INSECT CONTAMINATION PROTECTION FOR LAMINAR FLOW SURFACES

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INTRODUCTION

The ability of modern airplane surfaces to achieve laminar flow has been well-accepted in recent years. Obtaining the maximum benefit of laminar flow for aircraft drag reduction requires maintaining minimum leading-edge contamination. Previously proposed insect contamination prevention methods have proved impractical due to cost, weight, or inconvenience. Past work has shown that insects will not adhere to water-wetted surfaces, but large volumes of water required for protection rendered such a system impractical. This paper presents results of a flight experiment conducted by NASA to evaluate the performance of a porous leading-edge fluid discharge ice protection system operated as an insect contamination protection system. In addition, these flights explored the environmental and atmospheric conditions most suitable for insect accumulation.
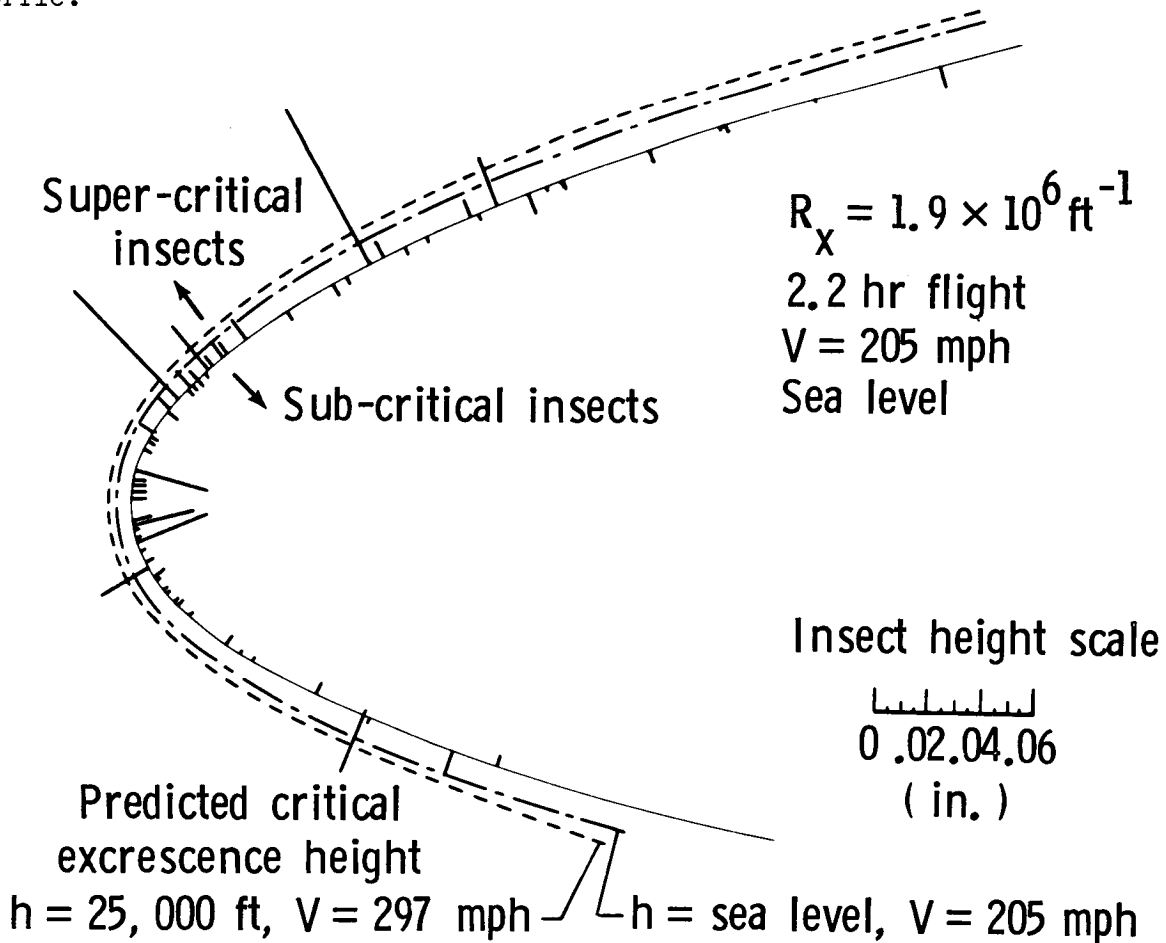
SKYROCKET II NLF FLIGHT EXPERIMENTS

The effect of insect contamination on natural laminar flow (NLF) wings by insect debris is an important consideration in NLF airfoil design as well as in the operation of airplanes with laminar flow wings. In practice, the seriousness of insect debris contamination will likely be dependent on airplane characteristics and mission. During flight tests on the Bellanca Skyrocket (ref. 1), a representative insect debris contamination pattern was accumulated by flying for 2.2 hrs at less than 500 ft above ground level at calibrated airspeed (V_c) equal to 178 knots. Chemical sublimation was used to distinguish between insect strikes that caused transition and those that did not.

