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by

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February 1970

AIR CONDENSATION EFFECTS AT M = 8.5 MEASURED ON THE DRAG AND THE WAKE OF A MAGNETICALLY SUSPENDED 20° CONE

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SUMMARY

Schlieren pictures of the near wake of a 20° cone and drag measured by magnetic balance[1,2] both show effects of air condensation at temperatures below that predicted for condensation onset by previous work[3] with other indicators. Above this level supersaturated air may be used for hypersonic testing with complete absence of effects due to air condensation.

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* Replaces RAE Technical Report 70022 - ARC 32346.

CONTENTS

1 INTRODUCTION

It has been established that testing with supersaturated air at hypersonic speed can be done without air condensation effects with compression surfaces[3,4] and with some expansion surfaces[3]. However, the effect of air condensation on the near wake and on drag have not until now been investigated. The addition of a magnetic suspension system[1] to the R.A.E. 7 in × 7 in hypersonic wind tunnel has allowed this study, which is now described.

2 TEST CONDITIONS AND TECHNIQUES

The two models tested were sharp cones of 20° total angle and length 5.67 inches. One had a flat base with sharp corner, the other had a rounded base of 0.5 inch radius at the corner. Each model was suspended magnetically at zero incidence[2] and tested at $M = 8.5$. Drag was measured by calibration of the drag coil current and the wake shock position was measured from schlieren pictures. Stagnation temperature was measured by a thermocouple in the settling chamber just upstream of the nozzle, and stagnation pressure was measured to 0.2 per cent accuracy on a Bourdon gauge. Reynolds number based on cone length was 0.8 million at $p_o = 400$ psi and 1.0 million at $p_o = 500$ psi.

3 RESULTS

Fig.1 shows a diagram of the principle features of the flow with condensation discovered in previous work[3]. The recompression zone indicated by pitot tube, which results from the interaction of the condensation process with the nozzle wall and subsequent focussing, is several inches wide and advances upstream as temperature is reduced.

3.1 Flat base cone wake pictures

In Fig.2, schlieren pictures of the near wake of the flat base cone at various temperatures with condensing flow, show the wake shock dilated compared with the supersaturated non-condensing flow. Fig.3 shows the sudden increase in diameter (a) of the wake shock at its source, as temperature is reduced below condensation onset. With further reduction in temperature there is a slight tendency to greater dilation. The axial position of the wake shock source as a ratio b/d decreases suddenly at condensation onset and is further reduced with decrease in temperature. The mechanism of the wake shock dilation may be either recondensation of air in the base expansion, thus limiting the expansion, or interaction between the recompression zone and the wake. The former mechanism seems the more likely. However, Fig.5 shows that with a turbulent boundary layer produced by a castellated trip on the cone the wake shock is not dilated with condensation.

3.2 Flat base cone drag measurements

Fig.4 shows the variation in overall drag coefficient, C_D, with temperature. Above the predicted temperature for condensation onset C_D is constant, but just below this level C_D drops rapidly by up to 15 per cent and then rises again as temperature is further reduced. This effect on drag is similar to the effect on pitot pressure measured[3] in the empty tunnel in the same position as the model. The pitot pressure drops rapidly with reduction in temperature below the level for air condensation onset, rises again with the passage of the recompression zone over the pitot, and then drops again at still lower temperatures. The effect on drag is mainly caused by changing total head in the stream produced by the wave pattern set-up by the condensation, although some reduction in base drag must be attributed to the condensation effect on the wake.

3.3 Rounded base cone wake pictures

Fig.6 shows that the rounded base cone wake shock is larger in diameter and is unaffected by condensation. It is presumed that no recondensation occurs in the base expansion and that the recompression front does not interact with the wake to affect the base pressure.

3.4 Rounded base cone drag measurements

Fig.7 shows that the drag of the rounded base cone is affected by condensation in much the same way as the flat base cone, and supports the predicted temperature for condensation onset.

3.5 Comparison of results with previous work

Fig.8 shows the pressure versus temperature relationship for air condensation onset both for steady state and for fast expansion. Daum and Gyarmathy give a line which is derived partly from results from a range of tunnel sizes and is conservative for most tunnels. The R.A.E. results for pitot pressure, static pressure, pitot temperature, shock wave angle, drag, wake shock position all agree and the condensation line derived runs asymptotically towards the Daum and Gyarmathy line.

