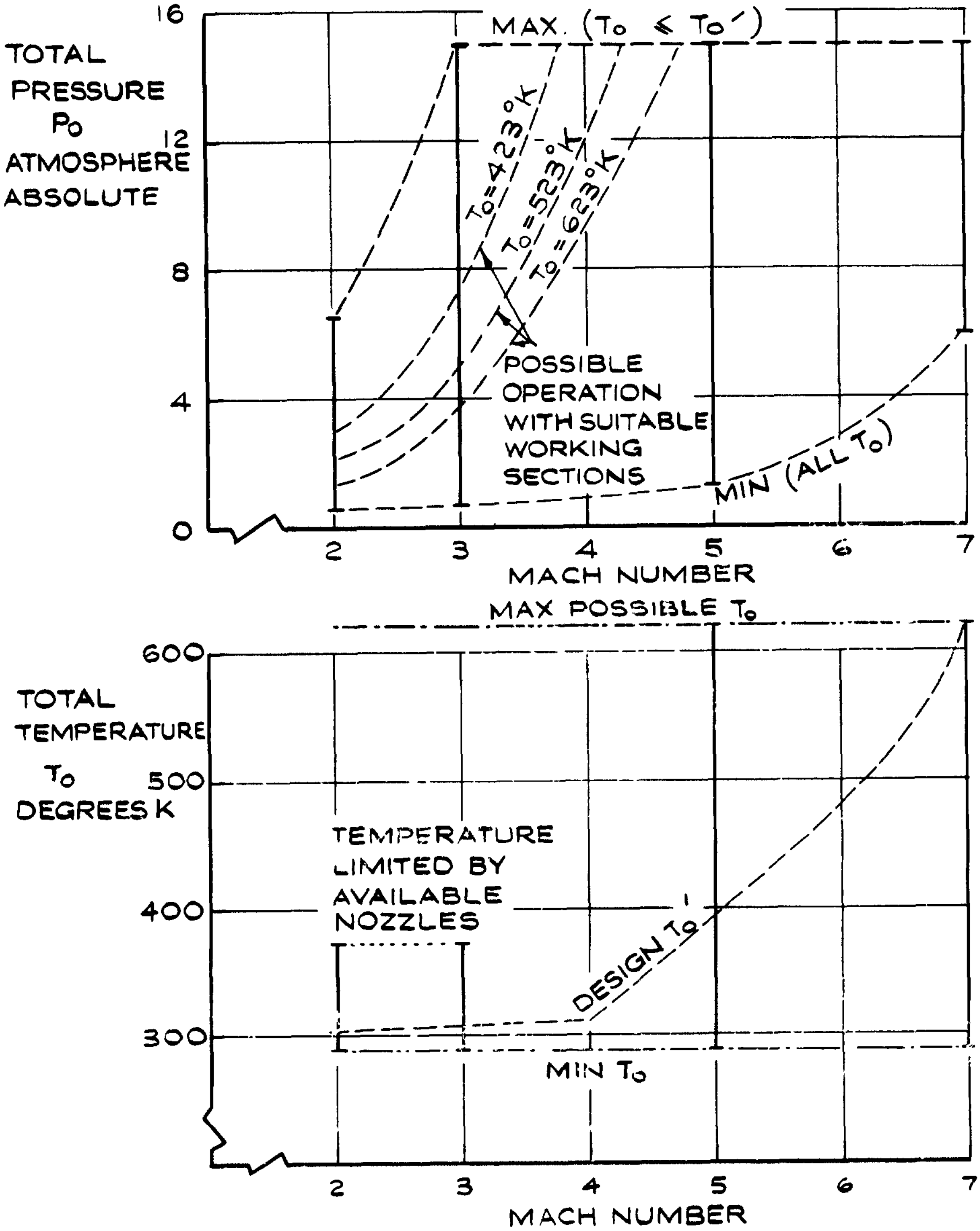


FIG.30 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE, N.P.L., 15 in x 10 in

4.2.7 Tunnel: 12 inch × 9 inch.

Mach numbers: 2·5, 3·4 and 4·3 (fixed liners)

Location: R.A.E. (Bedford)

Safety: Flutter tests acceptable (see Section 2 and Remarks)

Working section: 12 inches × 9 inches.

P_o: Estimated, at M = 2·5 , $P_{o_{max}}$ = 1·4 atm abs , $P_{o_{min}}$ = 0·25 atm abs

M = 2·5 ,	$P_{o_{max}}$ = 1·4 atm abs ,	$P_{o_{min}}$ = 0·25 atm abs
M = 3·4 ,	" = 3·7 " "	" = 0·50 " "
M = 4·3 ,	" = 4·0 " "	" = 1·20 " "

(see Fig.31)

dP_o/dt: Not yet determined.

T_o: Not yet determined.

Sting mounting: No.

Wall mounting: No.

Time to commence run: Not yet determined.

Time to shut down and open tunnel for access to model: Not yet determined.

Running time: Expected to lie between 1 min at $P_{o_{max}}$ and continuous running at $P_{o_{min}}$.

Remarks: The present working section is not adapted to take wind tunnel models. It is a $\frac{1}{4}$ scale model of the H.S.S.T. at Bedford and would require much development to make it into a tunnel suitable for flutter model tests or dynamic response tests. The designed compressed air supply is not yet available. Flutter tests would be acceptable in principle if safety nets were fitted to protect the evacuating pumps and their valves.

