

FLIGHT INVESTIGATION OF INSECT CONTAMINATION AND ITS ALLEVIATION

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SUMMARY

An investigation of leading-edge contamination by insects was conducted at Dryden Flight Research Center with a JetStar airplane instrumented to detect transition on the outboard leading-edge flap and equipped with a system to spray the leading edge in flight. The results of airline-type flights with the JetStar indicated that insects can contaminate the leading edge during take-off and climbout at large airports in the United States. The results also showed that the insects collected on the leading edges at 180 knots did not erode at cruise conditions for a laminar flow control airplane and caused premature transition of the laminar boundary layer. None of the superslick and hydrophobic surfaces tested showed any significant advantages in alleviating the insect contamination problem. While there may be other solutions to the insect contamination problem, the results of these tests with a spray system showed that a continuous water spray while encountering the insects is effective in preventing insect contamination of the leading edges.

INTRODUCTION

One of the concerns of the designers of a laminar flow control airplane is the possibility that insect remains gathered on the leading edges of the wing during take-off will cause premature transition of the laminar boundary layer during cruise flight. If this occurs, a significant increase in drag could result, possibly negating the fuel savings that laminar flow control can achieve.

Previous insect tests made with a Handley Page "Victor" jet in England (ref. 1) showed that insect remains on the leading edges of the wing were eroded to only one-half their height after a high altitude cruise flight. This erosion of insect remains leads to the possibility that laminar flow might be maintained at the low unit Reynolds numbers obtainable at very high cruising altitudes. Also, experience with an F-94 laminar flow control glove wing indicated that insect contamination was not a problem in flight tests at Edwards Air Force Base at altitudes above 6000 m (20 000 ft). (See ref. 2.) However, the insect population at Edwards Air Force Base is probably much less than in most other areas of the United States.

An examination of the leading edges of jet airplanes based at Langley Research Center before the present flight investigation indicated that insect remains high enough to cause transition at altitudes above 12 000 m (40 000 ft) were present. Whether these insects were picked up during take-off and remained on leading edges during cruise or whether they were only picked up during landing could not be determined, however.

SYMBOLS

C_L	airplane lift coefficient
c	wing chord
h	altitude
k	roughness height
M	Mach number
R_k	roughness Reynolds number, $\frac{u_k k}{\nu}$
s	surface distance from the leading edge
u_k	velocity at top of roughness in laminar boundary layer
x	distance from leading edge along chord
Λ	leading-edge sweep
ν	kinematic viscosity
DFRC	Dryden Flight Research Center
L.E.	leading edge
LFC	laminar flow control

DISCUSSION

In order to investigate the insect contamination problem, a flight experiment was conducted using a JetStar airplane at Dryden Flight Research Center. Four aspects of the problem were investigated: (1) investigate the extent of the insect problem at large airports, (2) if the insects were found to be a problem, determine whether insects would erode during cruise flight to a height below that which causes transition, (3) test the ability of new surfaces like superslick and hydrophobic surfaces to alleviate the problem of insect



contamination, and (4) test a leading-edge spray system to determine how well it would protect the leading edge.

A photograph of the JetStar airplane used in the experiments is shown in figure 1. A view of the left outboard leading-edge flap instrumented for this experiment is shown in figure 2. The instrumented flap covered 230 cm of the leading edge spanwise. Figure 3 shows a close-up photograph of the instrumentation used on the flap. The pitot probes shown in figure 3 were spaced every 5 cm spanwise along the flap.

A cross-section drawing of the leading-edge flap showing the instrumentation and spray system is shown in figure 4. The boundary-layer pitot tubes shown 0.13 cm above the surface were located at the outer edge of the laminar boundary layer on the leading edge so that the thicker turbulent boundary layer would cause a reduction in the pitot pressure measured by these tubes, if transition occurred ahead of the pitot tubes. This reduction in pressure from the reference pitot pressure obtained from the reference probe at 5 cm above the surface was calibrated by test flights with known transition locations so that the location of transition on the insect contamination flights could be determined. The spray nozzle, shown under the leading edge, sprayed the mixture out in front of the leading edge where the airstream blew it back onto the leading edge during take-off and flight. These nozzles were designed especially for these tests to protect the upper surfaces of the leading edge only and would not be satisfactory for an actual laminar flow control airplane since the spray nozzles themselves would cause transition on the lower surfaces. Two spray tubes at different angles were used since the spray was blown back at different angles at the various angles of attack encountered during the take-off run and during flight.

A plan view drawing of the JetStar's outboard wing section indicating the test surfaces is shown in figure 5. Each of the five test areas was 46 cm wide. The first two test areas inboard were superslick Teflon surfaces. The next two were hydrophobic coatings. The first of the hydrophobic coatings is used on the airplane windshields to shed rain and the second is used on radomes to shed rain. The fifth surface was a standard reference surface of aluminum alloy. Also, shown are the boundary-layer pitot tubes on the upper surface and spray nozzles under the leading edge.

The effect of three-dimensional-type roughness on the boundary layer on the leading-edge flap of a JetStar at cruise conditions ($M = 0.70$, $h = 11\ 600$ m (38 000 ft) and $C_L = 0.3$) is shown in figure 6. The curves shown in this figure are based on the criteria for roughness height to cause transition given in reference 3. Roughness heights above the crosshatched area will cause transition and those below the crosshatched area will not cause transition. In the crosshatched area, the shape of the roughness particle determines whether it will cause transition. As shown in figure 6, roughness heights above about 0.023 cm will cause transition on the JetStar leading edge and heights below about 0.008 cm will not cause transition.

In order to determine if insects high enough to cause transition would accumulate on the leading edges of airplanes that take-off at large

airports, the JetStar was flown on 15 airline-type take-offs at the locations shown in figure 7. These flights consisted of a normal take-off and climbout without spraying the leading edge. After reaching a cruise altitude of 11 600 m (38 000 ft), the pitot-tube pressures were recorded at Mach 0.70 and a C_L of 0.3. After landing, the leading-edge test areas were inspected and the location of any insects on the leading edges were recorded and their heights measured with a microscope. Insects were found on all but two of the 15 airline-type flights. The number of insects found ranged from 3 to 17.