4 CONCLUSIONS

Tests at $M = 8.5$ with magnetically suspended 20° cones having laminar boundary layers, showed that the overall drag coefficient decreased rapidly at a temperature just below the level predicted for condensation onset. It is concluded that this effect is caused by air condensation, and the subsequent rise in C_D is caused mainly by the passage over the model of the recompression front which is associated with the condensation process. In addition, for the flat base model only, there is a dilation of the wake shock with condensation, but whether this is caused by recondensation in the base expansion or by an interaction between the wake and the recompression front is not known. It is concluded that the use of supersaturated air for hypersonic wind tunnel testing, down to the temperatures predicted for condensation onset in previous work, should be free from condensation effects of any kind.

SYMBOLS

a	diameter of wake shock at source
b	distance of wake shock source from base
d	diameter of model
C_D	overall drag coefficient
p_o	stagnation pressure
M	Mach number
T_o	stagnation temperature

REFERENCES

No.	Author	Title, etc.
1	A. Wilson B. Luff	The development, design and construction of a magnetic suspension system for the R.A.E. 7 in × 7 in (18 × 18 cm) hypersonic wind tunnel. R.A.E. Technical Report 66248 (1966)
2	J. F. W. Crane	Performance aspects of the R.A.E. magnetic suspension system for wind tunnel models. R.A.E. Technical Report 68274 ARC 31072 (1968)
3	J. F. W. Crane R. J. Marshall	Air condensation effects measured in the R.A.E. 7 in × 17 in (18 × 18 cm) hypersonic wind tunnel. ARC R & M 3511 (1968)
4	F. L. Daum G. Gyarmathy	Condensation of air and nitrogen in hypersonic wind tunnels. AIAA J., Vol. 6 No. 3 (1968)

