CONTINUOUS COLOURED SMOXE-WIRE TECHNIQUE FOR FLOW VISUALISATION

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Abstract

A continuous coloured smoke-wire technique has been developed for flow visualisation in wind tunnels. The improved contrast of coloured smoke sheet facilitates flow visualisation. In the present technique, a vertical smoke-wire is used for introducing controlled sheets of smoke streaklines during a wind tunnel run. Regulated drops of a mixture of paraffin oil with coloured dye are allowed to fall along the stainless steel wire. The wire is thus coated with a thin film of falling paraffin or with minute coloured droplets along the length. The oil mixture subsequently evaporates through the resistive heating of the wire thus producing a sheet of coloured streaklines. The present technique has been used in the NAL 0.9m low speed wind tunnel for flow visualisation around the wing of an aircraft configuration and also a delta wing model at high incidence.

1. Introduction

Smoke-visualisation has contributed considerably to better understanding of the qualitative behaviour of complex flow structure. First used by Mach [1], the technique rapidly found wide applications. Two distinct methods have been developed [2-4] for flow visualisation in wind tunnels. The smoke is either .introduced from outside through rakes mounted upstream of the test section or it is generated within the test section by electrically heating a thin wire coated with oil. A typical example of the latter method is described by Corke et al., Batill et al. and Nagib [5-7].

For flow visualisation in air, optically dense smoke (referred here as vaporized oil) streaklines are often introduced into the flow field. Most of these smoke-wire techniques [8] of intermittent type are limited mainly by the duration of time of generation of smoke which essentially limits the effective wind tunnel run time for flow visualisation.

The continuous smoke-wire technique, discussed here, incorporates a vertical heated wire, called smoke-wire, and has been developed to minimize the above limitation and to maximize its adaptability to low speed wind tunnels. The present technique is capable of generating the coloured/white smoke for long durations without much attention. In the present experimental set-up, the quality and density of the smoke streaklines during a wind tunnel run are controlled by adjusting oil-dye mixture flow rate through regulating the pressure of the oil reservoir (in which liquid paraffin-dye mixture/liquid paraffin is stored) and manually controlling the heating current of smoke-wire.

2. Technique Development

Experimental set up for the continuous generation of smoke using a thin wire for flow visualisation in low speed wind tunnels is as shown in the Figure 1. The set-up consists of mainly five components. The upper and lower support clamps, oil reservoir, wire insert and a heating circuit.

The upper support which is attached to the tunnel wall, holds the oil reservoir in position. The oil reservoir is a hollow cylindrical vessel which has three openings. There is one threaded opening at the centre of the top side of the oil reservoir. It is through this passage, the smoke-wire is inserted which passes through the second opening at the bottom of the oil reservoir. The top passage is also used to fill the reservoir and is threaded to accept a mild

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steel screw plug with an '0' ring to provide a pressure-tight seal. To the third opening in the side of the reservoir, a metal nipple is welded which provides a passage for introduction of compressed air for pressurizing the oil during tests.

The lower most passage is designed to accept a threaded metal plug-tube assembly. This assembly is screwed to the reservoir with an '0' ring to provide a pressure-tight seal. The metal-plug tube assembly consists of a 10 mm metal plug with external threads corresponding to the internal threads provided at the lowermost passage of the oil reservoir. A stainless steel tube of 0.4 m m internal diameter is welded at the centre of the threaded plug. This is the tubing through which the smoke-wire in the present set-up, (of 0.2 mm diameter) extends across the test section of the tunnel, controls the size of the drops forced on to the wire. The important parameter to control the size of the oil drops is the ratio of `.he metal tube internal diameter to the wire outer diameter. When this ratio is large, larger oil drops are produced which tend to fly off the smoke-wire thereby limiting the maximum useable free-stream velocity for flow visualisation studies. Small ratio will result in requirement of higher air pressures to force oil on to the smoke-wire. Diameter ratio of 2 was used in the present studies and was found to give satisfactory results.

The other 'end of the smoke-wire is fastened to the ground support structure through a tension spring. The spring keeps the wire in tension and prevents it from sagging while it is being heated during tunnel runs.

