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Superseding AIR1102A

Transparent Area Washing Systems for Aircraft

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature

STABILIZED NOTICE

This document has been declared "Stabilized" by the AC-9 Technical Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

FOREWORD

Changes in this revision are format/editorial only.

INTRODUCTION

Windshield and sensor window washing systems generally consist of a fluid application system for removal of insect debris,[1] salt spray, and dust.

Although approximate fluid quantities and flow rates for satisfactory system performance have been established, the design and location of the distribution nozzles will be unique to each new aircraft design. Ground and flight test programs will therefore be required following preliminary design of the system to demonstrate system performance.

1. It has been shown by trajectory analysis and test that it is not feasible to deflect the average flying insect by means of mechanical deflectors or jet blasts.

1. SCOPE:

This information report presents data and recommendations pertaining to the design and development of transparent area washing systems for aircraft.

2. REFERENCES:

1. AS580A, "Pilot Visibility from the Flight Deck Design Objectives for Commercial Transport Aircraft," Society of Automotive Engineers Aerospace Standard, Revised 1 October 1968.

2. U.S. Department of Agriculture Technical Bulletins:

   TB 1158, Collecting Insects by Airplane in Southern Texas, P. A. Glick, February 1957.

   TB 1222, Collecting Insects by Airplane with Special Reference to Dispersal of the Potato Leafhopper, P. A. Glick, April 1960.

   TB 1255, Airborne Movement of the Pink Bollworm and Other Arthropods, P. A. Glick and L. W. Noble, November 1961.

3. MIL-E-38453A (USAF), dated 2 December 1971. "Environmental Control, Environmental Protection, and Engine Bleed Air Systems, Aircraft, General Specification for."

4. ASTM D 1141-52, "Standard Specification for Substitute Ocean Water," Reapproved 1971.

5. H. R. Meline, D. H. Anderson, E. A. Nelson, "Salt Spray Deposit Removal System," Research Incorporated, Hopkins, Minn., under Navy Contract NOas 59-6025-C, Progress Reports No. P4051-1 through P4051-5, Dated January through May 1959.

6. J. D. Booker, E. Evans, "Flight Trials of a System for Clearing Insect Debris From an Aircraft Windscreen," Royal Aircraft Establishment Technical Report No. 66013, January 1966.

7. A. C. Durson, "Exterior Windshield Clearing Test," General Dynamics/Convair, Report RT-63-038, Dated 14 September 1964 (F-111 test).

8. MIL-I-18259 (Aer) dated 26 October 1954, "Installation of Window Anti-icing, De-greasing, and Washing Systems, General Specification for."

9. R. Celniker, "Analysis of Results of Windshield Washing and Rain Removal Development Test Program, B-1 Air Vehicle," B-1 Division, Rockwell International Corporation, Report NA-72-606, 31 July 1972.

3. SYSTEM REQUIREMENTS:

3.1 Area To Be Cleared:

Washing of the windshield panels need be provided only for those panels directly forward of the pilot and copilot. Washing systems should provide a minimum clear area satisfactory for the mission requirements of the specific aircraft. AS580 (reference 1) as it applies to precipitation clearing may be used as a guide.

Washed areas of sensor windows are determined by the geometry of the sensor scanning requirements.

3.2 Operational Envelope:

The system should function in all normal aircraft attitudes at low altitude for all speeds up to a limit defined by vision limitations. For commercial aircraft, FAR 25.103 states an airspeed of 1.6 V_{stall}. Specific aircraft operational requirements may require adequate washing action also be provided while the aircraft is parked on the ramp and during taxi.

3.3 Types and Intensity of Contaminants:

3.3.1 In general there are very little data available to establish specific design requirements for the intensity of contaminant to be removed. It is recommended that during development testing conservative simulations of the contaminant in question be used.