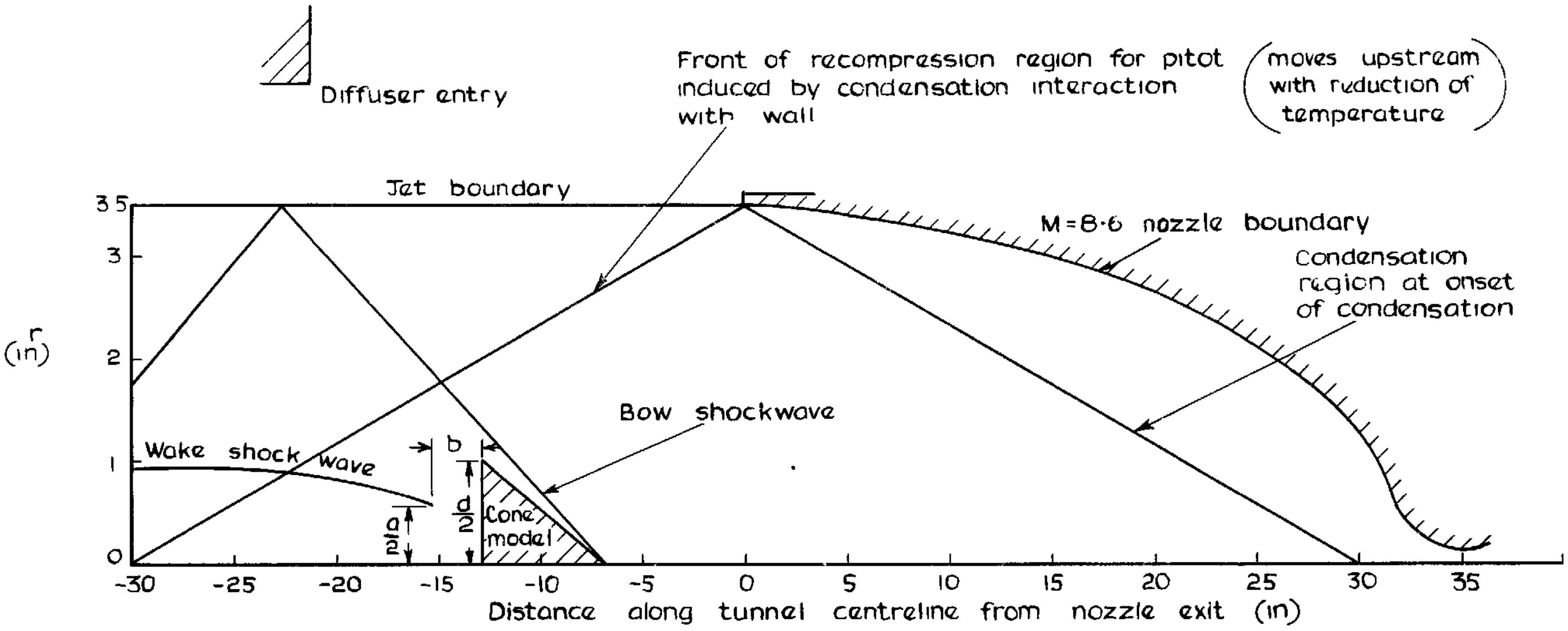


Fig.1 Diagram of wave patterns with air condensation (after Ref 3)

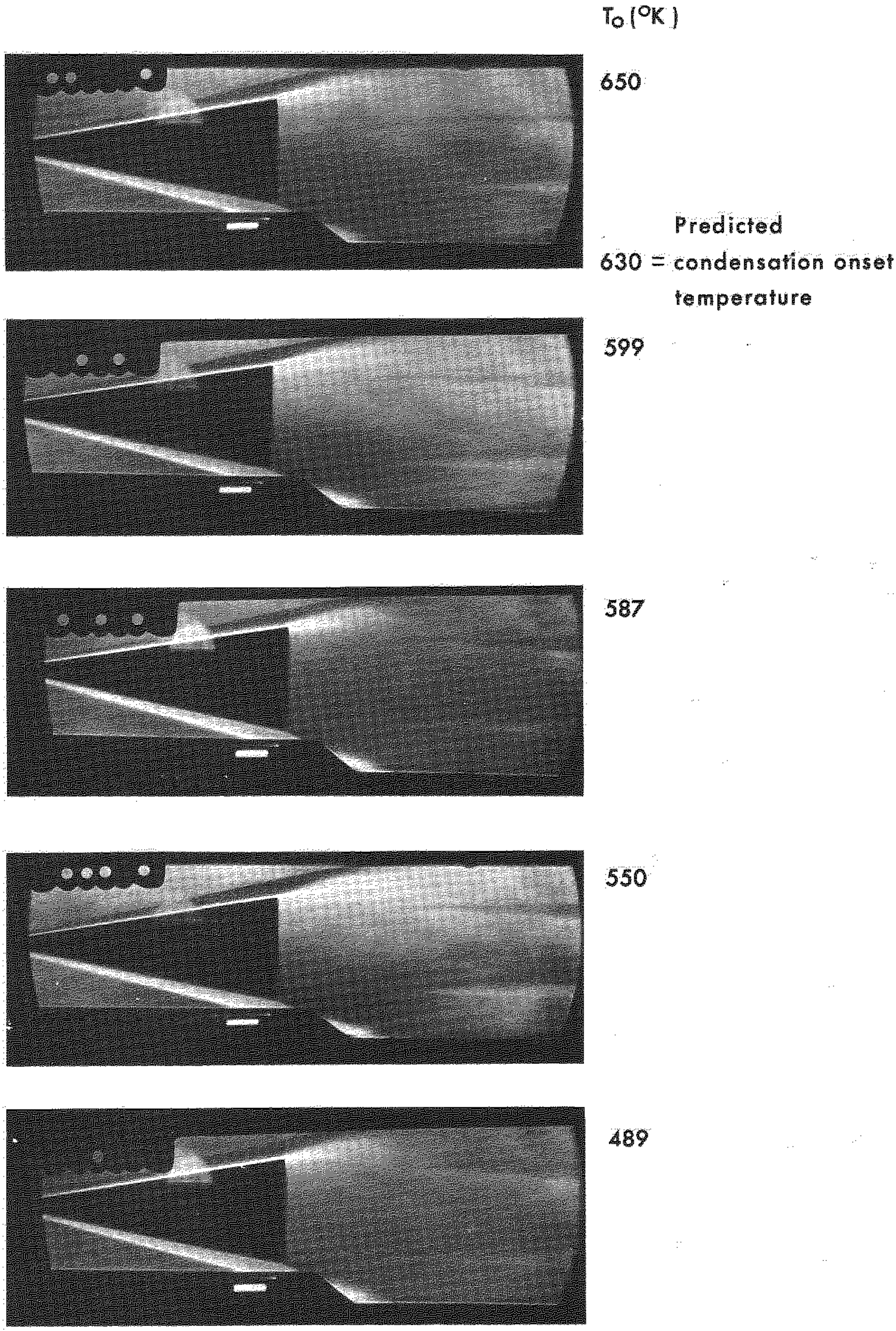


Fig.2 Effect of condensation on the laminar wake of a sharp 20° cone with flat base, $M = 8.52$, p_0=400psi

