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Aircraft Vortex Detection System Using Dual Laser Beams

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THE intense vortices generated by heavy aircraft during takeoff tend to linger over the runway on calm days or drift across adjacent runways with a cross wind. These large swirling masses of air were observed using smoke sources by Garodz.[1] Vortices are generally invisible to the human eye and can cause severe control problems for smaller aircraft attempting to land or take off.[2] Large aircraft separations are now being employed to allow the vortices to decay. This practice may be wasteful of runway use time if, for example, the generated vortices drift off quickly in a cross wind. It would appear, then, that airports are in need of a reliable vortex detection system which is relatively simple, is insensitive to runway heating effects, and does not interfere with visibility or normal airport functions. This Note reports laboratory experiments on a vortex detection system that may meet most of these requirements.

Funk and Johnston[3] have proposed an optical vortex detection system dependent upon the deflection of individual laser beams that cross the runway. In order to sample the complete length of the runway it was proposed that a series of beams be used between towers that line both sides of the runway. The vortex detection system reported in this note differs from that of Ref. 3 in two important ways. First, the laser beams are to be directed along the length of the runway, and second, the laser beams are to be used in pairs to detect the difference in the deflection of these beams. These changes make the dual beam system less susceptible to runway heating effects and they eliminate the need for towers along both sides of the runway.

The experimental system used in this study consisted of two parallel laser beams, each about 1 mm in diameter, which were relayed down the center of a wind-tunnel test section (see Fig. 1). A 2-mw helium-neon laser located at the wind tunnel entrance was used to produce the two beams of equal intensity by passing the laser output beam through a beam-splitter. The two beams were positioned in a horizontal plane just below a horizontally held NASA 65_3-618 airfoil with a chord of 9.5 cm and a span of 25 cm. One end of the airfoil was fastened to the tunnel wall while the free end shed the vortex approximately in the center of the wind tunnel. The lateral position of the two beams was adjusted so that the midpoint between the two beams was located at the center of the trailing vortex. The location of the trailing vortex within the wind tunnel was determined by a velocity traverse and was confirmed by smoke visualization tests.

At the end of the test section a system of plane mirrors, shown as a single long mirror in Fig. 1, deflected the two beams out of the wind tunnel approximately 370 cm behind the airfoil and directed them to an optical receiver composed of a photomultiplier, a pair of knife edges, and a light filter. At the optical receiver, the two beams of light first encounter two knife edges that faced in opposite directions, thereby blocking off about half of each beam. The remaining light which passed by the two knife edges was focused by a positive lens through a pinhole mask and a narrow-band optical filter whose transmission was centered at the 632.8-μm wavelength of the laser. The light then illuminated a photomultiplier tube. The purpose of the pinhole mask and filter was to minimize room light and to avoid saturation of the photomultiplier. The total amount of light that passed by the knife edges and reached the photomultiplier tube was proportional to the anode current which was measured with a slow response micro-micro ammeter.

The optical beam alignment was made while the tunnel was not in operation. The knife edges were then adjusted to block half of each beam. The ammeter reading, I_o, for the no-wind reference conditions was carefully noted. When the wind-tunnel fan was turned on, producing a mean velocity of 13.7 m/sec in the tunnel, the ammeter reading increased above I_o and remained higher as long as there was air flow in the wind tunnel. The ammeter reading returned to the same initial value when the air flow was reduced to zero. When the airfoil was removed from the tunnel, the photomultiplier current was essentially the same whether or not there was air flow in the tunnel. Typical current readings as a function of the lateral beam separation for a 10° angle of attack are shown in Fig. 2. It can be seen that there is a measurable increase in the photomultiplier current due to the wing tip vortex. This current increase is shown to be strongly dependent on the lateral separation between the two laser beams.

The response of the dual laser beam detection system to thermal convection was tested by inserting a 750 w hot plate into the wind tunnel directly beneath the airfoil assembly. For these tests the airfoil was removed and there was no air flow in the wind tunnel. The 15 cm diam hot plate, which was located about 14 cm below the dual laser beams, produced a strong vertical thermal plume that visibly perturbed the light that traversed it. The photomultiplier current, however, was not affected by the presence of the hot plume, as shown in Fig. 2.

When one of the two beams was blocked off completely, the resulting single beam system showed a substantial change in the photomultiplier output due to the presence of the hot plate. The normalized current, I/I_o, for the single beam system varied from 1.02 to 1.05. This is considerably greater than the dual beam response shown in Fig. 2.

