Federal Aviation Administration
Aviation Rulemaking Advisory Committee

Transport Airplane and Engine Issue Area
Engine Harmonization Working Group

Task 2 – Inclement Weather

Task Assignment

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Aviation Rulemaking Advisory Committee; Transport Airplane and Engine Subcommittee; Propulsion Harmonization Working Group

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of establishment of Propulsion Harmonization Working Group.

SUMMARY: Notice is given of the establishment of the Propulsion Harmonization Working Group of the Transport Airplane and Engine Subcommittee. This notice informs the public of the activities of the Transport Airplane and Engine Subcommittee of the Aviation Rulemaking Advisory Committee.

FOR FURTHER INFORMATION CONTACT: Mr. William J. (Joe) Sullivan, Executive Director, Transport Airplane and Engine Subcommittee, Aircraft Certification Service (AIR-3), 800 Independence Avenue SW., Washington, DC 20591, Telephone: (202) 267-9554; FAX: (202) 267-5364.

SUPPLEMENTARY INFORMATION: The Federal Aviation Administration (FAA) established an Aviation Rulemaking Advisory Committee (56 FR 2190, January 22, 1991) which held its first meeting on May 23, 1991 (56 FR 20492, May 3, 1991). The Transport Airplane and Engine Subcommittee was established at that meeting to provide advice and recommendations to the Director, Aircraft Certification Service, FAA, regarding the airworthiness standards for transport airplanes, engines and propellers in parts 25, 33, and 35 of the Federal Aviation Regulations (14 CFR parts 25, 33, and 35).

The FAA announced at the Joint Aviation Authorities (JAA)—Federal Aviation Administration (FAA) Harmonization Conference in Toronto, Ontario, Canada, (June 2-5, 1992) that it would consolidate within the Aviation Rulemaking Advisory Committee structure an ongoing objective to "harmonize" the Joint Aviation Requirements (JAR) and the Federal Aviation Regulations (FAR). Coincident with that announcement, the FAA assigned to the Transport Airplane and Engine Subcommittee those projects related to JAR/FAR 25, 33, and 35 harmonization which were then in the process of being coordinated between the JAA and the FAA. The harmonization process included the intention to present the results of JAA/FAA coordination to the public in the form of either a Notice of Proposed Rulemaking or an advisory circular—an objective comparable to and compatible with that assigned to the Aviation Rulemaking Advisory Committee. The transport Airplane and Engine Subcommittee, consequently, established the Propulsion Harmonization Working Group.

Specifically, the Working Group's tasks are the following: The Propulsion Harmonization Working Group is charged with making recommendations to the Transport Airplane and Engine Subcommittee concerning the FAA disposition of the following subjects recently coordinated between the JAA and the FAA:

Task 1—Bird Ingestion: Update turbine engine bird ingestion requirements, including size and number of birds and pass/fail criteria (FAR 33.77)

Task 2—Inclement Weather: Update the inclement weather requirements for rain and hail in turbine engines (FAR 33.77).

Task 3—Vibration Surveys: Determine test requirements and pass/Fail criteria for turbine engine vibration tests (FAR 33.83).

Task 4—Rotor Integrity: Determine test requirements and pass/fail criteria for turbine, compressor, fan, and turbosupercharger rotor overspeed tests (FAR 33.27).

Task 5—Turbine Rotor Overtemperature: Clarify test and pass/fail requirements for turbine engine overtemperature tests to assure consistent certification criteria (FAR 33.88).

Task 6—Windmilling: Exmaine current turbine engine windmilling requirements and specify appropriate test and analysis requirements (FAR 33.92).

Reports:

A. Recommend time line(s) for completion of each task, including rationale, for Subcommittee consideration at the meeting of the subcommittee held following publication of this notice.

B. Give a detailed conceptual presentation on each task to the Subcommittee before proceeding with the work stated under items C and D, below. If task 1-6 require the development of more than one Notice of Proposed Rulemaking, identify what proposed amendments will be included in each notice.

C. Draft a Notice of Proposed Rulemaking for tasks 1-6 proposing new or revised requirements, a supporting economic analysis, and other required analysis, with any other collateral documents (such as Advisory Circulars) the Working Group determines to be needed.

D. Give a status report on each task at each meeting of the Subcommittee.

The Propulsion Harmonization Working Group will be comprised of experts from those organizations having an interest in the tasks assigned. A working Group member need not necessarily be a representative of one of the organizations of the parent Transport Airplane and Engine Subcommittee or of the full Aviation Rulemaking Advisory Committee. An individual who has expertise in the subject matter and wishes to become a member of the Working Group should *write* the person listed under the caption **FOR FURTHER INFORMATION CONTACT** expressing that desire, describing his or her interest in the task, and the expertise he or she would bring to the Working Group. The request will be reviewed with the Subcommittee and Working Group Chairs and the individual will be advised whether or not the request can be accommodated.

The Secretary of Transportation has determined that the information and use of the Aviation Rulemaking Advisory Committee and its subcommittees are necessary in the public interest in connection with the performance of duties of the FAA by law. Meetings of the full Committee and any subcommittees will be open to the public except as authorized by section 10(d) of the Federal Advisory Committee Act. Meetings of the Propulsion Harmonization Working Group will not be open to the public except to the extent that individuals with an interest and expertise are selected to participate. No public announcement of Working Group meetings will be made.

Issued in Washington, DC, on December 4, 1992.

William J. Sullivan,

Executive Director, Transport Airplane and Engine Subcommittee, Aviation Rulemaking Advisory Committee.

[FR Doc. 92-30113 Filed 12-10-92; 8:45 am]

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Recommendation Letter

Gerald R. Mack
Director
Airplane Certification

Boeing Commercial Airplane Group
P.O. Box 3707, #MS 67-UM
Seattle, WA 98124-2207

November 7, 1995
B-T01B-ARAC-95-010

Mr. Anthony J. Broderick (AVR-1)
Associate Administrator for Regulations and Compliance
Department of Transportation
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington DC 20591

BOEING

Dear Mr. Broderick:

On behalf of the Aviation Rulemaking Advisory Committee, I am pleased to submit the enclosed draft NPRM and draft AC action on the following subjects:

NPRM	**Rain and Hail Ingestion Airworthiness Standards**
AC 33.78-1	**Turbine Engine Power-Loss and Instability in Extreme Conditions of Rain and Hail**

The enclosed package is in the form of a Notice of Proposed Rule Making, including preamble, draft rule, economic analysis and legal analysis, and a final draft Advisory Circular AC 33.78-1 pertaining to operation of turbine engines in extreme rain and hail. The package was developed by the Engine Harmonization Working Group (WG) chaired by Paul Jodon, Textron-Lycoming, and F. Fagegaltier, JAA. The membership of the group is a good balance of interested parties in the U.S., Europe and Canada. The group is currently focusing on other issues tasked to the WG, but can be available if needed for docket review.

The members of ARAC appreciate the opportunity to participate in the FAA Rulemaking process and fully endorse this recommendation.

Sincerely,

Gerald R. Mack
Assistant Chairman
Transport Airplane & Engine Issues Group
Aviation Rulemaking Advisory Committee

Enclosure

cc:	M. Borfitz	(617) 238-7199
	P. Jodon	203-385-2256
	S. Miller	227-1320

Acknowledgement Letter

U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

DEC 20 1995

Mr. Gerald R. Mack
Aviation Rulemaking Advisory Committee
Boeing Commercial Airplane Group
P.O. Box 3707, M/S 67-UM
Seattle, WA 98124-2207

Dear Mr. Mack:

Thank you for your November 7 letter forwarding the Aviation Rulemaking Advisory Committee's (ARAC) recommendation for rulemaking on Rain and Hail Ingestion Airworthiness Standards, and the associated draft advisory circular on Turbine Engine Power-Loss and Instability in extreme Conditions of Rain and Hail.

The recommendation was submitted in a format suitable for processing and, therefore, will be presented to the Federal Aviation Administration management as quickly as possible. I would like to thank the aviation community, and particularly the Engine Harmonization Working Group, for its commitment to ARAC and its interest in this matter. We pledge to consider your recommendation as a high-priority action.

Sincerely,

Anthony J. Broderick
Associate Administrator for
Regulation and Certification

U.S. Department
of Transportation

**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

MAY 21 1997

Mr. Gerald R. Mack
Aviation Rulemaking Advisory Committee
Boeing Commercial Airplane Group
P.O. Box 3707, M/S 67-UM
Seattle, WA 98124-2207

Dear Mr. Mack:

In response to a task announced in the Federal Register on December 11, 1992 (57 FR 58840), the Aviation Rulemaking Advisory Committee (ARAC) developed a notice of proposed rulemaking (NPRM) to change the water and hail ingestion standards for aircraft turbine engines. The NPRM was published in the Federal Register on August 9 and the comment period closed on November 7, 1996. Comments received in response to the NPRM were considered to be non-substantive. Consequently, the final action will be developed internally by the Federal Aviation Administration (FAA).

Let me thank ARAC and, in particular, the Engine Harmonization Working Group, for its dedicated efforts in completing the task assigned by the FAA.

If you have any questions, please contact Thomas Boudreau at (617) 238-7117.

Sincerely,

Joseph A. Hawkins
Director, Office of Rulemaking

Recommendation

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 33

[Docket No. XXXXX; Notice No. XX-XXX]

RIN: 2120-XXXX

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This notice proposes changes to the water and hail ingestion standards for aircraft turbine engines. This proposal addresses engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. This proposal also harmonizes these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). The proposed changes, if adopted, will establish one set of common requirements, thereby reducing the regulatory hardship on the United States and worldwide aviation industry, by eliminating the need for manufacturers to comply with different sets of standards when seeking type certification from the Federal Aviation Administration (FAA) and JAA.

DATES: Comments to be submitted on or before [Insert date 90 days after the date of publication in the **Federal Register**].

ADDRESSES: Comments on this notice should be mailed in triplicate to: Federal Aviation Administration, Office of the Chief Counsel, Attention: Rules Docket (AGC-10), Docket No.   , 800 Independence Avenue, SW., Washington, DC 20591. Comments delivered must be marked Docket No.   . Comments may be inspected in Room 915G weekdays between 9:00 a.m. and 5:00 p.m., except on Federal holidays.

FOR FURTHER INFORMATION CONTACT: Thomas Boudreau, Engine and Propeller Standards Staff, ANE-110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803-5229; telephone (617) 238-7117; fax (617) 238-7199.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to submit written data, views, or arguments on this proposed rule. Comments relating to the environmental, energy, federalism, or economic impact that might result from adopting the proposals in this notice are also invited. Substantive comments should be accompanied by cost estimates. Comments should identify the regulatory docket number and should be submitted in triplicate to the Rules Docket address specified above. All comments received on or before the closing date for comments specified will be considered by the Administrator before taking action on this proposed rulemaking. The proposals contained in this notice may be changed in light of comments received. All comments received will be available, both before and after the closing date for comments, in the Rules Docket for examination by interested persons. A report summarizing each substantive public contact with FAA personnel concerned with this rulemaking will be filed in the docket. Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must include a preaddressed, stamped postcard on which the following statement is made: "Comments to Docket No........." The postcard will be date stamped and mailed to the commenter.

Availability of NPRMs

Any person may obtain a copy of this NPRM by submitting a request to the Federal Aviation Administration, Office of Public Affairs, Attn: Public Inquiry Center, APA-200, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-3484. Communications must identify the notice number of this NPRM.

