IN-FLIGHT PROPELLER FLOW VISUALIZATION USING FLUORESCENT MINITUFTS

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The fluorescent minituft flow visualization technique (Crowder, J. P., Astronautics & Aeronautics, Nov. 1980, pp. 54-56) was originally developed for non-intrusive flow visualization in wind tunnel testing. This note describes a recent extension of the method to in-flight flow visualization on propellers.

The basis of the method is the use of extremely thin nylon monofilament for the minitufts, a process of attaching them to the test surface with small drops of lacquer-like adhesive, and the use of fluorescense photography for recording the minituft patterns. Using this method, thousands of minitufts can be applied to small, high speed wind tunnel models without affecting the airflow. Therefore, the minitufts can remain in place throughout a wind tunnel test, permitting non-intrusive flow visualization data to be acquired at any time.

The greatest problem in developing a flow visualization experiment for propellers is the high centrifugal acceleration which acts on any kind of indicator, such as oil or tufts. The very small size of fluorescent minitufts helps, in this regard, to make them relatively unaffected by centrifugal forces. Simple dimensional analysis suggests that the aerodynamic forces on a tuft, for a given velocity and radius, depend on the tuft diameter while the centrifugal forces depend on the cross-section area, or diameter squared. Therefore, as the tuft diameter is reduced, the centrifugal force will decrease at a greater rate than the aerodynamic force. Consequently, at some particular tuft size, the centrifugal loading will become insignificant.

Furthermore, the tuft airloads depend on the dynamic pressure, the rotational component of which is proportional to the rotational rate Ω squared, times the radius R squared, or $\Omega^2 R^2$, while the centrifugal forces on the tufts depend on $\Omega^2 R$. Thus the ratio of aerodynamic to centrifugal forces increases as the radius is increased.

From this reasoning it seems certain that for some combination of tuft diameter, rotational rate, radius and Reynolds number, fluorescent minitufts will properly indicate surface flow direction. These effects are difficult to determine analytically so actual demonstration of minituft behavior requires experimental trials.

The greatest difficulty in using the fluorescent minituft method is in providing sufficient ultraviolet illumination to make the very small tufts photographically visible. For stationary wind tunnel models, the usual illumination source is a pulsed xenon flash lamp with an electrical power for each pulse of 2000 Joule and a duration of about five milliseconds.

Propeller flow visualization and other rotating machinery applications typically involve motion rates so fast that the illumination duration must be on the order of one microsecond to produce an image with tolerable blur. This is very difficult to achieve for such high energy levels.

A test program to demonstrate the fluorescent minituft method for in-flight propeller flow visualization was sponsored by Machen, Inc. in support of their flight test program of the Machen Superstar. This airplane, shown in Figure 1, is a re-engined version of the Piper Aerostar. The airplane was experiencing high speed performance limitations attributable to the propeller performance. The fluorescent minituft method was applied to help identify the propeller flow characteristics to aid in designing new propellers for the airplane.

The flashlamp power supply, weighing over one hundred pounds, including the a.c. inverter, and occupying several cubic feet is just visible in the cabin through the door. The flash lamp was placed in a forward fuselage compartment rather than in the cabin window because the plastic window material was opacque to the ultraviolet radiation. The lamp-to-propeller distance was about eight feet. The camera was located in the cabin door window, shown open in Figure 1.

Figure 2 shows the typical appearance of the in-flight minituft propeller flow visualization results. The flight condition in this case was close to maximum cruise speed with a propeller tip Mach number of 0.93. The line of local separation evident along the outer half-radius is most likely a shock wave induced separation bubble. From the reflections of the minitufts on the shiny aluminum surface of the spinner, one can get an indication of the centrifugal force biasing of the minituft direction.

Figure 3 shows the propeller flow condition during climb at high altitude, approaching the service ceiling. As expected, there is extensive separation on the propeller surface.

These pictures graphically show the type of flow visualization results that can routinely be achieved on rotating surfaces. This technique is suitable for a wide variety of aerodynamic problems including helicopter rotors, turbomachinery, and wind turbines, in addition to propeller flow visualization. The method is easy to implement and can produce data images over a wide range of conditions with little or no interference to the flow or test procedures.

