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A STATIC-AIR FLOW VISUALIZATION METHOD TO OBTAIN A TIME HISTORY OF THE LIFT-INDUCED VORTEX AND CIRCULATION

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16. Abstract

An investigation of a recently proposed method of flow visualization has been conducted at the National Aeronautics and Space Administration's Langley Research Center. This method of flow visualization is particularly applicable to the study of lift-induced wing tip vortices through which it is possible to record the entire life span of the vortex. To accomplish this, a vertical screen of smoke is produced perpendicular to the flight path and allowed to become stationary. A model is then driven through the screen of smoke producing the circular vortex motion made visible as the smoke is induced along the path taken by the flow and is recorded by high-speed motion pictures.

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A STATIC-AIR FLOW VISUALIZATION METHOD TO OBTAIN A TIME HISTORY OF THE LIFT-INDUCED VORTEX AND CIRCULATION

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Langley Research Center

SUMMARY

An investigation of a recently proposed method of flow visualization has been conducted at the National Aeronautics and Space Administration's Langley Research Center. This method of flow visualization is particularly applicable to the study of lift-induced wing tip vortices through which it is possible to record the entire life span of the vortex. To accomplish this, a vertical screen of smoke is produced perpendicular to the flight path and allowed to become stationary. A model is then driven through the screen of smoke producing the circular vortex motion made visible as the smoke is induced along the path taken by the flow and is recorded by high-speed motion pictures.

As a result of a more precise examination of the motion of the wing tip vortex afforded by this flow visualization method, it is suggested that by introducing a positive pressure gradient downstream of the wing tip it may be possible to cause the vortex to break down. This has been tested by employing a parachute attached to the wing tip and located approximately one chord length behind the wing trailing edge. The visual data obtained of the vortex resulting from the parachute configuration indicates that the vortex is virtually eliminated in this manner.

INTRODUCTION

There are a number of ways available today that may be used to make the flow in a test facility visible as it moves over various shaped objects such as spheres, cylinders, airfoil sections, or any object designed to move at such a speed that air resistance is a concern. This has been accomplished by introducing smoke or other light materials into the air stream (dye in the case of water tunnel) upstream of the model and observing the path traced by the visible material as it is carried by the flow over the model. This is very informative of the various flow phenomena such as flow separation, regions of stagnant flow, reverse flows, and the effect of mutual interference between bodies and has been a tremendous aid to the aerodynamicist in his research.

When employing the established flow visualization methods for the lift-induced wing tip vortex studies in the wind tunnel one observes only an instant in the life of the wing tip vortex and may even form the false impression that the vortex is being emitted from the wing. The air molecules affected by the wing tip in actual flight are set in a circular motion as the wing passes with little or no longitudinal motion with the exception of the air molecules in the vortex core itself. The air molecules are affected in a manner similar to water molecules in the wave action of the sea where there is vertical motion of the molecules with no horizontal motion. This movement of air molecules only in the vertical plane is quite apparent in actual flight tests where the airplane is flown upwind of a tower supporting a smoke bomb. The wing tip vortex produced by the aircraft drifts through the smoke produced by the smoke bomb and is made visible.

Based on observations made in the wind tunnel and in flight tests, a new flow visualization method has been suggested such that the true motion of the vortex may be readily observed and recorded under controlled conditions from the moment the vortex is created throughout its life span to the point that it dissipates. To accomplish this, a vertical screen of smoke is produced perpendicular to the flight path and allowed to become stationary. A model is then passed through the smoke screen producing the circular vortex motion which may be recorded throughout its entire life span by high-speed motion picture cameras. The results in this paper were originally reported in a 1971 Langley working paper. These results are also included in reference 1.

APPARATUS AND PROCEDURES

Test Facility

This investigation was conducted in the Langley Towing Tank Facility using the 54.86 meter monorail catapult system of this facility. This catapult is normally used to launch model aircraft into the tank to study seaplane landing performance or the water ditching characteristics of land based aircraft. The catapult is composed of a dolly propelled by a cable along a single rail at speeds up to 33.52 meters per second. The rail is located approximately 1.22 meters above the water level in the 5.49 meter wide tank.