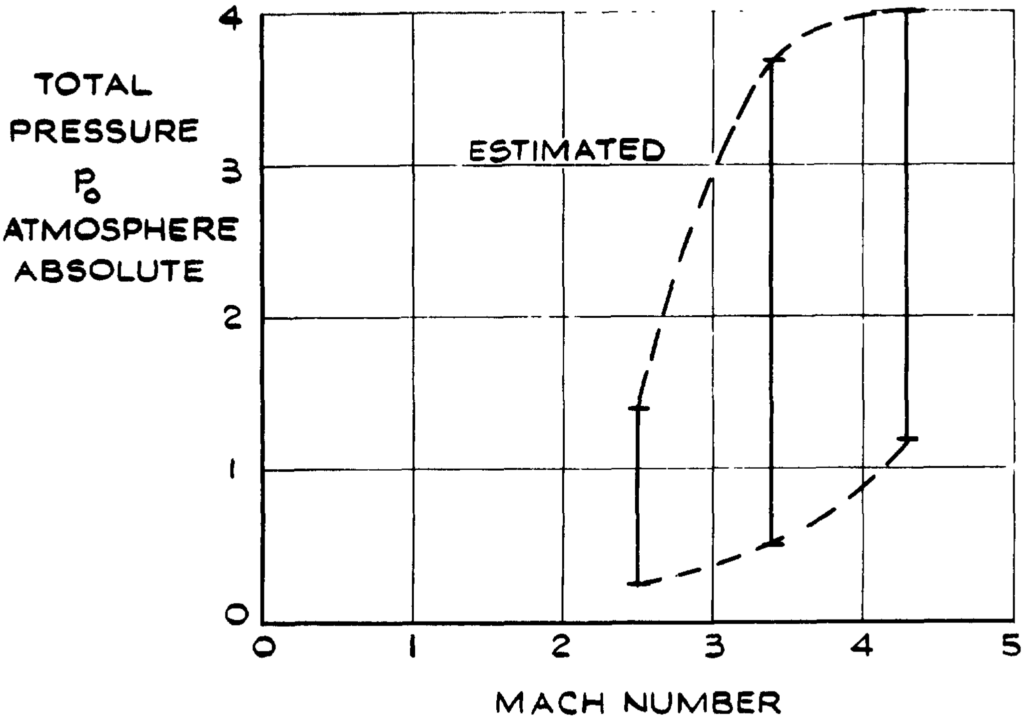


FIG. 31 RANGES OF TOTAL PRESSURE OVER THE MACH NUMBER RANGE. R.A.E. (BEDFORD), 12 in x 9 in

4.2.8 Tunnel: 10 inch × 10 inch.

Mach numbers: 1·5, 2·0, 2·5, 3·0, 3·5, 4·0 (fixed liners, see Remarks below)

Location: University of Bristol.

Safety: Flutter tests acceptable (see Section 2)

Working Section: 10 inches × 10 inches

P_o: Maximum storage pressure = 30·6 atmospheres absolute
Minimum total pressure = starting pressure (see Fig.32)

dP_o/dt: Pressure can be varied by adjustment of plug valve setting. Rates not yet determined.

T_o: Ambient temperature at start of run, followed by slow fall of about 10°C, depending on run length and conditions.

Sting mounting: Yes. Quick return to zero incidence. Roll position preset.

Wall mounting: Yes.

Time to commence run: $3\frac{3}{4}$ hours to reach max. storage pressure. 10 sec to establish flow.

Time to shut down and open tunnel for access to model: 20 min to remove sidewalls.

Running time: Maximum running times are shown in Fig.32.

Remarks: Additional liners exist for M = 1·4, 2·8, 3·6 but they are slightly distorted. Up to the present the tunnel has been run only at M = 2·8 and performance at other Mach numbers is estimated. Some turbulence due to buffeting at the plug valve. Work in progress to reduce this effect.

