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by

A. P. Cox

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ROYAL AIRCRAFT ESTABLISHMENT

MEASUREMENTS OF THE VELOCITY AT THE VORTEX CENTRE ON AN A.R.1 DELTA WING BY MEANS OF SMOKE OBSERVATIONS

by

A.P. Cox

SUMMARY

Measurements have been made by using a smoke technique of the axial velocity near the centre of the leading edge vortex on a delta wing of aspect ratio 1 at $\alpha = 20^{\circ}$. By simultaneously breaking trails of smoke at the vortex centre and in the free stream and analysing a film of the result, it is shown that the velocity at the centre is at least 40% higher than free stream. Near the trailing edge the velocity at the centre decreases rapidly to approximately free stream velocity.

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1 INTRODUCTION

Some doubts have been expressed as to the validity of pressure measurements which have shown that the axial velocity at the centre of the leading edge vortices shed from slender wings is appreciably higher than the free stream velocity. This note describes some brief tests where a smoke technique has been used to provide a qualitative check that the velocity at the vortex centre is indeed higher than that of the free stream. The tests were made in the R.A.E. No.1 $11\frac{1}{2}$ ft × $8\frac{1}{2}$ ft tunnel in February 1959 on a sharp-edged delta wing of aspect ratio 1, the edge chamfer being 5° in a chordwise direction (Fig.1).

2 DETAILS OF SMOKE TECHNIQUE

The experiment consisted of observing the movement of broken smoke trails, one inside and one outside the vortex. The smoke was obtained from small pieces of plastic sponge soaked in titanium tetrachloride which is a volatile liquid having a vapour which hydrolises in damp air to give a dense cloud of titanium oxide together with hydrochloric acid.

Fig.3 shows the method devised for breaking the trails simultaneously and instantaneously. At three chordwise stations, shown in Figs.1 and 2 a vertical wire was fixed between the model and the tunnel floor, passing through the centre of the vortex when the wing incidence was 20°. The smoke pellets were shot across the stream off the wire by plucking it, thus giving a clean break in the trails. This was done by pulling on a length of thread tied to the wire until the thread broke. Contamination of the wire by the liquid was avoided by threading the plastic on to a short length of 1 mm tubing with a washer between it and the wire. The pellet was located by sliding it on to a small horizontal piece of 30 S.W.G. wire (Fig.3).

Several runs at $\alpha = 20^{\circ}$ were made for each chordwise station using one pellet at the vortex centre and another further from the wing (Fig.1). The smoke trails were filmed by a ciné camera outside the tunnel at 100 frames per second, the tunnel speed being approximately 2 ft per second. Because of the narrow field of view of the camera and to avoid parallax, a separate camera position was used for each station (Fig.2).

3 ANALYSIS OF RESULTS

Starting at the instant of release, the positions of the ends of the smoke trails were plotted at 0.02 sec intervals. Fig.4(a) shows a typical result, but for clarity this only includes points at 0.1 sec intervals. The distance (a) from the release point was measured for each point and this was plotted against time as in Fig.4(b). It will be seen that the velocity as represented by the slopes of the curves is greater for the centre of the vortex than for the trail further from the wing.

The ratio of the velocities varied from 1.42 to 1.33. Near the trailing edge, the velocity at the vortex centre changed rapidly to about free stream velocity. The exact position of this change appeared to vary slightly between runs but was always close to the trailing edge.

Fig.5 shows two enlargements from the film. The first was taken at the instant that the pellets were released and the second shows the positions of the trails after 0.45 secs. The upper trail which was at the vortex centre has travelled much further than the lower trail, the end of which is indicated by the puff of smoke.

In order to determine the difference in velocity between the lower trail and the free stream, titanium tetrachloride was poured down the wire at 0.6 C and the resulting sheet of smoke is illustrated in Fig.6. Analysis of the movement of the eddies from the wire showed that this difference was negligible.

4 ACCURACY OF RESULTS

There are three sources of error which might have a significant effect on the result of these tests, but all would suggest that the answer quoted is an underestimation of the true velocity of the vortex centre:-

(a) As the smoke trail has a definite width, the velocity measured is that of the edges of the trail. Faster moving smoke at the centre will be obscured by that outside it.