This figure depicts the heights and positions of the insects collected along the span of the right wing. Insects that caused transition are denoted as supercritical and those that did not are denoted as subcritical. The figure illustrates that only about 25 percent of the insects collected caused transition at sea level. Analysis shows that at a more typical cruise altitude of 25,000 ft where the boundary layer is thicker, caused by a lower unit Reynolds number, only about 9 percent of the insects would have caused transition. Thus, even though large numbers of insects might be collected on a wing leading edge, relatively few of them can be expected to cause transition at high cruise altitudes. The sample insect contamination data presented here serve to illustrate a certain inherent level of insensitivity of this particular combination of airfoil geometry and operating conditions to insect contamination. It is important to recognize that although sufficient insect contamination can seriously degrade airplane performance, the occurrence of serious contamination levels is infrequent for many combinations of place, time of day, time of year, airfoil geometry, and mission profile.

Super-critical insects

Sub-critical insects

$R_x = 1.9 \times 10^6 \text{ft}^{-1}$

2.2 hr flight

V = 205 mph

Sea level

Insect height scale

0 .02 .04 .06

(in.)

Predicted critical excrescence height

h = 25, 000 ft, V = 297 mph — h = sea level, V = 205 mph

INSECT CONTAMINATION PROTECTION TECHNIQUES

Previous attempts to develop insect contamination protection systems have included mechanical devices (temporary paper covers, scrapers, deflectors), and surface films (solid or quasi-static films which were washed off, adhesive surface coatings, resilient surface or fluid films discharged onto the surface). The figure lists the previous systems tested for insect contamination protection. All of these systems, to some degree, successfully protected surfaces against insect contamination; however, most of these concepts suffered some shortcoming in practicality. Two of the less practical approaches to contamination protection from the past include jettisoned paper coverings (refs. 2 to 4) and mechanical wiping or scraping devices (refs. 3 and 4) which traveled along the wing leading edge after take off. While such devices do work, the drawbacks for commercial applications are obvious.

Past research on leading-edge films and coatings (ref. 5) included quasi-static films, soluble films, and ice coatings. These soluble films provided very effective insect contamination protection in the wind tunnel experiments by Coleman. The principal shortcomings of these concepts are their mechanical complexity and impracticality for most aircraft operational environments. Also, these approaches only provide protection once per flight; after the protective coating has been removed, the airplane must land to have another protective coating applied on the ground. Passive resilient surfaces were suggested by Wortmann (ref. 6) and supported by Carmichael (ref. 7) for contamination protection. Materials for leading-edge coverings included solid rubber, foam rubber, and solid or foam silicone materials. While Wortmann's exploratory results with resilient surfaces were very promising for low speed airplane applications, the poor rain erosion characteristics for the limited number of materials tested appears as a serious drawback to higher speed aircraft applications. Retractable deflectors have been successfully tested in wind tunnel and flight evaluations (refs. 8 and 9). The systems utilized on the current NASA Jetstar laminar flow control (LFC) flight experiments (ref. 10) incorporate the deflector concept and the liquid spray concept.

Previous work on liquid discharge systems includes injection of water and surfactants (wetting agents) onto the leading edge, thereby preventing insect accumulation on the wet surface. Peterson's flight experiments (ref. 8) illustrated that continuous flow of water over the wing leading edge would prevent insect debris from adhering on a wing. However, the significant shortcoming of previous water discharge approaches was that very large volumes of water were required for successful contamination protection.

Among the various insect protection concepts discussed above, the fluid injection approach appears to hold the most promise, provided the required fluid flow rates can be reduced to practical levels. The present paper discusses results of a flight investigation of a porous surface fluid discharge type of system installed on an unswept wing. These flight experiments demonstrated successful insect contamination protection using very small quantities of an ice protection fluid (glycol/water solution).