Model

A dimensioned drawing of the semispan model wing is shown in figure 1. The wing panel was built-up of wood using an NACA 64_1-A012 airfoil section and covered with aircraft fabric in an attempt to keep the model as light as possible. A reflection plane was installed at the root of the wing as part of the semispan configuration. The span of the wing was 0.92 meters giving an aspect ratio of three for the complete wing. The dimensions and position of the parachute is a mean size of the parachutes tested. Nylon cloth and light chord were used to construct these parachutes. The end plate was constructed of plywood 0.64 centimeters thick. The leading edge was rounded while the trailing edge was tapered. The end plate was designed to form two vortices, one from each trailing tip, and to be variable such that the mutual interference of the two vortices could be maximized by increasing or decreasing the tip separation. The distance between the end plate tips was fixed for this test.

Smoke Generation

A commercial hand-held fogging gun was used to produce the screen of smoke required by the method of flow visualization. Kerosene was supplied to the smoke generator under a pressure of 103.421 kN/m^2 where it was heated and sprayed from a nozzle forming the required screen of smoke.

Measurements

Motion pictures and still pictures were taken of the vortex formation as the wing panel moved through the screen of smoke. The cameras were located approximately 12 meters upstream from the smoke screen position. The motion picture camera was operated by 64 frames per second or approximately two- and two-thirds times the normal frame speeds while the still photographs were taken at 1/10 second intervals.

DISCUSSION OF RESULTS

Vortex Visualization

An investigation has been conducted to establish the merits of a new static-air flow visualization method. A series of still photographs taken of the vortex flow patterns induced by the lifting wing panel are shown in figures 2, 3 and 4. Although the individual photographs in each figure are small, upon close examination of each picture it is possible to obtain quantitative as well as qualitative information about the vortex flow.

The first photograph in figure 2 shows the model as it had just passed through the smoke screen causing the vortex motion shown in the following views. The wing panel seen on the left side of this photograph is moving toward the viewer at approximately 17 meters per second at a lift coefficient of approximately 0.80. A reflection of the smoke screen and vortex may be seen in the water in the tank below the model. The lift-induced vortex formed rotates in a counter-clockwise direction indicated by the smoke entrained from the right side of each picture toward the left by the circulatory field around the vortex. The vortex moves downward and inward toward the plane of symmetry under the influence of the wing downwash. It is possible through this flow visualization method to measure these changes in vortex position with time as well as determine the growth rate of the vortex diameter in the plane of the smoke. Some particles of smoke are induced upstream along the periphery of the vortex core resulting possibly from the lower pressure associated with the more recently created vortex forward of the screen. This feature of the flow visualization system affords a three-dimensional view of the aircraft wake revealing a time history of the vortex core diameter, the meander of the tubular image of the vortex core, and the interaction of the vortices where a multi-vortex system exists. The actual value of the induced rolling moment at a particular position along the flight path must be determined by a measuring device introduced into the core of the vortex itself such as a small instrumented wing panel.

It was observed in the motion pictures during these tests that there is a definite acceleration to the vortex core motion shortly after the model had passed. The reason for this apparent energy addition is uncertain but detailed observation such as this would be difficult if not impossible in other flow visualization methods.

Vortex Reduction

Tests were made with the end plate shown in figure 1 installed on the wing tip. A comparison of the visual data (fig. 3) obtained for the end plate configuration with that of the plain tip configuration indicate that the span of the vortex tends to be greater and there is a delay in the complete roll-up of the vortex caused by the end plate. These effects reduce the effect of the tip vortex on the downwash behind the wing panel itself, resulting in a reduction in induced drag usually associated with end plating but do not effect the key problem of vortex persistence. It may be conjectured that other tip treatments such as blowing tips, baffles placed perpendicular to the stream, and various end plate configurations will only effect the flow in the immediate region of the wing but will have only small effect on the development of the vortex in the far-field. Based on this assumption it was proposed that a positive pressure gradient employed downstream of the wing, at approximately the point that the wing tip vortex core starts to develop, might cause the vortex to dissipate. To test this possibility, the parachute shown in figure 1 was attached to the wing tip and propelled through the stationary smoke screen. In comparing the visual data with and without the parachute, it was noted there is a strong tip vortex formed for the plain wing panel configuration while little or no vortex motion is observed with the parachute installed. Quantitative data obtained in later tests have verified these visual results.