Persons interested in being placed on the mailing list for future NPRMs should request, from the above office, a copy of Advisory Circular No. 11-2A, Notice of Proposed Rulemaking Distribution System, which describes the application procedure.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

History

Industry Study

In 1987 the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. Consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to Federal Aviation Regulation (FAR) part 33, if appropriate. AIA, working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of FAR part 33 do not adequately address this threat.

Engine Harmonization Effort

The FAA is committed to undertaking and supporting harmonization of standards in FAR part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and Propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. This partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which were considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards.

This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On XXXXX XX, 1995, the TAEIG recommended to the FAA that it proceed with rulemaking and associated advisory material even though one manufacturer has expressed reservations. This NPRM and associated advisory material reflects the ARAC recommendations.

Disposition of objections

One manufacturer participating in the TAEIG has expressed reservations with the proposal. The reservations focused on the degree of conservatism built into the assumptions regarding weather statistics. These reservations include concerns about a bias in the hail characterization towards geographical areas of extremely high hailstorm probabilities and with an apparent rounding up of the hail threat definition from 8.7 g/m^3 to 10 g/m^3. The manufacturer also expressed concern regarding the lack of standardized test procedures and analytical methods for compliance within the industry.

During the early phase of defining the environmental threat, for both rain and hail, engineering judgment suggested that expressing rain water content (RWC) and hail water content (HWC) as a function of a joint probability was an appropriate method. That joint probability is the product of the prior probability of a storm occurring at a given point and the conditional probability of a given water concentration value occurring within that storm. Given the potential for a pilot to avoid a storm and the ability for an engine to recover sufficiently for continued safe flight, a joint probability of 10^{-8} was determined adequate for establishing the certification standards for rain and hail. Accounting for hail shaft exposure times, the hail threat levels could vary from 8.7 g/m^3 to 10.2 g/m^3. The choice of 10 g/m^3 was agreed to by the TAEIG as the certification standard that would be suitable for all applications. It was not simply a round up. Admittedly, the only credible hail data available was for high hail probability areas in North America and Europe. While these data may not represent the average world environment, they do represent areas of high commercial air traffic through which aircraft equipped with turbine engines normally operate.

The TAEIG also considers the proposal and the associated harmonization activity to be an effective method of reaching a more uniform method for compliance by manufacturers. That activity has already fostered a significant sharing of knowledge on the subject.

Current Requirements

The current water and large hailstone ingestion standards are valid tests for addressing permanent mechanical damage resulting from such ingestions. However, they do not adequately address engine power-loss and instability effects, such as run down and flameout at lower than takeoff-rated power settings for turbine engines installed on airplanes.

The TAEIG concluded that, with respect to power-loss and instability effects, the current water ingestion standard is adequate for turbine engines installed on rotorcraft (turboshaft engines) as an alternative to the new rain and hail ingestion standards. The TAEIG reached this conclusion after it had reviewed the service experience of rotorcraft turbine engines and could not find an in-service event that would indicate that the current water ingestion standards are inadequate for that application. There are differences between rotorcraft and airplanes that help to explain the differences in the service experience of rotorcraft turbine engines versus other turbine engines. Rotorcraft turbine engines operate at higher power settings during descent than turbine engines installed on airplanes. Also, rotorcraft operate at lower flight speeds than airplanes. The combination of higher engine power and lower flight speed significantly reduces the water concentration amplification effects on rotorcraft turbine engines. Therefore, the proposed new rain and hail ingestion standards apply to all turbine engines, while a harmonized version of a four percent water to engine airflow by weight ingestion standard is proposed as an alternative for turbine engines installed on rotorcraft.

General Discussion of the Proposals

§ 23.901(d)(2), § 23.903(a)(2) and § 25.903(a)(2).

The proposed amendments would revise § 23.903(a)(2) and § 25.903(a)(2) to be consistent with the proposed part 33 changes. Additionally, proposed § 23.901(d)(2) would replace the current text with new text requiring each turbine engine installation to be constructed and arranged not to jeopardize compliance of the engine with § 23.903(a)(2). This would ensure that the installed engine retains the acceptable rain, hail, ice, and bird ingestion capabilities established for the uninstalled engine under § 23.903(a)(2).

§ 33.77.

The proposed amendments would remove the large hailstone ingestion standards now specified in § 33.77(c) and (e), and place them in new § 33.78(a)(1) and (c). The proposal would also harmonize the four percent water to engine airflow by weight ingestion standard, currently specified in § 33.77(c) and (e), and place it in new § 33.78(b) as an alternative standard for rotorcraft turbine engines to the proposed new rain and hail ingestion standards. New water and hail ingestion standards for all turbine engines will be introduced in new § 33.78(a)(2). All rain and hail ingestion standards would then be found in one section, as in the current JAR-E.

The intent of the current water ingestion standard is to address a number of concerns including power-loss, instability, and the potential hazardous effects of water associated with case contraction. As stated previously, there have been numerous power-loss and instability events on airplane turbine engines since the standard was promulgated (39 FR 35463; October 1, 1974). The need to better address power-loss and instability effects at lower than takeoff-rated power settings led to the proposed new standards for all turbine engines (new § 33.78(a)(2)). Collectively, the proposed new standards and the proposed changes as contained in new § 33.78(a)(2) and (b) also better address potential concerns associated with case contractions on turbine engines since they are based on a more thorough understanding of the in-flight effects of rain and hail ingestion.

§ 33.78.

The proposed § 33.78 would consolidate all harmonized rain and hail ingestion standards for turbine engines, and the corresponding harmonized acceptance criteria, into a single section. The proposal also introduces new rain and hail ingestion standards for turbine engines to address the power-loss and instability phenomena identified by AIA and AECMA.

Currently, FAR part 33 and JAR-E have different acceptance criteria for the water and large hailstone ingestion standards. In general, FAR part 33 does not permit any sustained power or thrust loss after the ingestion, while JAR-E permits some power or thrust loss and some minimal amount of mechanical damage. The TAEIG determined, however, that the current FAA post ingestion power loss criterion does not consider thrust and power loss variabilities, such as inherent measurement inaccuracies. Therefore, allowing some measured power or thrust loss would be reasonable but must not reduce the level of safety intended by these requirements.

The TAEIG concluded that sufficient airplane performance margins exist to permit sustained post ingestion power or thrust losses up to 3 percent at any value of the power or thrust setting parameter. Variabilities and uncertainties associated with thrust and power measurements could conceivably result in upwards of a 3 percent power or thrust measurement error. Therefore, measured post ingestion power or thrust losses up to 3 percent are acceptable and do not represent a reduction in the level of safety provided by current FAA water and large hailstone ingestion standards. However, measured post ingestion power or thrust losses greater than three percent, at any value of the primary power or thrust setting parameter, can only be accepted when supported by appropriate airplane performance assessments.

The TAEIG also discussed levels of acceptable engine performance degradation that might be experienced as a result of certification testing. This degradation is a power or thrust reduction when pre-test and post test comparisons are made at any given values of the engine manufacturer's normal performance parameters other than the primary power or thrust setting parameter. This power or thrust degradation must not affect the measured power or thrust of the engine at any value of the primary power or thrust setting parameters, but will tend to reduce the available gas path temperature margin of the engine after the test. It is the judgment of the working group, based on certification and development test experience, that current and future technology engines should be capable of demonstrating less than 10 percent engine performance degradation from a single hail or rain ingestion event. Some members of the TAEIG believe that values greater than 10 percent can be safely accommodated, but consensus could not be obtained in defining this uppermost value. The TAEIG accepted the 10 percent value as a compromise certification standard for future use in the context of rain and hail ingestion testing. In the event that future certification tests result in engine performance degradations that exceed 10 percent, the actual demonstrated level must be evaluated for acceptability against the criterion of aircraft safety.

The proposed new rain and hail ingestion standards to address the power loss and instability phenomena refer to a proposed new FAR part 33 appendix for a definition of maximum concentrations of rain and hail in the atmosphere. It is expected that a combination of tests and analyses will be needed to demonstrate compliance. Therefore, this proposal allows for various means of compliance.

Allowing various means of compliance has distinct advantages. The variables associated with an ingestion event are best addressed through a combination of tests and analyses. Also, it is anticipated that further insight into the phenomenon of rain and hail ingestion will be gained through the development of these various compliance methods. Finally, the TAEIG believes that applicants will develop compliance methods which minimize the cost impact.

Rain and hail ingestion standards embodied in this rule represent an extremely remote probability of encounter (1×10^{-8}). They are based on current assessments of atmospheric and meteorological conditions and aircraft engine service experience. Both the FAA and the JAA agree that the need for further revised standards should be considered in the future if warranted by later additional service and atmospheric data warrant.

Appendix B

Proposed Appendix B defines the certification standard atmospheric concentrations of rain and hail. These values were derived through detailed meteorological surveys and statistical analyses and represent an extremely remote aircraft encounter.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1990 (44 U.S.C. 3501 et seq.), an evaluation of the paperwork burden of this proposal is not required since there are no recordkeeping or reporting requirements associated with this proposed rule.

Preliminary Regulatory Evaluation, Initial Regulatory Flexibility Determination, and Trade Impact Assessment

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980, requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: 1) would generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; 2) is not significant as defined in DOT's Regulatory Policies and Procedures; 3) would not have a significant impact on a substantial number of small entities; and 4) would not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

<u>Incremental certification costs</u>

The proposed rule would permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods would most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment would likely be the most costly. Incremental cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for airplane turbine engines would be approximately $667,000; this includes $300,000 in additional engineering hours, and $367,000 for the prorated share of the cost of a test facility.

Incremental manufacturing and operating costs

Predicting the rule's effect on manufacturing costs is complicated by design/cost tradeoffs, the large number of permutations of modifications that could achieve the desired result, and because engine design takes place in the context of constant technological change. Based on discussions with industry representatives, the FAA expects that, once rain/hail centrifuging and engine cycle models are established, compliance would be accomplished through design modifications that would have little impact on manufacturing costs. Such design features may affect: 1) fan blade/propeller, 2) spinner/nose cone, 3) bypass splitter, 4) engine bleeds, 5) accessory loads, 6) variable stator scheduling, and 7) fuel control. Similarly, the FAA expects that the rule would have a negligible effect on operating costs (again, based on discussions with industry representatives).

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of FAA and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the proposed rule, as summarized below. However, the following summary should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. The historical record shows that many accidents (not included in the following benefit estimates) were caused by other forms of water such as snow and graupel. It is possible that the aircraft in some of these cases would have benefited from the proposed rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

Benefits of prevented aircraft damage

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the proposed rule. These classifications are: 1) large air carrier aircraft (major and national air carriers), and 2) other air carrier aircraft (large regional, medium regional, commuter, and other small certificated air carriers).

An examination of accident records for the period 1975-90, indicates that, in the absence of the proposed rule, the probability of a hull loss due to a water induced loss of engine power is 0.0104 per million airplane departures for large air carriers, and 0.0276 per million airplane departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the proposed standards would reduce the accident rate by two orders of magnitude. That is, the rule is expected to be 99 percent effective in reducing water ingestion accidents. FAA estimates that the annual average benefits per airplane from prevented aircraft damage would be approximately $337 and $97 for large air carriers and other air carriers, respectively.

Benefits of prevent injuries and fatalities

Using projections from the *FAA Aviation Forecast*, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61 percent. The average regional airplane is assumed to have 30 seats and a load factor of 51 percent. The estimated distribution of fatal, serious, and minor injuries is derived from the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane would be $3,062 for large air carriers and $706 for other air carriers.