(b) The smoke pellet must create a disturbance in the vortex which would tend to reduce the velocity of its centre.

(c) The effect of the leading edge vortex was to move the trail furthest from the wing nearer the camera than that in the vortex centre as they both travelled rearward, and this will cause a parallax error. The effect is generally small and is non-existent at the chordwise position in Fig.5. The maximum error would occur at the wing trailing edge. Rough calculation showed that this could amount to an underestimation of vortex centre velocity by between 5 and 10%.

5 CONCLUSIONS

It has been demonstrated in these tests that the velocity of the centre of a leading edge vortex on a delta wing of A.R.1 at $\alpha = 20^\circ$ is at least 1.4 times free stream velocity changing rapidly near the trailing edge to near free stream velocity. All the more likely sources of error would make this result an underestimation of the true value.

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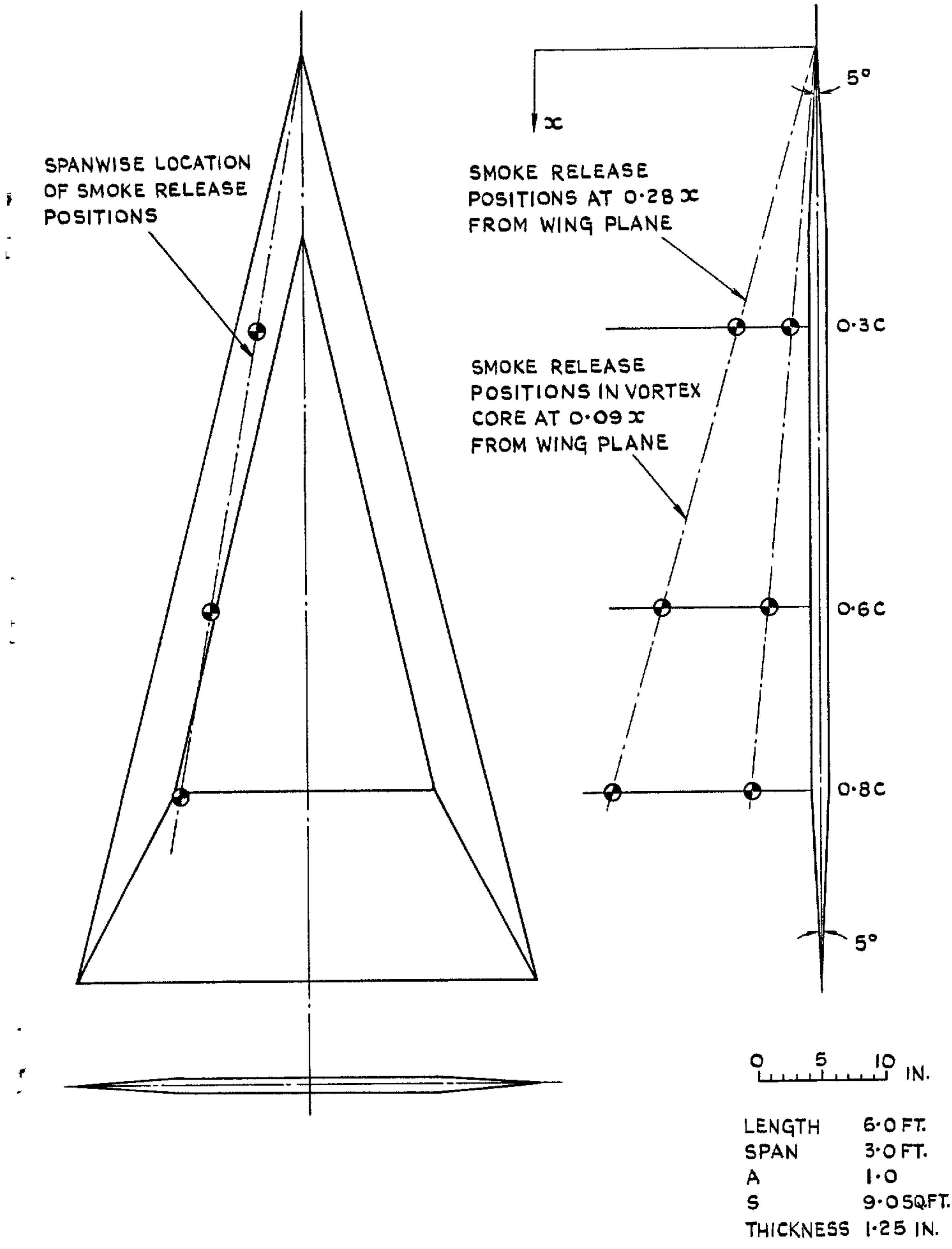