A plot of the test results from three of the airline-type flights is shown in figures 8, 9, and 10. These airline-type flights were made from Los Angeles, Sacramento, and San Francisco in November 1977 and all the landings for inspection of the leading edge after the high altitude cruise were made at DRFC. The figures show an outline of the test areas on the leading-edge flap and the location of insects found on the leading edge are indicated by circles. The area of the circles indicates the measured height of the insect as shown by the keys in the figures. Active pitot tubes are indicated along the top line of the flap outline and transition measured at cruise conditions indicated by a crosshatched area ahead of a pitot tube. The distance ahead of the pitot tubes that transition occurred as determined from the measured pitot pressures is represented by the length of the crosshatched area ahead of the pitot tube, but the area of the crosshatched region does not indicate the actual area of turbulent flow, which is generally wedged shaped and may be either larger or smaller than the crosshatched area shown. The exact shape of the area of turbulent flow could not be determined from pitot-tube data since they were spaced too far apart.

As shown in figures 8 and 9, transition was caused by insect remains on the leading edge ahead of one of the pitot tubes on each of these flights. Apparently, then, some means of protecting the leading edges must be used if transition caused by insect remains is to be avoided.

A close-up photograph of an insect splatter before and after a 15-min cruise at 11 600 m (38 000 ft) and $M = 0.75$ is shown in figure 11. The insect was picked up on the Teflon tape surface during low passes over agricultural fields near DRFC at 180 knots. It was located at $s/c \approx 0.015$ and its measured height both before and after the high altitude cruise was 0.018 cm. Both the measured heights and the closeup photographs in figure 11 indicated that no erosion of the insect remains took place during the high altitude cruise. As stated in the introduction, tests with a Handley Page "Victor" jet in England (ref. 1) indicated that insect remains were eroded to about one-half their height after a high altitude cruise. Apparently, the reason for this difference was because the insects were blown against the leading edges of the "Victor" jet at about 50 knots and the wings, legs, and antenna were still intact after impact. The height of the insects was probably reduced when the wings, legs, and antenna were eroded by the high altitude cruise. During the JetStar tests, the insects were impacted at 180 knots and erosion of the wings, legs, and antenna took place immediately and no further erosion took place at cruise conditions.

In order to give the JetStar leading-edge spray system a severe test, the JetStar was flown at low altitudes over agriculture fields near DFRC in an area with a high density of flying insects. The photograph in figure 12 shows the density of insect splatters on the leading edge of the JetStar after a typical series of low passes.

Two of the types of insects found over the fields near DFRC are shown in figure 13. The photograph on the left shows an aphid whose body diameter is about 0.8 mm and the photograph on the right shows a checkered beetle whose body diameter is about 2.3 mm. These insects were collected in a net from a light plane during low passes over the same agriculture field used in the JetStar experiments.

After the low passes with the JetStar were completed, it was landed at Dryden Flight Research Center and the leading edges were examined to determine the location and size of any insect remains on the leading edge. The JetStar was then flown to an altitude of 11 600 m (38 000 ft) and the pitot-tube pressure data were taken at $M = 0.70$ and $C_L = 0.3$. Five types of low pass flights were made with the JetStar to test the spray system:

- (1) No spray
- (2) Water-detergent spray after all low passes
- (3) Large droplet water-detergent spray after each low pass
- (4) Continuous water spray during low passes
- (5) Intermittent water-detergent spray during low passes

The first test was a calibration flight without spray to determine how many insect splatters were encountered during the low passes. As shown in figure 14, many insect splatters accumulated on the leading edge and transition occurred in front of many of the pitot tubes during the high altitude portion of this flight.

Next the spray system was used in an attempt to wash the insects off the leading edges. A photograph of the spray pattern from the spray tubes under the leading edge is shown in figure 15. The body shown in the foreground is the wing-mounted auxiliary fuel tank. The JetStar was in level flight at an altitude of 900 m (3000 ft) and a speed of 180 knots when this photograph was taken. Shown in figure 16 are the results of spraying the leading edge with a water-detergent mixture (0.3 percent liquid detergent) for about 2 min at a rate of 58 kg/min/m^2 of frontal area after all low passes were completed. As can be seen, the spray mixture was not able to wash the insect remains off the leading edge after impact and transition occurred ahead of many of the pitot tubes during the high altitude portion of this flight.

A large droplet water-detergent spray was tried next and the results are shown in figure 17. The spray rate was increased to 205 kg/min/m^2 for about 5 sec after each low pass over the agriculture fields. This larger spray rate was obtained by increasing the diameter of the spray nozzles and blocking off some of them so that only the areas indicated in figure 17 were sprayed. The large droplet spray eliminated some of the insects and reduced the height of the remaining insects in the sprayed areas. Although none of the remaining insects were high enough to cause transition, it is not known whether this

kind of spray would erode larger insects below the critical height. No high altitude portion of this flight was flown.

The results of a continuous water spray is shown in figure 18. Water was sprayed at 24 kg/min/m^2 continuously while encountering the insects during the low passes. No insects were found in the sprayed areas and the boundary layer was laminar ahead of all the pitot tubes during the high altitude portion of the flight. These results show that a continuous water spray was effective in protecting the leading edge from insect contamination. Although the spray system was not optimized for these tests, the analysis of reference 4 showed that the weight penalty of a spray system should be less than 1 percent of the gross weight of an LFC airplane.