Benefit-Cost Analysis

The benefits and costs of the proposed rule are compared for two representative engine certifications using the following assumptions: 1) for each certification, 50 engines are produced per year for 10 years (500 engines), 2) incremental certification costs are incurred in year "0", 3) engine production begins in year "3", 4) the first engines enter service in year "4", 5) each engine is retired after 10 years, 6) the discount rate is 7 percent. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the airplane accident rate) this analysis assumes that each airplane has two engines.

For each airplane/engine type, the annual benefit per aircraft is the sum of the expected property and casualty benefits. The total benefit for each type certification, then, is the product of the per aircraft annual benefit and the number of aircraft in service summed over the life of the engines. Thus, for representative type certifications, discounted lifecycle benefits would be approximately $3.7 million and $0.8 million for large air carriers and other air carriers, respectively.

FAA finds that the rule would be cost-beneficial. Under conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage would exceed discounted costs by a factor ranging from 5.5 ($3,661,084/$667,000) for large air carriers to 1.3 ($864,696/$667,000) for other air carriers.

Harmonization Benefits

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act (RFA) of 1980 was enacted by Congress to ensure that small entities are not unnecessarily or disproportionately burdened by Government regulations. The RFA requires a Regulatory Flexibility Analysis if a rule is expected to have a "significant economic impact on a substantial number of small entities." Based on the standards and thresholds specified in implementing FAA Order 2100.14A, Regulatory Flexibility Criteria and Guidance, the FAA has determined that the rule would not have a significant impact on a substantial number of small manufacturers or operators because no turbine engine manufacturer is a "small entity" as defined in the order.

International Trade Impact Assessment

The rule would have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine engines in the U.S.

Federalism Implications

The regulations proposed herein would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

* * * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

* * * * *

(2) Each turbine engine must either-

(i) Comply with §33.77 and §33.78 of this chapter in effect on **[Insert effective date of final rule]**, or as subsequently amended; or

(ii) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to **[Insert effective date of final rule]** and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

* * * * *

PART 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 1344, 1354(a), 1355, 1421, 1423, 1424, 1425, 1428, 1429, 1430; and 49 U.S.C. 106(g).

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

*   *   *   *   *

(2) Each turbine engine must either-

(i) Comply with §33.77 and §33.78 of this chapter in effect on **[Insert effective date of final rule]**, or as subsequently amended; or

(ii) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to **[Insert effective date of final rule]** and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

*   *   *   *   *

PART 33 - AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 1344, 1354(a), 1355, 1421, 1423, 1424, 1425; and 49 U.S.C. 106(g).

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

*   *   *   *   *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

*   *   *   *   *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

Foreign Object		Test Quantity	Speed of Foreign Object	Engine Operation	Ingestion
BIRDS:					
	3-Ounce Size.	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1-1/2-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff.	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
	1-1/2-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff.	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
	4-pound size.	One, if it can enter the inlet.	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes.	Maximum cruise.	Aimed at critical area.
			Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Takeoff.	Aimed at critical area.
ICE:		Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in.	Maximum cruise.	To simulate a continuous maximum icing encounter at 25 °F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) All engines.

(1) The Ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum rough air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstone number and size shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet area of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 2-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet area more than 100 square inches (0.0645 square meters).

(2) Except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability during any three minute continuous period in rain and during any 30 second continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) Engines for rotorcraft. As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotorcraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) continuation of the rain ingestion during subsequent rapid deceleration to takeoff power.

(c) <u>Engines for supersonic airplanes.</u> In addition to complying with paragraph (a)(1) of this section, a separate test for supersonic airplane engines only, shall be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain or hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject water constituents; and

(3) The subject water constituents, stopped by the protection device, will not obstruct the flow of induction air into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

APPENDIX B TO PART 33--CERTIFICATION STANDARD ATMOSPHERIC CONCENTRATIONS OF RAIN AND HAIL

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hailstones fabricated from ice to simulate hail conditions, the use of water droplets and hailstones having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hailstone, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

FAR GUIDANCE MATERIAL

TURBINE ENGINE POWER-LOSS AND INSTABILITY IN EXTREME CONDITIONS OF RAIN AND HAIL

33.78-1

ANE-110

1. PURPOSE. This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate compliance with the requirements contained in Section 33.78(a)(2) of the Federal Aviation Regulations (FAR) pertaining to operation of turbine engines in extreme rain and hail.

2. BACKGROUND. In 1988 the Aerospace Industries Association (AIA) initiated a study of airplane turbine engine power-loss and instability phenomena that were attributed to operating in inclement weather. AIA, working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes when operating in an extreme rain or hail environment. AIA and AECMA further concluded that the rain and hail ingestion requirements contained in section 33.77 do not adequately address these threats. Consequently, the FAA and the Joint Aviation Authorities (JAA) have promulgated new water and hail ingestion standards.

3. DEFINITIONS. The following terms are defined for the purpose of this AC.

a. Critical point(s). Operating conditions within the engine flight envelope at which an engine's operability margin is reduced to a minimum level. Operability margin includes compressor surge and stall margin, fuel control run down margin, combustor flameout margin, and instrumentation sensing errors.

b. Flameout. The total extinction of flame within the combustor, resulting in a run down and ultimately, a shutdown of the engine.

c. Hail. Water in a solid granular state, either in its naturally occurring form or in a fabricated form, for the purpose of testing engines.

d. Hail water content (HWC). The concentration, in the air, of water in the form of hail, expressed in grams of hail per cubic meter of air.

e. Rain. Water in liquid droplet state, either in its naturally occurring form, or created artificially by discharging water from spray nozzles for the purpose of testing engines.

f. Rain water content (RWC). The concentration, in the air, of water in the form of rain, expressed in grams of rain per cubic meter of air.

g. Run down. The uncommanded reduction of engine rotor speed that will result from the fuel control steady state operating line coinciding with the fuel control acceleration schedule.

h. Scoop factor. The ratio of nacelle inlet (highlight) area to the area of the captured air stream tube (Scoop factor = A_H/A_C). The scoop factor increases with decreasing engine speed and increasing aircraft speed due to the increase in inlet airflow spillage, resulting from a smaller captured air stream tube (refer to Figure 1-1).

i. Stall. An airflow breakdown at one or more compressor airfoil stages.

j. Surge. The response of an entire engine that is characterized by a significant airflow stoppage or reversal in the compression system.

k. Sustained power or thrust loss. A permanent reduction in power or thrust at the engine's primary power set parameter (e.g., rotor speed, engine pressure ratio, torque, shaft horsepower).

4. DISCUSSION. The body of this AC is arranged in four sections, with each providing background for the succeeding section. Section 1 provides an overview of the power-loss and instability phenomena associated with operating airplane turbine engines in extreme rain or hail. Section 2 elaborates on some of the turbine engine design aspects that affect engine operability in rain or hail. Finally, Sections 3 and 4 describe acceptable methods for demonstrating that the engine type design will operate acceptably throughout its operating envelope when exposed to the identified rain and hail threats.

SECTION 1. POWER-LOSS AND INSTABILITY PHENOMENA

5. GENERAL. There have been multiple engine power-loss and instability events, forced landings, and accidents attributed to turbine engine malfunction in extreme conditions of rain or hail. Investigations have revealed that ambient concentrations of rain and hail can be amplified significantly through the engine core at certain combinations of flight speed and engine power or thrust condition. In some instances, the resulting increased amounts of ingested rain and hail has been sufficient to produce engine anomalies such as surging, power loss, and engine flameout.

6. METEOROLOGICAL DATA. Appendix B to FAR Part 33 defines the atmospheric conditions of rain and hail for the purpose of establishing certification test standards. Note that the concentrations defined for rain and hail in Appendix B represent ambient conditions, not test conditions at the engine inlet.

7. RAIN AND HAIL CONCENTRATION AMPLIFICATION AND ATTENUATION EFFECTS. During in-flight encounters with rain and hail, changes in engine power or thrust and flight speed can alter the rain or hail concentration within the engine for any given atmospheric rain or hail content.

a. Scoop Factor Effect (Refer to Figure 1-1). The inlet capture stream tube for airflow varies widely across the spectrum of engine power and flight speed. At low engine power and high flight speed, the air intake requirements are minimal in comparison to the available ram air. Consequently, a significant portion of the air in front of the inlet spills outside the inlet lip (see Figure 1-1). Due to their mass, large rain droplets and hail are relatively unaffected by this spillage, and will be captured by the inlet. The amount of rain or hail captured through the inlet will be established by the inlet area. The amount of this amplification effect is equal to the ratio of the nacelle inlet area (A_N) to the captured air stream tube area (A_c). Further, bypass turbofan engines may have an additional internal scoop factor effect due to the divergence of the engine core stream tube from the nacelle inlet to the core inlet at low engine power and high flight speed. Therefore, although the scoop factor effects are generally amplification effects, the amplification is greatest when high flight speed is combined with low power or thrust.

b. Relative velocity centrifuging effects. Some of the rain and hail will be centrifuged away from the engine core by a fan and, to a lesser extent, away from the engine by a propeller. This beneficial effect is dependent upon the fan or propeller geometry and rotational speed, inlet design and location, engine design, aircraft velocity, and on the sizes of the rain droplets and hailstones.

(1) Turbofan and turbojet engines (Refer to Figure 1-2).

(i) Rain. The inlet diffusing flow field pressure gradients act to shear large droplets into small droplets that decelerate and enter the fan at velocities close to the inlet air velocity. As depicted in Figure 1-2, the majority of droplets that enter the engine at gas path speeds will strike the fan and be centrifuged away from the engine core. The forces acting upon