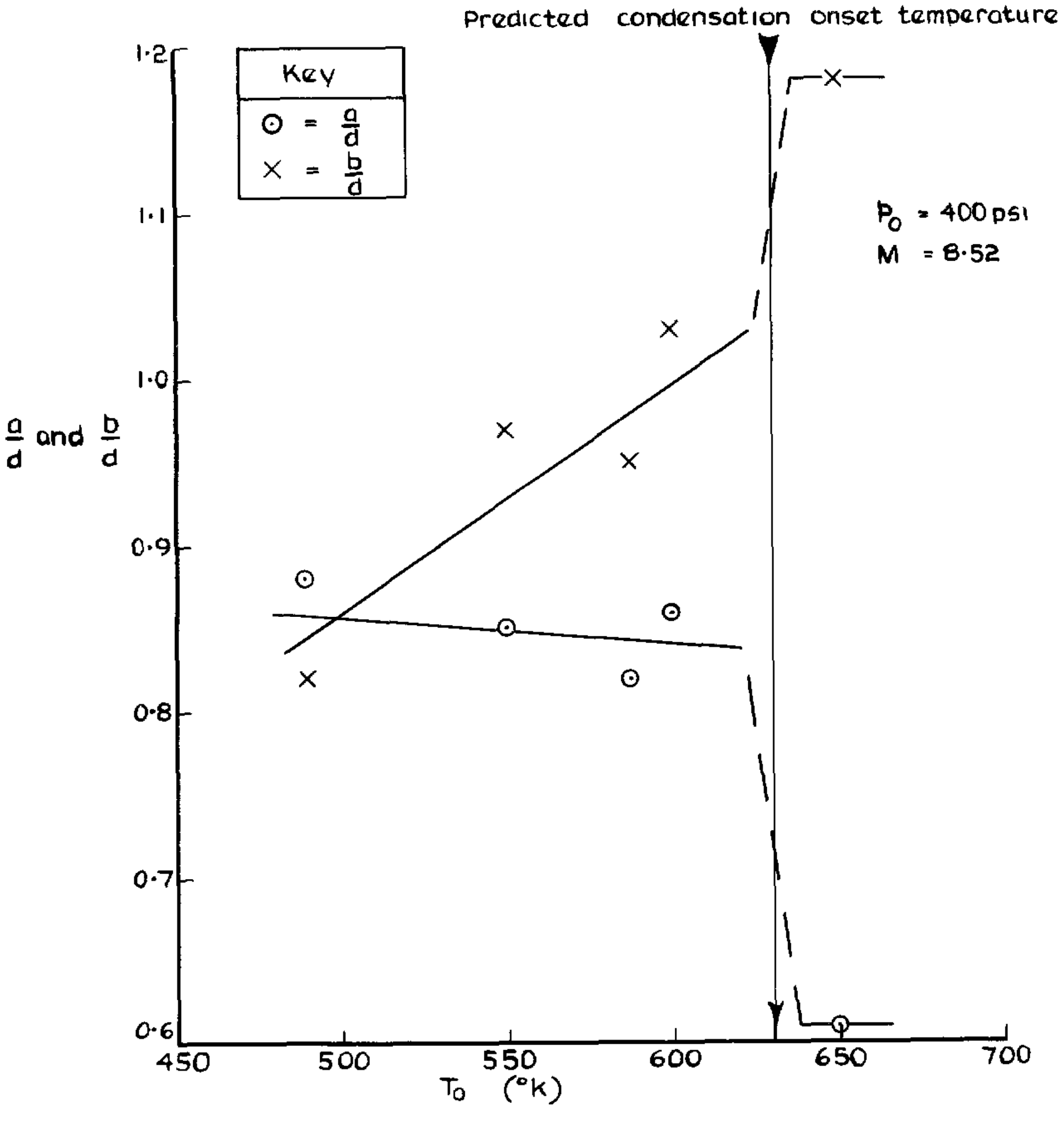


Fig 3 Variation of wake shock source position of the flat base cone with temperature