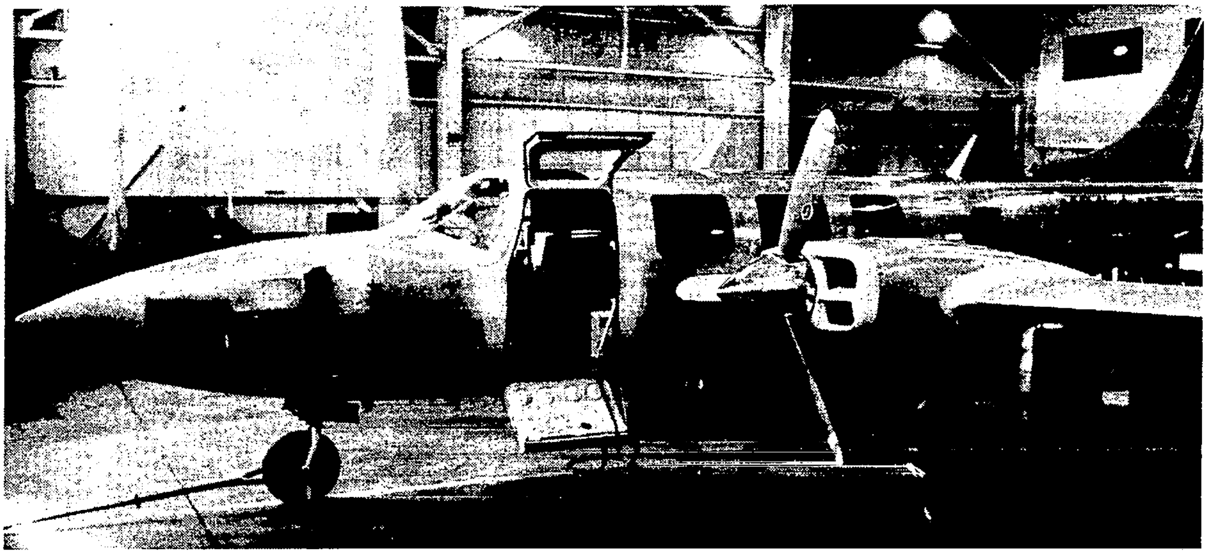

Figure 1.- Ultraviolet flash lamp installation in Machen Superstar.

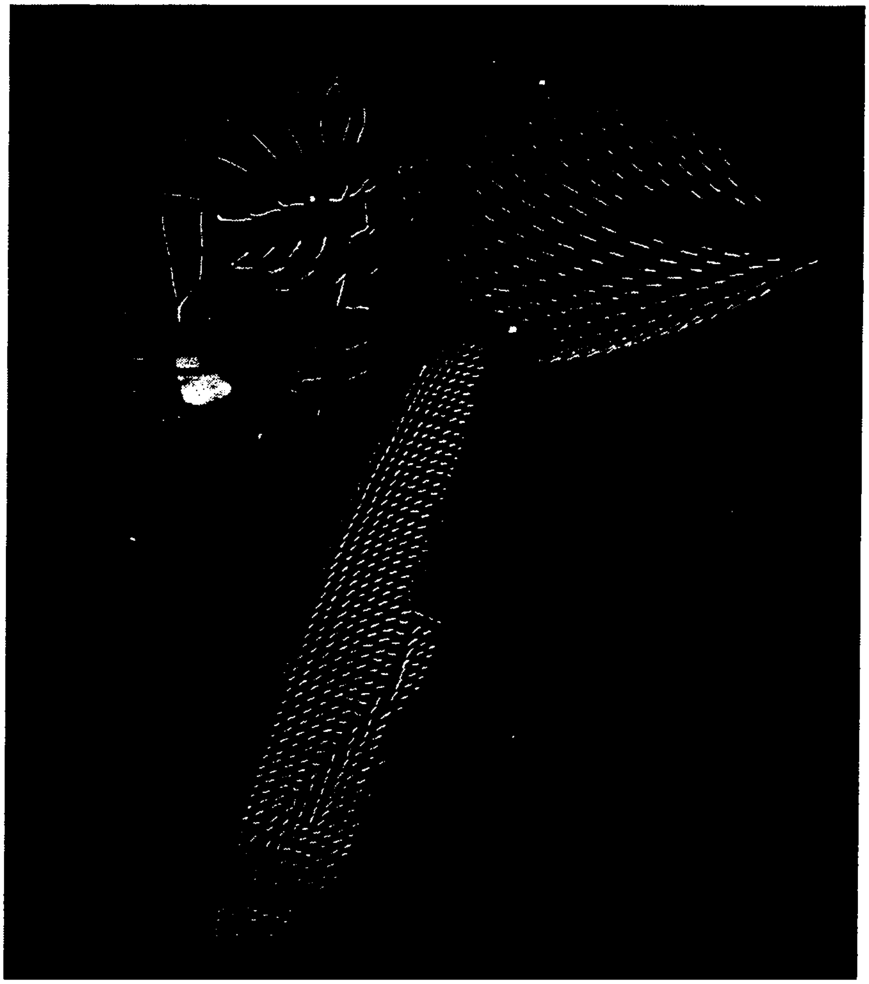

Figure 2.- Fluorescent minitufts on Machen Superstar propeller. 25,000 ft; 285 kt IAS; M-tip = 0.93; Advance ratio = 1.87; Power coef = 0.21.