FIG.1. G.A. OF MODEL.

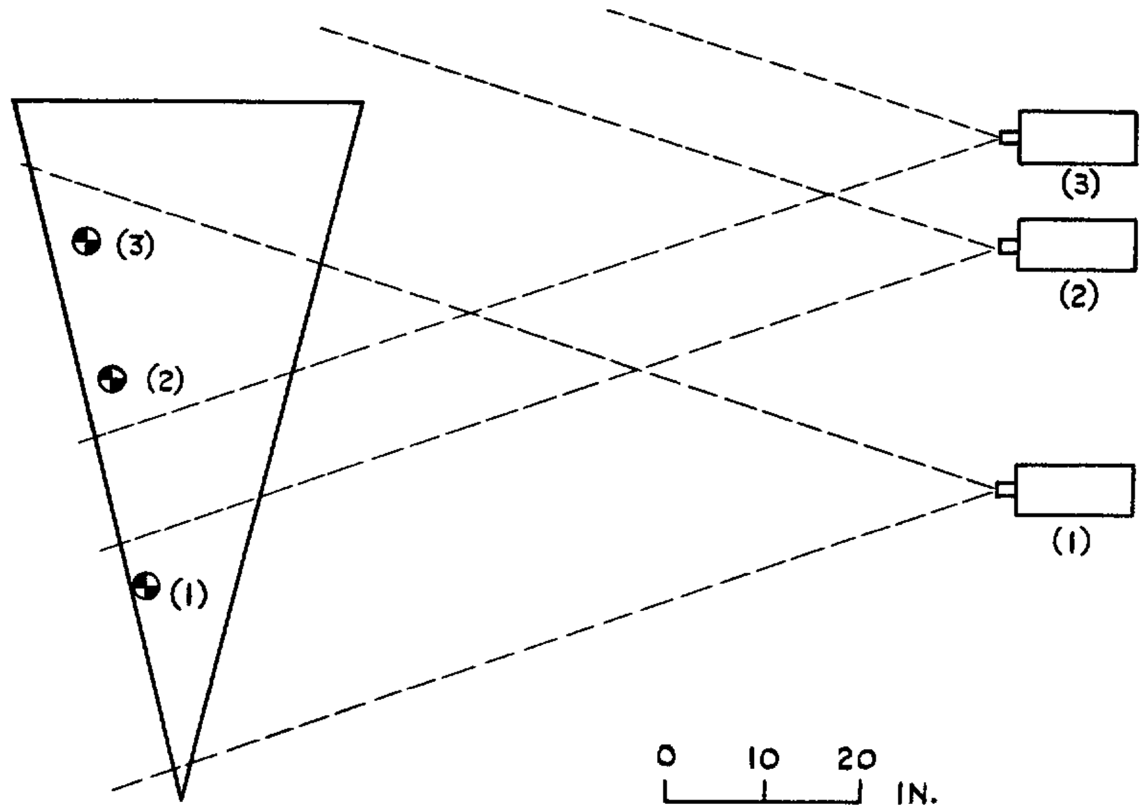