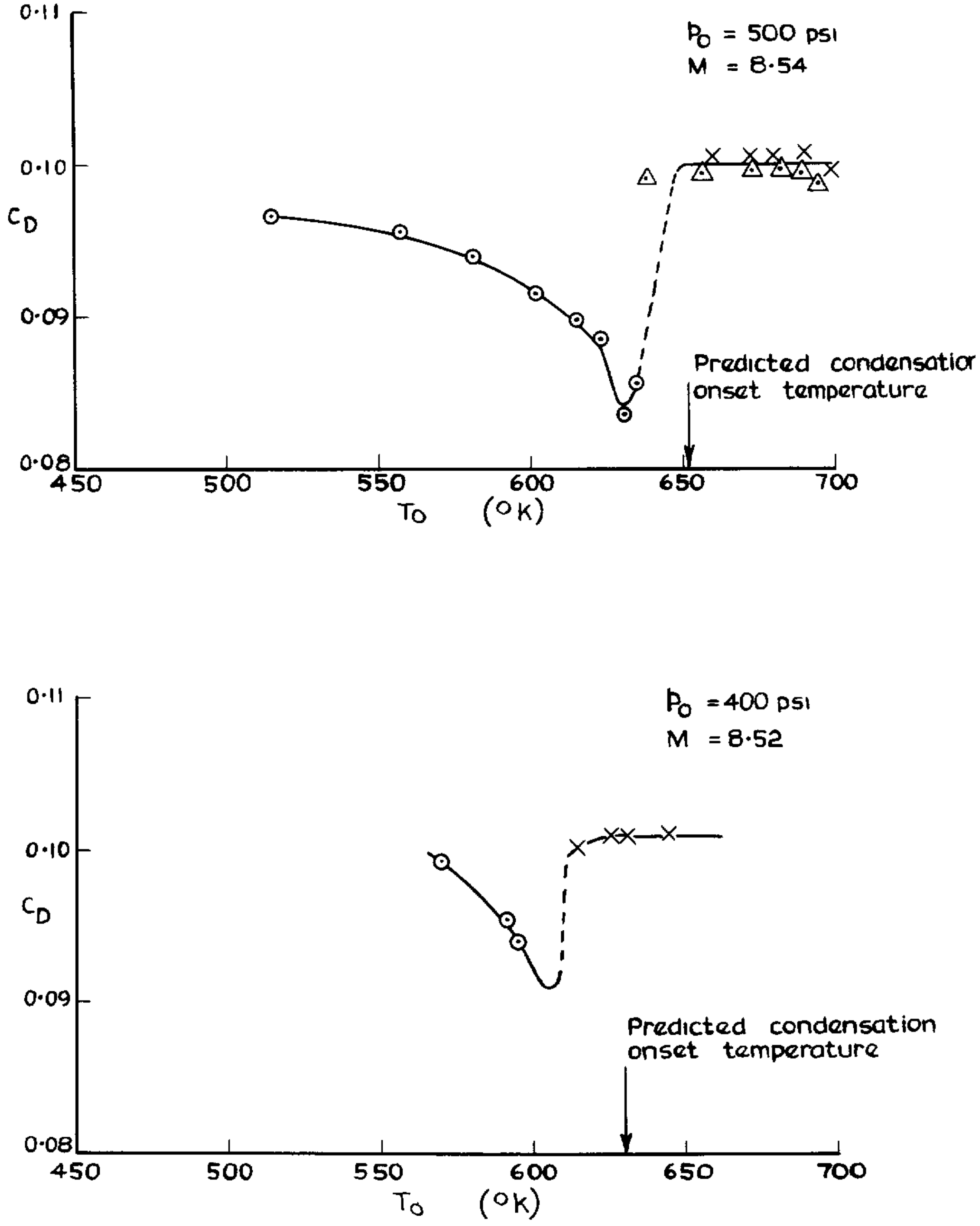


Fig.4 Variation of overall drag coefficient for the flat base cone with temperature showing the effect of air condensation