PAST INSECT CONTAMINATION PROTECTION TECHNIQUES

- Paper covering
- Scrapers, wipers
- Deflectors
- Soluble films
- Resilent surface
- Liquid spray systems
- Porous leading edges

ICE AND INSECT PROTECTION FOR LAMINAR AIRFOILS

Among the various insect protection concepts tested, the fluid injection approach appears to hold the most promise, provided the required fluid flow rates can be reduced to practical levels. In these systems, fluids are discharged onto the test surface creating thin sheets that wet the surface either through slots or through metal skins made porous by election beam or laser beam drilled holes. The holes are about 0.0025 in. in diameter with a spacing of about 0.0205 in. Porous, woven sintered stainless-steel mesh is also a candidate surface material. These porous metal leading-edge concepts are based on the TKS, Ltd. (British) ice protection system (see ref. 9) which has been certified for ice protection on several aircraft using monoethylene glycol (MEG) and water fluid solutions. One of the interesting properties of MEG observed by TKS personnel is that the fluid acts as a solvent for insect body protein content. The drying of this protein content serves as the glue which causes the adhesion of insect debris to impacted surfaces. Therefore, this solvent property of MEG may serve to enhance its effectiveness in insect contamination protection, thus reducing the fluid required to small, practical quantities.

Porous leading-edge fluid system
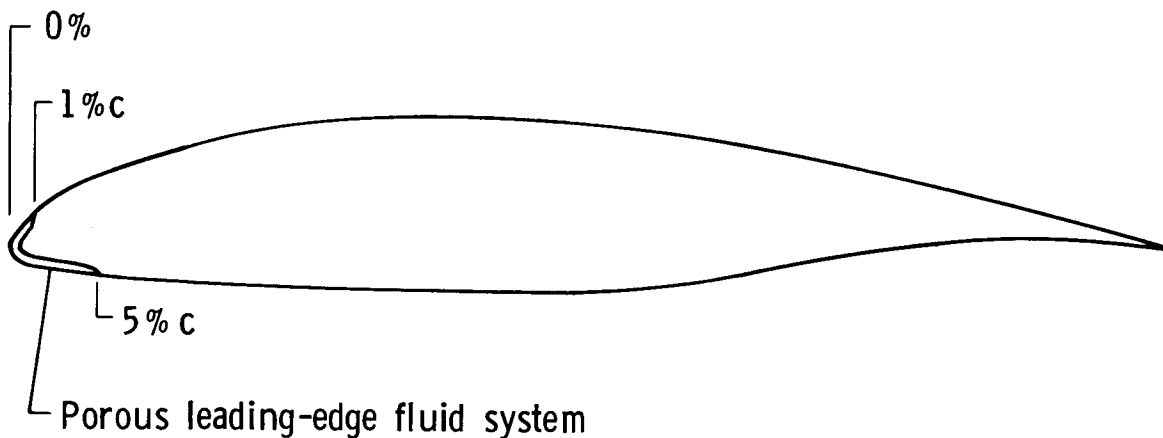
- Electron beam drilled sheet titanium
- Laser beam drilled sheet titanium
- Sintered stainless steel weave