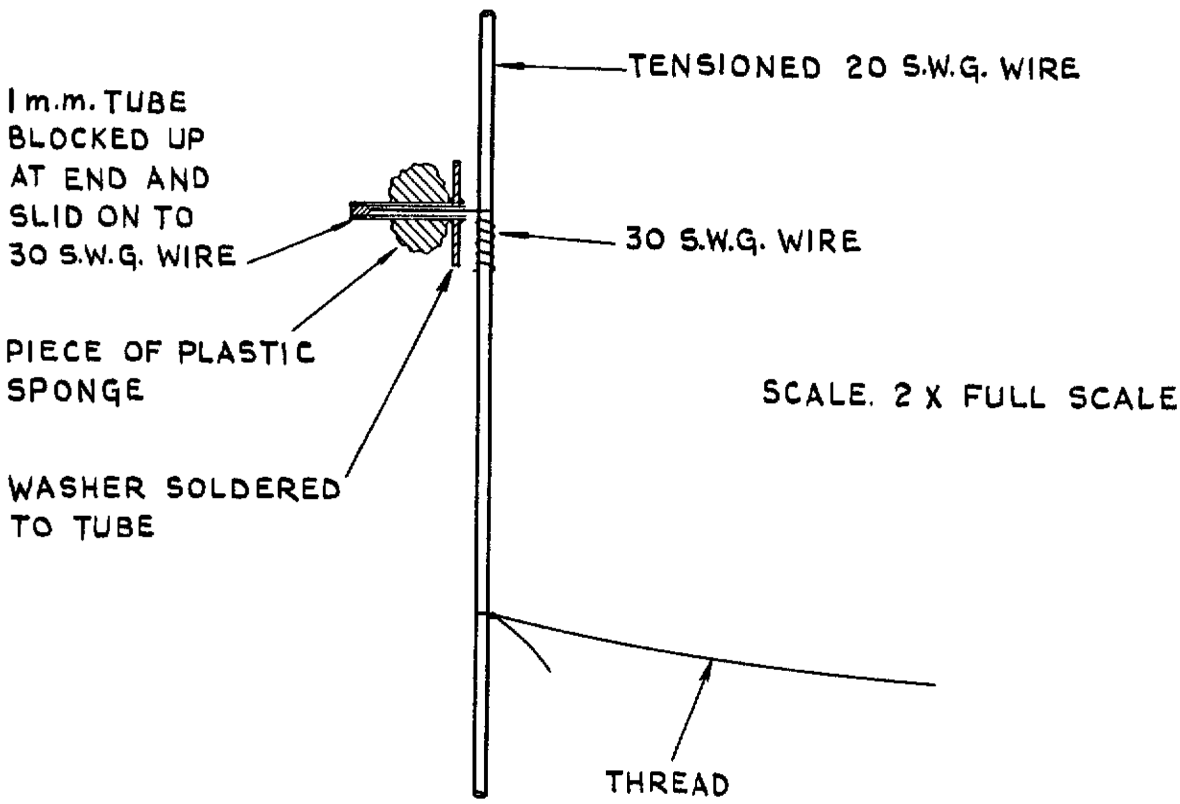