In an attempt to use less spray, an intermittent spray during the low passes was tried next. A water-detergent mixture at 29 kg/min/m^2 was sprayed alternately "on" for 2 sec and "off" for 3 sec while encountering insects. The results shown in figure 19 indicate that an intermittent water-detergent spray was unsuccessful since many insect remains were found on the leading edge. No high altitude portion of this flight was flown

CONCLUDING REMARKS

An investigation of the insect contamination problem was conducted at Dryden Flight Research Center with a JetStar airplane instrumented to detect transition on the outboard leading-edge flap and equipped with a system to spray the leading edge in flight. The results of airline-type flights with the JetStar indicated that insects can contaminate the leading edge during take-off and climbout at large airports in the United States. The results also showed that the insects collected on the leading edges at 180 knots did not erode at cruise conditions for a laminar flow control (LFC) airplane and caused premature transition of the laminar boundary layer. None of the super-slick and hydrophobic surfaces tested showed any significant advantages in alleviating the insect contamination problem. The Teflon surfaces, however, were easier to clean after the test flights than either the hydrophobic or aluminum surfaces. Very light pressure while wiping the leading edge with a damp cloth was sufficient to clean the insect remains off the Teflon surface.

While there may be other solutions to the insect contamination problem, the results of these tests with a spray system showed that a continuous water spray while encountering the insects is effective in preventing insect contamination of the leading edges. Although the spray system was not optimized for these tests, an analysis has shown that the weight penalty of a spray system should be less than 1 percent of the gross weight of an LFC airplane

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1. Lachmann, G. V.: Aspects of Insect Contamination in Relation to Laminar Flow Aircraft. C.P. NO. 484, British A.R.C., 1960.
2. Pfenninger, W.; and Groth, E.: Low Drag Boundary Layer Suction Experiments in Flight on a Wing Glove of an F-94A Airplane With Suction Through a Large Number of Fine Slots. Boundary Layer and Flow Control, Volume 2, G. V. Lachmann, ed., Pergamon Press, Inc., 1961, pp. 981-999.
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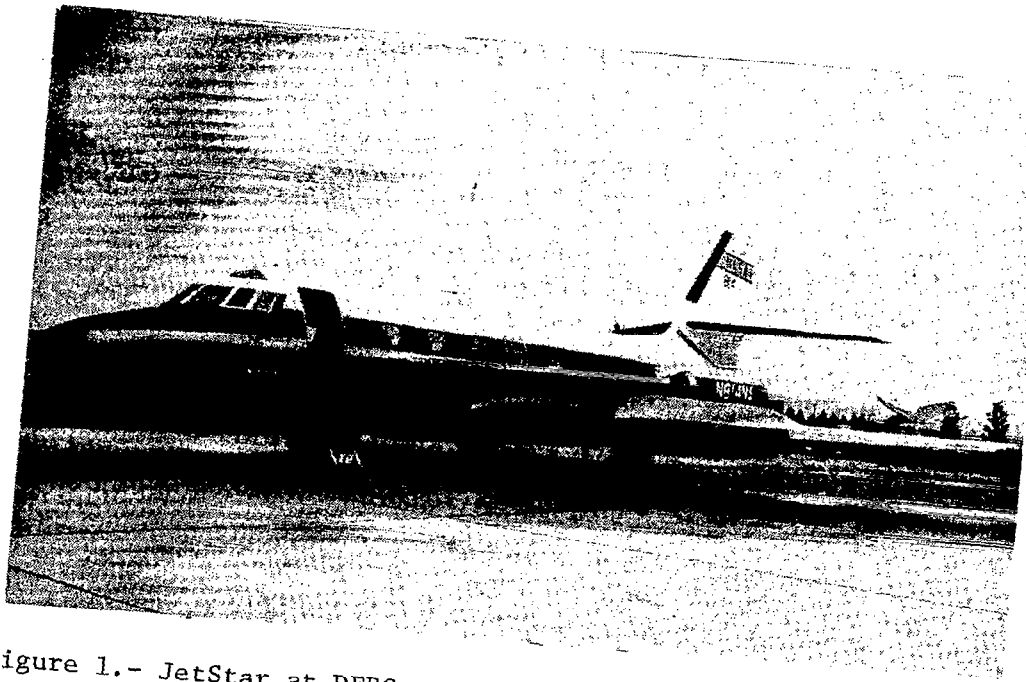


Figure 1.- JetStar at DFRC used in LFC insect contamination study.

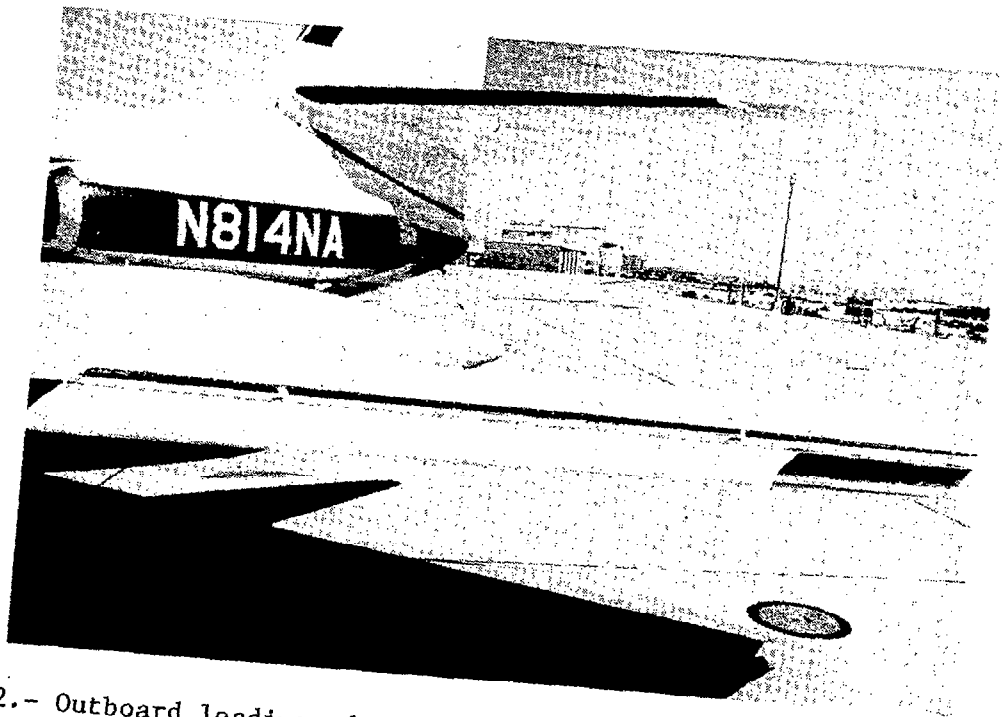


Figure 2.- Outboard leading-edge flap of JetStar instrumented for LFC insect contamination study.

