SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.
485 LEXINGTON AVENUE
NEW YORK 17, N.Y.

AEROSPACE INFORMATION REPORT

AIR 805

JET BLAST WINDSHIELD RAIN REMOVAL SYSTEMS FOR AIRCRAFT

Issued 2-1-64
Revised

1. INTRODUCTION:

1.1 The purpose of this information report is to present factors which affect the design and development of jet blast windshield rain removal systems for aircraft. A satisfactory analytical approach to the design of these systems has not yet been developed. Although detailed performance data are available for some test configurations, rain removal systems will generally be unique to specific aircraft. This then requires a preliminary design for the system based on available empirical data to be followed with an extensive laboratory development program. Development work now in progress on advanced military and commercial aircraft will undoubtedly add to or supersede the present data, and possibly form a basis for analytical solutions. Revisions to this report will be made as significant new information becomes available.

1.2 The general design objectives as to areas cleared and flight velocities are based on FAA Civil Air Regulation Part 4b (Reference 1). Rain intensities are also specified, based on U. S. Weather Bureau classifications and textbook data. Any rain removal system for a transport aircraft is a compromise involving efficiency of rain removal under all operating conditions, cost, weight, effect on airplane performance, on operating procedures, reliability, and maintenance.

1.3 Design data on nozzle configuration, air flow, glass and interlayer temperatures are necessarily general, as the rain removal system will be unique to each aircraft.

1.4 Laboratory tests with simulated rain and air at flight velocity are the most effective developmental tools for assuring an adequate system. Detailed information on laboratory testing is available in WADC Technical Report 58-444, "Design Manual for Windshield Jet Air Blast Rain and Ice Removal" (Reference 2).

2. DESIGN OBJECTIVES:

2.1 Rain clearing shall be provided for the windshield panels directly forward of the pilot and co-pilot. The system shall maintain that portion of the windshield clear such that each pilot has adequate vision along the flight path in all normal aircraft attitudes for speeds up to 1.6 V_{stall} (Vs_1) Per CAR 4b.351.

2.2 Rain clearing shall be required for all rain intensities up to that classified as "heavy" rain. Heavy rain is defined by the U.S. Weather Bureau as 0.31 inch per hour or more (Table I); however, droplet diameter is not specified. Heavy rain is defined in reference 3 and Table II as 0.59 inch/hour at a droplet size of 1.5mm, and is the recommended value for design. In continental USA the probability of exceeding this rainfall rate is approximately 1 hour in 500 hours (average value based on Table 6-3 of Reference 4).

 Printed in U. S. A.

2.3 There is no quantitative description, measure, or definition of the degree of windshield clearance which permits "satisfactory visibility." Therefore, opinion as to the adequacy of a particular system will vary widely with various pilots or observers.

Photographic documentation, of both laboratory and flight tests, is a method of evaluating system adequacy. A method of rating visibility was developed in Reference 2 and may prove useful in evaluating data obtained under various conditions.

3. SYSTEM DESIGN CONSIDERATIONS:

3.1 Jet blast rain removal systems operate on the principle of blanketing the outside surface of the windshield with a protective wall of high velocity, high temperature air. The object of the jet blast is twofold:

1) Prevent water impingement on the windshield by deflecting incoming raindrops.

2) Evaporate surface water which penetrates the jet blast.

At the present state-of-the-art, complete prevention of droplet impingement in the "cleared area" is not practical due to bleed air penalties. Near the nozzle, a completely dry area will exist; however, impingement and subsequent evaporation may result in the upper portions of the "cleared area".

3.2 Required air flow rate for good visibility is a function of airspeed, windshield configuration, rain intensity, supply air temperature, nozzle configuration, and nozzle air velocity. Current operational aircraft use airflow rates from 20 to over 60 lb/min. per panel. Laboratory tests of various configurations show relatively poor clearing at airflow rates of 2 lb/min/inch of nozzle width, but good visibility has been obtained at rates of 4.5 to 7 lb/min/inch of width (Reference 2). These values will vary with each specific airplane configuration and system design.

3.3 Supply air for the typical jet blast rain removal system used on current operational jet aircraft is extracted from the engine. Hence, airflow is at a premium and supply conditions change with engine RPM. Specific conditions to be considered for design purposes are take-off, approach, touchdown, and taxi. Engine bleed air temperature may vary from 250° F at idle to as high as 880° F at take-off power. Similarly, engine bleed pressures will be a minimum at idle and a maximum at take-off. For aircraft that use direct engine bleed air from the main engines for rain removal, touchdown (idle engines) will normally be the most critical design point, as bleed air pressure and temperatures are at a minimum. A pressure limiting valve can be employed under some conditions to prevent excessive air flow at high engine power conditions. Where visibility requirements impose a required minimum airflow, consideration must be given to protection of the glass for the higher bleed temperature and pressure conditions existing at the higher engine power settings.

3.4 Nozzle design will vary with windshield and fuselage configuration, but will usually consist of a plenum chamber and either a continuous or interrupted slot, or a row of holes for discharge of air over the windshield. A continuous slot normally gives better visibility for a given air flow.

3.4.1 Where a row of orifice holes or nozzles is used, the nozzle spacing to diameter ratio should, in general, be less than 1.7 in order to avoid streaks of rain between the individual nozzles. Staggered row hole patterns have been used when larger nozzle areas are needed than a single row will produce.