NASA conducted flight experiments to determine insect accumulation rates and protection efficiency under a variety of flight and atmospheric conditions using a Cessna 206 equipped with a TKS porous leading edge as shown in the figure. Test conditions, including location and time of day, were sought which would provide maximum insect population density (insects/million ft^3), thus providing maximum rates of insect accumulation on the test airplane. For these tests, the TKS system was deactivated on all surfaces except the right wing leading edge. The insect protection system effectiveness could then be evaluated by comparing the right, protected wing with the left, unprotected wing, for various flight and atmospheric conditions. Flight durations for these tests ranged from 10 to 50 min.; the airspeed was between 80 and 130 mph and the altitude was 50 ft.
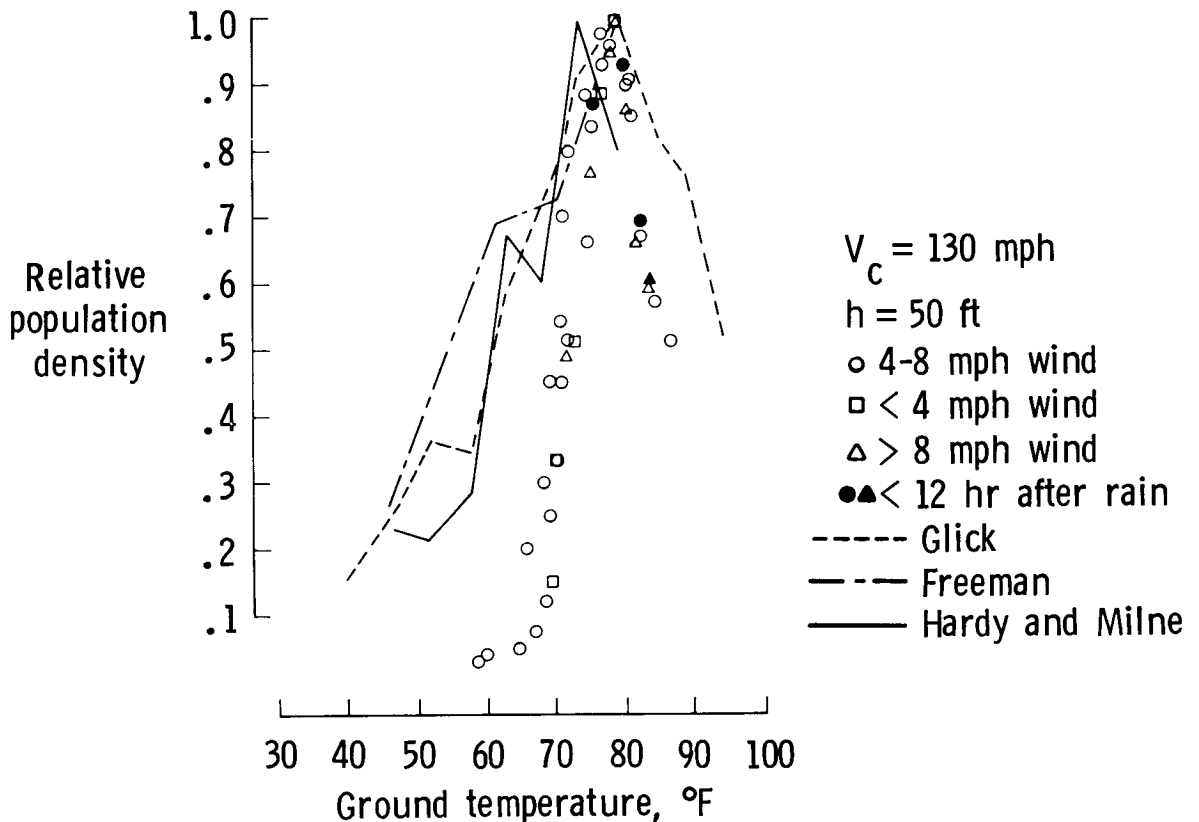

Porous leading edge

FACTORS AFFECTING RATE OF INSECT ACCUMULATION

This figure lists six factors that affect the rate of insect accumulation. Bragg (ref. 11) showed in recent analytical studies that the insect impact pattern is affected by airfoil section geometry. Past research (refs. 12 to 16) has shown that flight conditions such as altitude and airspeed affect the insect accumulation on aircraft. Certain atmospheric conditions such as temperature, wind speed, and humidity or moisture significantly affect the number of insects present. These atmospheric conditions as well as the effect of altitude will be further discussed in this presentation.

- **Airfoil geometry**
- **Altitude**
- **Airspeed**
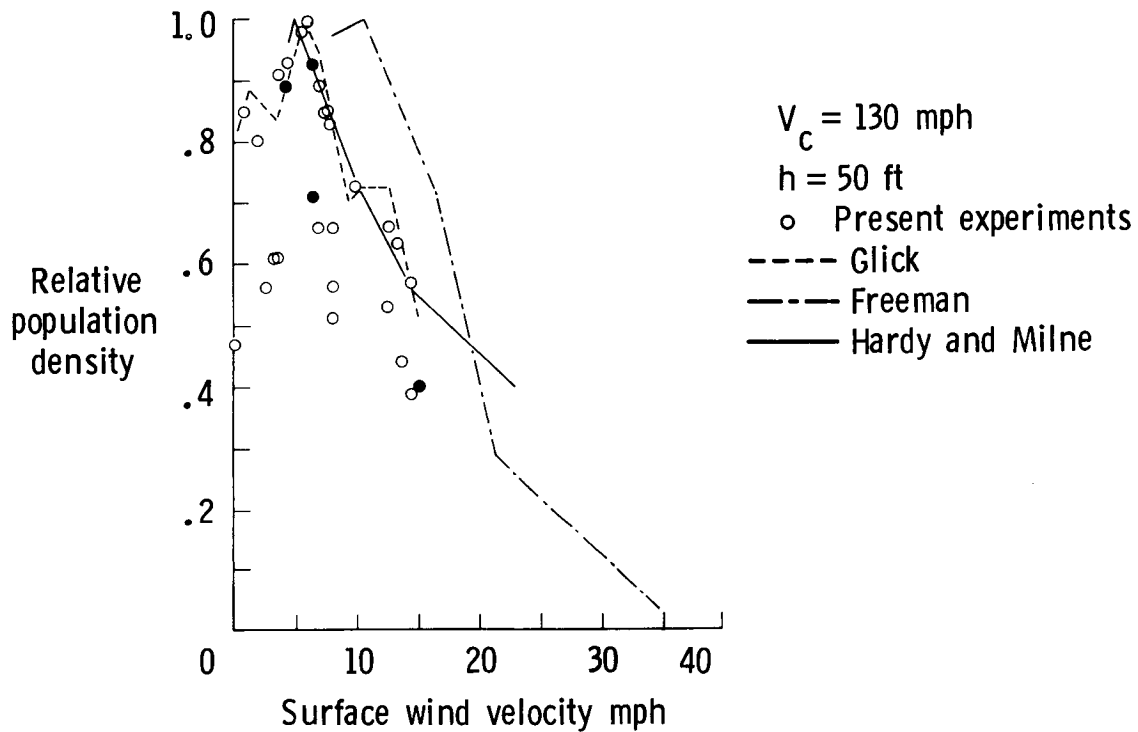- **Temperature**
- **Wind speed**
- **Humidity/moisture**