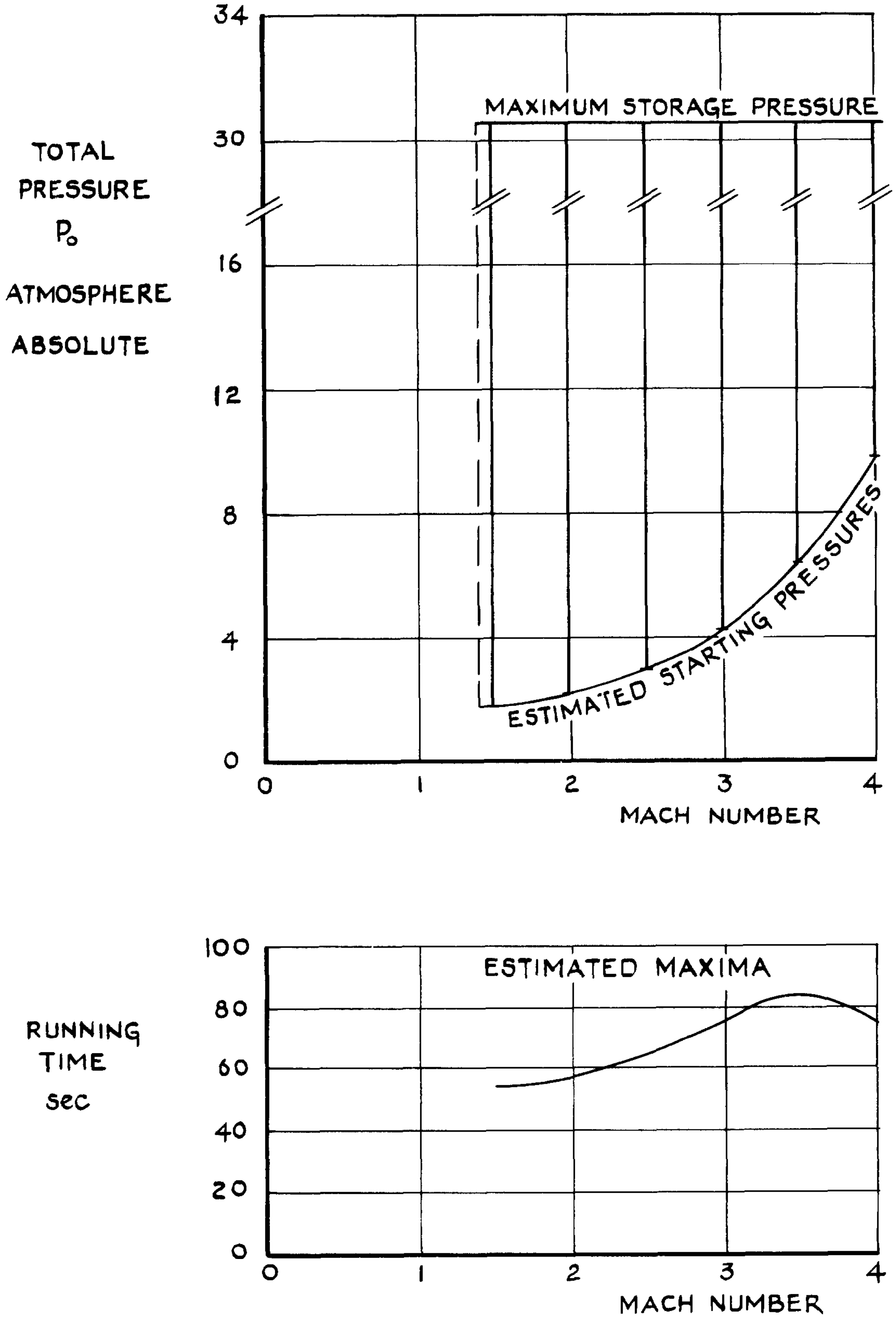


FIG. 32 RANGES OF TOTAL PRESSURE AND RUNNING TIME OVER MACH NUMBER RANGE. UNIVERSITY OF BRISTOL, 10 in x 10 in

4.2.9 Tunnel: ° No.14 Supersonic

Mach numbers: 1·4, 2·2, 2·5, (fixed liners); 1·4, 1·6, 1·8, 2·0 (fixed half-liners)

Location: R.A.E. (Farnborough)

Safety: Flutter tests acceptable (see Section 2)

Working Section: 9 inches × 9 inches

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation possible; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: No.

Wall mounting: Yes, sidewall.

Time to commence a run: 5 min, except the first run. Approximately 10-15 min for the initial decompression.

Time to shut down and open tunnel for access to model: a few min.

Running time: Depends on initial pressure in low pressure reservoir. A typical time is 40 sec at M = 2·0.

Remarks: The tunnel is used mainly for demonstrations. There is no significant random excitation except during starting.

4.2.10 Tunnel: 9 inch x 6 inch

Mach numbers: 1·4, 1·5, 1·6, 1·8 (fixed liners)

Location: University of Southampton

Safety: Flutter tests acceptable (see Section 2)

Working Section: 9 inches x 6 inches.

P_o: Atmospheric pressure.

dP_o/dt: No controlled variation possible; total pressure equals atmospheric pressure.

T_o: Ambient temperature.

Sting mounting: Yes. No remote roll control.

Wall mounting: Yes.

Time to commence run: $2\frac{1}{2}$ hr pumping for initial storage of compressed air (see Remarks), 5 sec to bring tunnel up to speed.

Time to shut down and open tunnel for access to model: 3 sec to shut down, 4 min for access.

Running time: Maximum times are 20 sec to 1 min depending on Mach number.

Remarks: Additional pumping capacity is to be provided which will reduce the time to reach the maximum working pressure to about $1\frac{1}{2}$ hours (this is an induced flow tunnel).

Random excitation is not significant but extra turbulence can be provided deliberately at a low level. The tunnel has been used mainly for oscillatory work.

5 HYPERSONIC TUNNELS

5.1 Tunnel: Hypersonic Gun Tunnel

Mach numbers: 6,7,8 (profiled nozzles)

Location: Bristol Siddeley Engines Ltd., Bristol

Safety: Flutter tests acceptable (see Section 2 and Remarks below)

Working Section: Open jet into chamber.
Diameter of nozzle outlet 6·25 inch at M = 6
8·0 inch at M = 7
10·5 inch at M = 8

P_o: $P_{o_{max}} = 272$ atm abs
$P_{o_{min}} = 136$ atm abs approximately } Independent of M (see Fig.33)

dP_o/dt: No controlled total pressure variation during a run.

T_o: $T_{o_{max}} = 1300°K$. Tunnel usually operated at T_o sufficient to avoid condensation of air, plus a small margin. Thus, $T_{o_{min}}$ is approximately 460°K at M = 6, 590°K at M = 7, 740°K at M = 8 (see Fig.33).

Sting mounting: Yes. Preset.

