Performance Degradation of Natural Laminar Flow Airfoils Due to Contamination by Rain or Insects

By R. JOHN HANSMAN JR.

Boeing Assistant Professor
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

INTRODUCTION

High L/D laminar flow airfoils, which have become common in competition sailplanes over the past two decades, are extremely sensitive to surface contamination in the form of insects, water or ice. In order for these airfoils to operate within the low drag "laminar bucket", a laminar (smooth) boundary layer must be maintained over a substantial fraction of the wing chord. Any significant irregularity or protuberance from the surface causes the boundary layer to become turbulent in a wedge-shaped region downstream of the irregularity. If the turbulent boundary region becomes substantial, the drag on the airfoil will increase, reducing the L/D. In addition the turbulent boundary layer may be susceptible to premature separation, resulting in an increase in stall speed. The size at which an irregularity or roughness element becomes significant is, at present, not well understood; however, some investigators have suggested that laminar-to-turbulent transition will occur when the Reynolds number, based on the roughness height and the velocity at the top of the roughness, exceeds some critical value. Critical values from 50 to 600 have been quoted.[1]

The two primary contamination mechanisms which affect sailplane operations are insect impingement, where the insect residue exceeds the critical roughness height, and water contamination during flight though rain. A brief discussion of each of these mechanisms follows.

INSECT CONTAMINATION

Performance degradation due to insect contamination has been a major area of concern to competition pilots for the past decade. The magnitude of the insect contamination problem depends primarily on the insect population density, which is a function of meteorological and entomological factors. In a typical environment, the density of insects decays rapidly with altitude, as is shown in **Figure 1** from the early work on insect contamination by Coleman.[2] The insect population density is often anomalously high in thermals, be-

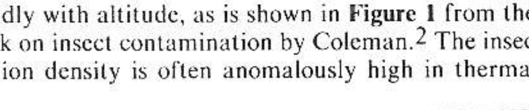

Figure 1: Typical insect distribution with altitude.

cause the insects tend to be advected up from the surface by the circulation pattern within the thermal. As a result, sailplanes, which spend a significant fraction of time in thermals, tend to be more prone to insect contamination than other types.

When an insect impinges an aircraft component, the collection of insect debris will result if the impact velocity is sufficiently large to cause rupture of the insect. Coleman experimentally investigated rupture velocities and found then to vary from 10 m/s for Aphides to 20 m/s for Mormoniella, with a mean value of 11 m/s.[2] The typical residue pattern for an airfoil consists of a narrow region around the stagnation streamline where the insects adhere essentially intact. Further aft, the residue consists mainly of shallow fluid deposits which decrease in density to the aft limit of impingement. Boermans and Selan[3] conducted flight measurements of insect impingement patterns in the Netherlands and found that 55% of the ruptures occurred in the first 2.5% of the chord while 35% of the events occurred in the first 1% of the chord. For Standard Class sailplanes, the insects were evenly distributed on the upper and lower surfaces. For flapped airfoils, they found that the insect debris tended to collect on the upper surface. Boermans and Selan took the insect pattern accumulated in flight on an AS-W 19B in the wind tunnel. Measurements indicated an increase in drag of 20% or greater at angles of attack of 5 degrees or more and a reduction in the width of the drag bucket. Lift was not significantly affected.

One surprising result was that, for low angles of attack, there was little increase in the drag. This is consistent with results from the NASA Langley Research Center by Holmes et al[4] who observed, by chemical techniques, the transition from a laminar to turbulent boundary layer downstream of insects accreted at low level by a Bellanca Skyrocket II. The results, shown in **Figure 2**, indicate that near the stagnation point even very-large insect remains did not cause transition. Further aft, insects greater than the critical excrescence height produced turbulent wakes. Typical turbulent wedge patterns are shown in **Figure 3**.

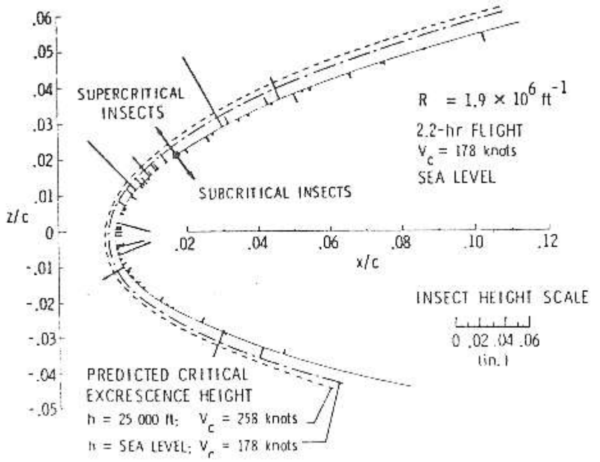

Figure 2: Insect contamination pattern on Bellanca Skyrocket II.