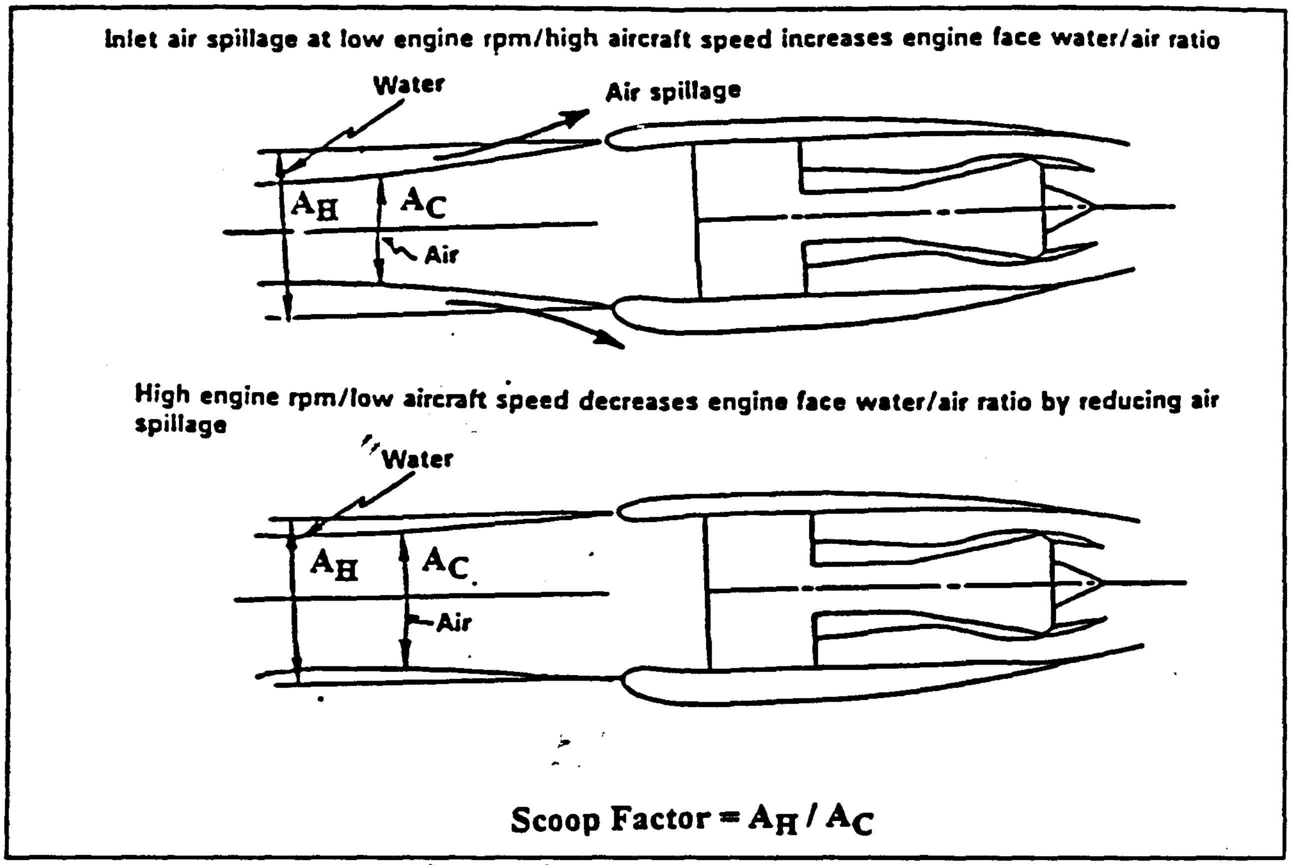

Figure 1-1. Scoop Factor

the rain droplets in flight will vary with airplane velocity and altitude. A portion of the rain droplets entering the engine may have sufficient mass, such that deceleration to gas path velocity is not possible. At low engine rotational speeds and high flight speeds, the velocity of the large rain droplets, relative to the fan, may allow that portion of the rain droplets to pass through the fan without impact (refer to hail velocity vector diagram in Figure 1-2).

(ii) Hail. Hail particles will maintain their size and will not be significantly affected by the inlet flow field. Consequently, the hail particles will enter the engine close to aircraft speed. At low engine rotational speeds, a significant portion of the hail particles, like large rain droplets, may pass through the fan without impact (see Figure 1-2).

(2) Turboprop engines.

(i) Rain. When compared to a turbofan engine, the inlet flow field effect of the propeller on droplet size and the relative velocity centrifugal effects are reduced because of the lower solidity of the propeller. Conducting this type of test without the propeller, either by using some other load- absorbing device or running the gas generator alone, normally results in an added degree of conservatism. Unlike turbofan engines, the propeller rotational speed does not vary significantly in flight, regardless of power setting. Thus, any beneficial effect of the propeller will remain reasonably independent of altitude and power setting. Where an inlet particle separation system is incorporated, credit may be taken for its characteristics.

(ii) Hail. As with rain, the effects of the propeller on hail ingestion are generally considered beneficial so that conducting a hail test without a propeller should result in an added degree of conservatism. Another consideration is the effect of the propeller spinner. In a continuous hail encounter, the spinner may redirect hail into the general area of the engine intake. The trajectory of this material will influence the effective inlet concentration and should be included in any supportive analysis for other than full scale powerplant tests.

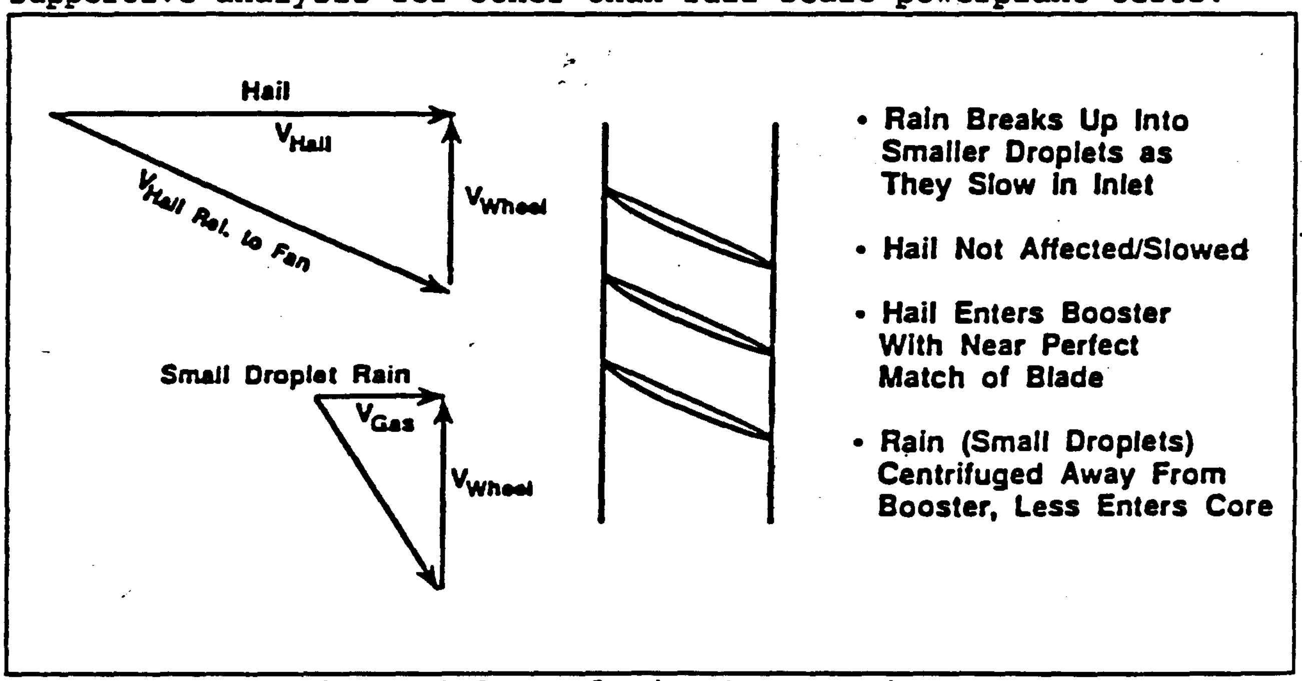

Figure 1-2. Velocity Vector Diagram

8. ROTORCRAFT TURBINE ENGINES. For rotorcraft applications, testing to the requirements of FAR Section 33.78(a)(2) may be replaced by the static rain ingestion test specified in FAR Section 33.78(b). While it may be possible to define in-flight rain and hail concentration amplification and attenuation effects for rotorcraft installations similar to airplane installations, these effects are typically small. When compared to airplanes, the proportionately higher engine power during descent and the lower flight speeds of rotorcraft results in a small scoop factor effect. Rotorcraft turbine engines might not have rotating components that centrifuge rain or hail away from the engine. While differences in centrifuging capability between static test conditions and flight operation is an important consideration for turbofan engines, it typically has no applicability to rotorcraft turbine engines. Increasing the ambient rain concentration from Appendix B values to 4 percent water droplet flow to airflow, by weight, will usually compensate for any flight effects.

9. TURBINE ENGINE OPERABILITY EFFECTS. As stated previously, rain and hail ingested into a turbine engine can be at greater than ambient concentrations in the engine at certain combinations of flight speed and engine power condition. Ingestion of water through the engine core can produce a number of engine anomalies, including surging, power or thrust loss, and flameout. These anomalies are partly a result of the changes in the thermodynamic cycle of the turbine engine because of the presence of water as a result of ingesting rain or hail.

a. Compressor rematch. The presence of rain or hail particles or water from melted hail in the gas path causes the compressor to assume new operating conditions. The net overall effect may result in an increase in high compressor operating line, with a corresponding decrease in high compressor surge and stall margins.

b. Engine control response (Refer to Figure 1-3). The fuel control steady-state operating line will move upward toward the acceleration schedule as the amount of ingested rain or hail increases (see Figure 1-3). A higher operating line means that more fuel is required to sustain steady-state operation. When the operating line coincides with the acceleration schedule, the fuel control may be unable to deliver additional fuel to accommodate the increasing rain or hail ingestion. Under this condition, the engine may run down and could result in sub-idle engine operation, a loss of throttle response, or flameout.

c. Combustor response. The evaporation, in the combustor, of the liquid water resulting from the ingestion of rain or hail will cause a reduction in combustor flame temperature and will

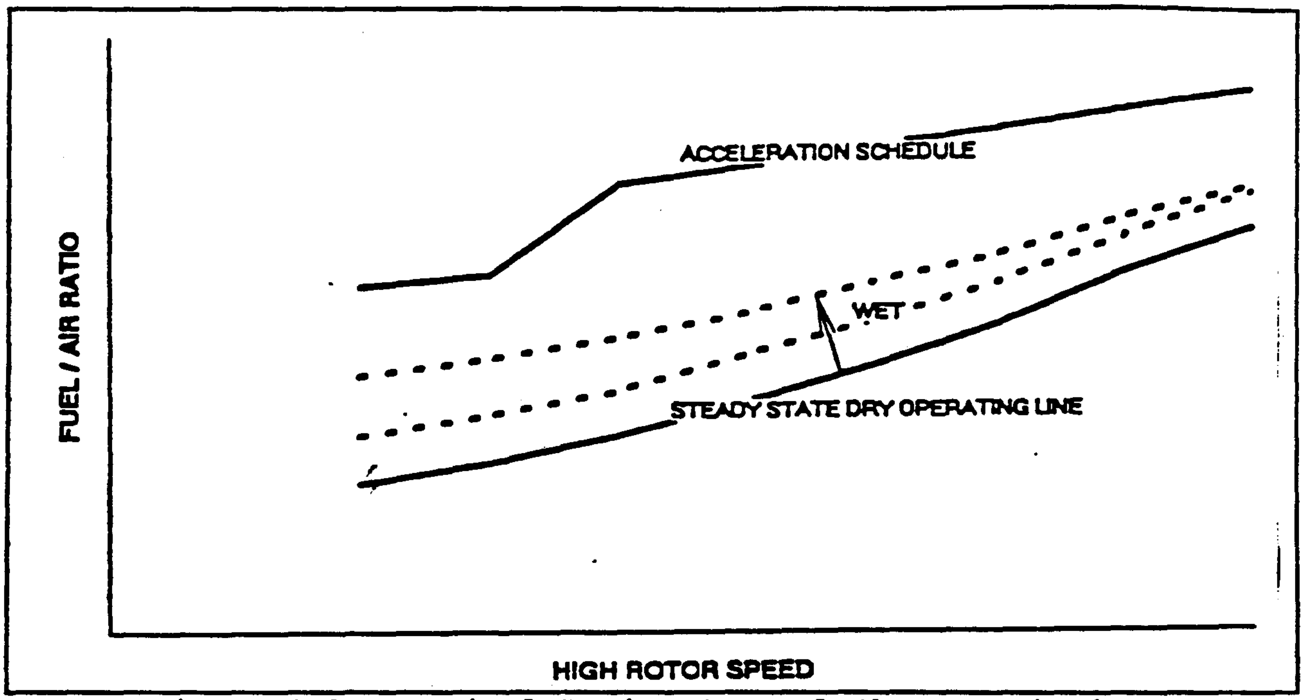

Figure 1-3. Typical Engine Control Characteristics

negatively affect combustor performance. The reduced temperature will result in slowing of the chemical reaction rate and inhibit complete combustion. This results in reductions in combustor efficiency and stability. Typically, the combustor is most susceptible to flameout when it is required to operate at a sub-idle operating condition. Therefore, a flameout condition may be preceded by engine run down as discussed previously in paragraph 9b.