EFFECT OF TEMPERATURE ON NORMALIZED INSECT POPULATION DENSITY

In this figure, insect accumulation data obtained during the Cessna 206 tests are compared with data from previous insect population studies (refs. 13 to 15). Relative population density is plotted against temperature. The present data were obtained by dividing the number of insects accumulated by the accumulation time, airspeed and exposed frontal area to yield insect population density. The present data are shown in three wind speed categories; data have been normalized to the largest population density value from each category to compare with the previous studies. The data show that insect accumulation rate is strongly dependent on temperature. Accumulation rates steadily increased with increasing temperature up to about 77°F. Above 70°F, the correlation is good between the earlier studies and the present experiments. As the temperature decreases below 70°F, the decrease in relative population density is much less in the earlier studies than for the present tests, but the curves do follow similar trends. The differences may be attributed to variations in the types of insects indigenous to the test areas. Data obtained less than 12 hrs after precipitation show a slight increase in the rate of insect accumulation compared to data points at similar temperatures and wind speeds. Previous researchers concluded that no absolute correlation existed between precipitation and insect accumulation rates. The most important factor is that insect accumulation rates are greatest between 70°F and 80°F with a peak near 77°F.

V_c = 130 mph

h = 50 ft

o 4-8 mph wind

□ < 4 mph wind

△ > 8 mph wind

●▲< 12 hr after rain

----- Glick

— -— Freeman

——— Hardy and Milne

# EFFECT OF WIND VELOCITY ON NORMALIZED INSECT POPULATION DENSITY

This figure compares the effect of wind speed on the Cessna 206 insect accumulation data with data from the earlier studies (refs. 13 to 15). The relative population density is plotted against surface wind speed. For the present experiments, only the data obtained where the temperature is above 72°F were plotted so that the effect of temperature on insect accumulation rate data is minimized. All of the data have been normalized to the largest population density value. Wind speeds from 4 to 8 mph yielded the highest relative population densities with slightly reduced population densities for calm winds. Above 8 mph, the earlier studies and the present data indicate large reductions in population density. Although the present tests offer no data for wind conditions over 15 mph, earlier studies show that insect debris accumulations on airplanes will be significantly reduced for wind speeds above 20 mph.

$V_c = 130$ mph

$h = 50$ ft

o Present experiments

---- Glick

—·—· Freeman

——— Hardy and Milne

Relative population density

Surface wind velocity mph

VERTICAL DISTRIBUTION OF POPULATION DENSITY

The vertical distribution of insects has been well documented and summarized by Coleman (ref. 12). The results are curve-fitted and shown in this figure along with averaged population data obtained in the present tests at altitudes from 50 to 1000 ft. For each flight, the airplane made a quick ascent to the test altitude, flew until a large number of insect strikes were accumulated, and then quickly descended and landed. With this flight test procedure, the majority of the insects collected would be obtained at the test altitude condition.