3.3.2 With regard to insects, reference 2 provides some background information indicating that the average density is one insect per 5000 ft^3 (141.6 m^3) between 200 and 500 ft (approximately 60 and 150 m) above the ground, although certain insects, such as locust swarms, can exist at much higher altitudes. Only 25% of the insects are of the type which will create appreciable residue on the windshield, and include bees, wasps, moths, beetles, and hoppers. Paragraph 3.1.2.5 of MIL-E-38453A (reference 3) states: "The system performance shall be based on encountering insects of honeybee size (120 mg) at a concentration of one per 20,000 ft^3 (566 m^3)". The larger insects, such as the honeybee, are expected to make smears of 1 to 2 $inches^2$ (approximately 6.5 to 13 cm^2) per strike in an elongated pattern consisting wholly of the viscera. Tests have shown that exoskeletons do not remain on the windshield.

Freshly killed and frozen flies and bees have been used to reproduce the insect problem both by inducing them into the ground test facility air stream or by squashing them directly onto the windshield just prior to testing. One technique is to use a small diameter blow gun using high pressure air at one end.

3.3.3 Salt spray has been a problem for aircraft flying over sea water at altitudes below 500 ft (152.4 m). Rare cases of salt spray reaching an altitude of 2000 ft (609.6 m) have been reported.

Simulation of salt accumulation for system development purposes has been accomplished by spraying several coatings of ocean water or a substitute on the test article until a heavy coating is built up. ASTM specification D 1141-52 (reference 4) defines a simulation of average ocean water.

Reference 5 provides more background on salt spray removal.

3.4 Visibility:

There is no quantitative description, measure, or definition of the degree of washing effectiveness which permits “adequate visibility”. Therefore, opinion as to the adequacy of a particular washing system will vary with various pilots and observers. Preliminary test data, using fine images in the background (newsprint), and using pilots for opinion, have shown that about 30% of the forward windshield area may be covered with insect smears before washing is essential for landing. Laboratory tests with bee smears and a background scene have shown that about 30 to 50 bees per ft^2 (320 to 535 bees per m^2) may be tolerated before washing is essential, provided the pilot is not looking toward the sun. Sunlight destroys viewing of distant objects by intense lighting of insect smears.

Photographic documentation is of general value as a record for comparison of laboratory and flight experience. However, it is limited for direct evaluation since viewing through a windshield by a pilot involves dynamic three-dimensional color vision.

4. SYSTEM DESIGN CONSIDERATIONS:

4.1 Washing Principles:

The principles of washing are not completely understood. However, the following observations are presented as background information.

a. The washing fluid flows on to the contaminant and diffuses into the material, thus softening, dissolving, and weakening its structure and adherence characteristics.

b. The airstream carries the washing liquid over the surface at a velocity determined by surface drag. The liquid is believed to flow along with the surface streamlines except where initial impingement forces or gravity forces determine otherwise. The drag or scrubbing effect ultimately overcomes the adherence forces and removes the dissolved or softened contaminant from the surface. Tests prove that higher air velocities will increase the fluid drag forces resulting in easier removal. Washing has been successfully accomplished at airspeeds up to 650 mph (290 m/s) (reference 9). The additional scrubbing imposed by a windshield wiper is more effective than airstream effects alone at low airspeeds.

4.1 (Continued):

c. Diffusion and softening of insect smears is enhanced by temperature, thus injecting washing fluid at 140° - 180 °F (60° - 82 °C) results in easier removal, especially at the lower airspeeds.

d. Evaporation of the washing fluid will take place resulting in loss of fluid temperature and reduction of process effectiveness at distances over about 25 inches (63.5 cm) from the washing fluid nozzles.

e. Fluid flow tends to break into rivulets, especially when rain repellents have been applied to the windshield prior to washing, tending to reduce washing effectiveness. This is offset, however, by the fact that rain repellent has a slight benefit in the removal of insect smears.

4.2 Fluids:

Work done in England (reference 6) indicates that the best washing action for the removal of insect bodies is obtained with a solution of approximately 99.8% distilled or deionized water and 0.2% low-foaming, non-ionic, liquid detergent. This solution has been shown to work satisfactorily in flight without the use of wipers, although a light white film is left on the window due to the detergent. This film, however, does not appear to seriously affect visibility. Detergents used in the tests of reference 9 did not leave a residue.