10. CASE CONTRACTION. As rain or hail is ingested into the engine, the temperature of the compressor case may decrease at a faster rate than the compressor rotor. This would result in a reduction in compressor blade tip clearances and may result in blade tip rubs. Turbine engine types, such as turbojets, that have a significant scoop factor effect but lack design features to direct rain or hail away from the engine core (e.g., fan blades, bypass splitter, etc.) may be more susceptible to damage resulting from case contraction.

SECTION 2. DESIGN FACTORS

11. GENERAL. The response of a turbine engine to a rain or hail encounter depends on a number of design and operational factors. The manufacturer can greatly improve the operability of the engine during an extreme rain or hail encounter by incorporating certain

design features. However, the manufacturer should be aware that there may be a trade-off with some of these design features. For instance, a spinner designed to maximize hail rebound and rain droplet centrifuging may also result in a spinner which is more susceptible to large ice accretions.

12. DESIGN FEATURES. With knowledge of the power-loss and instability phenomena, the applicant can incorporate design features that increase the engine's tolerance to water.

a. Fan blade or propeller design and operating speeds. The fan blade or propeller, under the right conditions, can effectively centrifuge small droplets of rain away from the engine core. Hail particles and large droplets of rain can also be moved away from the engine core by the fan blade or propeller, but with considerably less effectiveness. The applicant should consider the relative velocity effects at the critical points when establishing fan blade or propeller geometry and operating speeds.

b. Spinner or nose cone. A spinner or a nose cone can effectively deflect rain and hail away from the engine core. Designing the spinner or nosecone to maximize hail deflection requires knowledge of the post impact trajectory characteristics of hail particles.

c. Bypass splitter. In the case of turbofan engines, increasing the gap between the fan blade trailing edge and the bypass splitter will normally tend to enhance the benefits, to the engine core, of the centrifugal effects of the fan blade.

d. Engine bleeds. Engine bleeds provide a direct means of extracting rain and hail out of the engine core and a direct means of increasing compressor surge and stall margins. The effectiveness of the bleed in extracting liquid water or hail particles out of the engine core will depend on the radial distribution of the water or hail particles, the location of the bleed, the bleed entrance geometry, and the bleed control logic. Also, in the case of hail, the bleed should be designed to minimize the likelihood of clogging.

e. Engine and aircraft accessory loads. Accessory loads will tend to move the fuel control operating line closer to the acceleration schedule and, therefore, should be minimized.

f. Fuel control. Fuel controls that schedule fuel using a rate change of compressor speed should provide consistent acceleration and deceleration thrust response during rain or hail ingestion.

g. Variable stator vane. The schedule of the variable stator vanes directly controls the compressor performance and stability characteristics. Weather-related sensing or scheduling errors may cause a loss of surge or stall margin.

13. OPERATIONAL FACTORS. With knowledge of the power-loss and instability phenomena, the applicant can establish an operating envelope which minimizes the power-loss and instability threats.

a. Increased power levels. Increasing engine power or thrust will increase rotor speeds and air intake requirements. This is beneficial because an increase in rotor speed will tend to improve centrifuging, while an increase in airflow will tend to decrease the adverse scoop factor effect.

b. Avoidance of engine transients. Avoidance of engine transients improves the stall and surge tolerance of the engine and reduces the likelihood of run down. However, avoidance of throttle transients should not be used by the applicant to show compliance with the rain and hail ingestion requirements.

c. Decreased flight speeds. Reduced aircraft speed, like increased power levels, is beneficial because it improves centrifuging while decreasing the adverse scoop factor effect.

SECTION 3. CRITICAL POINT ANALYSIS

14. GENERAL. Compliance with the requirements of FAR Section 33.78(a)(2) is a two-step procedure. The first step is to identify, through analysis, the critical operating points for rain and hail ingestion. The second step is to test the engine at selected critical points to validate the engine's capability to adequately withstand extreme rain and hail encounters. The applicant should develop a critical point analysis and submit the analysis to the appropriate FAA Aircraft Certification Office (ACO) for concurrence, prior to the rain and hail ingestion testing.

15. CRITICAL POINT ANALYSIS ELEMENTS. The purpose of the critical point analysis is to identify operating points within the engine flight envelope where operability margins are minimized due to the presence of rain or hail . The analysis should encompass the full range of all pertinent variables. These variables include, but are not limited to:

a. Atmospheric conditions. The rain and hail threats identified in Figure B1 and Tables B1 through B4 of Part 33, Appendix B, should be used for this purpose. The critical point analysis should consider the effects of nominal, as well as extreme, levels of rain or hail on the function of all relevant engine components and systems.

b. Rain and hail concentration amplification and attenuation effects. The analysis should quantify the amount of rain and, separately, the amount of hail ingested into the engine core. Therefore, amplification and attenuation effects, such as the scoop factor effect and the relative velocity effect, should be quantified. This may necessitate assessing a representative installation aerodynamic flow field and probable flight profiles. In the case of rain ingestion, droplet breakup characteristics need to be established or conservatively assessed. In the case of hail ingestion, the trajectories of hail particles after impacting nose cones, spinners, inlet surfaces, blades and vanes, etc. need to be established or conservatively assessed for determining critical points.

c. Engine power level. The entire envelope of power conditions should be analyzed. While run down and flameout are predominantly low power anomalies, compressor stability problems could occur at high power.

d. Engine parasitics. The variability of engine parasitics, such as air bleeds and accessory loads, should be analyzed for their effect on the critical points.

16. CRITICAL POINT ANALYSIS PROCEDURE. The critical point analysis is an assessment of the engine's capability throughout its operating envelope, given the range of event variables described above and any engine operability condition which is affected by ingested rain or hail. Typical operability conditions to consider include surge and stall margin, fuel control run down margin, combustor flameout margin, and instrumentation sensing errors. The critical point analysis should also address case contraction.

SECTION 4. COMPLIANCE METHODS

17. GENERAL. An engine compliance test method consistent with the critical point analysis permits the use of a ground level static facility with appropriate means of conducting engine tests with rain and hail ingestion at the increased concentrations that are necessary to simulate in-flight rain and hail concentration amplification effects and to compensate for the differences between the critical point conditions and the ground level test conditions. Other possibilities for demonstrating compliance include wind tunnel testing, direct core water-injection tests, component rig tests, scale model tests, and analyses.

18. TEST POINT SELECTION. The critical hail point(s) and rain point(s) that yield the least operability margin should be demonstrated by engine ingestion testing. Further, additional test points should be considered if any of the operability margins are determined to be minimal (i.e., compressor surge and stall, combustor blow out, fuel control run down, instrumentation sensing errors, etc.).

19. CRITICAL POINT TESTING AT GROUND LEVEL. The applicant may test the engine at ground level conditions, provided the relevant engine operational factors of the critical points are reproduced in a meaningful relationship.

a. Test compensation. The applicant should compensate for differences between the critical point conditions and the test facility conditions. These differences may include:

(1) Air density. The critical point percentage of rain and hail concentration by weight should be reproduced during the test. For example, 20 g/m^3 of rain at 20,000 feet is approximately 3 percent water by weight. At sea level, this percentage of water requires nearly 40 g/m^3 to compensate for the higher air density (refer to Figure B1 in Part 33, Appendix B).

(2) Scoop factor. The appropriate rain and hail concentration amplification due to the scoop factor effect should be applied to further increase the quantities of rain and hail for the ground level tests. This necessitates having knowledge of the inlet diffusing flow field throughout the engine power or thrust range and flight envelope.

(3) Engine rotational speeds. The low rotor speed for the ground level test should be no greater than the altitude critical point condition. This is particularly important for turbofan engines since rotational speed determines the rain and hail separation effects which prevent some of the rain and hail from reaching the engine core. The rain and hail concentrations may be adjusted to compensate for any necessary deviation from critical point rotational speeds.

(4) Variable systems. All variable systems, such as engine bleeds, whose position can affect engine operation in rain and hail, should be set in the position associated with the critical point.

(5) Engine power extraction. It should be shown by analysis or testing that margin exists for extraction of the representative electrical or shaft power loads and service air bleeds.

(6) Thermodynamic cycle differences. There may be thermodynamic cycle differences between the test point and the critical point which affect the operability of the engine. There should be compensation for these cycle differences, or it should be shown that these differences provide additional conservatism.

(7) Enthalpy of water. Rain and hail concentrations may be adjusted to ensure that the heat extraction resulting from their ingestions is the same as the critical point. If the ingestion of liquid water droplets is accepted (paragraph 20.) for critical hail point testing, then the water concentration should at least be increased to compensate for the heat of fusion of ice.

(8) Rain droplet breakup. In the ground level test environment, forces applied to accelerate the simulated rain droplets to flight speed, as well as shear forces between the droplets and the engine airflow, are apt to break up the droplets. This breakup can result in additional centrifuging by the fan or propeller and spinner. The concentration of the rain may need to be adjusted to compensate for the added centrifuging resulting from ground level testing.

b. Engine test facility. The engine test facility should provide a uniform water droplet or hail spatial distribution within the critical area of a plane within the engine intake, such plane being agreed to by the appropriate FAA ACO. The facility should also provide proper droplet or particle sizes, and proper velocity distributions, unless otherwise justified in accordance with Appendix B to FAR Part 33.

c. Instrumentation. Instrumentation and data sampling rates should be sufficient to establish rain and hail temperature and concentrations, particle velocities and size distributions, and engine response. Primary exhaust water to air ratio measurements, via gas sampling, should be considered. Instrumentation accuracy and repeatability should be demonstrated by suitable means.

d. Test procedure. The test procedure should consider the following for operability critical point tests and for the thermal shock (rain only) critical point test.

(1) Stabilize the engine at the critical point conditions.

(2) Take steady-state data readings before introducing rain or hail.

(3) Start continuous transient data recording prior to initiation of rain or hail flow.

(4) Establish altitude equivalent rain or hail flow at proper inlet velocity and size distribution.

(5) Conduct operability critical point tests at the following steady-state conditions:

(i) Deliver rain for a minimum of 3 minutes, at the altitude equivalent concentration defined in Figure B1 and Table B1 of Part 33, Appendix B.

(ii) Deliver hail for a minimum of 30 seconds, at the altitude equivalent concentration defined in Figure B1 and Table B2 of Part 33, Appendix B.

(6) When testing low power critical points (i.e., flameout, run down), conduct tests with ingestion at the following transient conditions:

(i) Accelerate the engine with one-second throttle movement to an appropriate power or thrust setting (e.g., 50% rated takeoff power or thrust) from the minimum rotor speed defined by the critical point analysis.

(ii) Decelerate engine with one-second throttle movement from an appropriate power or thrust setting (e.g., 50% rated takeoff power or thrust) to minimum rotor speed defined by critical point analysis.