FIG. 2. CAMERA LOCATION CORRESPONDING TO EACH SMOKE RELEASE POSITION.



SMOKE TRAIL IS PRODUCED BY SOAKING SPONGE IN $TiCl_4$. BY PULLING ON THE THREAD, THE TENSIONED 20 SW.G. WIRE IS SLIGHTLY DEFLECTED. WHEN THE THREAD BREAKS, THE DEVICE IS SHOT FROM THE WIRE, THUS BREAKING THE SMOKE TRAIL.

FIG. 3. DETAILS OF METHOD OF PRODUCING AND BREAKING SMOKE TRAILS.

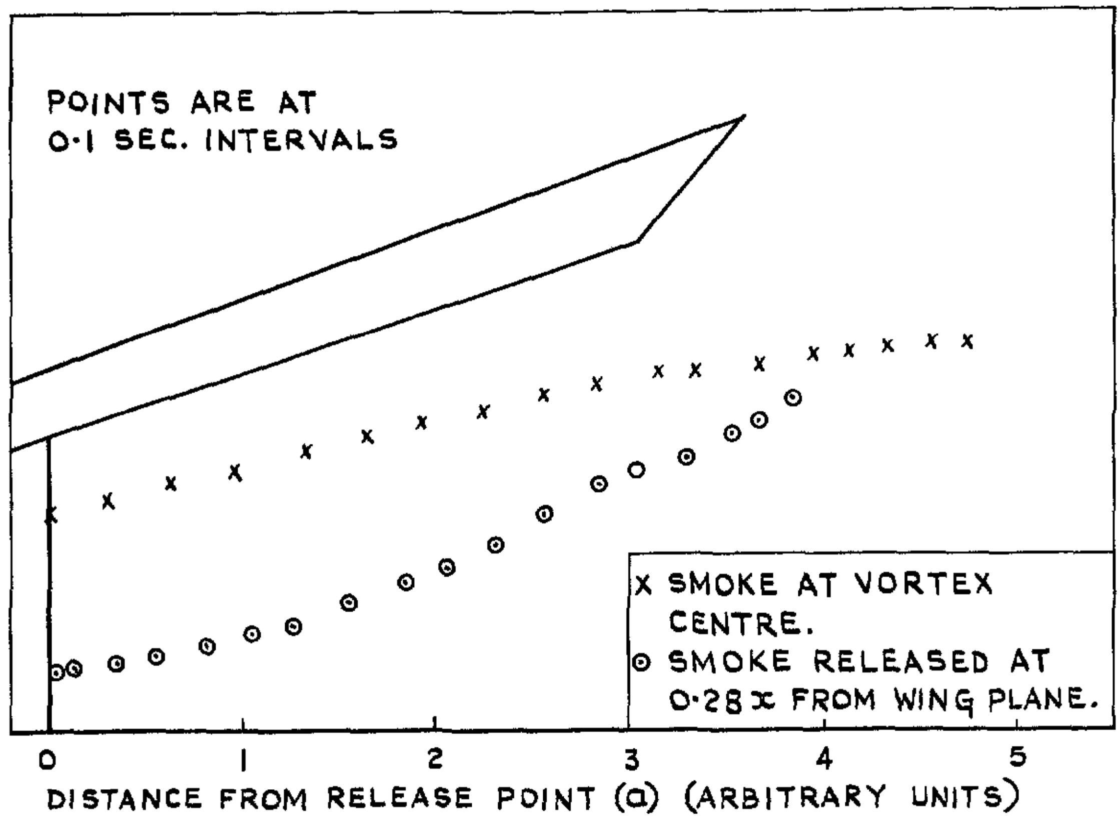


FIG. 4(a). TYPICAL PLOT OF ENDS OF SMOKE TRAILS RELEASED AT $0{\cdot}6\,C_o$.