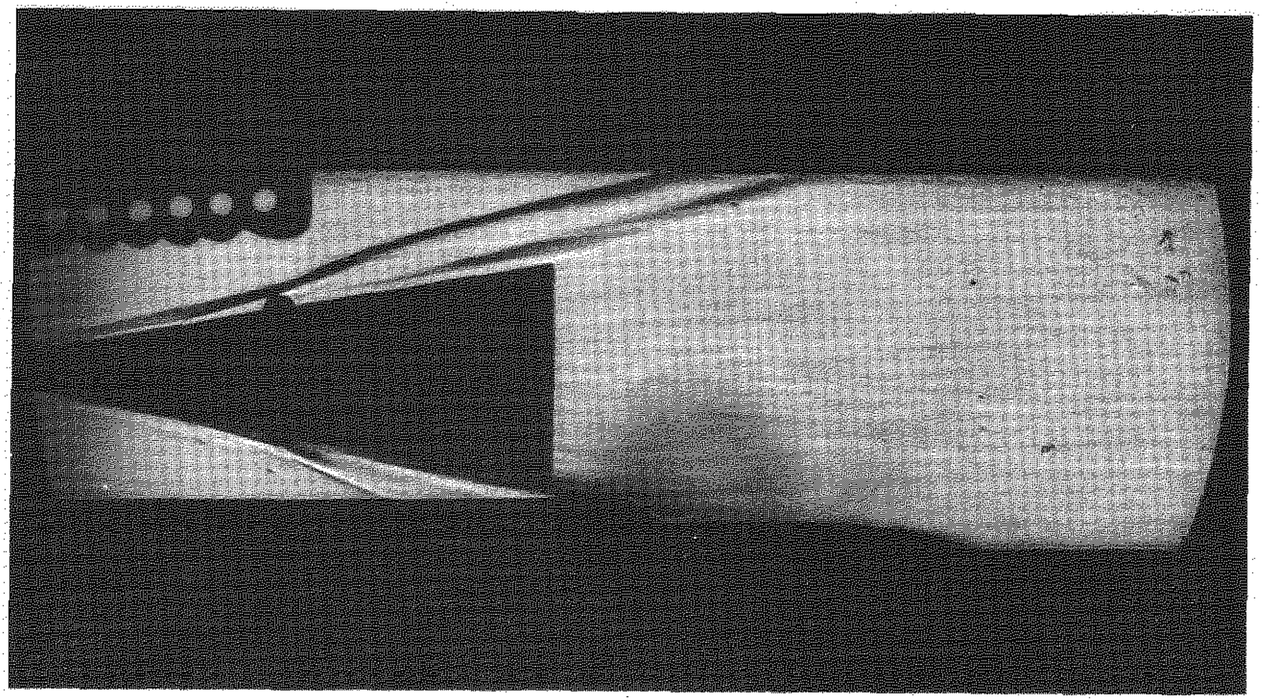
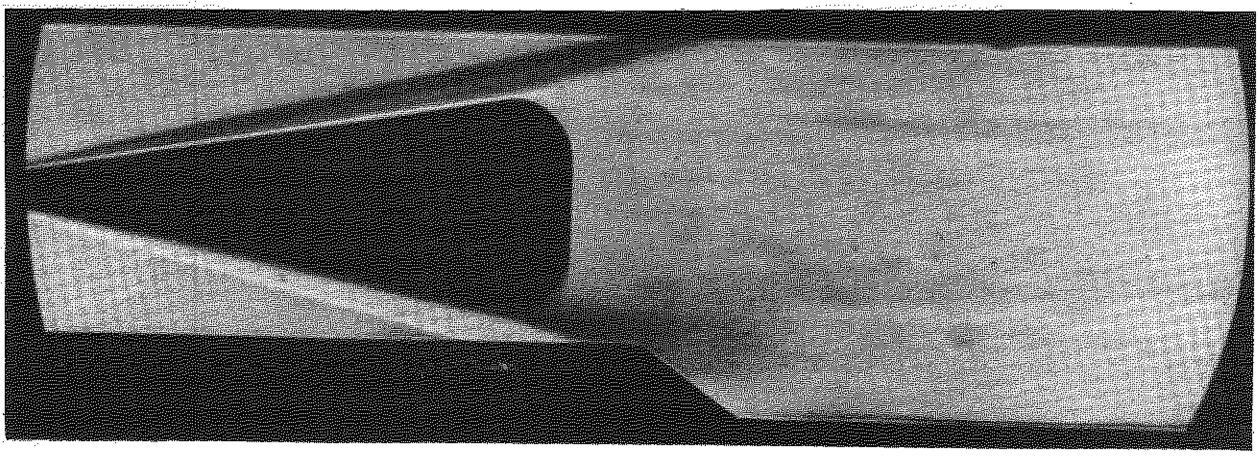