(7) Conduct the thermal shock critical point test by delivering rain for 3 minutes at the critical power or thrust condition following a normal stabilization period without water ingestion. Maximum rain ingestion rate should occur within 5 seconds.

e. Probable factors. It should be demonstrated by test or analysis that the engine tested in accordance with paragraph 19d would have operated acceptably if exposed to other probable factors associated with a rain or hail encounter. These other probable factors would include, but are not be limited to, typical engine performance losses, installation effects, and typical auto-throttle power excursions.

f. Acceptance criteria. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. A momentary surge or stall that arrests itself without operational intervention (e.g., without throttle manipulation) is acceptable. If, after test, it is found that damage has occurred, further running or other evidence may be required to show that subsequent failures resulting from the damage are unlikely to occur before the damage is rectified. Engine performance should be measured before and after the rain and hail ingestion tests to assess steady state performance changes. Data should be normalized according to the applicant's standard practices and the evaluation of sustained loss or degradation of power or thrust should encompass the full range of engine power or thrust.

(1) Sustained power or thrust loss. Shift or error in measured thrust or power against the primary thrust or power set parameter(s) (i.e., fan speed, engine pressure ratio, Torque, etc.) as a result of the test should be limited to 3 percent for reasons of airplane safety.

(2) Power or thrust degradation. A change of engine corrected thrust or power of up to 10 percent from rated or pretest levels when using the applicant's normal performance parameters (i.e., exhaust gas temperature, high rotor speed, etc.), excluding the primary thrust or power setting parameter, is acceptable provided the criteria for sustained power or thrust loss is met.

20. OTHER COMPLIANCE ALTERNATIVES. Analysis may be used in lieu of, or in combination with, engine testing to demonstrate compliance with the requirements. The analytical methods used must have a sufficient validation basis to justify the accuracy of the predictions or be shown to yield conservative results. The amount of validation (i.e., engine test, rig test, experimental test, etc.) should be proportional to the complexity of the analytical methods used and to the criticality of the particular calculation to the prediction of engine operability.

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U.S. Department of
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FEDERAL AVIATION
ADMINISTRATION

Washington, D.C. 20591

PRELIMINARY REGULATORY EVALUATION, INITIAL REGULATORY FLEXIBILITY DETERMINATION, AND TRADE IMPACT ASSESSMENT

Airworthiness Standards: Water and Hail Ingestion Standards

Notice of Proposed Rulemaking
(14 CFR Part 33)

Office of Aviation Policy and Plans
Aircraft Regulatory Analysis Branch, APO-320
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Executive Summary

This regulatory evaluation estimates the benefits and costs of a proposed rule that would revise of Title 14 of the Code of Federal Regulations (CFR). The proposed rule would modify aircraft turbine engine water and hail ingestion standards in response to industry and Federal Aviation Administration (FAA) concerns over the hazards posed by a recently discovered turbine engine power-loss phenomenon associated with inclement weather operation. The rule would also harmonize existing rain and hail ingestion standards contained in the CFR and Joint Aviation Requirements (JAR). To this end, existing and proposed water and hail ingestion requirements would be consolidated into a new section of 14 CFR part 33. Parts 23 and 25 would be amended accordingly. The major provisions of the rule are summarized below.

First, the generic large hailstone test requirement now specified in §33.77(c) and (e) would be transferred to §33.78(a)(1). Although the test procedure would not be modified, the acceptance criteria would be. Current regulations preclude a sustained power or thrust loss following the ingestion of hail under the conditions specified in §33.77(e). The Aviation Rulemaking Advisory Committee (ARAC) Engine Harmonization Working Group (EHWG) concluded, however, that on the basis of service experience "sufficient airplane performance margins exist to permit sustained post ingestion power and thrust losses of up to 3 percent." Under the proposed rule, then, ingestion of large hailstones "may not cause unacceptable mechanical damage or unacceptable power or thrust loss." Unacceptable power loss is defined (in guidance material that would accompany the proposed rule) as a shift or error in measured thrust of greater than 3 percent. This provision relaxes the current acceptance requirement, thus there would be no incremental certification, design, manufacturing, or operating costs.

Second, the current water ingestion test requirement (which calls for the ingestion of 4% water by engine airflow weight) would be transferred to §33.78(a)(2). In this case, both the test procedure and acceptance criteria would be amended. While research conducted by industry indicates that the existing water ingestion standard does not, by itself, provide an adequate safety margin against the threat of water-induced power loss, the EHWG concluded that it does have value as a further test against the hazard of mechanical damage caused by engine case contraction. Thus, the proposed rule would retain the current water ingestion test with two modifications: First, the test acceptance criteria would be revised (in a fashion similar to the large hailstone ingestion test). The revisions to the acceptance criteria, again, relax the current requirement and would not generate incremental costs. Second, the sequence of power settings would be altered. Industry representatives also agree that there would be negligible costs associated with the proposed sequence of power settings and throttle transients.

Third, the proposal would introduce additional water and hail ingestion standards under §33.78(b). These would require that airplane turbine engines be capable of operating in certification standard concentrations of rain and hail (introduced in a proposed Appendix to 14 CFR Part 33) without experiencing flameout, run down, surge, stall or loss of acceleration or deceleration capability. Under the new rule, engines would be tested at selected critical points--that is, points within the engine flight envelope where operating margins are minimized due to the presence of rain or hail--at water concentrations that would also take into consideration: 1) atmospheric conditions, 2) water concentration and amplification effects, 3) engine power levels, and 4) engine parasitics (such as air bleeds and accessory loads). FAA conservatively estimates that incremental costs associated with this provision would be approximately $667,000 per certification (although costs would be significantly lower for certification of derivative types). Predicting this provision's effect on manufacturing and operating costs, however, is complicated by the nature of design/cost tradeoffs, the number of permutations of modifications which could achieve the desired result, and because engine design takes place in the context of constant technological change. Based on statements from industry, FAA expects that, once rain/hail centrifuging and engine cycle models are established, compliance would be accomplished through design modifications that would have little impact on manufacturing or operating costs.

Finally, the rule would amend 14 CFR parts 23 and 25 consistent with the proposed changes to part 33. Specifically, §23.901(d)(2) would require that a turbine engine installation be constructed and arranged so as not to "jeopardize the compliance of the engine with §23.903(a)(2)." The amendments to part 33 contained in this proposal, then, would be included by reference in §23.903(a)(2). Paragraph 25.903(a)(2) would be similarly revised. There are no incremental costs associated with this provision.

The benefits of the proposed rule are based on industry studies, and records from the FAA Accident/Incident Database and the National Transportation Safety Board (NTSB). An examination of these records for the period 1975-90, indicates that, in the absence of the proposed rule, the probability of a hull loss is 0.0104 per million airplane departures for large air carriers, and 0.0276 per million airplane departures for other air carriers. According to industry representatives, compliance with the proposed standards would reduce the event rate by two orders of magnitude. Under the assumption that the rule's effect on the accident rate is equiproportional, FAA concludes that the expected benefit for large air carriers (majors and nationals) is approximately $3,400 per airplane per year and that the expected benefit for other air carriers (large regionals, medium regionals, and commuters and other small certificated air carriers) is approximately $800 per airplane per year. Thus, for representative type certifications, discounted lifecycle benefits would be approximately $3.7 million and $0.8 million for large air carriers and other air carriers, respectively.

FAA finds the rule to be cost-beneficial. Under very conservative production, service life and incremental engine certification cost assumptions, the expected benefits of prevented casualties and aircraft damage would exceed costs by a factor ranging from 5.5 for large air carriers to 1.3 for other air carriers.

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Airworthiness Standards:

Water and Hail Ingestion Standards

I. Introduction

This regulatory evaluation estimates the benefits and costs of a proposed rule that would revise Title 14 of the Code of Federal Regulations (CFR). (A comparison of the current and proposed rules appears in Appendix I.) The proposed rule would modify aircraft turbine water and hail ingestion standards in response to industry and Federal Aviation Administration (FAA) concerns over the hazards posed by a recently discovered turbine engine power-loss phenomenon associated with inclement weather operation. The rule would also harmonize existing rain and hail ingestion standards contained in the CFR and Joint Aviation Requirements (JAR). To this end, existing and proposed water and hail ingestion requirements would be consolidated into a new section (§33.78) and 14 CFR parts 23 and 25 would be amended accordingly. The proposed rule's provisions are summarized below.

First, the rule would remove the hail and water ingestion standards now specified in §33.77(c) and (e). The generic large hailstone test requirement and the supersonic engine hailstone test requirement would be transferred to §33.78(a)(1) and §33.78(c), respectively. While the acceptance criteria for these tests would be revised, there would be no modifications to the test procedures themselves. The current water ingestion test requirement would be transferred to §33.78(a)(2). In this case, both the test procedure and acceptance criterion would be amended.

Second, additional water and hail ingestion requirements would be introduced in §33.78(b). These new requirements address a power-loss instability phenomenon identified by the Aerospace Industries Association (AIA) and the Association Europeenne des Constructeurs de Material Aerospatial (AECMA). By a procedure to be approved by FAA, manufacturers would have to show that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to the maximum concentrations of rain and hail (defined in proposed Appendix B to 14 CFR part 33). Acceptable engine operation would exclude flameout, rollback, surge, stall, loss of acceleration capability, unacceptable mechanical damage, or other adverse engine anomalies.

Finally, the rule would amend 14 CFR parts 23 and 25 consistent with the proposed changes to part 33. Specifically, §23.901(d)(2) would require that a turbine engine installation be constructed and arranged so as not to "jeopardize the compliance of the engine with §23.903(a)(2)." The amendments to Part 33 contained in this proposal, then, would be included by reference in §23.903(a)(2). Paragraph 25.903(a)(2) would be similarly revised.

II. Background

Aircraft turbine engines require sophisticated control systems because they are often run at speeds and temperatures close to their limits of durability and because their operation involves a large number of operating variables (e.g. inlet temperature, inlet pressure, compressor discharge temperature, turbine blade temperature) and control variables (e.g. primary fuel flow rate, guide vane and stator angles, bleed valve settings). The system manipulates the control variables to give the desired thrust constrained by engine operating limits. Operating limits, which vary for different engines, reflect speed limits set by stresses in the rotating components, turbine temperature limits, and compressor or fan pressure-ratio limits. In addition, engine performance can be greatly affected by environmental factors.

In a 1987 AIA study of icing effects on high bypass ratio (HBPR) turbofan engines, researchers discovered a separate power-loss phenomenon linked to operation in severe rain or hail storms. This discovery raised concerns that part 33 water ingestion test procedures, design considerations, and analysis methods were inadequate for ensuring safe engine operating margins in heavy weather. As a result, FAA recommended that AIA initiate a subsequent study (AIA study PC 338-1) to find the causes of the phenomenon, to determine the degree to which it affects turbine-engine aircraft operations, and to quantify weather conditions that are related to the phenomenon for the purpose of evaluating existing water ingestion standards and drafting new standards if necessary. An AIA task group was formed in March, 1988, and the results of the study were presented to FAA in June, 1990.

Industry tests revealed that, when operated in rain or hail, engine core water concentration can be significantly amplified through "relative velocity" and "scoop factor" effects. The relative velocity effect refers to the ability of the fan to centrifuge water away from the engine core. At high flight speed and low engine RPM, the velocity of large rain droplets or hailstones, relative to the fan, may allow significant amounts of water to pass through the fan without impact. The scoop factor refers to the ratio of the nacelle inlet area to the cross-section of the captured air stream tube. At high flight speed and low engine speed, air intake requirements are small relative to the available ram air. Consequently, a significant portion of the air in front of the inlet spills outside the inlet lip. Engine core water concentration is increased since, due to their mass, rain droplets and hailstones are less affected by this spillage.