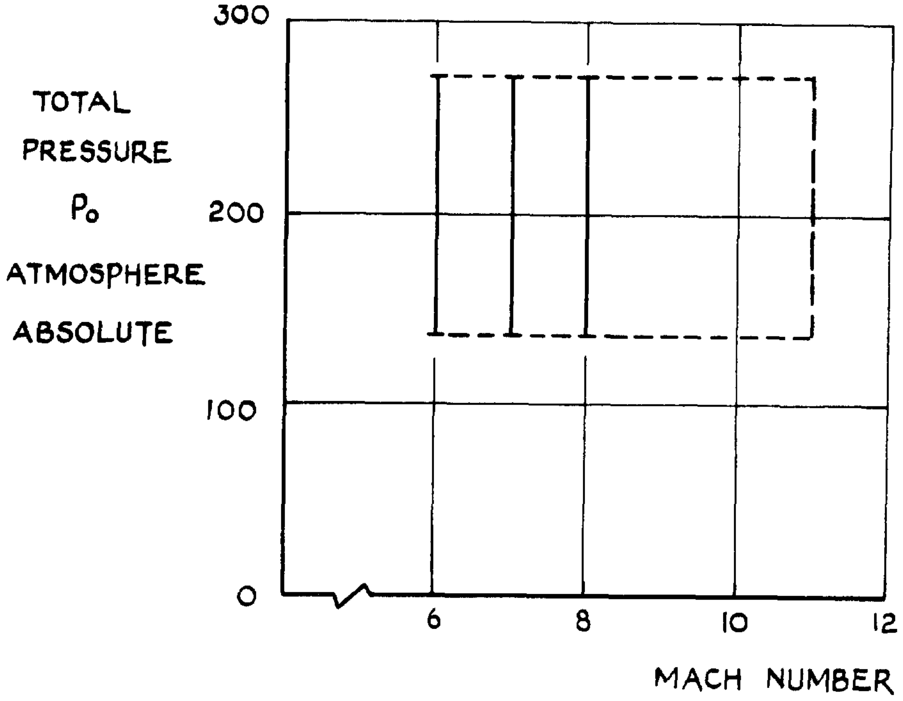
Wall mounting: Mounting for half models could be provided.

Time to commence run: To compress driver, 2 hr between runs. Somewhat longer at start of day.

Time to shut down and open tunnel for access to model: Approximately $\frac{1}{4}$ hour.

Running time: Approximately 0·05 sec at all M.

Remarks: The driving gun is connected to the test chamber by a flexible coupling to reduce the transfer of mechanical vibration. The vacuum chamber is provided with a trap to collect model fragments.



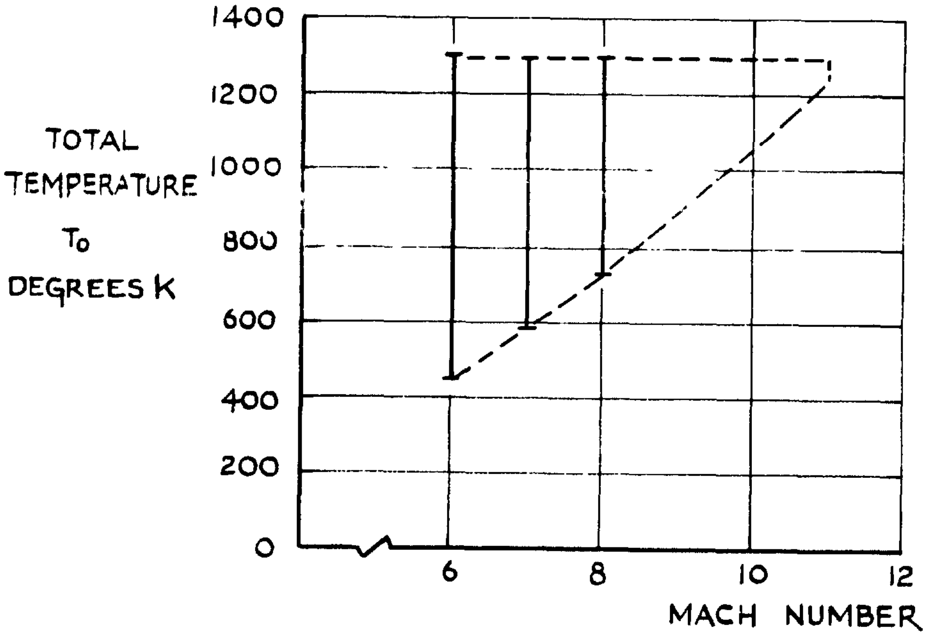


FIG. 33 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. BRISTOL SIDDELEY ENGINES LTD., HYPERSONIC GUN TUNNEL

5.2 Tunnel: No.3 Hypersonic Gun Tunnel.

Mach numbers: 7-12 (adjustable conical nozzle; usual settings 8,10,12)

Location: R.A.R.D.E., Fort Halstead.

Working Section: 10 inch diameter (can be extended to 24 inch diameter)

Safety: Flutter tests acceptable (see Section 2)

P_o: Maximum, 1000 atm abs; Minimum, 100 atm abs } independent of M (see Fig.34)

dP_o/dt: No controlled total pressure variation during a run.

T_o: Up to 1600°K. It is proposed to raise T_o to 2000-2500°K, independent of M but dependent on running time. During a run the temperature falls at an average rate of 3°K/m sec. No control.

Sting mounting: Yes. No remote roll control.