As a more practical method of forming an unfavorable pressure gradient, tests were conducted with a metal disk probe-mounted downstream of the wing tip. The disk frontal area was comparable to that of the parachute, including the effect of the porosity of the parachute, with similar vortex attenuating results.

CONCLUDING REMARKS

The results of an exploratory investigation to determine the possibility of using a newly proposed static-air flow visualization method in the study of lift-induced vortices indicate the following:

1. It is possible through utilization of this static-air flow visualization method to observe under controlled conditions the entire life span of the lift-induced vortex from its initial formation through its dissipation.
2. Through this particular method of flow visualization, the effect of any wing tip treatment on the vortex development in the region of the wing as well as its lasting effect on the vortex development with time may be determined.
3. The visual results obtained for the various wing-tip configurations tested during this investigation suggested that a positive pressure gradient, produced by a tip mounted parachute, would force the vortex to break down.

REFERENCE

1. Patterson, James C., Jr.: Lift Induced Wing-Tip Vortex Attenuation. AIAA Paper No. 74-38. Presented at the AIAA 12th Aerospace Sciences Meeting, Washington, D. C., January 30 - February 1, 1974.

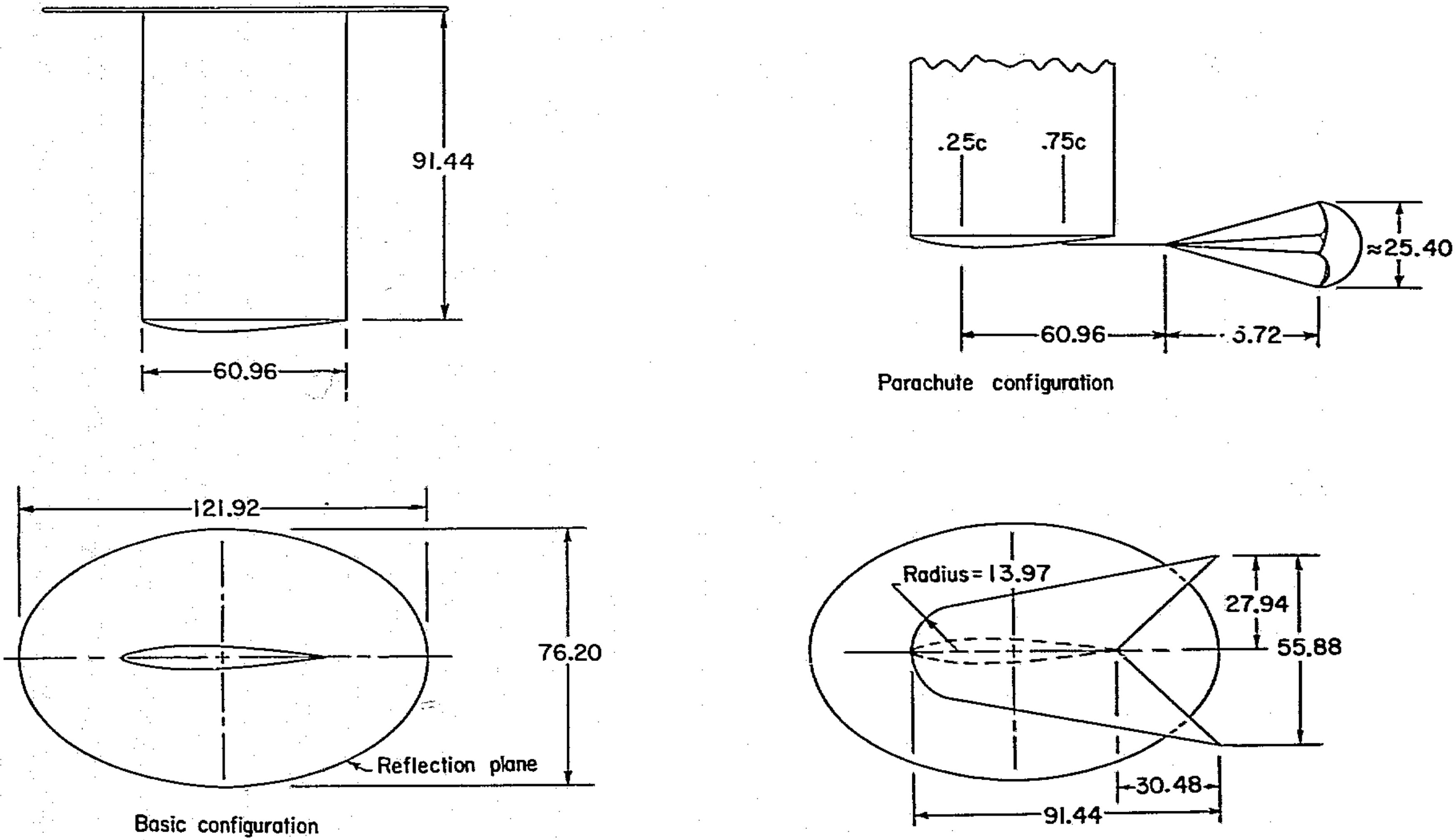

Figure 1. - Drawing of semispan model. All dimensions are in centimeters.

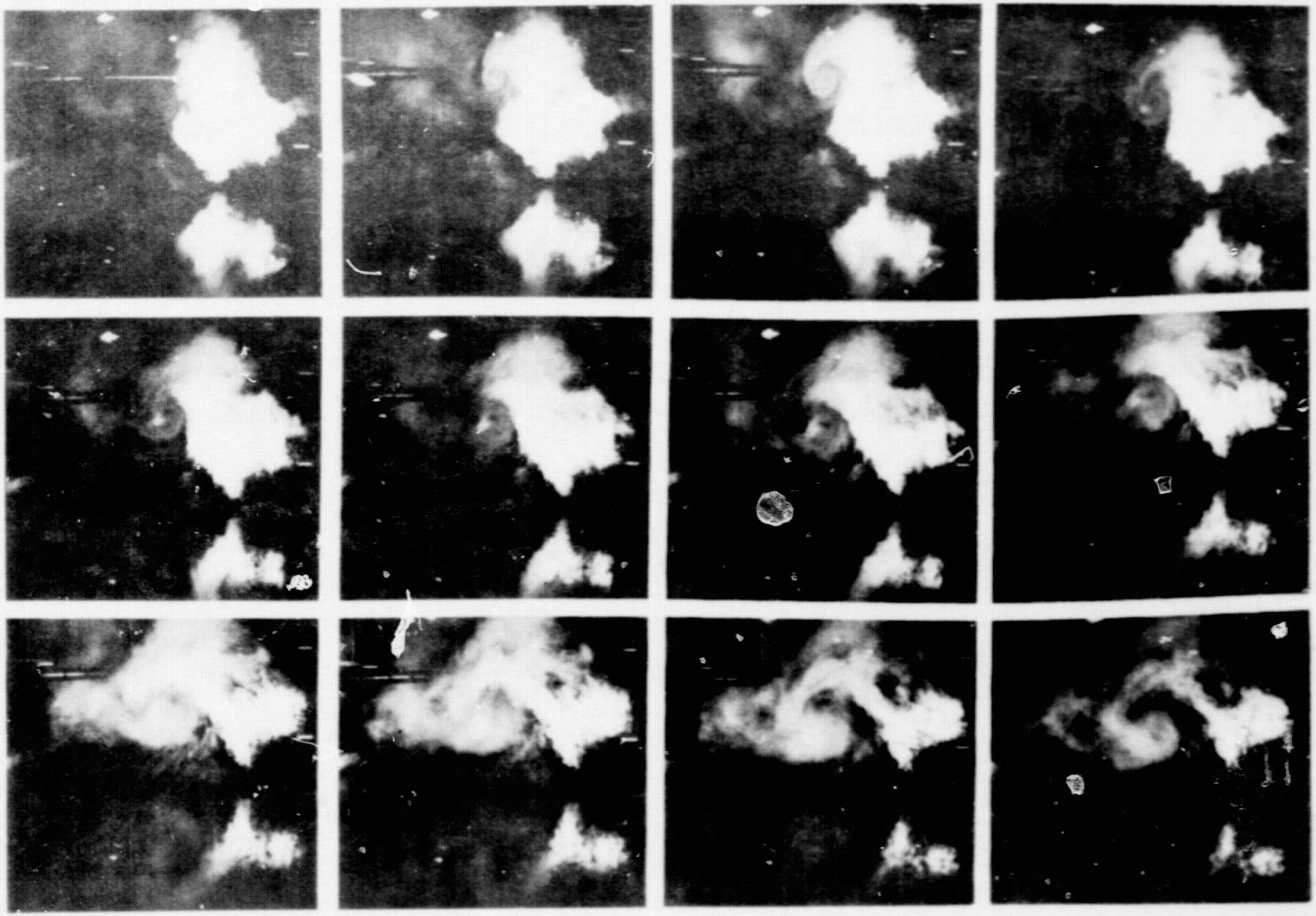

Figure 2. - Lift induced wing tip vortex produced by a semispan wing panel. Velocity = 17 meters/ sec, lift coefficient approx. 0.80, photographic rate = 1/10 sec/ frame.