High water concentrations, in turn, can affect turbine engine operation in two ways. First, the ingestion of water in the gas path can cause changes in compressor operating conditions. Industry studies showed that ingestion of excessive water can reduce compressor stall/surge margins. Second, water ingestion can affect engine control response. As the water-to-air ratio increases, the fuel required to maintain steady-state engine speed increases. However, as noted above, for a given set of operating conditions, fuel flow is constrained by engine operating limits. If the steady-state fuel requirement exceeds these constraints, the engine will run down.[1] This will result in a lack of throttle response, and may cause below-idle operation, surge or blowout.

PC 338-1 identified 114 weather related engine power-loss events involving HBPR turbofan engines in a sample consisting of 171.2 million engine hours (20.5 million airplane departures and 57.8 million engine departures) logged during revenue service in the ten year period 1980-89. One-hundred-one events occurred in flight, and, 85 of these culminated in an uncommanded in-air shutdown of the engine.[2] Twenty-six (31 percent) of the inflight shutdowns

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1 "Run down", or "roll back", is an uncommanded reduction of engine power.

2 PC 338-1 studied a number of weather factors including rain, hail, snow, turbulence, lightning, ice, and volcanic ash. The study sample consisted of A300, A310, A320, DC8-70, DC-10, L1011, B737, B747, B757, and B767 aircraft; and JT9D, CF6, CFM56, RB211, PW2000, PW4000, and V2500 engines. During 1971-89, turboprop engines had 42 aircraft events in 144.6 million aircraft flights (0.29 events per million flights), turbojet engines had 4 events in 200 million flights (0.02 events per million flights), and HBPR engines had 235

(aircraft events) involved rain or hail ingestion. Most of these cases could be ascribed to the amplification of atmospheric water in the engine core.[3] The report concluded that the water amplification effect was not adequately accounted for in 14 CFR part 33 and recommended revising current water and hail regulations.

In order to establish new water ingestion standards, additional weather information--including the frequency and intensity of severe rain and hail storms and the characteristics of rain droplets and hailstones--was required. Thus, AIA commissioned meteorological studies the results of which were used to construct the tables in proposed Appendix B to Part 33 (see Appendix II).

Rain intensity--measured by liquid water content (LWC), i.e. the mass of liquid water per unit of volume of air--and its frequency by location were obtained from publicly available weather data. These data were then used to estimate an equation relating annual occurrence probabilities to various LWC values. The proposed certification standard, based on an exceedance probability of 10^{-8}, calls for a concentration of 20 gm^{-3} at an altitude of 20,000.[4]

Hail was defined as frozen precipitation with a particle diameter of at least 0.5 cm. In a fashion similar to LWC, the relationship between hail water concentration and the annual probability of occurrence was estimated. HWC

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events in 25.6 million flights (9.17 per million flights). For events involving rain or hail, the HBPR rate was about 1.02 per million flights. *AIA PC 338-1 Study Results Presented to Regulatory Agencies, June 6-7, 1990.*

[3] The report concluded that: "Compliance with the proposed [water ingestion] standards [is] expected to diminish [the] occurrence rate by nearly two orders of magnitude." *Ibid.*, p 117.

[4] In tables B1 and B2 of proposed Appendix B, LWC and HWC certification standards are adjusted for altitude.

mechanical damage or unacceptable power or thrust loss." Unacceptable power loss is defined (in guidance material that would accompany the proposed rule) as a shift or error in measured thrust of greater than 3 percent.[7] As this provision relaxes the current acceptance requirement, there would be no incremental certification, design, manufacturing, or operating costs.

2. Ingestion of 4 percent water to engine airflow by weight (§33.78(a)(2))

While AIA research indicates that the existing water ingestion requirement does not, by itself, provide an adequate safety margin against the threat of water-induced power loss, the EHWG concluded that it does have value as a further test against the hazard of mechanical damage caused by engine case contraction. Thus, the proposed rule would retain the current water ingestion test with two modifications: First, the test acceptance criteria would be revised (in a fashion similar to the large hailstone ingestion criteria). The revisions to the acceptance criteria, again, relax the current requirement and would not generate incremental costs. Second, the sequence of power settings would be altered (the differences between the current and proposed sequences of power settings are listed in Appendix I). Industry representatives also agree that there would be negligible costs associated with the proposed sequence of power settings and throttle transients.

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[7] Where the shift or error is measured against the primary thrust or power set parameter (e.g. fan speed, N_1, or engine pressure ratio, EPR). An additional requirement in the proposed rule limits power or thrust degradation to 10 percent measured against performance parameters other than the primary parameter. This additional requirement is meant to clarify the test acceptance criteria and is not expected to have an incremental cost effect.

3. Additional water and hail ingestion test requirements (§33.78(b))

The proposal would introduce additional water and hail ingestion standards under §33.78(b). The new rule would require that aircraft turbine engines be capable of operating in certification standard concentrations of rain and hail without experiencing flameout, run down, surge, stall or loss of acceleration or deceleration capability. Engines would be tested at selected critical points--that is, points within the engine flight envelope where operating margins are minimized due to the presence of rain or hail--at water concentrations that would also take into consideration: 1) atmospheric conditions (specified in the Appendix B to part 33), 2) water concentration and amplification effects (i.e. scoop factor and relative velocity effects), 3) engine power levels, and 4) engine parasitics (such as air bleeds and accessory loads).

a. Incremental certification costs associated with §33.78(b)

The proposed rule would permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Analytical methods would most likely be the least expensive means to demonstrate compliance, while actual ingestion testing would be the most costly. Incremental cost estimates supplied by industry varied depending on engine model and the testing method used.[8]

[8] Estimates varied from $250,000 to over $500,000. It is important to note that these costs would be much lower for subsequent derivative type certifications. One manufacturer estimated that incremental certification costs for a derivative engine would be about $50,000.

FAA conservatively estimates that incremental certification costs for airplane turbine engines would be approximately $667,000--this includes $300,000 in additional engineering hours, and $367,000 for the prorated share of the cost of a test facility.[9]

Rotorcraft turbine engines are not subject to the requirements contained in §33.78(b). This follows because the scoop factor and relative velocity effects have little practical impact within the rotorcraft flight envelope. Rotorcraft normally descend at a proportionately greater power level and lower airspeed than airplanes.

b. Incremental manufacturing and operating costs associated with §33.78(b)

Predicting the rule's effect on manufacturing costs is complicated by design/cost tradeoffs, the large number of permutations of modifications that could achieve the desired result, and because engine design takes place in the context of constant technological change. Based on statements from industry, the FAA expects that, once rain/hail centrifuging and engine cycle models are established, compliance would be accomplished through design modifications that would have little impact on manufacturing costs. Such design features may affect: 1) fan blade/propeller, 2) spinner/nose cone, 3) bypass splitter,

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9 Several manufacturers have already constructed the necessary test facilities. In one case, the test facility incorporates other types of foreign object ingestion testing--the manufacturer estimated that the hail facility considered alone cost approximately $2 million (incremental test facility costs associated with the new water ingestion requirement are negligible). Assuming that: 1) the facility has a 30 year useful life, during which 10 (uniformly distributed) certification tests are performed and 2) the annual discount rate is 7%, then the incremental cost for the first certification is about $367,000.

4) engine bleeds, 5) accessory loads, 6) variable stator scheduling, and 7) fuel control. Similarly, the FAA expects that the rule would have a negligible effect on operating costs (again, based on discussions with industry).

4. Incremental costs associated with amendments to 14 CFR parts 23 and 25

Under existing §23.903(a)(2) and §25.903(a)(2), turbine engines for part 23 and part 25 airplanes must comply with §33.77 or be shown to have a foreign object ingestion service history, in similar installation locations, that has not resulted in any unsafe condition. The proposed rule would amend these paragraphs to include a reference to the new section §33.78. Thus, there would be no incremental costs associated with this provision.

B. Calculation of Expected Benefits

The PC 338-1 event history, and records from the FAA Accident/Incident Database and the National Transportation Safety Board (NTSB) show that rain or hail related, in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible. In its survey of HBPR turbofan engine operations, PC 338-1 reported that 77 percent of rain or hail induced in-flight shutdowns occurred in the descent, hold, or approach phases of flight.[10] An examination of the FAA Accident/Incident Database System and NTSB records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in descent phase. These accidents form the basis of the expected benefits for the proposed rule. However, what follows should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water.[11] Appendix IV shows that many accidents (not included in the benefit estimates that follow) were caused by other forms of water such as snow and graupel. It is possible that some of these cases would have benefitted from the proposed rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large aircraft designs incorporating fewer engines. PC338-1 identified seven events (not recorded in either the FAA or NTSB systems) in which rain and/or hail

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10 This is consistent with industry water ingestion studies since engine power during descent is low thus maximizing scoop factor and relative velocity effects. Out of 26 total inflight shutdowns involving rain or hail, 20 occurred during descent-approach-hold. In total, PC 338-1 documented 28 in-air HBPR turbofan shutdown events involving aircraft in descent-approach-hold during the period 1980-89 (this total includes shutdowns caused by snow, turbulence, lighting, ice, etc., in addition to rain and hail). Nineteen events involved one-engine and nine involved more than one engine. In 18 events, the aircraft were operating at low power (there was no information for the remaining 10 events). The study noted that the events involved three aircraft manufacturers and three engine manufacturers, but it did not provide information on specific aircraft or engine models, nor did it quantify property losses or casualties. (See footnote 2.)

11 This conclusion is based on discussions with industry representatives, but is not included in a formal comparison of benefits and costs.

affected two or more engines and resulted in an inflight shutdown of at least one engine.[12]

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.[13]

1. Benefits of prevented aircraft damage

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the proposed rule. These classifications are: 1) large air carrier aircraft(major and national air carriers), and 2) other air carrier aircraft (large regional, medium regional, commuter, and other small certificated air carriers).[14]

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12 Other incidents include: 1) April 25, 1990. A Lear 25D experienced a dual engine flameout caused by an encounter with hail and severe turbulence. Attempted air starts were unsuccessful and the aircraft sustained minor damage during a landing in a wheat field (there were no injuries). 2) May 24, 1988. A B737 made a forced landing on a levee outside New Orleans after both engines flamed out following an encounter with rain and hail.

13 Out of 28 inair shutdown events that occurred during descent, approach, or hold phases, the engine was successfully restarted in 16 cases; in one event the engine was restarted, then shutdown again; in 4 cases the engine either could not be restarted or restart was not attempted; there was no information for 7 of the cases. AIA PC 338-1 Study, op. cit., p 24.

14 These classifications arise from the nature of aircraft usage and accident data. Detailed calculations appear in Appendix II. One-hundred percent of major, national, large regional and medium regional departures were assumed to be of turbine-engine airplanes. The ratio of turbine to non-turbine departures for commuter and other small certificated carriers was estimated by using the ratio of the numbers of turbine to non-turbine airplanes reported in operation in 1993--Table 2.5, *Census of U.S. Civil Aircraft, Calendar Year 1993*. Otherwise, data sources include: the *FAA Statistical Handbook of Aviation, Calendar Year 1992*, Department of Transportation, Research and Special Programs Administration (RSPA) *Air Carrier Traffic Statistics* (various issues) and RSPA *Air Carrier Industry Scheduled Service Traffic Statistics* (various issues).