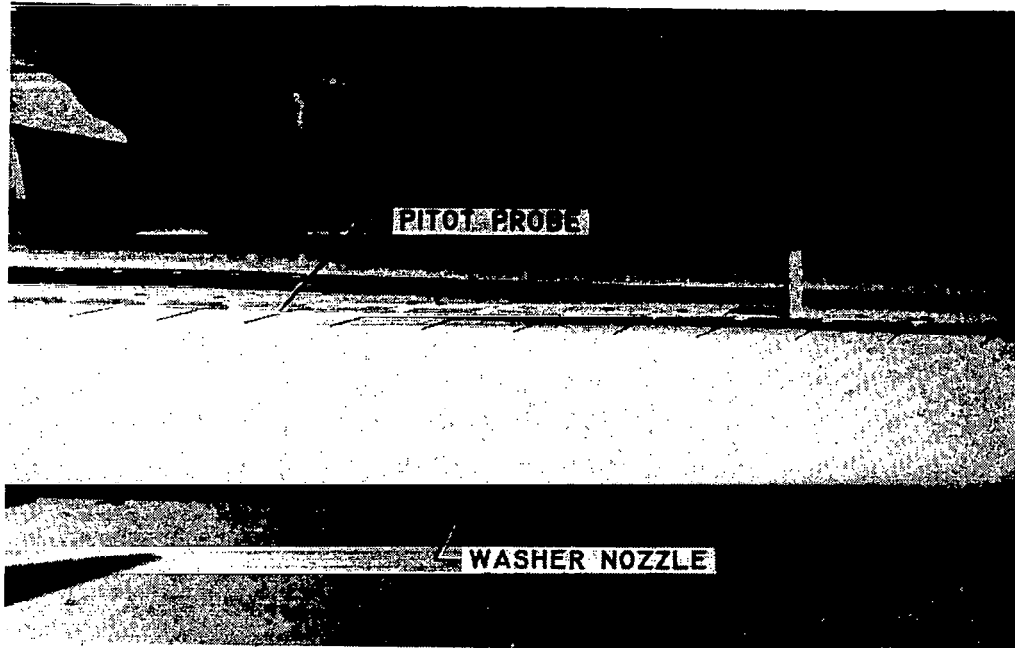


Figure 3.- Leading-edge-flap instrumentation and washer nozzles.

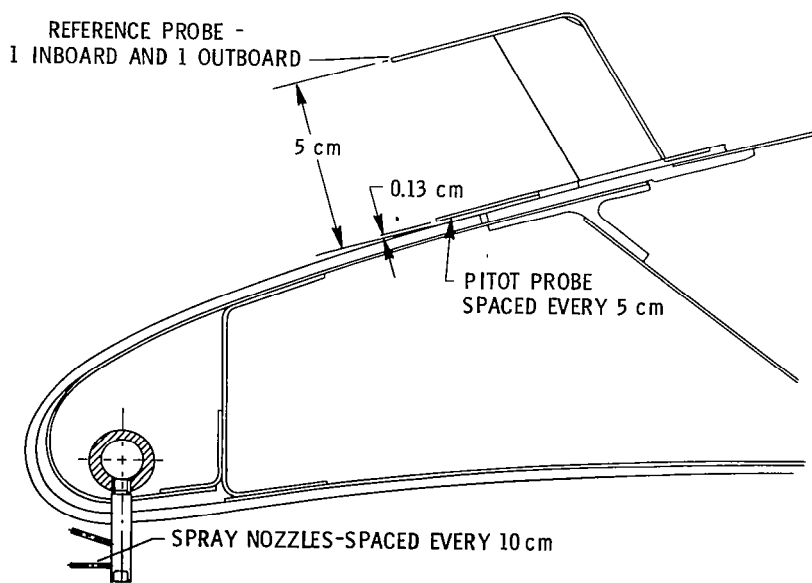


Figure 4.- Cross-section drawing of instrumented leading-edge flap.

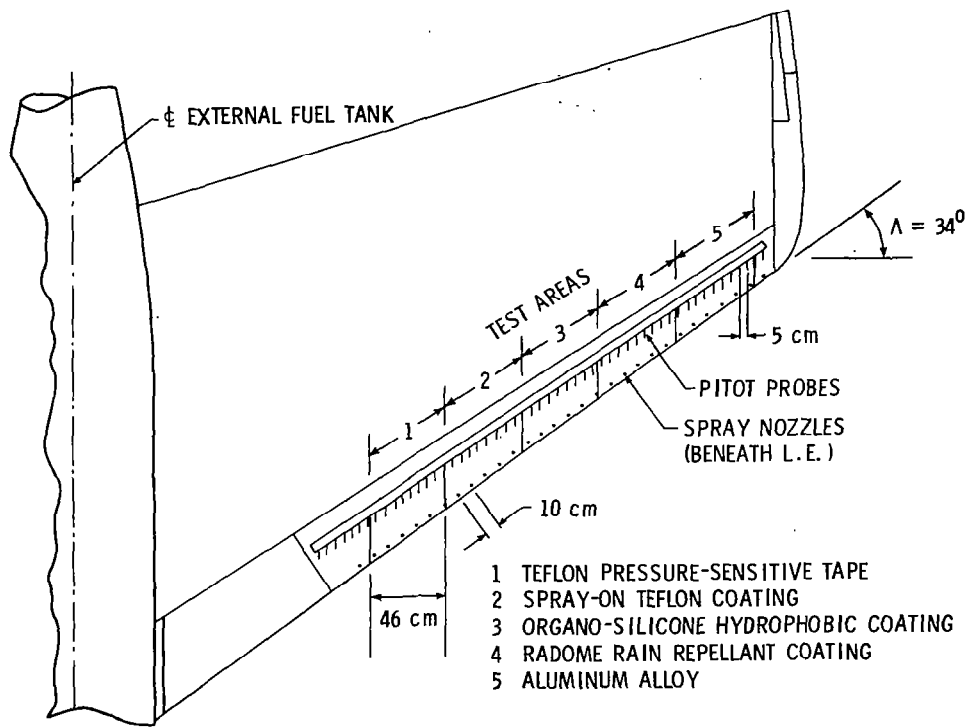


Figure 5.- Plan-view drawing of JetStar outboard wing area.