Fig.5 Effect of a castellated excrescence on the cone on the wake shock position with air condensation



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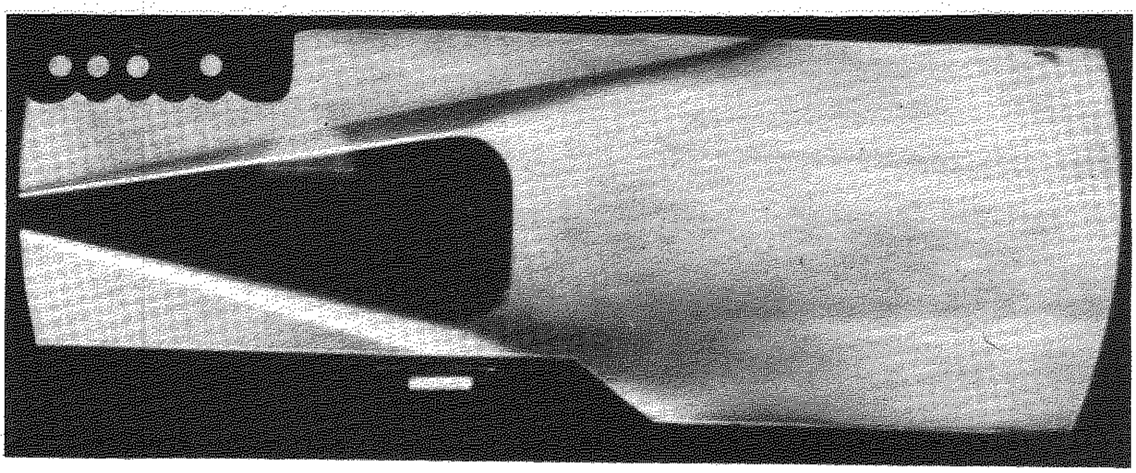

With condensation

Fig.6 Wake shock position of rounded base cone shows no effect of condensation

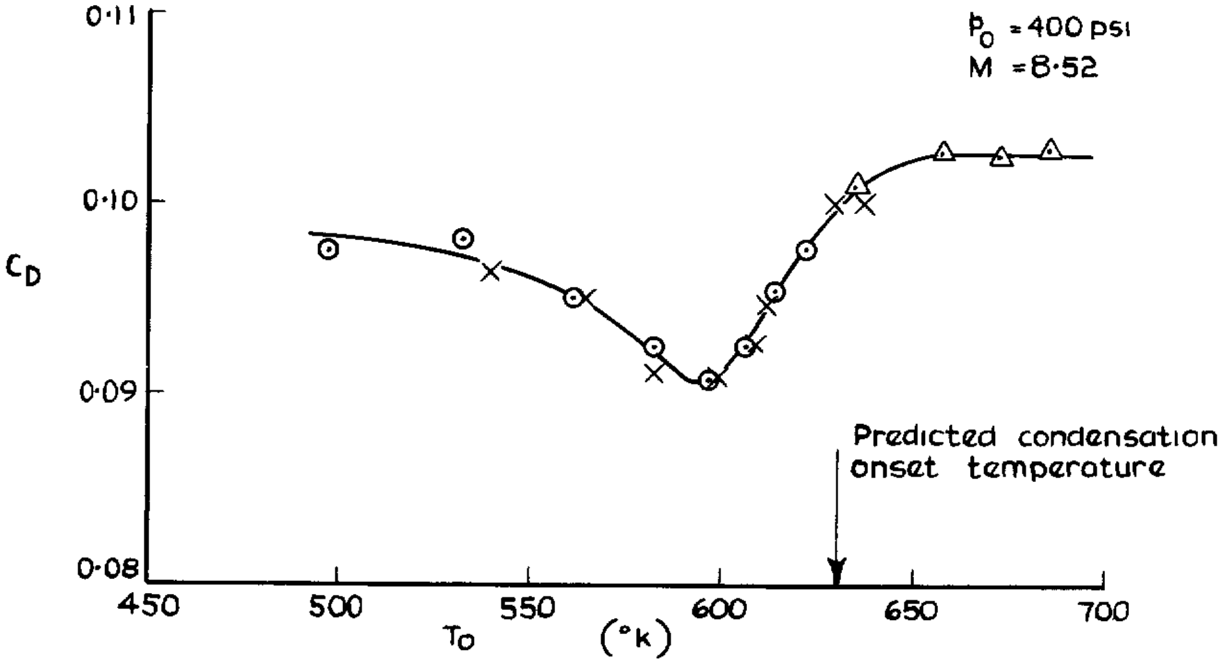

Fig.7 Variation of the overall drag coefficient of the rounded base cone with temperature showing the effect of air condensation