3.4.2 Best clearing will be obtained with the nozzle air blast oriented parallel to the windshield surface. This arrangement, however, produces maximum glass surface temperatures.

3.4.3 With a parallel nozzle — nozzle discharges parallel to the windshield surface — glass and interlayer temperatures may be excessive at bleed temperatures in excess of approximately 450^{o}F. Bleed air temperature can be limited by means of heat exchangers; however, substantial reduction in glass surface temperatures can be achieved, with a minor reduction in rain clearing performance, by tilting the nozzle away from the glass 10 to 20 degrees. Surface water may enter the low pressure area behind the tilted air stream. To prevent this condition, either mechanical or aerodynamic fences are required.

3.4.4 A variable deflector plate system has been used successfully, which allows parallel flow at low bleed air temperature and pressure, but deflects the air stream away from the glass by 20 degrees at high temperatures, thus avoiding the use of heat exchangers.

3.4.5 Nozzles are usually attached to primary fuselage structure. Nozzles must be designed to the highest pressure and temperature that can result from a single component failure in the pneumatic system. Insulation may be required between the nozzle and structure to prevent conduction of excessive heat to windshield frame and glass.

3.5 Excessive temperature can be a major problem with conventional combination glass and vinyl interlayer windshields. Operational experience has shown that maximum vinyl temperatures of 220^{o}F and maximum local glass surface temperatures of 300^{o}F will not result in vinyl bubbling or glass breakage. Glass breakage may occur with local temperatures of 380^{o}F and vinyl bubbling at 275^{o}F. (Note: these interlayer temperature limitations may not apply to high temperature interlayers in use on supersonic aircraft windshields.)

3.5.1 Temperature control may be achieved by system design, or by incorporation of a temperature sensing overheat shut-off system.

3.6 Windshield cleared areas considered adequate may be different for taxi, touchdown, and approach conditions.

3.7 If electrically heated windshields are provided for anti-icing, anti-fogging, or bird proofing, consideration must be given to protecting the glass against temperature effects of combined jet blast rain clearing and electrical windshield heating. Placement of interlayer temperature sensors for control of the electrical heating system and/or the jet blast system may provide the required degree of protection if proper consideration is given to location of hot spots due to variations in the electrically conductive coating.

3.8 Consideration should be given to the effects of operation of the jet blast system on other pneumatically powered systems, aircraft performance penalties and/or system operation procedure such as deteriorations of bleed air supply pressure.

3.9 Duct drains should be provided to prevent trapping any rain water or airplane cleaning solutions which might enter the system through the nozzles and subsequently soil the windshield surface when the system is operated.

4. <u>DEVELOPMENT CONSIDERATIONS</u>:

4.1 Development tests are normally required for a new aircraft configuration, and are the most effective means of insuring an adequate system. Analytical methods are not, as yet, adequate to assure an effective system.

4.2 Simulation of the forward fuselage, that is, windshield panels, supporting frames and structure, and a portion of the fuselage ahead of the panels, is needed.

4.3 Airflow over the windshields must be simulated at aircraft speeds up to $1.6V_s$ Pressure distribution over the windshield should be duplicated also, as far as practical.

4.4 Supply air pressures and temperatures must simulate the maximum and minimum bleed air levels anticipated in actual flight.

4.5 Rain simulation must be provided to simulate heavy rain, both as to intensity and droplet size. Droplet size is particularly difficult to simulate, due to droplet break-up with normal spray nozzles. Large drop sizes may be simulated by the methods described in Reference 2. Inadequate rain simulation can yield misleading test results.

4.6 Development problems will normally consist of obtaining adequate windshield cleared area at "touchdown" without excessive glass and interlayer temperatures at high rpm (take-off and approach).

4.7 Performance should be documented by photographs at the critical operating conditions in heavy rain. Performance should also be documented in moderate and light rain for comparison with flight test data.

5. FLIGHT TEST EVALUATION:

5.1 Taxi, take-off, approach and landing under actual rain conditions represent the best appraisal of system performance. Suitable documentation can be made in terms of photographs of windshield clearing performance, plus rain intensity from local weather bureau measurements in the area of operation.

5.2 Heavy rain is difficult to find, due to its low occurrence frequency. However, light and moderate rain is relatively easy to find. Tests in light and moderate rain may be satisfactory for evaluation if laboratory test data are available in light, moderate and heavy rain to form a basis for extrapolation of flight test results.

5.3 Flight in rain simulated by an aerial tanker is an alternate method of flight evaluation. However, steady state conditions under such a test are very difficult to obtain.

PREPARED BY
COMMITTEE A-9, AEROSPACE ENVIRONMENTAL SYSTEMS

REFERENCES

1. Civil Air Regulations, Part 4b, paragraph 351 (b).

2. WADC Technical Report 58-444, "Design Manual for Windshield Jet Blast Rain and Ice Removal" by Harry R. Meline and Ivan D. Smith; Research, Inc., Nov. 1958.

3. "Physics of the Air" by W. J. Humphreys

4. "Handbook of Geophysics" Revised Edition, U. S. Air Force, 1960- The Macmillan Company.