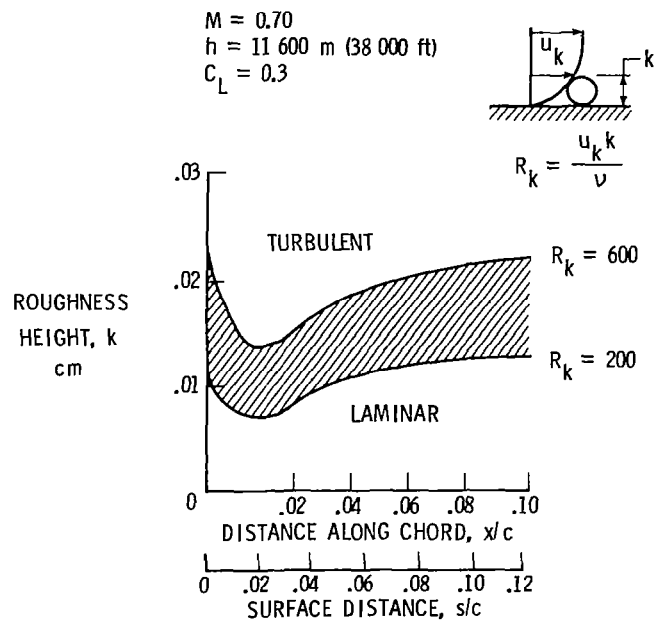


Figure 6.- Effect of three-dimensional roughness on JetStar leading-edge flap.

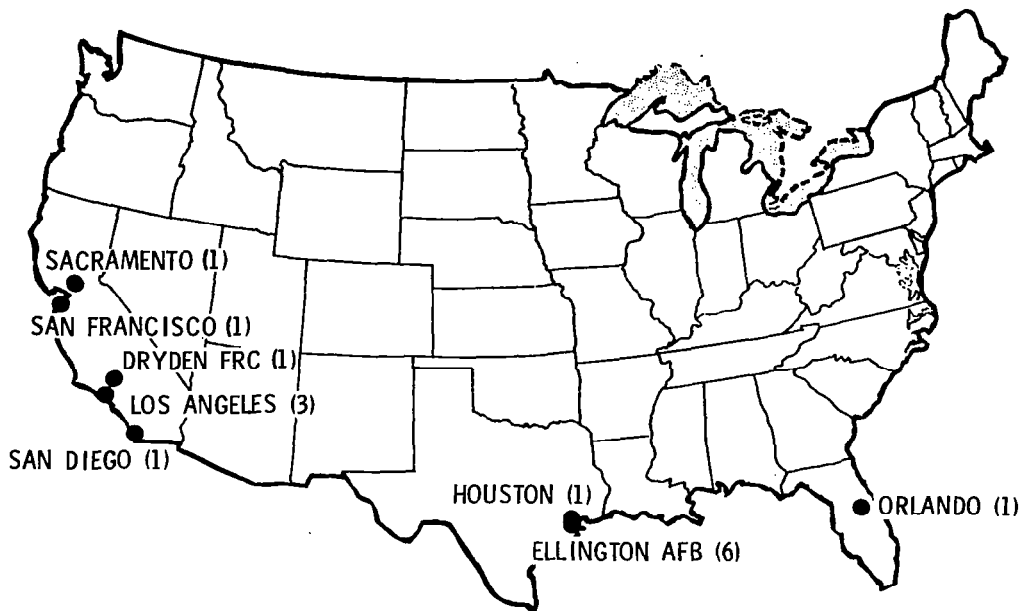


Figure 7.- Location of airline-type flights.

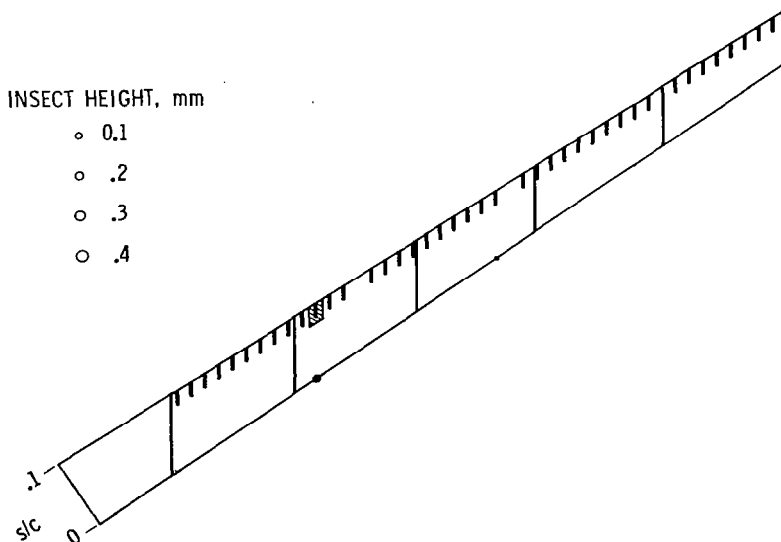


Figure 8.- Diagram of JetStar leading-edge flap showing results of airline-type take-off from Los Angeles International Airport.