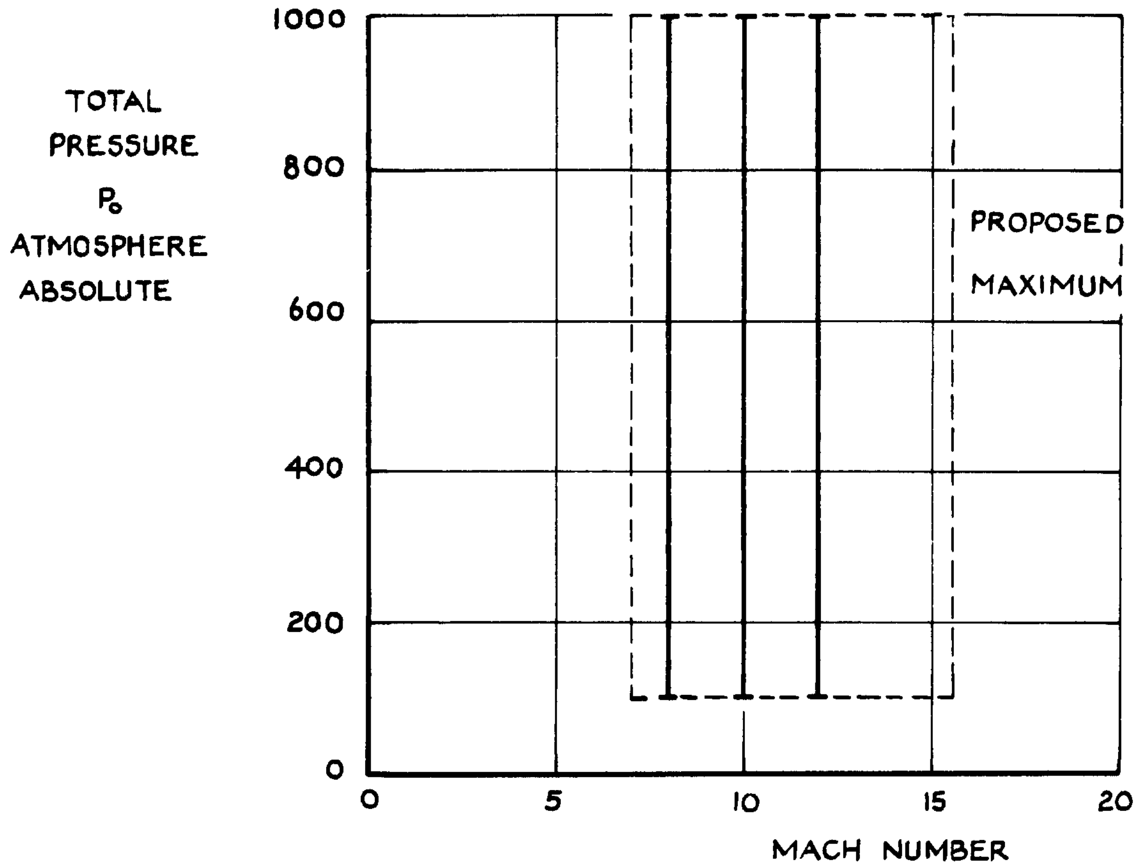
Wall mounting: No, but could be provided.

Time to commence run: 20 min approximately dependent on P_o.

Time to shut down and open tunnel for access to model: 20 min approximately, dependent on P_o.

Running time: Typical times are 0·05 sec at M = 8, 0·20 sec at M = 12.

Remarks: When T_o is raised to 2500°K the possible Mach number range will be extended to about M = 15·5. Random excitation has not been significant as yet. Some measurements of damping in pitch have been attempted.



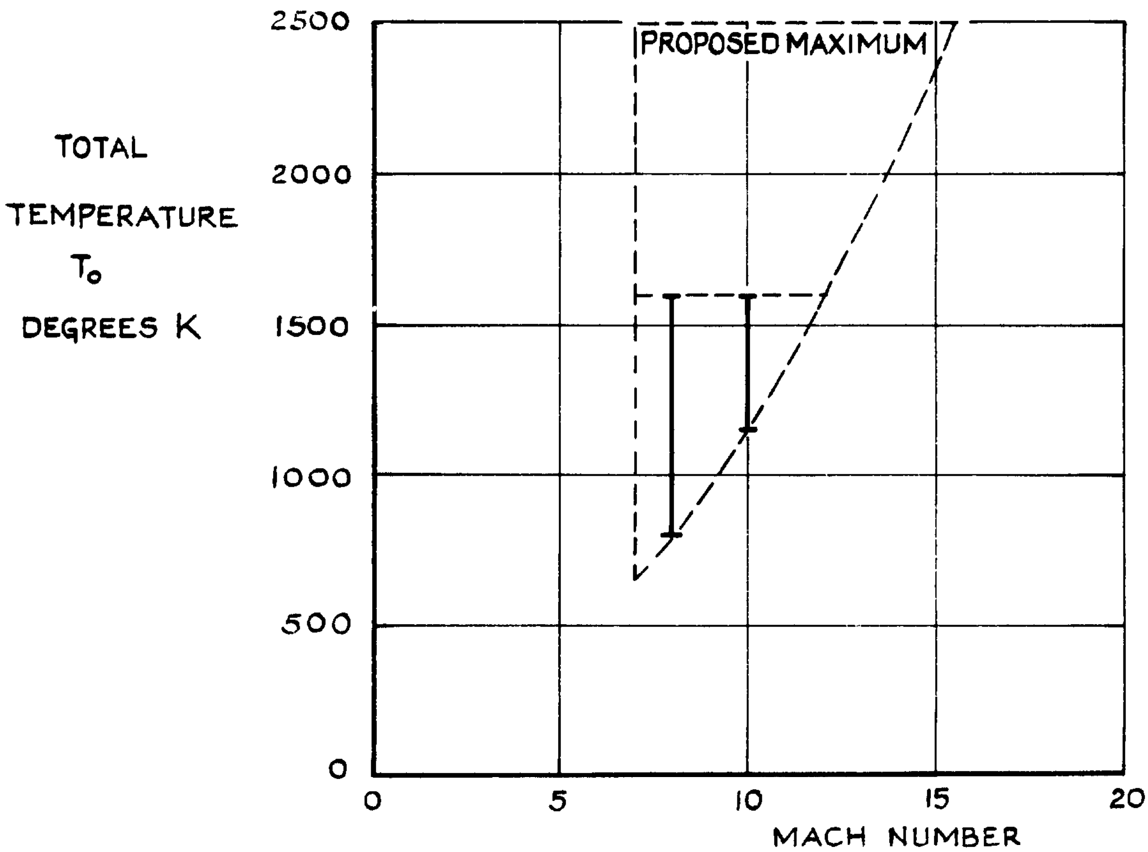


FIG. 34 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.R.D.E., Nº3 HYPERSONIC GUN TUNNEL