2.1 Continuous Coloured Smoke-wire Technique

Coloured smoke was produced continuously by evaporating a mixture of liquid paraffin and commercially available "Econc" dyes which are wax basedcoloured dyes. The wax based coloured dyes are used in the textile industry. These eyes are available both in powder, and liquid form. Only powder dyes were used In these present experiments. A mixture of liquid paraffin an colour dye is first prepared. The preparation of homogenised oil-dye mixture is a bit involved. Tlt+e liquid paraffin and powdered coloured due In carefully chosen proportions is taken in a dated container and the mixture is allowed too mix homogeneously in a rotating mill far a period of about eight hours or so. The mixture la finally filtered to avoid any thicker dye particles In the prepared mixture which may ultimately effect the continuous flow of the mixture through ttae thin annular area available between the to m internal diameter of the steel tubing and 0.2 mm diameter of the wire. The wire is kept under tension in order to avoid sagging during experiments.

It is important here to have enough concen.-tration of dye in the mixture. Otherwise the smoke will not be coloured sufficiently. On the other hand, if the concentration is excessive, there may be severe problem in obtaining the mixture flow through the small annular area available around the wire. A trial and error method is evolved to prepare a properly concentrated paraffin oil-dye mixture for coloured smoke generation for flow visualisation studies.

In this technique which is developed here, there is no limitation on the time duration of generation of coloured smoke which generally happens in most of the test techniques available [8]. The present technique is 'capable of generating coloured smoke for long durations (about ten minutes) without much maintenance. More than one vertical wire and colour dyes can also be used in the flow visualisation studies where required.

2.2 Smoke-wire Heating Control System

The smoke-wire is heated during the experi; ments by DC current from a power supply (0.30V, 3 amps). The oil drops falling on to the wire get evaporated, by resistive heating of the wire, generating the smoke during experiments. The portion of the wire which is inside the oil reser-. voir (Fig.1) is copper plated. The plating ensures minimum heat dissipation in the large mass of liquid stored in the oil reservoir due to good current conduction. The heating circuit consists basically of a regulated power supply with a switch. The current was controlled manually and a current of 3 amps was found to be adequate for these experiments.

2.3 Timing Circuit

A synchronization circuit was also designed and built for energizing the smoke-wire as well as automatic triggering of the camera after a pre-set time delay. The circuit consist-t mainly of three integrated circuits used as monostable multivibrators. In Fig.2, IC_1 and IC are triggered manually to initiate the operatih. A negative trigger at pin 2 of IC initiates the smoke-wire excitation through thl relay and smoke-wire duration is controlled by the combination of R_2 (resistor) and C_2 (capacitor).

The time delay for the camera is achieved through the combination of IC_1 and IC . The negative pulse that initiates IC , also ii'citiates a monoshot operation in IC_1 P~t this point the output of IC_1 (pin 1) goes low allowing C tr. discharge thro t' J When the capacitor voltage drops below 1 3 V'cc (5V) (at pin 2 of IC), output of IC (pin 3) goes high. Thus high output of IC trigiers the solenoid at the collector of th6 transistor 31, which in turn releases

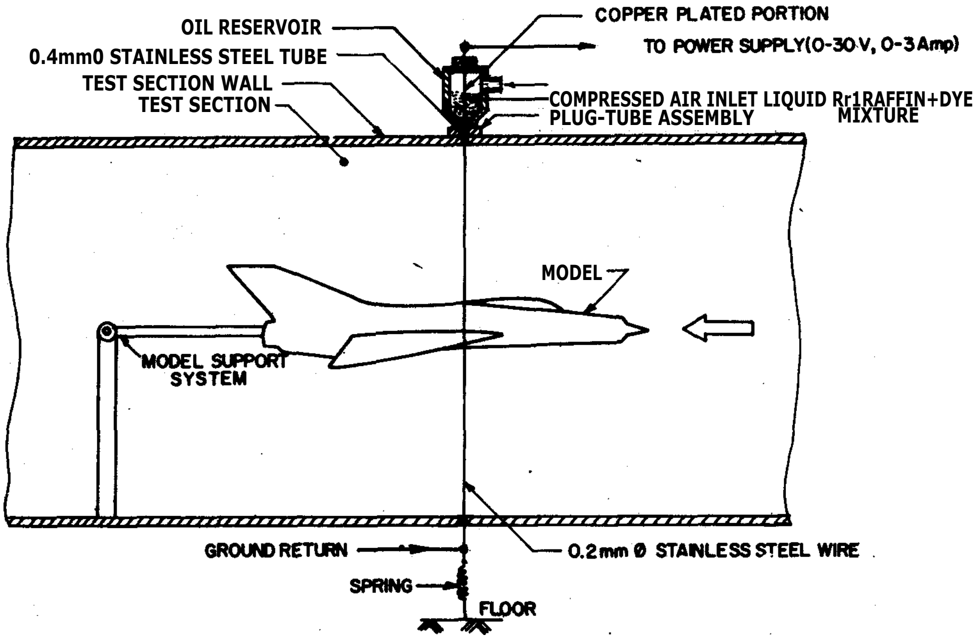

Fig.1 Set-up Smoke-Wire Flow Visualisation Technique (Low Speed Wind Tunnel)