Insect impingement trajectories have been modeled by Coleman[2], Bragg[1] and Hansman[5] in order to attempt to assess the sensitivity to contamination of particular airfoils.

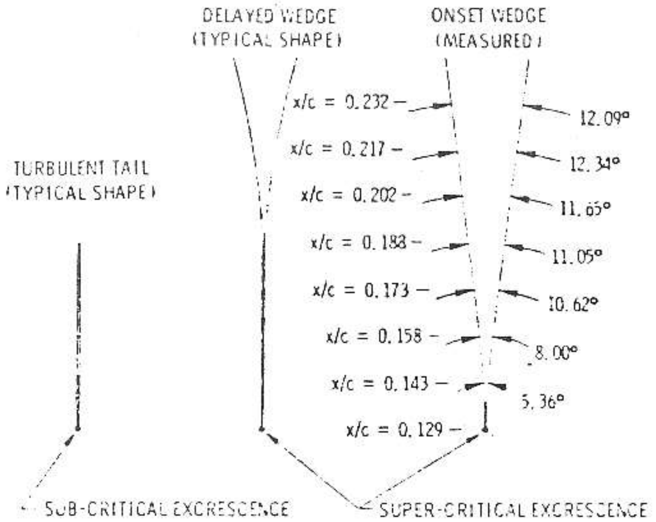

Figure 3: Turbulent wake geometries observed in flight on Skyrocket II laminar wing.

An example of a typical trajectory pattern is shown in **Figure 4** for a half body at 0 degrees incidence. Because of the wide range of conditions under which insect contamination occurs, it is difficult to make general conclusions on airfoil sensitivity. However, for low-density populations of massive insects, thinner airfoils will be less susceptible to contamination. Conversely, for high-density populations of light insects, the lower collection efficiency of thick airfoils makes them less sensitive.

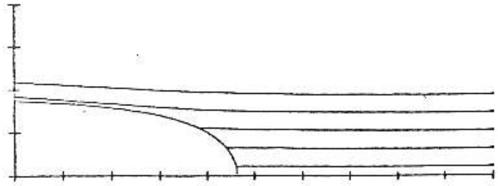

Figure 4: Insect impingement trajectories for 7 cm halbody

CONTAMINATION BY RAIN

Performance degradation in rain has been reported, qualitatively, by sailplane pilots. In addition, degradation of airfoil performance in rain is thought to cause changes in the longitudinal stability of canard-type aircraft[6], and also thought to be a contributing cause in several major windshear accidents[7]. Wind-tunnel experiments have been conducted in simulated rain at the NASA Langley Research Center on typical transport and canard-type airfoils. In addition, tests have been conducted at MIT on a typical sailplane airfoil to study the effects of surface wettability in rain.[10]

A schematic of the experimental set-up used in the MIT tests is shown in **Figure 5**. Water was injected from rain simulation nozzles 1.5 m upstream of a 6-inch chord Wortmann FX-67-K-170 (Nimbus II) airfoil. Extremely heavy rain rates of 440 mm/hr were simulated, at the operating Reynolds number of 330,000. The airfoil surface was prepared with different degrees of wettability. The nominal sur-

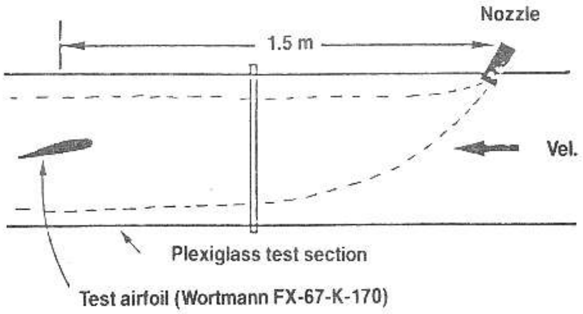

Figure 5: Schematic view of setup for simulated rain experiments

face was a clean epoxy gel coat, carefully sanded with 600 grit sandpaper prior to testing. The air/water contact angle of this partially-wettable surface was 53 degrees. A non-wettable surface with a 90-degree contact angle was obtained by waxing the airfoil surface. In addition, a soap-coated surface with a low contact angle was tested.

The results are shown in **Figure 6**. A significant loss of performance was observed for each surface wing, the non-wettable, waxed surface being the most degraded (75% reduction in maximum L/D) and the incompletely-wettable epoxy gel coat being the least degraded (45% reduction). Accompanying the L/D loss was an effective reduction in angle of attack of up to 2 degrees resulting from a downward translation of the lift polar. In photographic observations, the runback water layer was found to bead on the wax surface, and sheet on the wettable surfaces. The strong dependence on surface wettability of both the airfoil performance and the water behavior indicates that the degradation due to rain is primarily a result of the roughening of the surface, causing premature transition from a laminar to turbulent boundary layer.