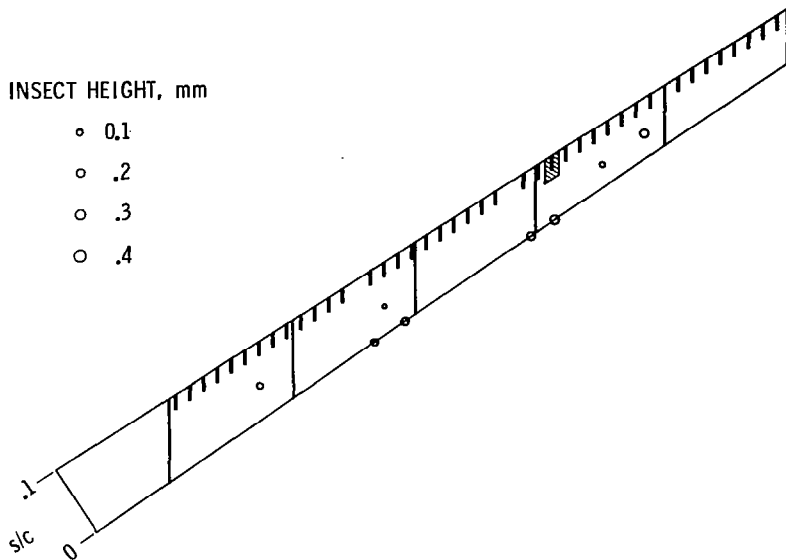


Figure 9.- Diagram of JetStar leading-edge flap showing results of airline-type take-off from Sacramento Metropolitan Airport.

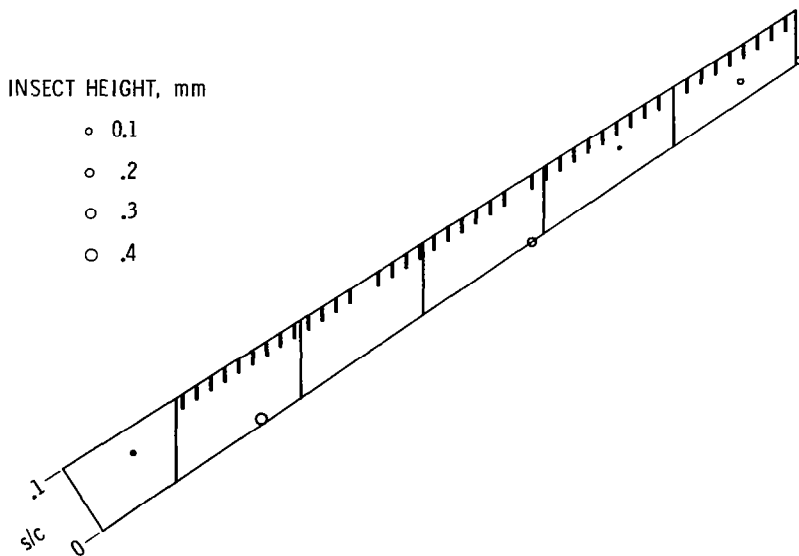


Figure 10.- Diagram of JetStat leading-edge flap showing results of airline-type take-off from San Francisco International Airport.

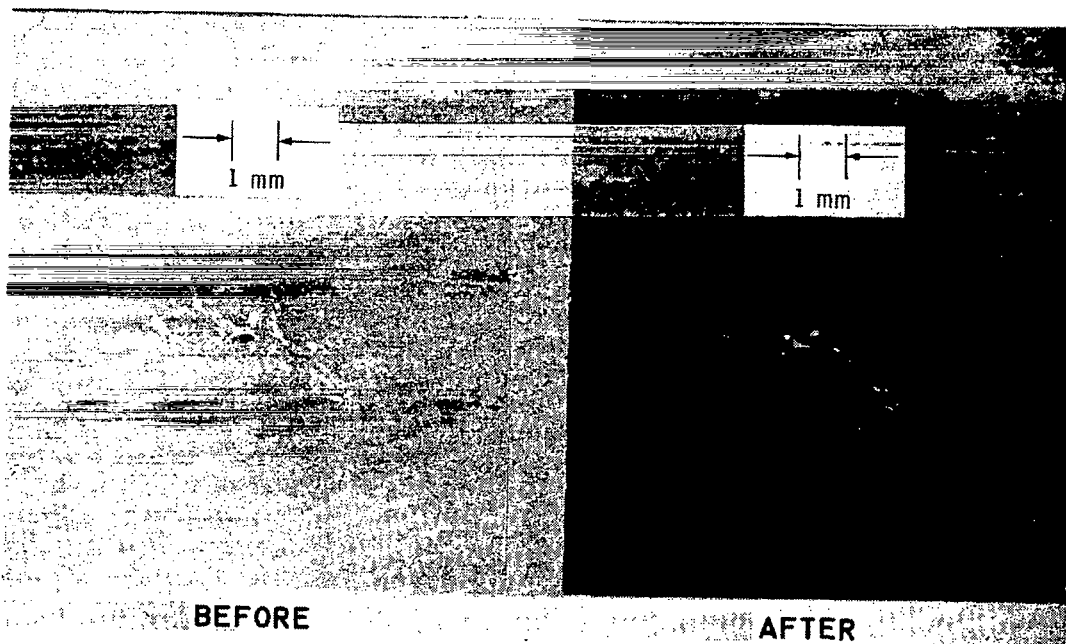


Figure 11.- Erosion of insect splatter by a 15-min cruise at $M = 0.75$ and $h = 11\,600\text{ m}$ (38 000 ft).