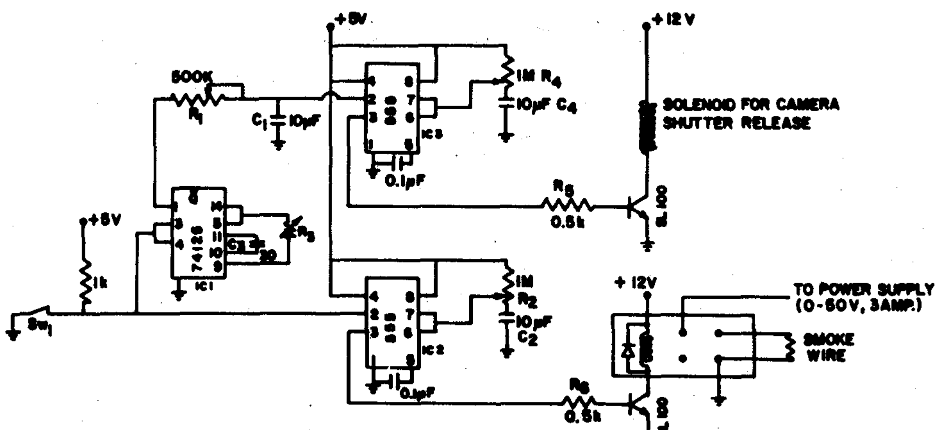

Fig.2 Timing Circuit

the camera shutter. The camera time delay is determined by the R_1, C_1 combination. The synchronization circuit which is designed and built will augment the capability of the present experimental set up to a great extent for further flow visualisation studies.

3. Results from Photographs of Flow Fields

The capabilities of the smoke-wire technique developed for flow visualisation is demonstrated by sample flow studies carried out in low speed wind tunnel over a model of aircraft wing' and for a delta wing model at high incidence. The smoke-wire was kept upstream of the region of interest for these models in the wind tunnels. The wind tunnel test section was illuminated by a 100b watt lamp.

Flow visualisation studies were carried out around the wing of the typical combat aircraft at free velo5ity of 6m/sec, Reynolds number of 0.75 x 10 based on the wing chord at mid span and angles of attack of 0 and 5 degrees. the discrete smoke streaklines clearly show (Fig.3a, 3b) the development of flow over and under the wing and also the wake region of a typical combat aircraft at 0 and 5 degrees angles of attack. It can be seen that the smoke streaklines are quite uniform and densely spaced. Smoke streaklines clearly indicate the leading edge bubble which is a region of low pressure over the top surface of the aircraft wing at 5 degrees of angle of attack.

The photographs (Figs. 5a and 7) illustrate continuous colour smoke-wire technique. Flow visualisation studies were carried out over a