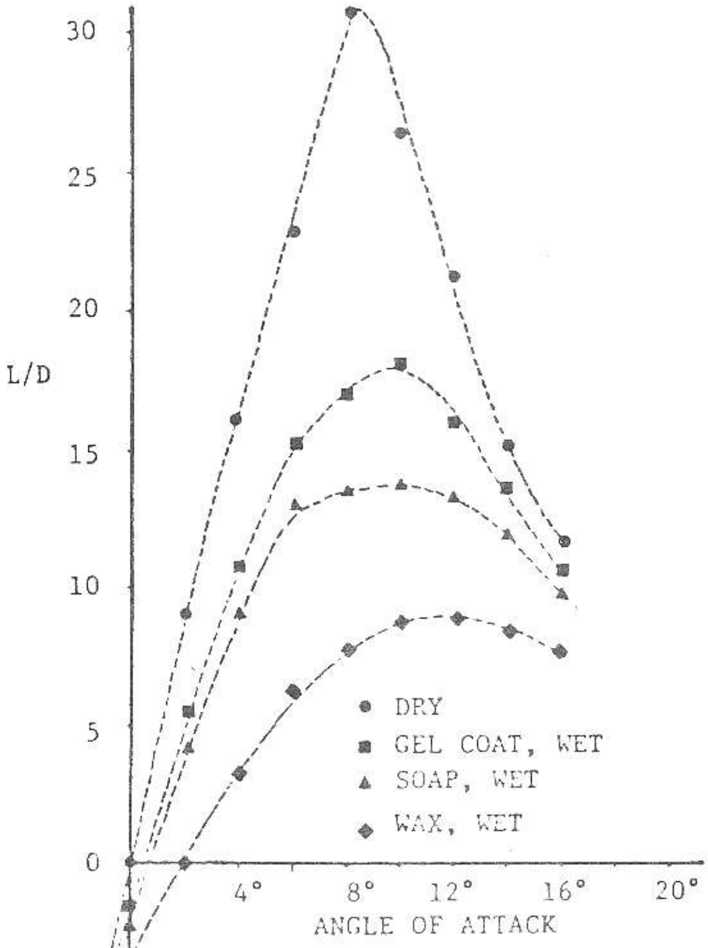

Figure 6: Lift to drag ratio vs. angle of attack for the surfaces tested.

Similar, but less extreme, results have been observed at higher Reynolds numbers by Yip et al[9] in tests on canard airfoils and by Dunham et al[8] on transport airfoils. One aspect of the performance degradation in rain, which does not occur for insect contamination and cannot be explained by simple transition of the boundary layer, is the downward translation in the lift polar. The loss in lift implies an effective reduction of the airfoil camber and may be a result of a differential transition behavior between the upper and lower surfaces. Because of difficulties in scaling, small scale models will shows a greater sensitivity to rain. Therefore, some caution must be exercised in extrapolating the low Reynolds number results to full scale. It is, however, clear that rain does degrade the airfoil performance and that surface wettability is an important effect. Waxing, therefore, should be avoided on sailplanes which require high performance and may be required to penetrate rain.

REFERENCES

1. Bragg, M.B. and Maresh, J.B., "The Role of Airfoil Geometry in Minimizing the Effect of Insect Contamination of Laminar Flow Sections", AIAA-84-2170, 1984.
2. Coleman, W.S., "Roughness Due to Insects", *Boundary Layer and Flow Control*, Vol. 2, Pergamon Press, 1961.
3. Boermans, L.M.M., and Selen, H.J.W., "Design and Tests of Airfoils for Sailplanes with Applications to the AS-W 19B", ICAS-82-5.2.2.
4. Holmes, B.J., Obara, C.J., Gregorekm, G.M., Hoffman, M.J. and Freuler, R.J., "Flight Investigation of Natural Laminar Flow in the Bellanca Skyrocket II", SAI 830717, 1983.
5. Hansman, R.J., "Studies of the Insect Collection Efficiency of Airfoils," Proc. 4th Intl. Symposium on the Science and Technology of Motorless Flight, 1984.
6. Hewes, D., "Effect of Rain and Bugs on Flight Behavior of Tail-First Airplanes," Part I-III, *Sport Aviation*, May-July, 1983.
7. Haines, P. and Luers, J., "Aerodynamic Penalties of Heavy Rain on Landing Airplanes", J. Aircraft, 20, III, 1983.
8. Dunham, R.E., Bezos, G.M., Gentry, C.L. and Melson, E., "Two-Dimensional Wind Tunnel Tests of a Transport-Type Airfoil in a Water Spray", AIAA-85-0258, 1985.
9. Yip, L.P. and Coy, P.F., "Wind-Tunnel Investigations of a Full-Scale Canard-Configured General Aviation Aircraft", ICAS 82-6.8.2., 1982.
10. Hansman, R.J. and Barsotti, M., "The Aerodynmamic Effect of Surface Wetting Characteristics on a Laminar Flow Airfoil in Simulated Heavy Rain", AIAA-85-0260, 1985.