Anti-freeze agents seriously degrade washing effectiveness of the solution with respect to insect residue in direct proportion to the reduction in freezing point. Wind tunnel tests (reference 7 and 9) using wash solutions of 50 - 70% ethyl alcohol in water showed that insect removal was incomplete in all tests, even after repeated wash cycles. This is believed to be due to the poor solubility of insect viscera in alcohol as compared with water and to the higher evaporation rates of alcohol and corresponding reduction in fluid and surface temperature. The wash solution does, however, remove the lighter residue or splatter between the thicker accumulations with resultant good visibility between the spots. A system trade-off is required with respect to the additional system complexity and fluid weight required to assure prevention of freezing of the 99.8% water solution as opposed to the degradation of washing effectiveness and increased volume of a reduced freezing point solution.

On those installations where a windshield wiper can be used in conjunction with the fluid, the overall effectiveness may not suffer with the reduced freezing point solution. No comparative tests are available for this combination.

For salt spray removal a mixture of 50% water and 50% alcohol has worked satisfactorily on several aircraft. Salt removal requires considerably less fluid for removal due to its higher solubility in water. Reference 5 discusses test work that supports this.

Other fluids that are considered either for their anti-freeze effect, nonflammability, or as specific contaminant solvents must be carefully examined as to their compatibility with aircraft materials which may be contacted by the fluids. The possibility of ingesting the overflow into ram scoops should also be considered.

4.2 (Continued):

Candidate fluids should be reviewed for any tendency to leave slow evaporating solvent or detergent residues that may build up with repeated applications resulting in impairment of visibility or restriction of lines and nozzles.

4.3 Quantity of Fluid:

For systems including insect removal as a requirement, the quantity of fluid found satisfactory falls in the range of 0.04 to 0.12 gal/inch (approximately 0.06 to 0.18 l/cm) of windshield base to be cleared per application. The derivation of flow requirements from laboratory or flight test may be referenced either to gal/inch (l/cm) of windshield base per application or to gal/in^2 (l/cm^2) of window coverage per application. No principle or empirical evidence exists at this time which would positively establish the correct reference. Since most systems apply an excess flow to allow for distribution irregularities and other unknowns, the windows are usually fully wetted over their entire length, thus the gal/inch (l/cm) of base criteria is currently recommended for extrapolation from laboratory tests or from one aircraft to another.

For systems where salt deposit removal is the prime consideration values as low as 0.003 gal/inch (approximately 0.045 l/cm) of windshield base per application have been used successfully. This covers the range of application rates used on known systems.

The quantity of fluid must be verified by development work on each new configuration. This quantity multiplied by the number of applications desired between system refills will give the capacity of the system reservoir.

Quantity of fluid and application time must be kept to a minimum due to obscuring of vision during application and to minimize the weight of fluid and reservoir size. An excess flow of washing fluid is generally required to allow for evaporation, distribution difficulties, and rivulet flow. Automatic timing of the washer fluid application is recommended to reduce the total volume of fluid required by minimizing excess usage.

4.4 Methods of Application:

4.4.1 Distribution: The fluid should be applied to the windshield or window from one or more nozzles located in such a manner that the airstream will carry the fluid over the critical vision areas.

If flight application without the aid of wipers is the primary consideration, a spray tube or several nozzles spaced along the base of the windshield to cover the approximate width of area to be cleared are recommended. Since the fluid will follow the streamlines, fluid may have to be introduced along the center post as well as along the base in order that the desired area is covered with fluid. Surface streamlines may be obtained in a wind tunnel using scale models and oil injections at nozzle locations as an aid to determining flow direction. Injection of fluid into the airstream at an angle will result in fluid trajectories quickly conforming with airflow direction, thus aiming at a high spot on the windshield is not effective.