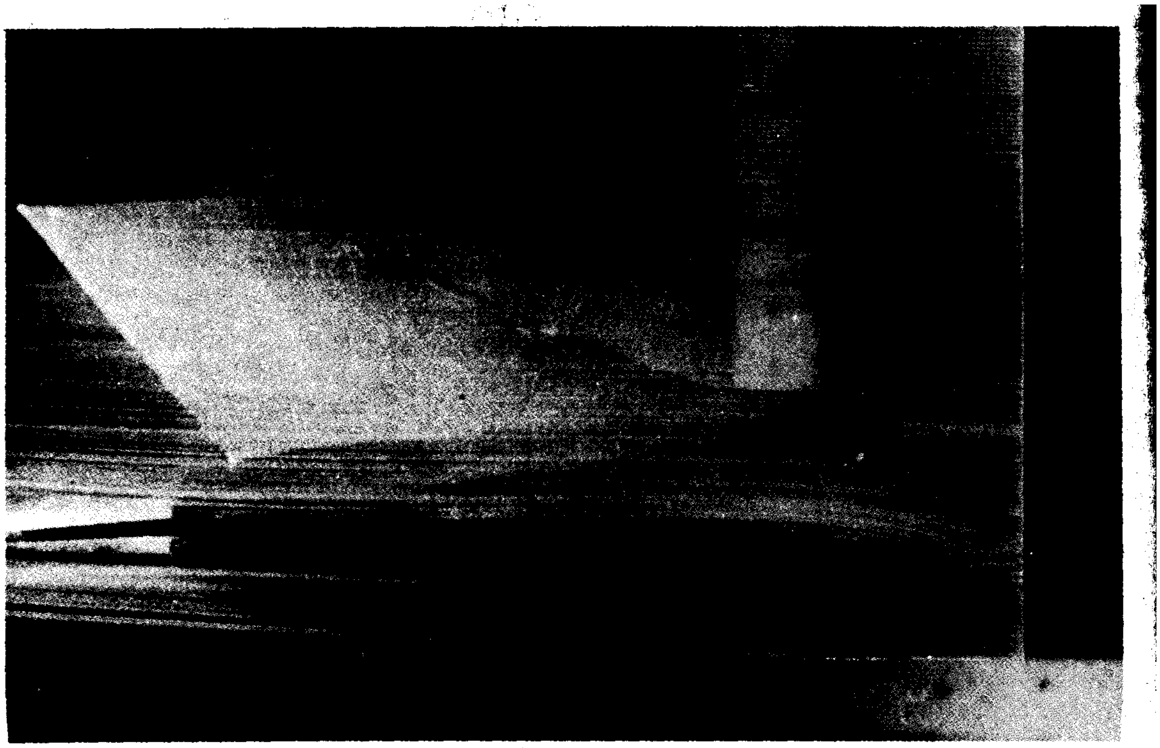

Fig.3a Visualisation of Flow Around an Aircraft Model Using Smoke Wire Technigye
(U=6m/sec, at =0°, Rec=0.75x10)

Fig.3b Visualisation of Flow Around an Aircraft Model Using Smoke Wire Techniq~e
(U=6m/sec, cc =5°, Re_c = 0.75x10)

delta wing model (Fig.4) at incidences of 20° and 40° at free stream velocity of 6m/sec. These photographs clearly show the development of coloured streaklines over and under the delta wing model at these angles of attack. The dye streaklines clearly indicate formation of leading edge vortices for the delta wing model. It can be seen that there is a larger vortex core for the delta wing at angle of attack of 40° than that of 20°. The two photographs (Figs 5a and 7) clearly show the effect -of angle of incidence in the flow field.

Figure 5b shows the flow computations by O.A. Kandil [Refs.9 and 10] on a delta wing at a = 15°, AR = 1. It can be seen , that the computed flow pattern is quite similar to that as observed in the present flow visualisation studies on a similar delta wing model.

Figure 6 shows the comparison of location of vortex centre line that is obtained from the present studies and that from available results [Ref.1,1J. For the NAL delta wing (-=20°, a=30°), vortex centre-line i.e. S/2 is 5° (as obtained from the photograph, Fig.5a). From the graph [Ref.101 as seen, for -/c = 0.666, O/c = 0.327 i.e. B = 9.81° or vortex centre line, S/2 = 4.90°. This shows a remarkable agreement between the results of the -present flow visualisation studies at NAL with the available results.

Figure 7 shows the photograph of the flow over NAL delta wing at 40° angle of attack. Dye streaks near the apex region show the initial development of vortex flow over the wing terminated by the large coloured, blurred

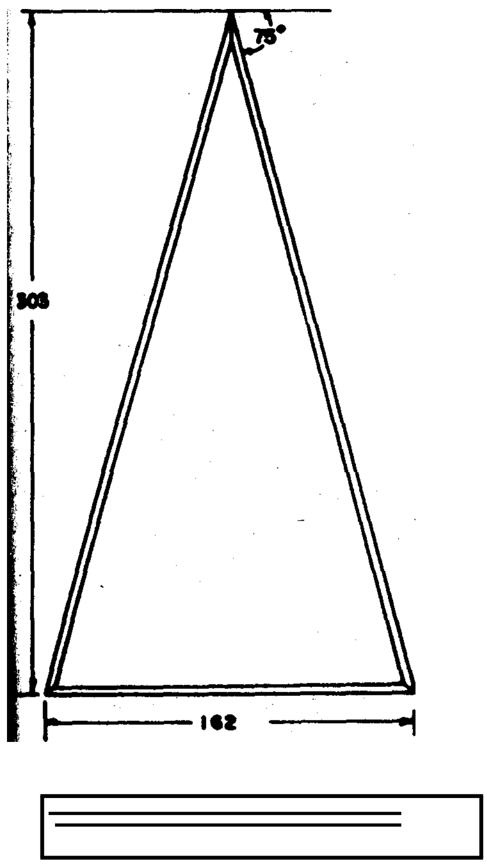

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Fig.4 Delta_ Wing Model (Sweep-75°, A.R.=1.07)