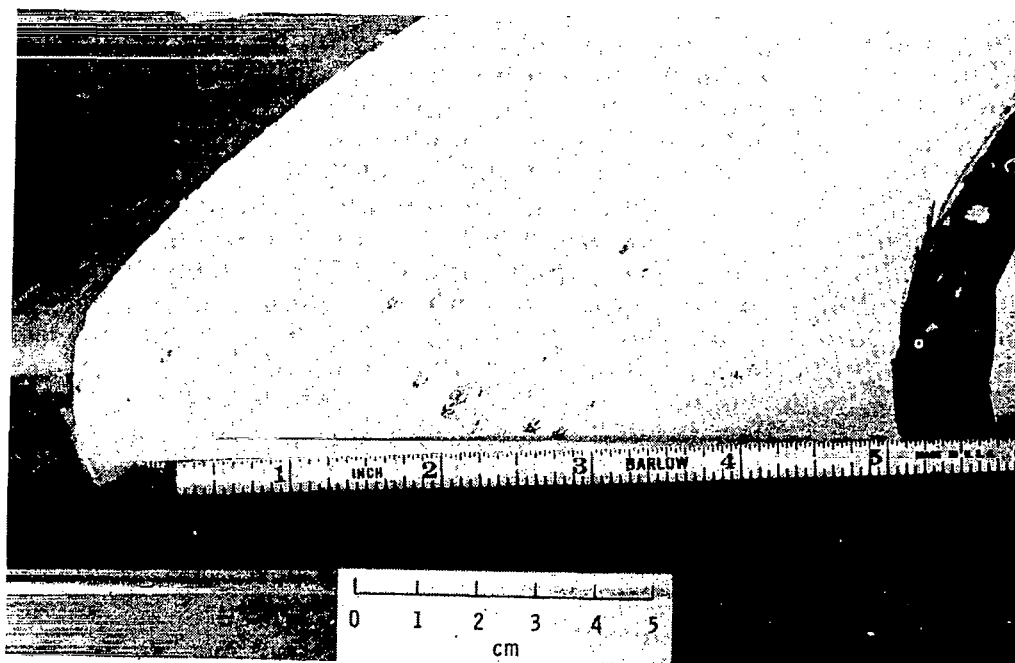
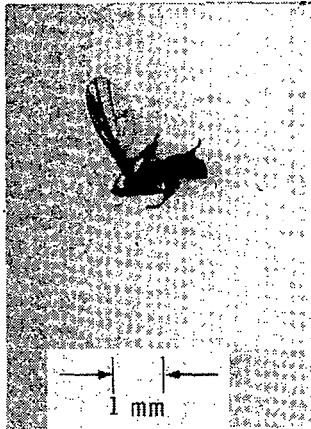
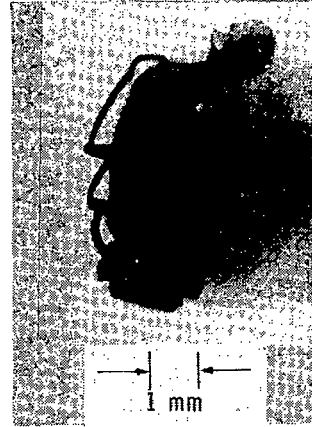


Figure 12.- Insect splatters on leading edge of JetStar after low passes over agriculture fields.



Aphid



Checkered beetle

Figure 13.- Typical insects found over agriculture fields near DFRC.

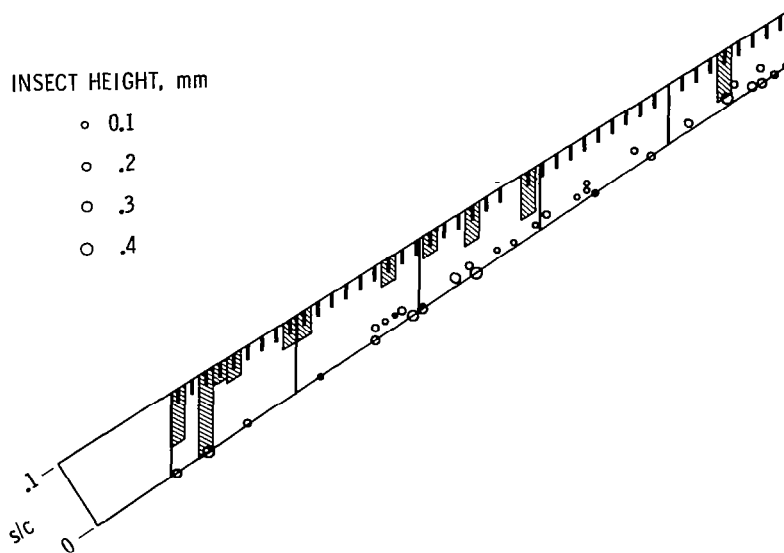


Figure 14.- Diagram of JetStar leading-edge flap showing results of low passes over agriculture fields without leading-edge spray.

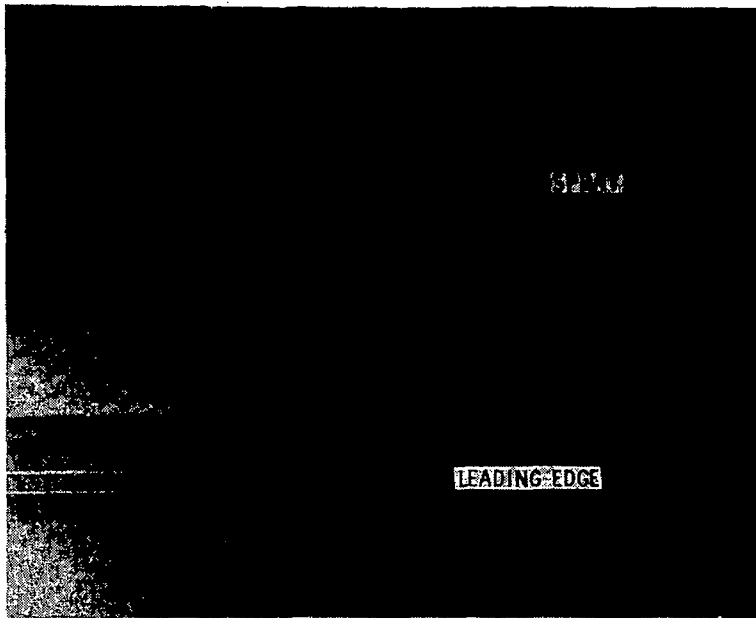


Figure 15.- Spray pattern from spray tubes under the leading edge.