This figure shows five data points; each data point is an average of all the population density data obtained at that test altitude. The distribution of insects rapidly decreases from ground level to 500 ft. The data suggest that insect protection for laminar flow airplanes is probably not necessary above 500 ft.
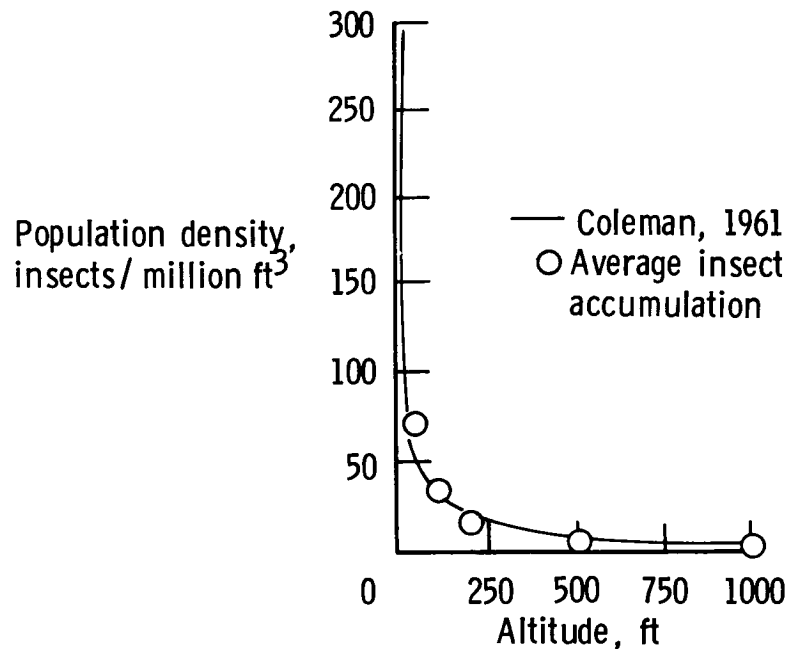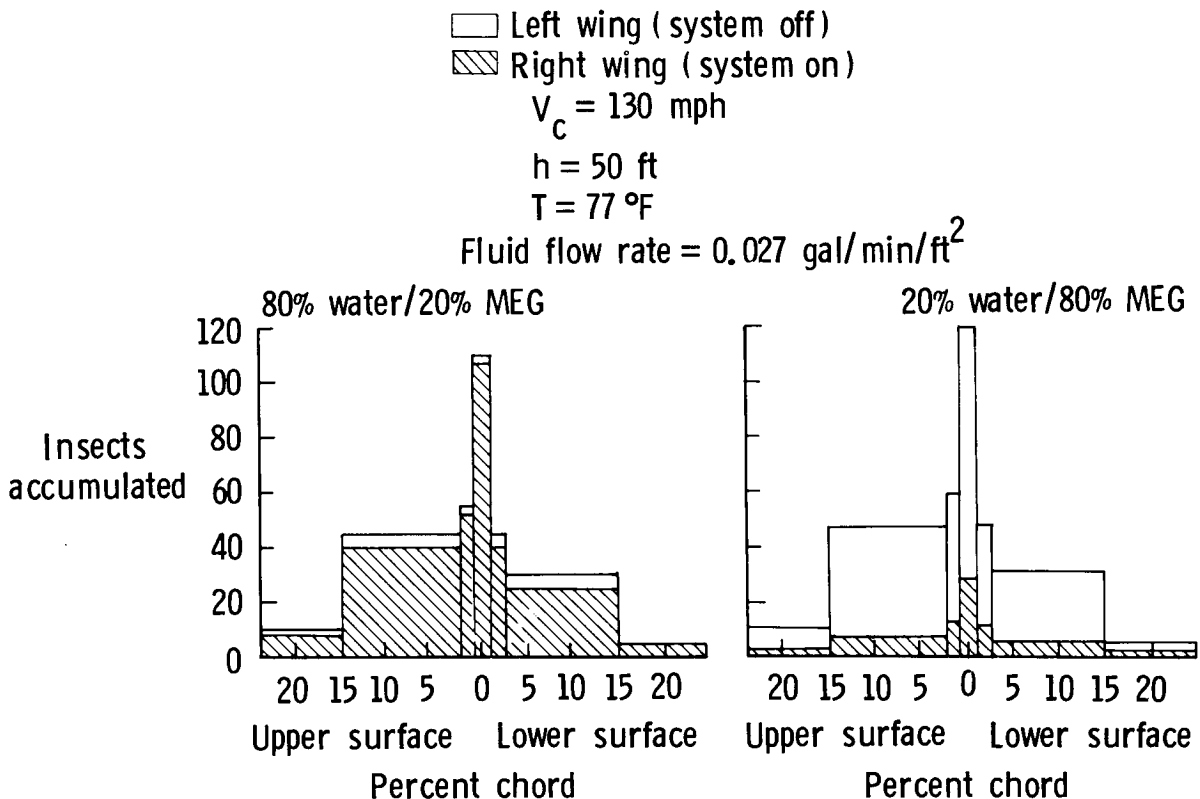
POROUS STAINLESS-STEEL PANELS FOR INSECT PROTECTION