5.3 Tunnel: Hypersonic Tunnel. Mach numbers: 6·8, 8·6, 10 (fixed liners)

Location: R.A.E. (Farnborough) Safety: Flutter tests acceptable (see Section 2)

Working Section: 7 inches × 7 inches

P_o: At M = 6·8 , $P_{o_{max}}$ = 52 atm abs ; $P_{o_{min}}$ = 7·8 atm abs (see Fig.35)
M = 8·6 , " = 52 " " ; " = 14·6 " "
M = 10 , " = 52 " " ; " = Not yet known

Starting pressures depend upon vacuum tank pressure and are somewhat higher than the $P_{o_{min}}$ quoted.

dP_o/dt: Pressure can be changed by manual operation of a valve. Rates not known.

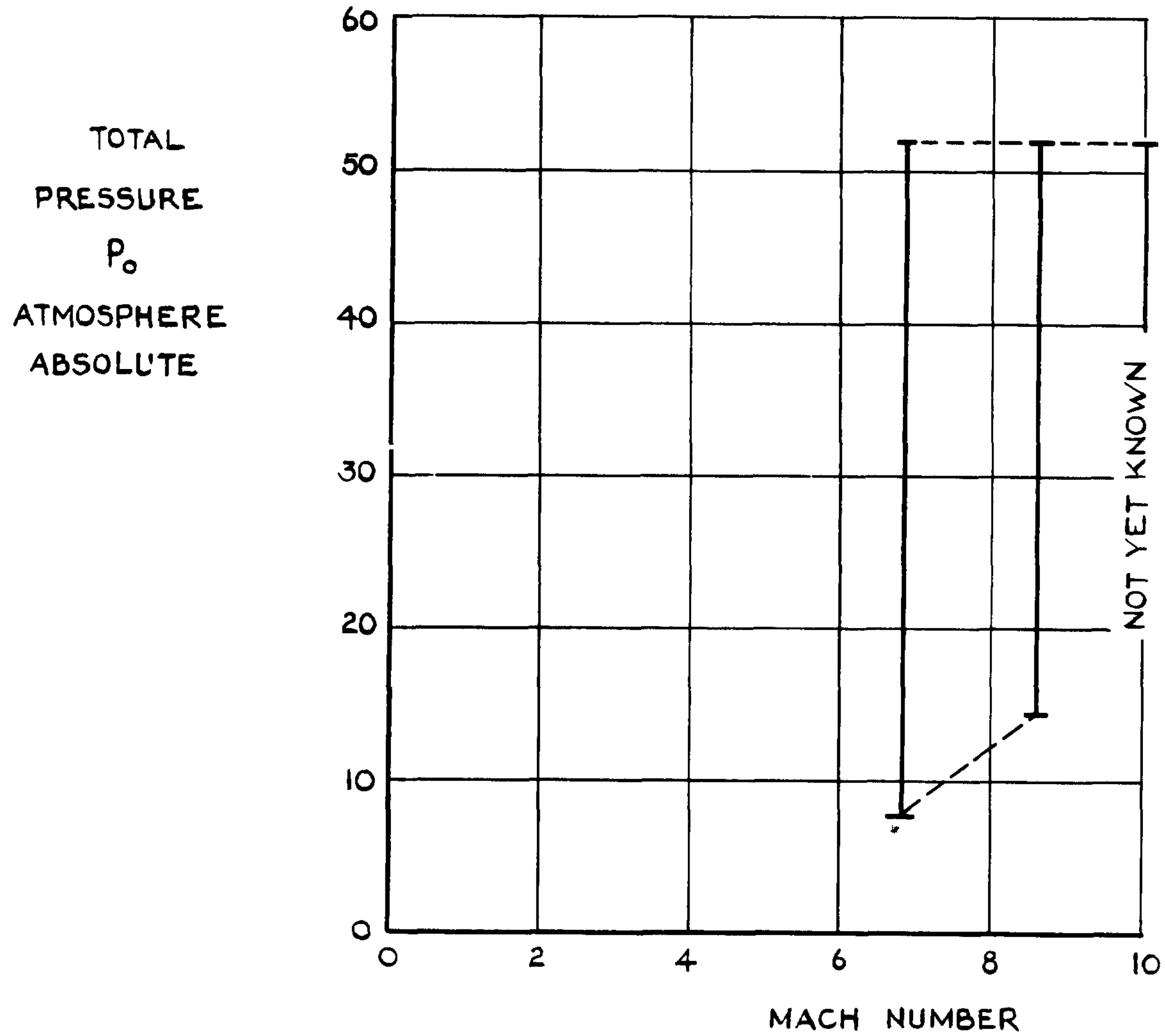
T_o: Determined by storage heater temperature. Can be preset, within about 10°C, in the following ranges:-
At M = 6·8 , $T_{o_{max}}$ = 950°K , $T_{o_{min}}$ = 670°K
M = 8·6 , " = 950°K , " = 770°K
M = 10 , " = 950°K , " = not yet known

Sting mounting: Yes. Roll control being incorporated in a new sting. Wall mounting: No.

Time to commence run: 1 day from cold; 5 hr to raise initial reservoir pressure; 3 hr to restore pressure after a run. Time to shut down and open tunnel for access to model: 5 min.