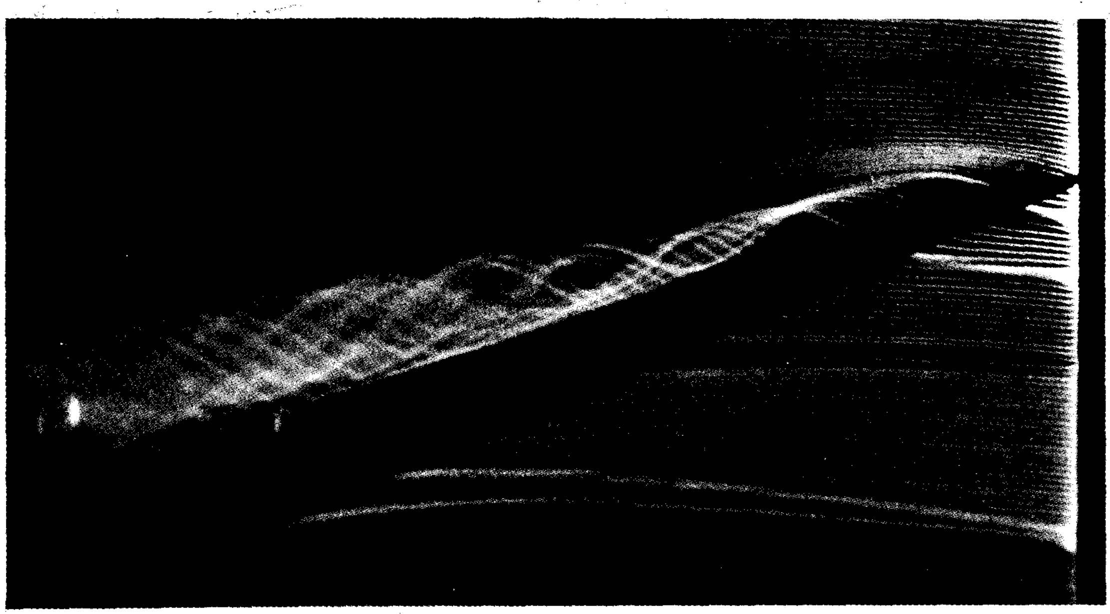


Fig.5a Continuous cola'ired Smoke-Wire Technique: Photograph Show Colour Dye Streaks Indicating Leading Edge Vortices on a Delta Wing (Sweep = 75°, A.R.=1.07]

Side View

Computed Flow (By O.A. Kandil) of a Delta Wing at ¢ =15°, A.R.=1(Ref: AGARD LS-98, 1979 and AIAA P77-1, 1977)