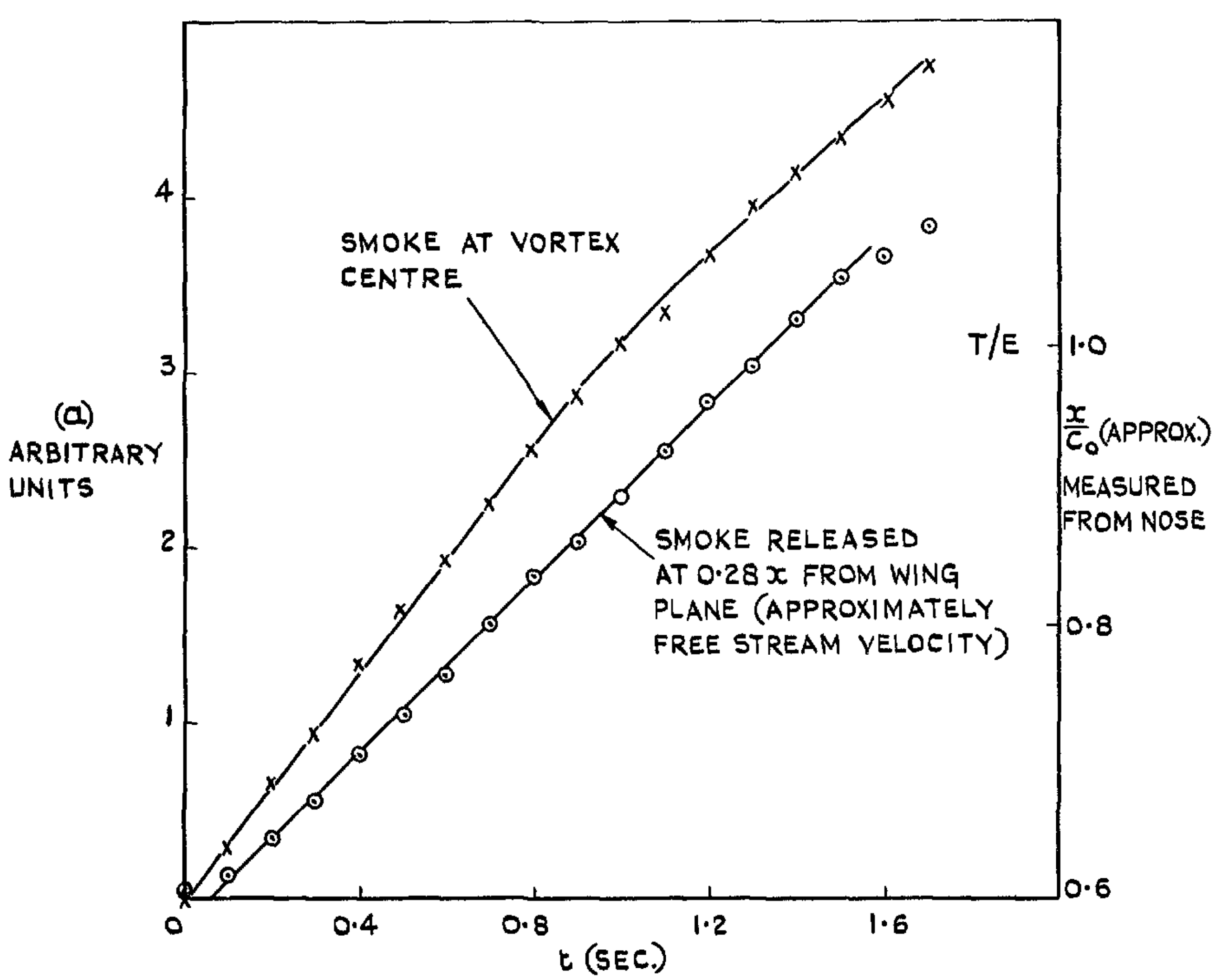


FIG. 4(b). DISTANCE – TIME RELATIONSHIP FROM FIG. 4(a).