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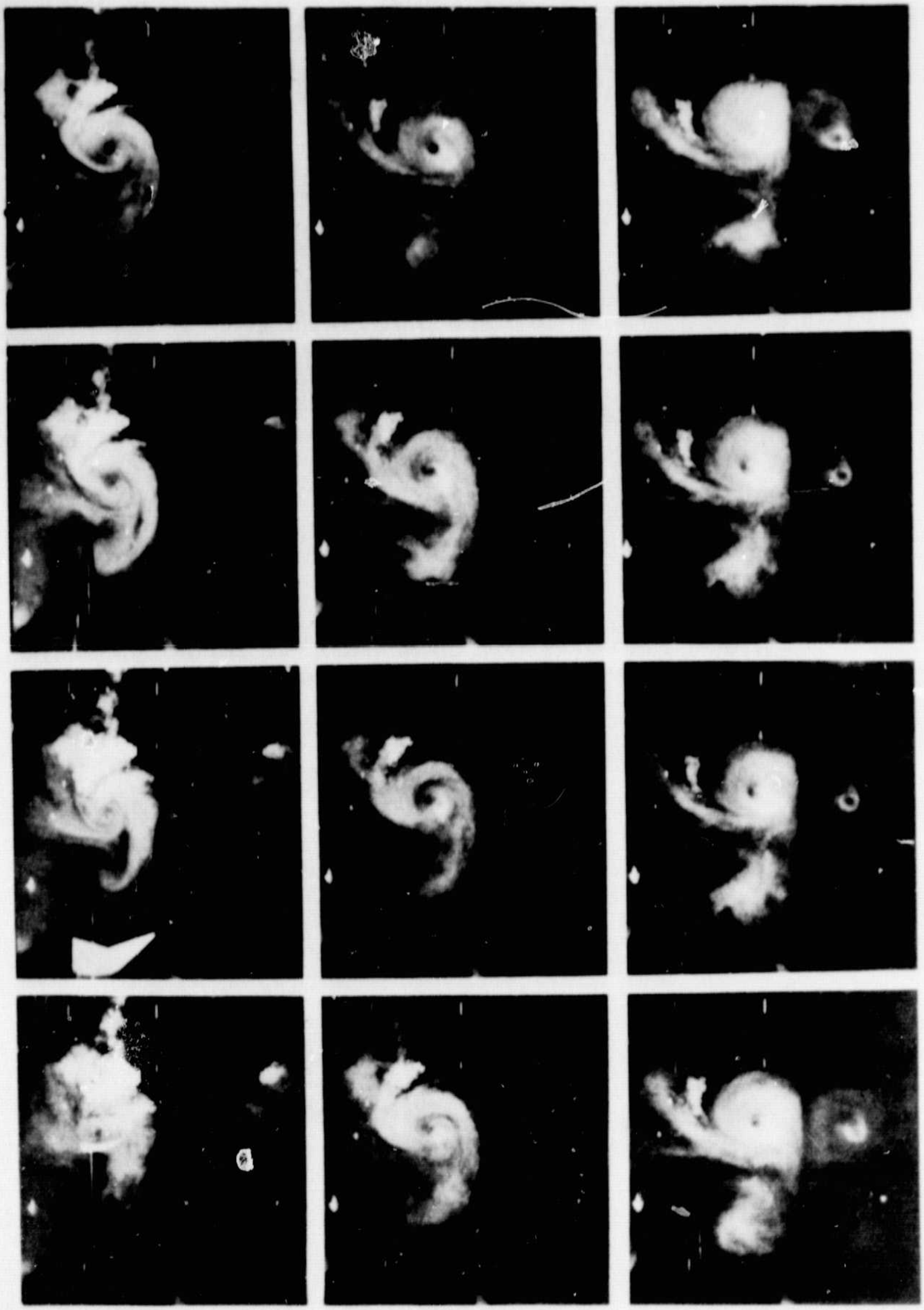

Figure 3. - The effect of an end plate on the lift induced wing tip vortex.