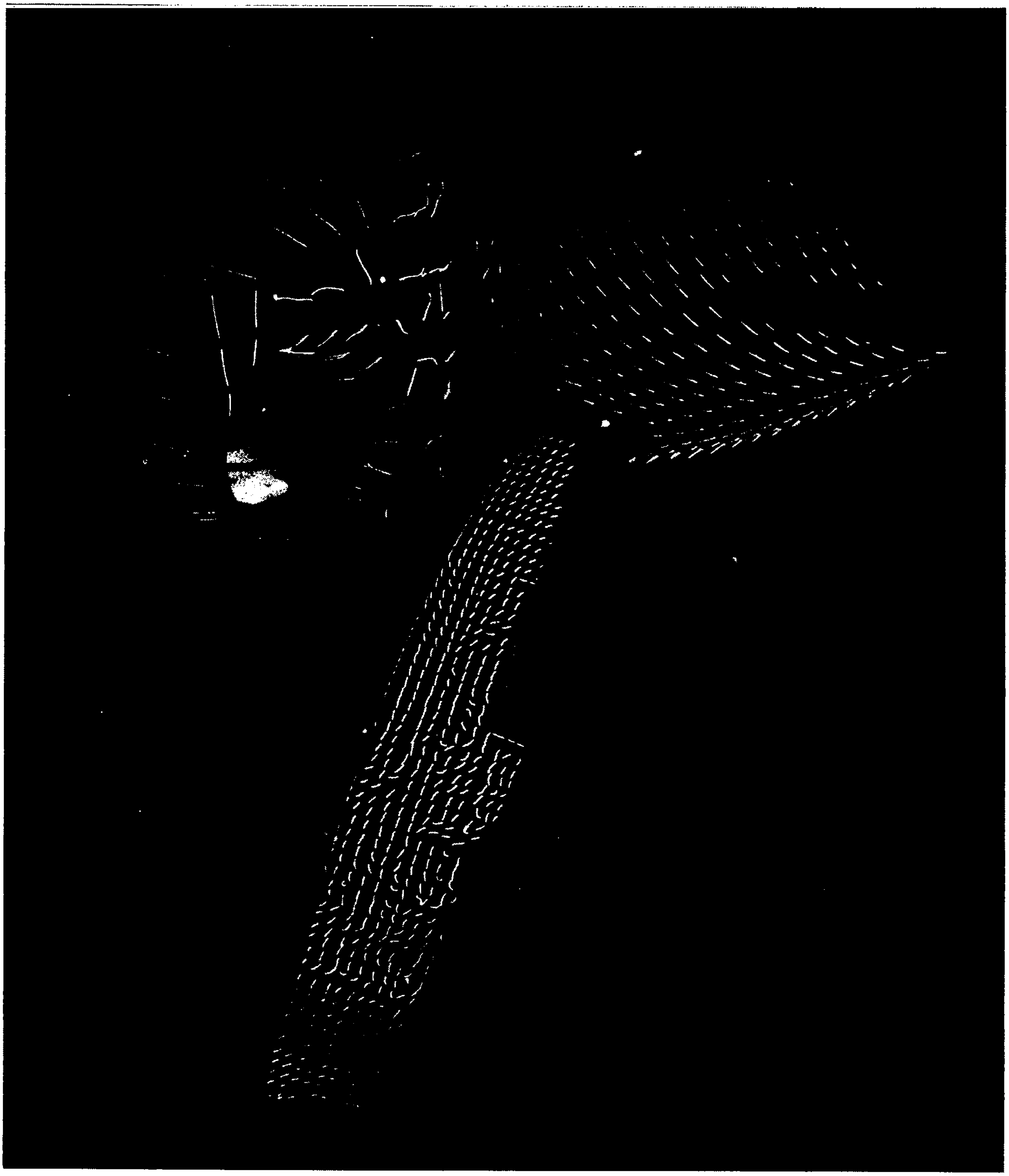

Figure 3.- Fluorescent minitufts on Machen Superstar propeller. 24,000 ft; Climbing; 120 kt IAS; Advance ratio = 1.18; Power coef = 0.27.