If static ground operation in conjunction with windshield wipers is the primary consideration, a three-hole nozzle configuration may be considered, with one hole aimed at the center of the wiper area, one aimed “high”, and one aimed “low”. Small angular tolerances are required to ensure that the fluid streams will hit in the wiper area during system ground operation. Hole angles become less critical in flight, because the airstream helps to carry and distribute the fluid. To reduce criticality of nozzle hole angles, the height of the nozzle above the plane of the windshield can be increased. However, the drag penalty and weight of the nozzle go up rapidly as the nozzle height increases.

The system should be designed so that only one windshield or window panel is washed at a time, since forward vision is temporarily obscured during the washing cycle. This also provides an added measure of redundancy in case of failure of one side.

Washing systems should not share lines or nozzle holes with rain repellent systems, due to differences in required nozzle configurations, and incompatibility of the two fluids. Further research effort may produce a fluid which will accomplish both functions, eliminating the need for separate systems. Water/alcohol windshield anti-icing may possibly be used also as a washing system for salt removal due to similarity of fluid composition and flow rates.

A means for purging the distribution lines may be required for some systems to prevent clogging and/or freezing of the fluid in the lines.

4.4.2 Methods for Fluid Expulsion: A positive displacement pump or pressurized reservoir may be used for propelling the fluid.

The pressurized reservoir requires a source of pressure such as engine bleed air. A simple on-off valve can be used to control the fluid flow. Composite units that regulate reservoir pressure, provide for venting the reservoir to ambient pressure when the system is shut off, and provide an overpressure relief valve have been developed. Nominal reservoir pressures of 10 to 30 psig (70 to 205 kPa) are satisfactory and provides protection against boiling at altitude.

4.5 General Design and System Installation Recommendations:

The design of the reservoir installation should take into account accessibility for ease of filling.

The need for quantity gauging as opposed to routine pre-flight “topping-off” of the reservoir should be evaluated based on customer needs and procedures. Both approaches have been used.

The design of the system should be such that there will be no loss of fluid during flight maneuvers or after the washing system is turned off. The use of water requires heating, drain, and surge provisions to prevent frozen water from clogging lines and valves and bursting lines and the reservoir. Reservoirs must be designed to include anti-burst and ice melting provisions. Ice melting is required where reservoirs are not emptied between flights.

Reference 8 covers general requirements for the design and installation of washing systems.

4.6 Development:

It is recommended that laboratory ground tests (see 5.1) be performed on the specific configuration in question to determine the most suitable nozzle configuration and the minimum amount of fluid required per application to provide the desired cleansing effect. If water is used, testing should include freezing situations to verify non-breakage of lines and reservoirs, and suitable ice melting and cold-weather filling capabilities.

5. TESTING AND DEMONSTRATION:

5.1 Ground Tests:

The prototype system can be tested in a static test rig. If inflight application of fluid is a system requirement, the testing can be accomplished using the test rig in conjunction with a wind machine. The testing should include a survey of system effectiveness throughout the operating envelope and an appraisal of visibility deterioration during and after the washing operation. This type of test rig can also be used to evaluate different fluids, various nozzle configurations, and quantity of fluid required per wash cycle. Tests at velocities as high as 650 mph (290 m/s) have been accomplished successfully with ground test rigs (see reference 9).

5.2 Flight Tests:

Adequacy of windshield and sensor window coverage and washing effectiveness should be evaluated over the applicable speed and altitude envelope. Because of the limited supply of fluid which can be carried aboard an aircraft, it may be necessary to determine the quantity required to accomplish satisfactory cleaning during the specified flight duration. Other aspects of system installation and operation which should be checked during the flight test phase are location and number of nozzles, corrosion of adjacent skin panels, residues of cleaning fluid on the windshield, satisfactory functioning of fluid quantity indicators, plugging of lines or nozzles due to sludge or residue, ease of replenishing fluid, and the effects of spillage on other aircraft components.

5.3 Demonstration:

The development test rig has been used successfully to reach agreement on the adequacy of a given windshield or window washing system. Once agreement is reached on the performance of the system on the test rig, a correlation of this performance to that under operational conditions in flight can be limited to fluid flow pattern and quantity of fluid applied per application.

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