This figure shows a closeup photograph of the porous stainless-steel panels on the Cessna 206. Although designed for ice protection, the TKS system on the Cessna 206 provided effective insect contamination protection. The test airplane was exposed to a high density of insects much longer than in a typical airplane operation environment. The system was not effective in removing insect debris in flight that had been accumulated on a dry surface prior to activating the TKS system. Altitude and airspeed had no effect on the system's ability to protect against insect contamination.
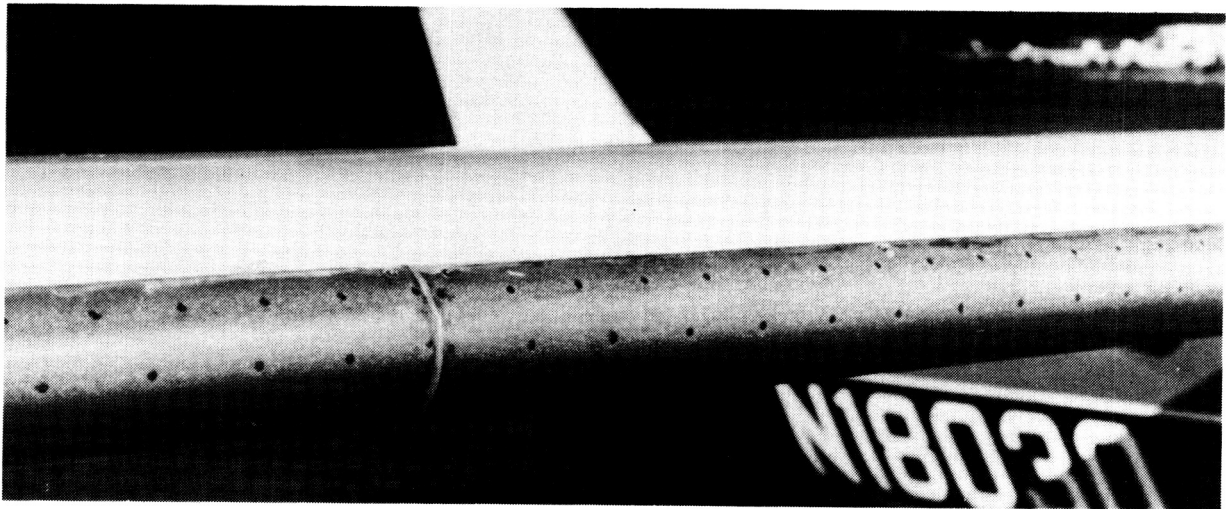
EFFECT OF SOLUTION MIXTURE ON INSECT PROTECTION

The most significant fluid property for successful insect protection was the ratio of water to mono-ethylene glycol (MEG) in the solution. This figure shows insects accumulated versus location on the upper and lower surface shown in percent chord. The shaded region denotes the right wing which had the TKS system activated. Data are shown for solution mixtures of 80 percent water/20 percent MEG and 20 percent water/80 percent MEG. This figure shows that even at the highest flow rate of 0.027 gal/min/ft^2, the system could not effectively prevent insect adhesion with the 20 percent MEG/80 percent water solution; the 80 percent MEG/20 percent water solution, however, was very effective, providing a 75 percent or greater reduction in the number of insect strikes which adhered to the surface. The effective insect protection observed in these tests can be attributed to both the TKS system design and the fluid properties. The porous skin allows a protective film to continually wet the airplane surface using a minimal amount of fluid. Because the MEG fluid acts as a solvent for insect body protein content, the effective insect contamination protection is enhanced, thus reducing the fluid required for protection.

☐ Left wing (system off)

▧ Right wing (system on)

V_c = 130 mph

h = 50 ft

T = 77 °F

Fluid flow rate = 0.027 gal/min/ft^2

FLUID REQUIREMENTS FOR INSECT PROTECTION

The flow rates shown to be effective for insect protection in the porous leading-edge flight experiments (ref. 16) were from 0.013 to 0.027 gal/min/(ft^2 of projected leading-edge frontal area). A typical business jet airplane with a 50-ft wing span and 12-percent thickness-to-chord ratio and average chord of 7 ft would require about 3 in. porous region in the panel. A flow rate of 0.16 to 0.33 gal/min would be required for a 68 to 82 percent reduction in insect accumulation. This is a significant improvement (about 100 fold) over the fluid injection approach tested by Peterson (ref. 8) which required about 24 gal/min for insect protection. It may be possible to further reduce the fluid flow rates required for contamination protection with the addition of a surfactant to the solution. A surfactant would reduce the tendency of the glycol fluid to form beads or rivulets and thus improve surface wetting.