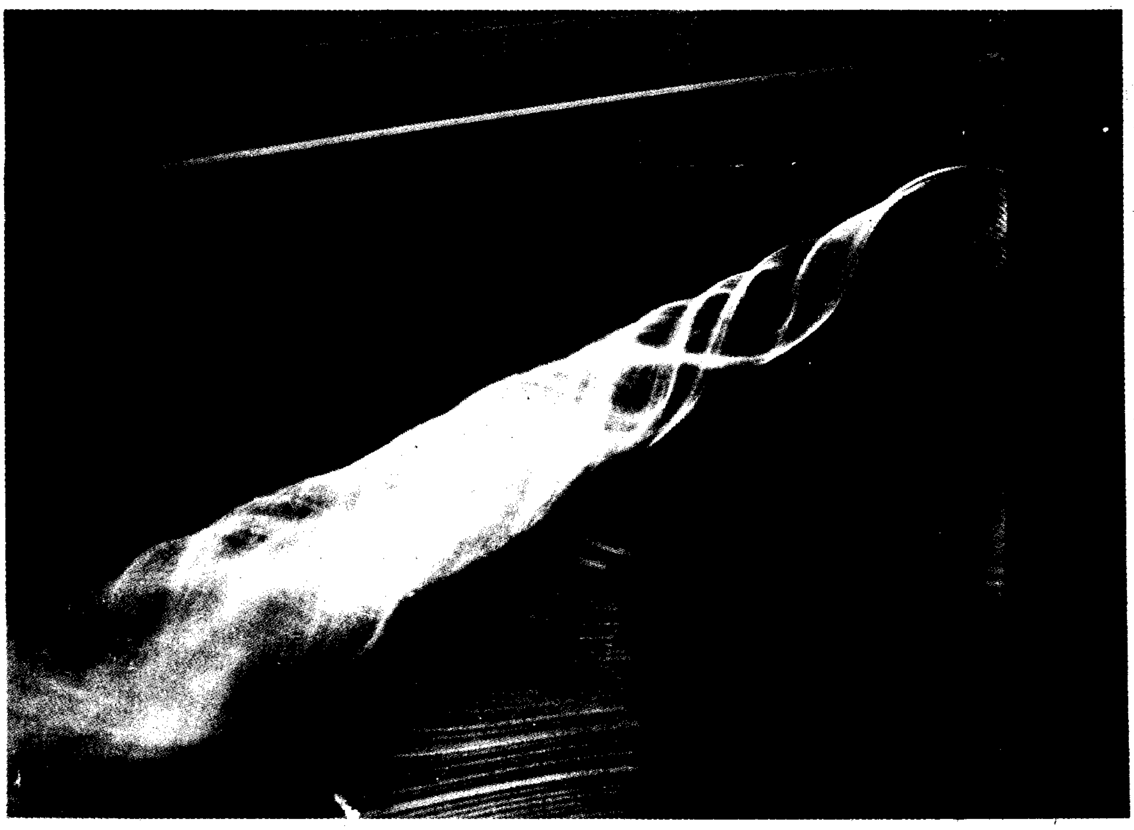


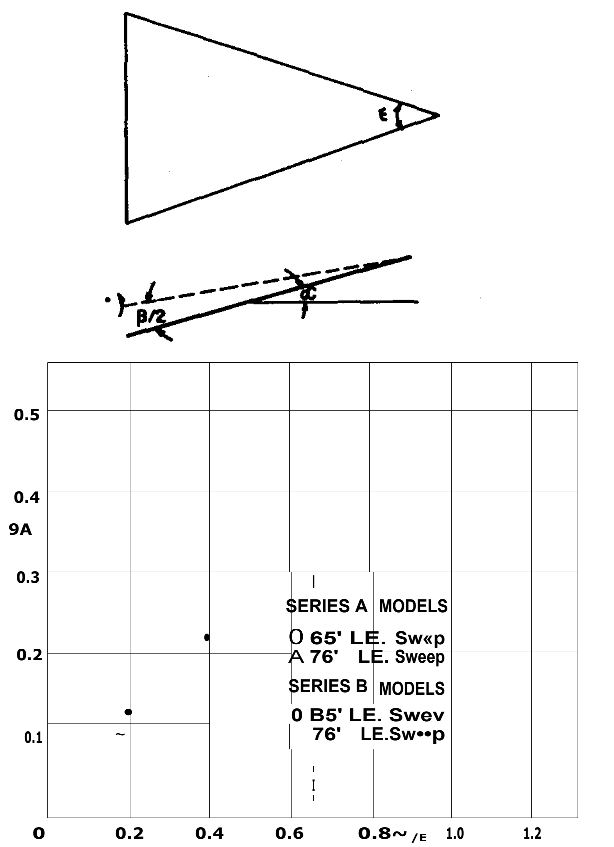
Fig.7 Photograph Show. Colour Dye Streaks Indicating Leading Edge Vortices on a Delta wing (Sweep=75, A.R.=1.07) with Vortex Breakdown

region (upstream of the trailing edge), indicating the vortex breakdown [Ref.11] over the wing at this angle of attack.

4. Conclusions

The smoke-wire technique is demonstrated to be capable of continuously generating controlled sheets of coloured smoke streaklines for flow visualisation in the low speed wind tunnel. The technique developed has been successfully used to visualize flow around the wing of a typical combat aircraft and also a delta wing mode at high angles of attack. The smoke-strgakline can be positioned any where in the region o; interest with respect to the model.

The technique developed can prove to bi very useful particularly for studying flow visua lisation around the aerospace vehicles whirl are being designed and where it is requires to check quickly aerodynamic performance a the vehicle necessary for preliminary desks estimates.



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FOR NAL DELTA WING (d. 2e. 301: 3/2.5' (NAL EXPTS.)
FROM ABOVE GRAPH: B/E .0.327 1.*. 3.9.8I OR R/214.90

Fig.6 Location of Vortex Centre-Lines

Acknowledgements

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