The optical vortex detection system works on the same principal as the schlieren system, i.e., the principal of light refraction. The individual laser beams act as schlieren system beams which are cut off by their own knife edge. Because of the orientation of the knife edges shown in Fig. 1, changes in the amount of light that is allowed past the knife edges can occur only when the light beams are deflected in the vertical plane within the wind tunnel. Vertical deflections in the light beam are, of course, caused by vertical density gradients along the path of the light beam. When both beams are deflected in the same direction, for example vertically, one beam is cut off more and the other less because the knife edges are facing in opposite directions. As a result, there is little net change in the total amount of light reaching the photomultiplier, and no change in the ammeter reading. If one beam deflects up and the other deflects down, then both beams experience the same change at the knife edges (for example, both may be cut off less), and a net change would result in the total amount of

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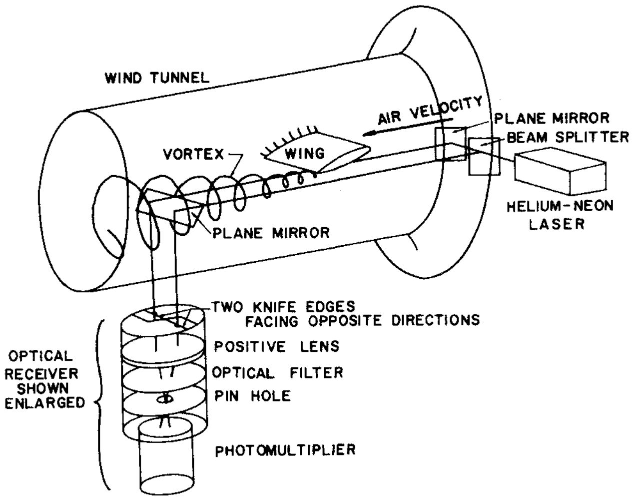

Fig. 1 Schematic arrangement of the dual beam laser vortex detection system in the low speed wind tunnel.

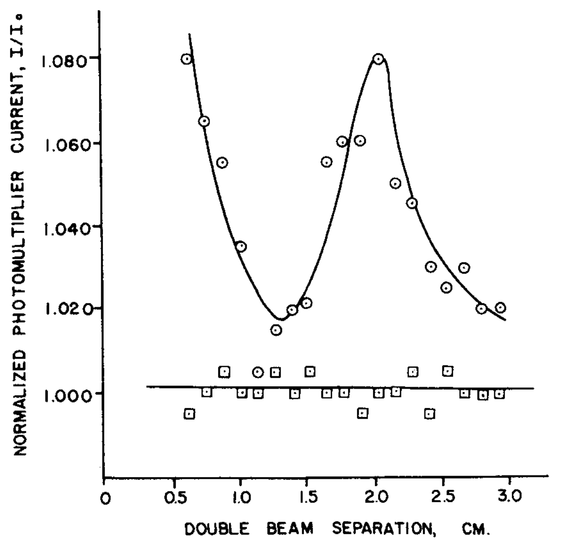

Fig. 2 Comparison of the vortex detection system response to a wing generated vortex with a thermal plume in the absence of a vortex. ⊙ = with vortex from wing at 10° angle of attack, $V = 13.7$ m/sec. □ = without wing but with hot plate under dual beams, $V = 0$.

light reaching the photomultiplier. If one beam is unaffected but the other is deflected in the vertical plane, a smaller net change in the photomultiplier current would result.

In full-scale operation over a runway, the laser beams should propagate above and parallel to the runway. Existing runway approach light towers on both ends of the runway could be used to house the necessary system of mirrors. This would not, therefore, add any new protruding structures adjacent to the runway. The beam separation and height above ground are variables which must be determined for best system response to a vortex. For safety, the laser wavelength should be selected such that the light beams would not transmit through the aircraft windshields. The laboratory tests described above indicate that, in principle, a full-scale system of this type should be able to detect wingtip vortices over a runway.

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Approximate Solution for Minimum Induced Drag of Wings with Given Structural Weight

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Introduction

In recent years great achievements have been obtained in reducing different kinds of drag for aircraft flying at high subsonic or transonic speeds. Surprisingly little attention has been paid, however, to the problem of minimizing induced drag. Elliptic spanwise loading has been known for a long time to be optimum in this respect if overall lift and wing span are given. In practical applications, the span cannot be chosen at will, but is restricted from structural considerations. Hence the spanwise loading that provides minimum induced drag in steady flight will be determined by overall lift, and by the weight of the wing. This weight changes during the flight as fuel is extracted from the tanks, and it is therefore very difficult to specify an auxiliary condition that holds true for the mathematical formulation of the optimization problem. If we take wing structural weight alone as the decisive factor, the problem can be solved, provided a relation is found between this weight and the relevant aerodynamic parameters. Such a solution was given by L. Prandtl[1]. He based it on the assumption that a direct proportionality exists between the weight of the spars and the local bending moment. Recently A. Klein and S. P. Viswanathan[2] worked out a solution for the case where the wing-root bending moment is prescribed. In this Note a solution is derived that is believed to represent an even better approximation for the optimization problem. It is based on the common practice to determine the structural weight of such wings for steady flight by the integrals of the spanwise shear-force and bending-moment distributions.

Formulation of the Problem

The integrals of the spanwise distributions of shear-force F and bending-moment M that are due to the airload are

$$\int_0^s F(y)dy = \frac{1}{2}\rho_\infty V_\infty^2 \int_0^s\int_y^s c(y')C_L(y')dy'dy$$

and

$$\int_0^s M(y)dy = \frac{1}{2}\rho_\infty V_\infty^2 \int_0^s\int_y^s c(y')C_L(y')(y'-y)dy'dy$$

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