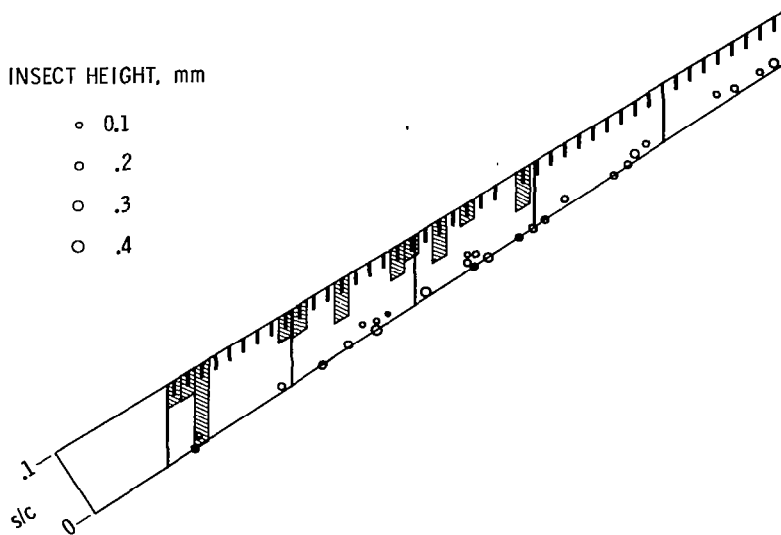


Figure 16.- Diagram of JetStar leading-edge flap showing results of water-detergent mixture spray after all low passes were completed.

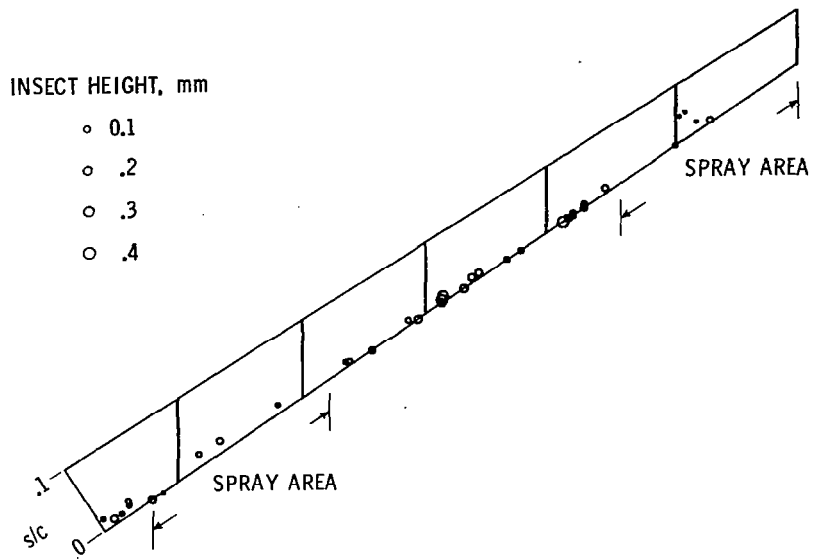


Figure 17.- Diagram of JetStar leading-edge flap showing results of large droplet water-detergent spray after all low passes were completed.

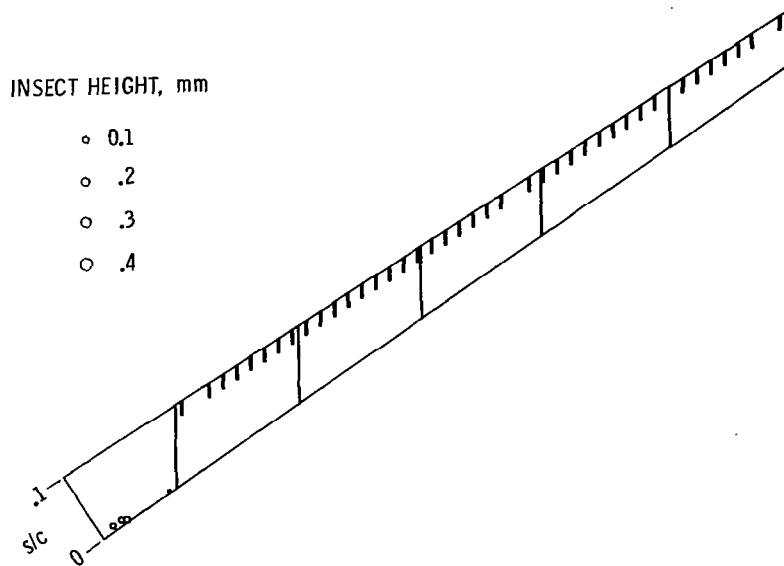


Figure 18.- Diagram of JetStar leading-edge flap showing results of continuous water spray during low passes.



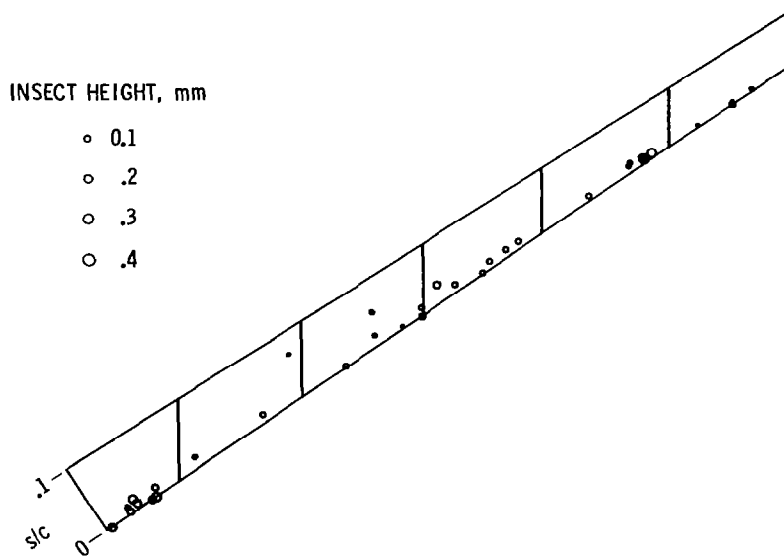


Figure 19.- Diagram of JetStar leading-edge flap showing results of intermittent water-detergent spray during low passes.