For typical business jet:

0.33 gal/min = 82% reduction in insects accumulated
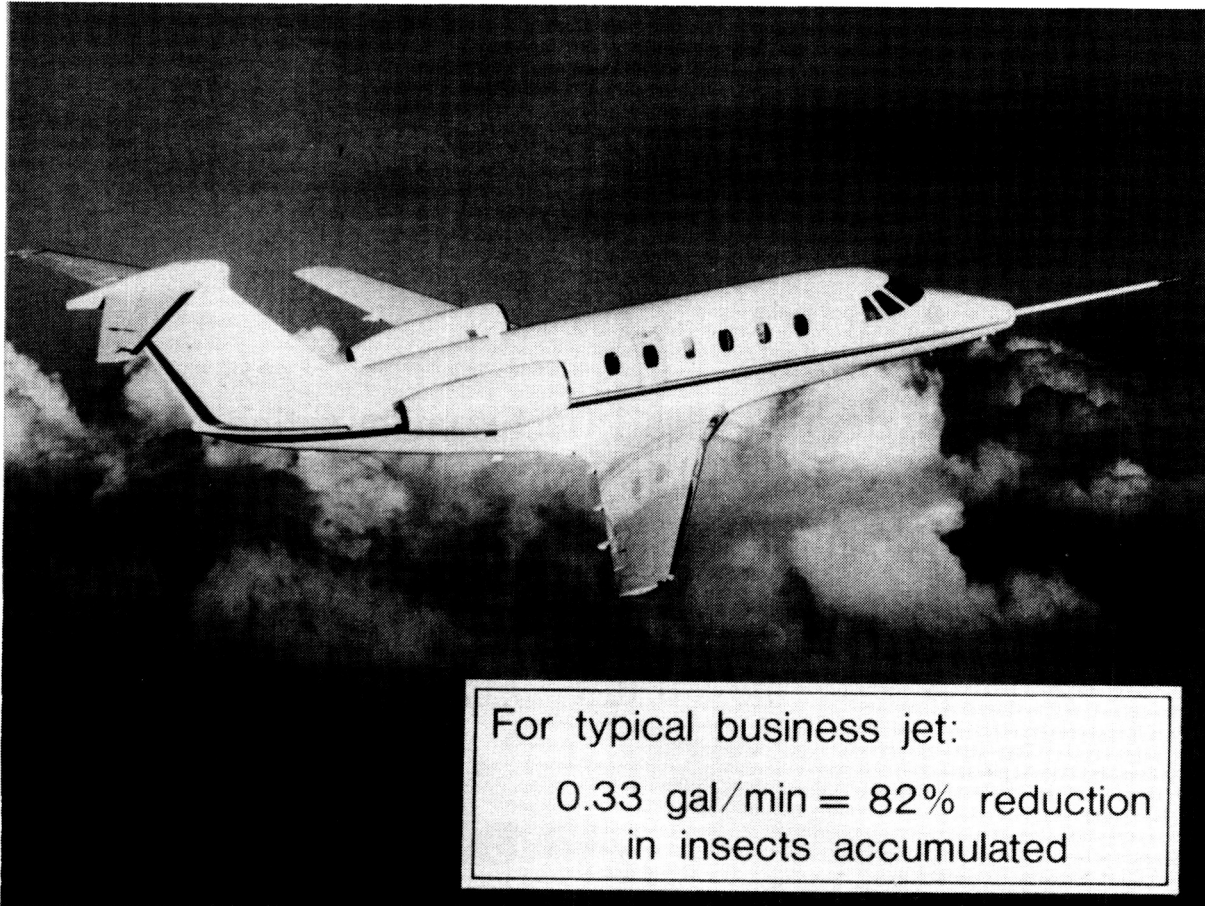
CONCLUSIONS

Previous studies have shown that the seriousness of insect debris contamination will likely be dependent on aircraft characteristics and mission. In many cases, insect debris may be minimized by minimizing airplane flight time in environmental and atmospheric conditions where insect population densities are at a maximum. Flight tests have shown that temperatures from 70°F to 80°F (with a peak near 77°F), wind speeds from 4 to 8 mph, and altitudes below 500 ft yield the highest insect population densities.

When insect contamination cannot be avoided, the porous leading-edge fluid discharge ice protection system has been shown to be an effective insect contamination protection system. Good insect contamination protection can be achieved using a solution of 80 percent MEG and 20 percent water at flow rates between 0.013 and 0.027 gal/min/ft^2 of projected leading-edge frontal area.

- **Maximum insect accumulations for:**
  - **Temperature - 70°F - 80°F**
  - **Wind speed - 4 - 8 mph**
  - **Altitude - < 500 ft**

- **Porous leading edge insect contamination protection is possible with:**
  - **Solution - 80% monethylene glycol/ 20% water**
  - **Flow rate - 0.013 - 0.027 gal/min/ft^2**

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