Running time: At $P_{o_{max}}$ running times are approximately 4 min at M = 6·8 and 5 min at M = 8·6. At $P_{o_{min}}$ a typical time is 15 min at M = 8·6. The tunnel has not yet been run at M = 10.

Remarks: The useful diameter of the working section is approximately 4 inches due to boundary layer effects. No significant random excitation has been observed.



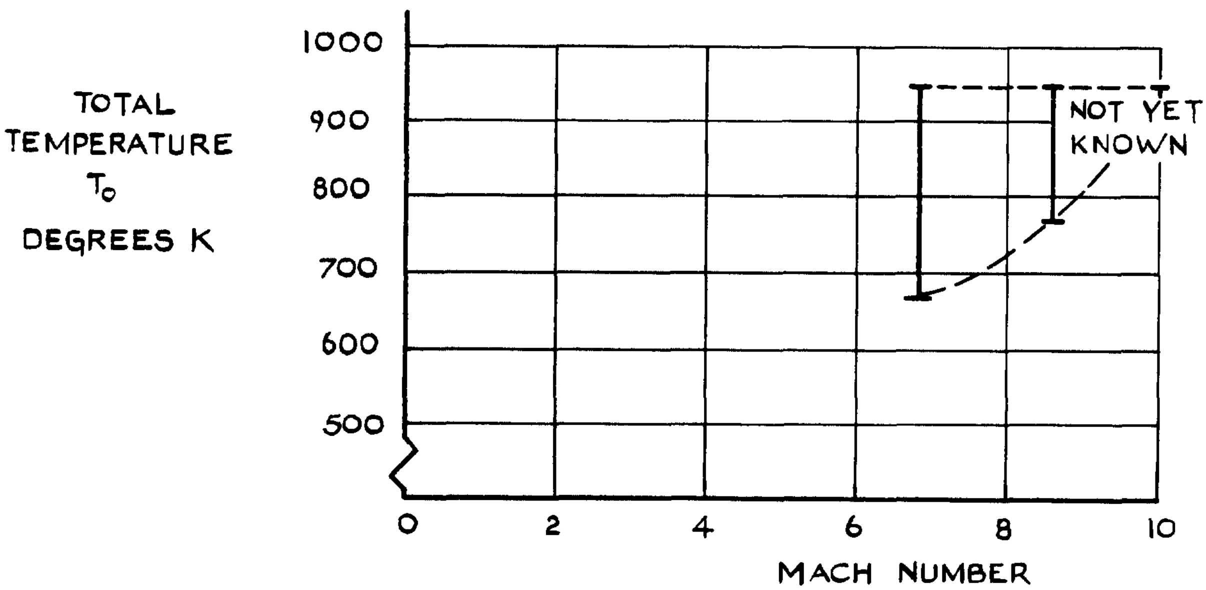


FIG. 35 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. R.A.E. (FARNBOROUGH), HYPERSONIC TUNNEL

5.4 Tunnel: Helium Tunnel

Mach numbers: 9,12,18

Location: N.P.L. Teddington

Safety: Flutter tests acceptable (see Section 2)

Working Section: 5 inch diameter.

P_o: Maximum storage pressure 135 atm abs.
Starting pressures not yet determined; minimum pressure is governed by starting pressure or useful running time (see Fig.36 and Running Time).

dP_o/dt: Some control possible. Rates not yet determined.

T_o: Ambient temperature, less some drop due to cooling by expansion in the storage and pipelines. No control but drop probably about 1°C/sec.

Sting mounting: Yes. No remote roll control.

Wall mounting: Not yet.

Time to commence run: Approx. 1 hr to reach maximum storage pressure. About 5 sec to start a run.

Time to shut down and open tunnel for access to model: Shut down in about 3 sec and open in 10-15 min.

Running time: Times are estimated and depend upon the total pressures to be used; maximum times, based on expected starting pressures, are approximately 35 sec at M = 5 or 10 and 40 sec at M = 20.

Remarks: The tunnel is expected to complete its commissioning trials in the Spring of 1965. An oscillatory derivative test rig is being prepared.