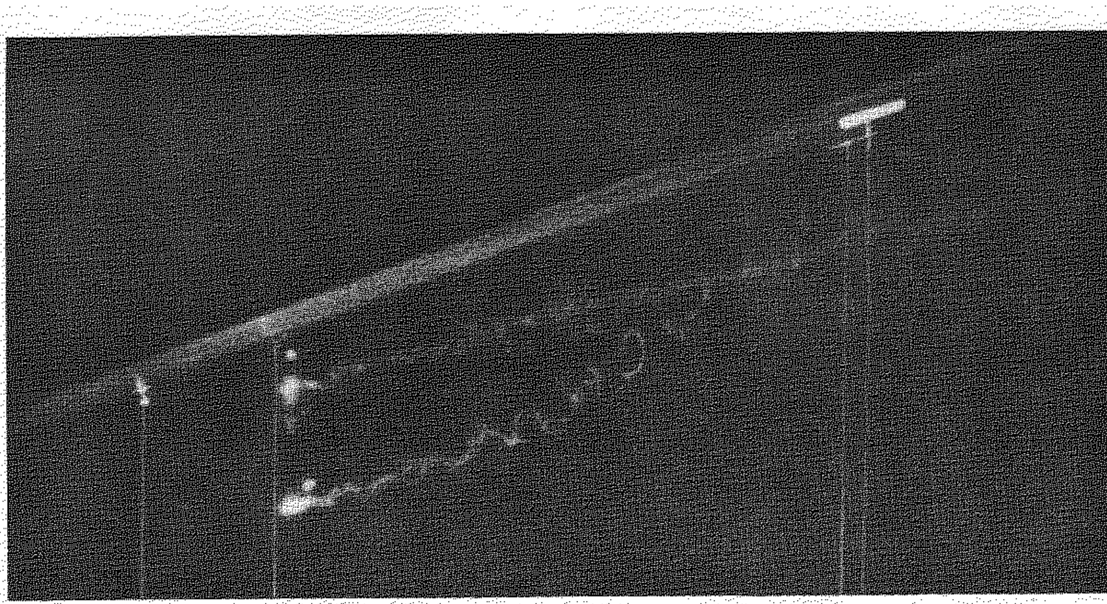


FIG.5a. SMOKE PELLETS RELEASED AT $0.3C_0$

FIG.5b. SMOKE TRAILS 0.45 sec. AFTER RELEASE

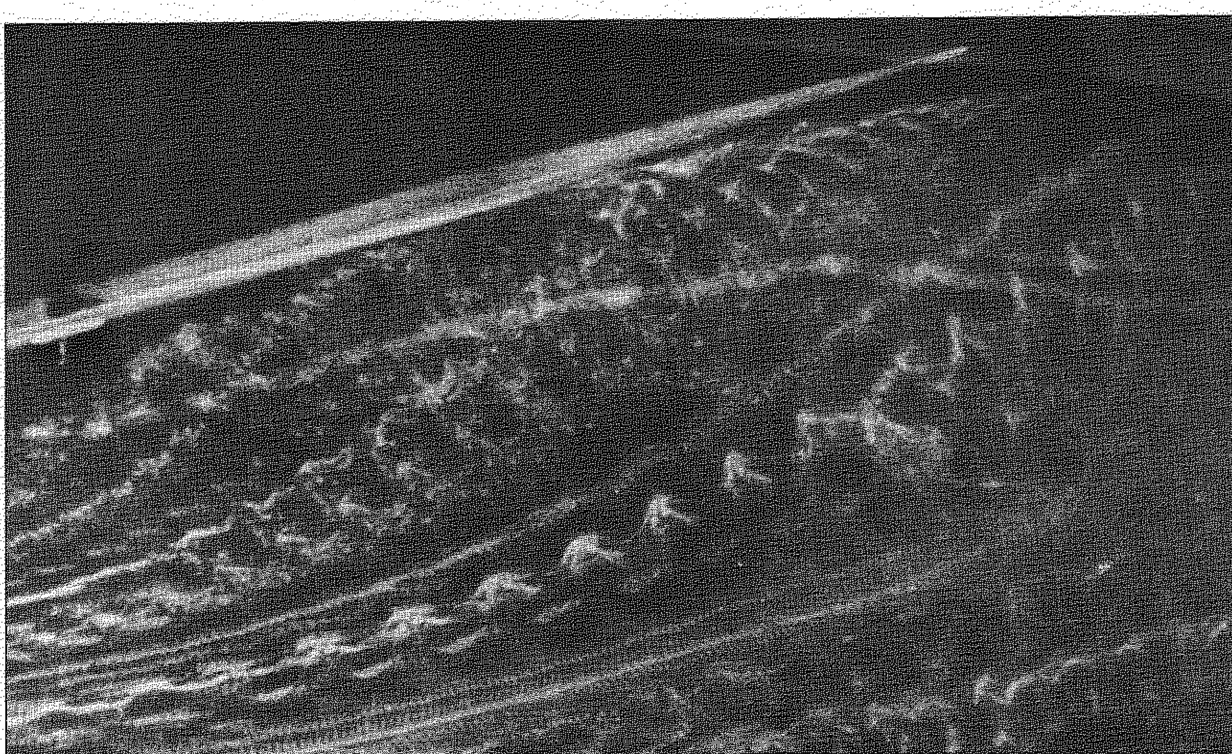


FIG.6. VIEW LOOKING SLIGHTLY REARWARD OF SMOKE STREAMING FROM WIRE AT $0.6C_0$

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