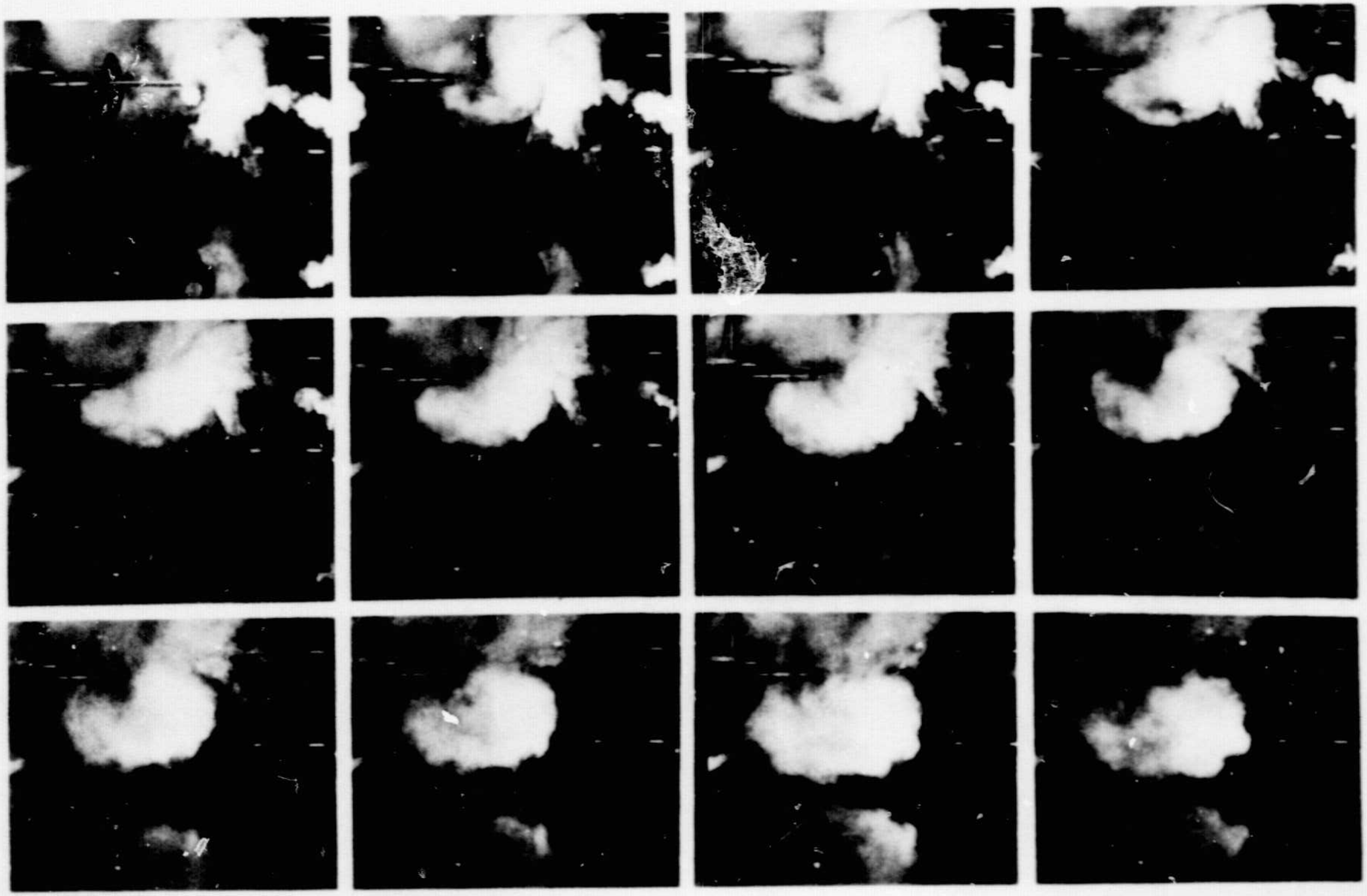

Figure 4. - The vortex attenuating effect of a wing tip mounted parachute.