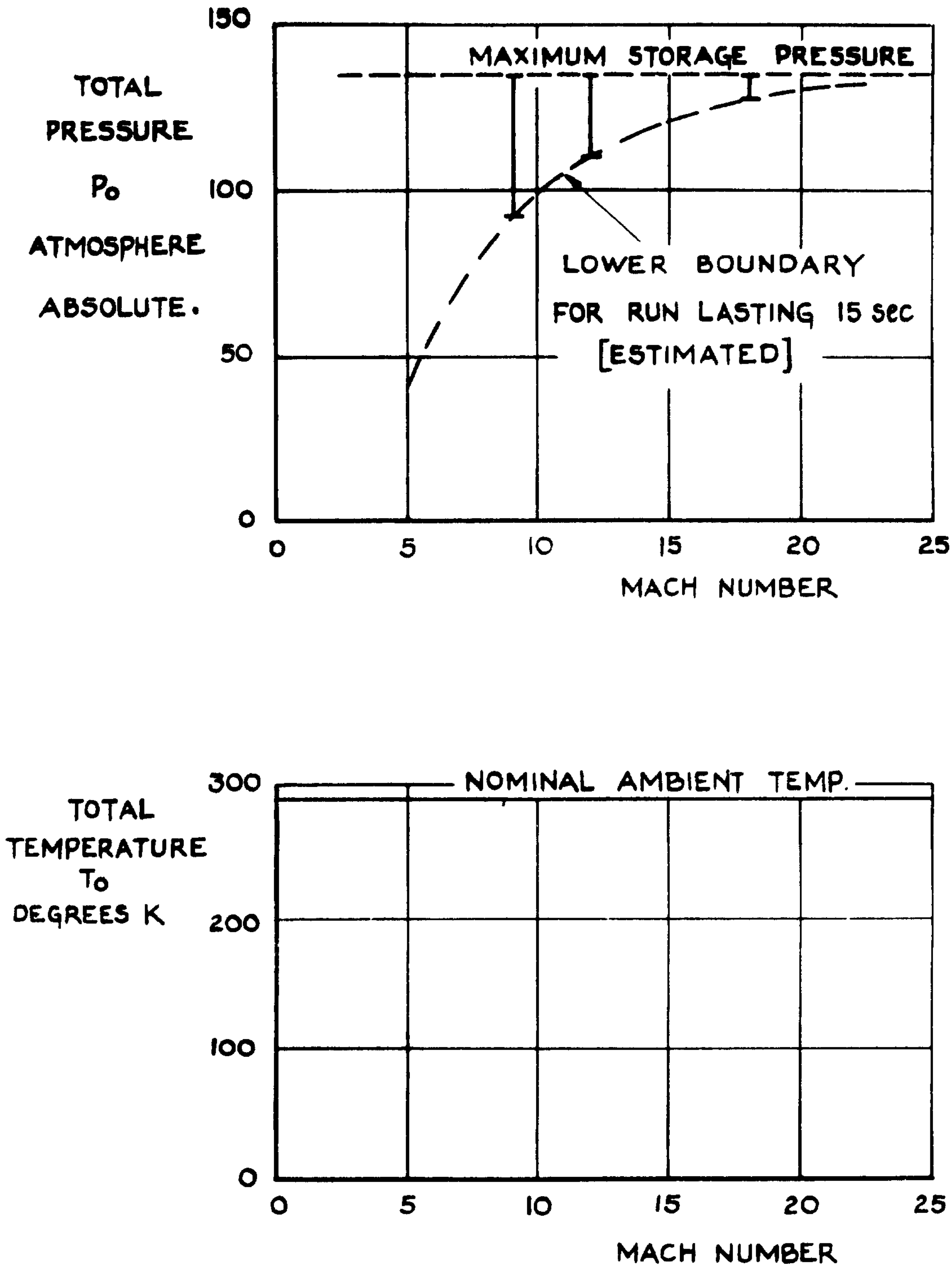


FIG.36 RANGES OF TOTAL PRESSURE AND TEMPERATURE OVER MACH NUMBER RANGE. N.P.L., HELIUM TUNNEL

6 INDEX OF TUNNELS

High-subsonic tunnels and transonic tunnels - continuously running			
Nominal size (in order of decreasing area)	**Mach number range**	**Location**	**Page No.**
9 ft x 8 ft †	0·2-1·45	Aircraft Research Association Ltd., Bedford	8
8 ft x 8 ft	0-2·8 (not transonic)	R.A.E. (Bedford)	10
8 ft x 6 ft *	0-1·28	R.A.E. (Farnborough)	12
4 ft x 3 ft	0·2-1·0	Handley Page Ltd., Colney Street, St. Albans	14
3 ft x 3 ft *	0·4-2·0	R.A.E. (Bedford)	16
$2\frac{1}{2}$ ft x $2\frac{1}{2}$ ft *	0·3-1·2	Short Brothers and Harland Ltd., Belfast	18
2 ft x 2 ft *	0·3-1·6	Hawker Siddeley Aviation Ltd. (de Havilland Div.), Hatfield	20
22 in x 20 in *	0·3-2·96	Hawker Siddeley Dynamics Ltd. (Coventry Div.)	22
2 ft x $1\frac{1}{2}$ ft *†	0·3-1·35	R.A.E. (Farnborough)	24
20 in x 20 in *	0·6-1·5	Hawker Siddeley Aviation Ltd., (Woodford Div.)	26
18 in x 18 in *	0·5-1·6	British Aircraft Corporation (Operating) Ltd. (Preston Div.), Warton	28
12 in dia * (largest transonic nozzle)	0-5·2	Bristol Siddeley Engines Ltd., Bristol	30
9 in x 8 in	0·4-2·5 (not transonic)	R.A.E. (Bedford)	32
High-subsonic tunnels and transonic tunnels - intermittent			
4 ft x 4 ft †	0·4-4·0	British Aircraft Corporation (Operating) Ltd. (Preston Div.), Warton	34
27 in x 27 in †	0·45-2·0	Hawker Siddeley Aviation Ltd. (Hawker-Blackburn Div.), Brough	36
36 in x 14 in *	0·4-1·6	N.P.L. Teddington	38
25 in x 20 in †	0·4-1·5	N.P.L. Teddington	39
18 in x 14 in *	0·4-2·5	N.P.L. Teddington	40
20 in x 8 in *	0·4-1·6	N.P.L. Teddington	42
12 in x 12 in	0-1·8 (not transonic)	Imperial College, University of London	43
$9\frac{1}{2}$ in x $9\frac{1}{2}$ in *	0·4-1·6	N.P.L. Teddington	44
10 in x 8 in *	0·2-1·8	Lanchester College of Technology, Coventry	45
10 in x 8 in *	0·2-1·55	Hawker Siddeley Dynamics Ltd. (Coventry)	46
9 in x 8 in †	0·3-1·3	Aircraft Research Association Ltd., Bedford	47
9 in x 6 in	0·4-1·8 (not transonic)	University of Southampton	48

* Slotted walls for transonic operation
† Perforated walls for transonic operation.

Index (continued)

Index (continued)

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No.	Author	Title, etc.
1	L. E. Leavy	A note on the temperature transients in a supersonic "blow-down" wind tunnel. J. Roy. Aero. Soc. 62, 572, 598-599, 1958
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