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Jet Blast Windshield Rain Removal Systems for Commercial Transport Aircraft

FOREWORD

Changes in this revision are format/editorial only.

1. SCOPE:

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 commercial transport 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.

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 statistical 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. 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., November 1958.

3. ARP580A, “Cockpit Visibility Requirements for Commercial Transport Aircraft.”

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

3. DESIGN OBJECTIVES:

3.1 Rain clearing should be provided for the windshield panels directly forward of the pilot and co-pilot. The system should be designed so that no single malfunction will result in a loss of clearing on both windshields. The system should maintain a sufficient portion of the windshield clear such that each pilot has adequate vision along the flight path in all normal aircraft attitudes for all speeds up to $1.6V_{stall}$ (Vs_1) per CAR 4b.351. Recommendations concerning the area to be cleared are contained in ARP580A (Reference 3). Clearing should also be provided during taxi and at speeds up to normal enroute climbout speeds, although some reduction in cleared area may occur.

Rain clearing should be available regardless of throttle setting. Clearance may be achieved exclusively with the jet blast system, or with a combination of the jet blast and a rain repellent fluid during the critical landing phase.

3.2 The jet blast system should be designed for all rain intensities up to that classified as “heavy” rain. Heavy rain is defined in Table 1 as 0.59 inch/hour at a volume median droplet size of 1500 microns, and the average probability of occurrence in the United States is approximately one hour in 500 hour (volume median is that value which divides the drop distribution into two equal parts on the basis of water content). The 0.59 inch/hour rain intensity is a good overall average value for operations throughout the continental U.S.; however, in certain climatic areas such as the Eastern Gulf Coast, higher rain rates can be encountered. In order not to compromise flight operations at such localities, the jet blast system should be capable of providing a minimal clear area for rain rates up to 1.6 inch/hour and a volume median droplet size of 2300 microns. The probability of occurrence for this higher rate is estimated as one hour in 500 hour in an area such as New Orleans (Reference 4).

3.3 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.

TABLE 1 - Precipitation Values[1]
(Air Density as at 0 C and 740 mm Press.)

Popular Name	Precipitation Intensity mm/hour	Precipitation Intensity in/hour	Droplet Diameter mm	Velocity of Fall Meter per Second	Milligrams of Liquid Water per Cubic Meter of Air	Grains of Liquid Water per Cubic Feet of Air
Clear	0.00	--	0.00	--	0.00	--
Fog	Trace	--	0.01	0.003	6.0	0.002
Mist	0.05	0.002	0.10	0.25	55.5	0.024
Drizzle	0.25	0.01	0.20	0.75	92.6	0.04
Light Rain	1.00	0.04	0.45	2.00	138.9	0.06
Moderate Rain	4.00	0.16	1.0	4.00	277.8	0.12
Heavy Rain	15.00	0.59	1.5	5.00	833.3	0.365
Excessive Rain	40.0	1.6	2.1	6.00	1851.9	0.81
Cloudburst	100 to 1000	4.0 to 40.0	3.0	7.00	4000 to 35,000	1.75 to 15.30

[1] Humphreys, W. J., Physics of the Air, p. 280 (Table of Rain Drop Size and Fall for Moderate Rain, 1 mm Diameter and ...)

4. SYSTEM DESIGN CONSIDERATIONS:

4.1 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.”

4.2 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/minute per panel. Laboratory tests of various configurations show relatively poor clearing at airflow rates of 2 lb/minute/inch of nozzle width, but good visibility has been obtained at rates of 4.5 to 7 lb/minute/inch of width (Reference 2). These values will vary with each specific airplane configuration and system design.

4.3 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, touch-down, and taxi. Engine bleed air temperature may vary from 150 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. Consideration must also be given to protection of the glass for the bleed temperature and pressure conditions existing at the higher engine power settings. A pressure limiting valve can be employed under some conditions to prevent excessive air flow at high engine power conditions.

If a gas turbine auxiliary power unit is installed, consideration may be given to its use as the primary or a supplemental source of air for the jet blast system. Factors to be considered are quantity of air available, maximum air temperature and the additional provisions required for in flight operation of the APU.

4.4 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.

4.4.1 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.

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

4.4.3 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 F. Bleed air temperature can be limited by means of heat exchangers; however, substantial reduction in glass surface temperatures can be achieved, with a 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. Another method of reducing windshield temperature is to provide for aspiration of the free stream air by the high velocity jet.

4.4.4 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.

4.4.5 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.

4.5 Excessive temperature can be a major problem with conventional combination glass and vinyl interlayer windshields. Experience with flat glass windshields has shown that maximum vinyl temperatures of 220 F and maximum local glass surface temperatures of 300 F will not result in vinyl bubbling or glass breakage. Associated factors such as airflow rate, temperature change rate and windshield mounting can influence the glass breakage problem.

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

4.6 Windshield cleared areas considered adequate may be different for taxi, touch-down, and approach conditions.

4.7 If electrically heated windshields are provided for anti-icing, antifogging, 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.

4.8 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.