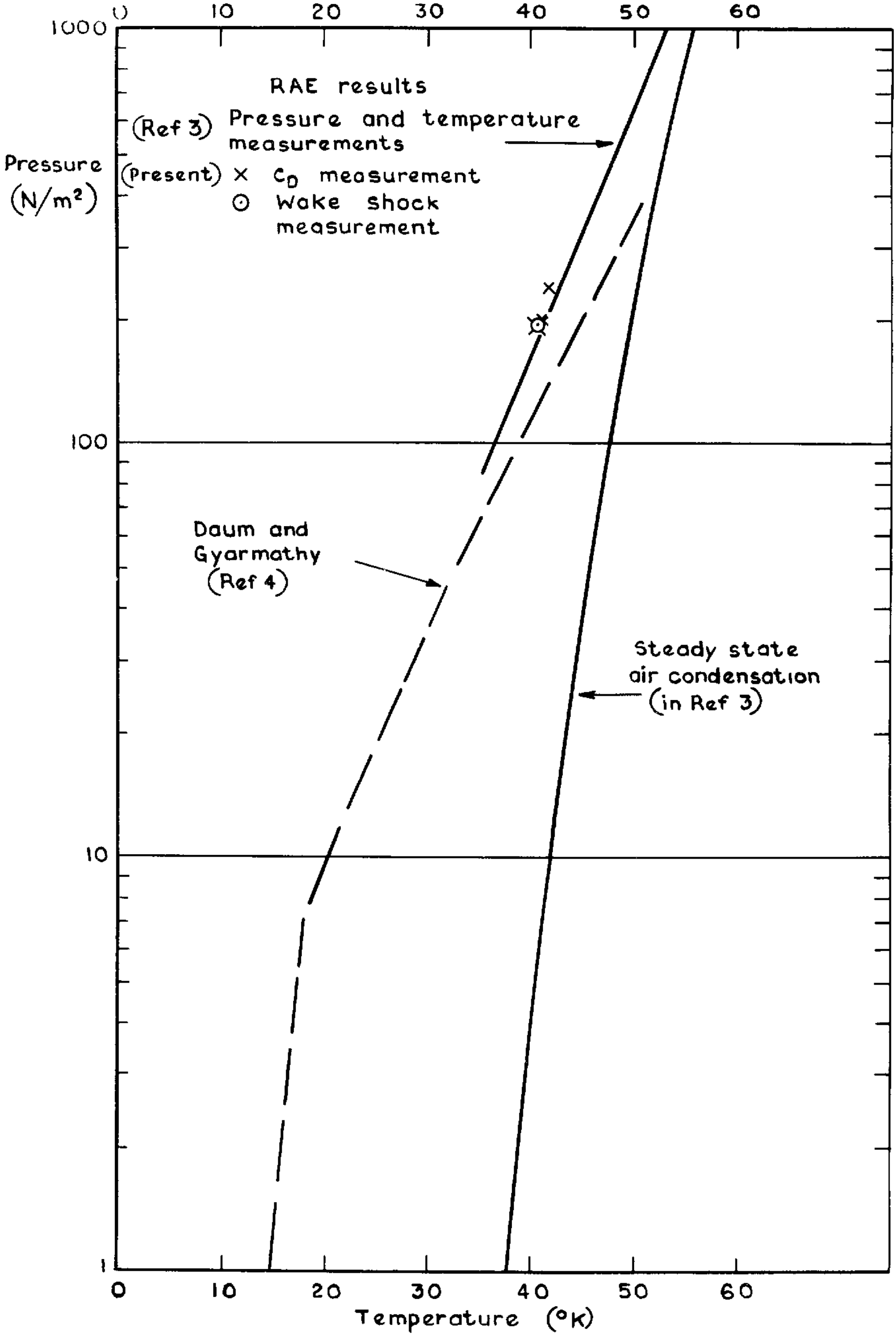

Fig.8 Air condensation line for fast expansions

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