III.) The replacement cost is assumed to be one-half of the original aircraft value.[15]

Table 2.--Annual Average Risk of Preventable Aircraft Damage Per Aircraft per Year

	Annual Depart per A/C	Rule's effect on Event Rate per mil depart	Replacement Cost	Expected Benefit/Yr per A/C
Large A/C	1,481	0.0103	$22.11 mil	$337
Other AC	716	0.0273	$ 4.95 mil	$ 97

2. Benefits of prevented injuries and fatalities

Projecting the numbers of prevented injuries is problematic since this benefit depends on trends in aircraft size and usage (e.g. flights, load factors, etc.). Using estimates from the most recent *FAA Aviation Forecast*, this analysis assumes that the average large air carrier aircraft has 168 seats and a load factor of 61%. The average regional aircraft is assumed to have 30 seats and a load factor of 51%. The estimated distribution of fatal, serious, and minor injuries is based on the actual distribution of casualties taken from the accident history.[16] For example, the projected number of casualties per large air carrier airplane crash is equal to the number of seats times the load factor times the historical percentage of people killed in such an accident (168 x 61% x 67% = 69 fatalities). The projected number of

15 Federal Aviation Administration, *Economic Values of Evaluation of Federal Aviation Administration Investment and Regulatory Programs*, Report FAA-APO-89-10, October, 1989.

16 During the period 1975-90, FAA identified 75 fatalities, 28 serious injuries and 5 minor injuries attributable to airplane accidents caused by rain or hail ingestion. Of these, 62 fatalities, 26 serious injuries and 5 minor injuries occurred in large air carrier jet aircraft; and the remaining casualties occurred in other air carrier turbine-engine aircraft.

fatalities per million departures then, is the projected number of people killed per accident times the projected accident rate.

Table 3.--Projected Casualties per Million Departures

	Per Million Departures		
	Fatal	Serious	Minor
Large AC	0.7152	0.3006	0.0622
Other AC	0.3584	0.0551	0.0000
Total	0.6177	0.2335	0.0452

These data are used to compute the annual average benefit from avoided fatalities and injuries. Again, FAA makes the assumption, based on industry analyses, that the casualty rate would decline equiproportionately to the accident rate under the proposed rule. The rule's expected effect on the annual risk of death or injury, is estimated in Table 4 by multiplying the expected reductions in casualty rates by the annual departures per aircraft from Table 2. The expected annual benefit, then, is the product of risk reduction and its corresponding casualty value (obtained from guidance material furnished by the Office of the Secretary of Transportation on March 14, 1995).[17]

Table 4.--Estimated Benefits of Prevented Casualties
Per Airplane per Year.

	Rule's Estimated Effect			Annual Benefit per AC		
	Fatal	Serious	Minor	Fatal	Serious	Minor
Large AC	0.7080	0.2976	0.0616	$2,831	$ 228	$ 3
Other AC	0.3548	0.0546	0.0000	$ 686	$ 20	$ 0

FAA estimates the annual benefit of prevented casualties per aircraft to be $3,062 for large air carriers and $706 other air carriers.

17 The values of a fatality, serious injury and minor injury are $2.7 million, $518,000, and $38,000 respectively.

C. Benefit-Cost Analysis

The benefits and costs of the proposed rule are compared for two representative engine certifications using the following assumptions: 1) for each certification, 50 engines are produced per year for 10 years (500 engines), 2) incremental certification costs are incurred in year "0", 3) engine production begins in year "3", 4) the first engines enter service in year "4", 5) each engine is retired after 10 years, 6) the discount rate is 7 percent. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the airplane accident rate) this analysis assumes that each airplane has two engines.

For each airplane/engine type, the annual benefit per aircraft is the sum of the expected property and casualty benefits derived in Tables 2 and 4. The total benefit for each type certification, then, is the product of the per aircraft annual benefit and the number of aircraft in service summed over the life of the engines. The benefit calculations are summarized in Tables 5.

FAA finds that the rule would be cost-beneficial. Under very conservative production, service life, and incremental engine certification cost assumptions, the expected benefits of prevented casualties and aircraft damage would exceed costs by a factor ranging from 5.5 ($3,661,084/$667,000) for large air carriers to 1.3 ($864,696/$667,000) for other air carriers.

D. Harmonization Benefits

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Table 5.--Estimated Benefits

		Engines			Benefits		Discounted Benefits	
Year	Disc.	Manuf	In srvc	AC in srv	Large Air Carriers	Other Air Carriers	Large Air Carriers	Other Air Carriers
0	1.00							
1	0.93							
2	0.87							
3	0.82	50						
4	0.76	50	50	25	$84,969	$20,068	$64,822	$15,310
5	0.71	50	100	50	$169,938	$40,137	$121,163	$28,617
6	0.67	50	150	75	$254,907	$60,205	$169,855	$40,117
7	0.62	50	200	100	$339,876	$80,274	$211,657	$49,990
8	0.58	50	250	125	$424,844	$100,342	$247,263	$58,400
9	0.54	50	300	150	$509,813	$120,411	$277,305	$65,495
10	0.51	50	350	175	$594,782	$140,479	$302,357	$71,412
11	0.48	50	400	200	$679,751	$160,548	$322,945	$76,275
12	0.44	50	450	225	$764,720	$180,616	$339,545	$80,196
13	0.41		500	250	$849,689	$200,684	$352,591	$83,277
14	0.39		450	225	$764,720	$180,616	$296,572	$70,046
15	0.36		400	200	$679,751	$160,548	$246,373	$58,190
16	0.34		350	175	$594,782	$140,479	$201,473	$47,585
17	0.32		300	150	$509,813	$120,411	$161,394	$38,119
18	0.30		250	125	$424,844	$100,342	$125,696	$29,688
19	0.28		200	100	$339,876	$80,274	$93,978	$22,196
20	0.26		150	75	$254,907	$60,205	$65,873	$15,558
21	0.24		100	50	$169,938	$40,137	$41,042	$9,694
22	0.23		50	25	$84,969	$20,068	$19,179	$4,530
23	0.21		0	0	$0	$0	$0	$0
Tot		500			$8,496,889	$2,006,845	$3,661,084	$864,696

IV. Regulatory Flexibility Determination

The Regulatory Flexibility Act (RFA) of 1980 was enacted by Congress to ensure that small entities are not unnecessarily or disproportionately burdened by Government regulations. The RFA requires a Regulatory Flexibility Analysis if a rule is expected to have a "significant economic impact on a substantial number of small entities." Based on the standards and thresholds specified in implementing FAA Order 2100.14A, Regulatory Flexibility Criteria and Guidance, the FAA has determined that the rule would not have a significant impact on a substantial number of small manufacturers or users.

V. International Trade Impact Assessment

The rule would have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine engines in the U.S. The rule harmonizes with existing and proposed JAR requirements.

Appendix I: Comparison of Current and Proposed Rules

Proposed	Current	Comments
§23.901(d)(2): Not jeopardize the compliance of the engine with §23.903(a)(2).	§23.901(d)(2): Provide continued safe operation without a hazardous loss of power or thrust while being operated in rain for at least 3 minutes with the rate of water ingestion being not less than 4 percent by weight, of the engine induction airflow rate at the maximum installed power or thrust approved for takeoff and at flight idle. The engine must accelerate and decelerate safely following stabilized operation under these rain conditions.	**No incremental cost.**
§23.903(a)(2): Each turbine engine must either- (i) Comply with §33.77 and §33.78 of this chapter in effect on [*effective date of final rule*], or as subsequently amended; or (ii) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to [*effective date of final rule*]; or (iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.	§23.903(a)(2): Each turbine engine must either- (i) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended; or (ii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition	**No incremental cost**
§25.903(a)(2): Each turbine engine must either- (i) Comply with §33.77 and §33.78 of this chapter in effect on [*effective date of final rule*], or as subsequently amended; or (ii) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to [*effective date of final rule*]; or (iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.	§25.903(a)(2): Each turbine engine must either- (i) Comply with §33.77 of this chapter in effect on October 31, 1974, or as subsequently amended; or (ii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.	**No incremental cost**
§33.77 Foreign object ingestion. (a) Ingestion of a 4-pound bird, under the conditions prescribed in paragraph (e) of this section, may not cause the engine to--...etc. (b) Ingestion of 3-ounce birds or 1-1/2-pound birds, under the conditions prescribed in paragraph (e) of this section, may not--...etc.	§33.77 Foreign object ingestion. (a) Ingestion of a 4-pound bird, under the conditions prescribed in paragraph (e) of this section, may not cause the engine to--...etc. (b) Ingestion of 3-ounce birds or 1-1/2-pound birds, under the conditions prescribed in paragraph (e) of this section, may not--...etc.	(a) No change. **No incremental cost.** (b) No Change. **No incremental cost.**

Proposed	Current	Comments
§33.77 (continued): (c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.	(c) Ingestion of water, ice, or hail, under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down. It must be demonstrated that the engine can accelerate and decelerate safely while inducting a mixture of at least 4 percent water by weight of engine airflow following stabilized operation at both flight idle and takeoff power settings with at least a 4 percent water-to-air ratio.	**See §33.78 for cost impact.**
(d) For an engine that incorporates a protection device, compliance with this section need not be demonstrated with respect to foreign objects to be ingested under the conditions prescribed in paragraph (e) of this section if it is shown that-- (1) Such foreign objects are a size that will not pass through the protective device; (2) The protection device will withstand the impact of the foreign objects; and (3) The foreign object, or objects, stopped by the protective device will not obstruct the flow of induction air into the engine, with a resultant sustained reduction in power or thrust greater that those values required by paragraphs (b) and (c) of this section.	(d) No change	
(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:	(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion contions.	
Ice: Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine. Speed of object: sucked in. Engine operation: maximum cruise. Ingestion: To simulate a continuous maximum icing encounter at 25°F.	Ice: Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine. Speed of object: sucked in. Engine operation: maximum cruise. Ingestion: To simulate a continuous maximum icing encounter at 25°F.	No change. **No incremental costs.**
	Hail...	Removed from table. **See §33.78 for cost impact.**
	Water...	Removed from table. **See §33.78 for cost impact.**

Proposed	Current	Comments
§33.78 Water and hail ingestion (a) All engines. (1) Ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum rough air speed, up to 15,000 ft (4,500 m), associated with a representative aircraft traveling at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss. 1/2 the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstone number and size shall be determined as follows--(i) One 1-in (25 mm) hailstone for engines with inlet area of not more than 100 sq ins (0.0645 m^2). (ii) One 1-in (25 mm) and one 2-in (50 mm) hailstone for each 150 sq ins (0.0968 m^2) of inlet area, or fraction thereof, for engines with inlet area more than 100 sq ins (0.0645 m^2).	From table in §33.77(e): Hail (0.8 to 0.9 specific gravity) For all engines: With inlet area of not more than 100 square inches: one 1-inch hailstone. With inlet area of more than 100 square inches: one 1-inch and one 2-inch hailstone for each 150 square inches of inlet area or fraction thereof. Speed of foreign object: Rough air flight speed of typical aircraft. Engine operation: Maximum cruise at 15,000 feet altitude. Ingestion: In a volley to simulate a hailstone encounter. 1/2 aimed at random over the inlet face, 1/2 aimed at critical engine face area.	**No incremental cost.**
(2) Sudden ingestion of at least four percent water to engine airflow by weight, using water droplets not exceeding 2 millimeters diameter, may not cause unacceptable mechanical damage, unacceptable power loss after the ingestion, or require the engine to be shutdown, when operated under the following conditions--(i) Three minutes at takeoff power following normal stabilization period at takeoff power without water ingestion. (ii) During subsequent rapid deceleration to minimum idle. (iii) Three minutes at minimum idle power to be certified for flight operation. (iv) During subsequent rapid acceleration to takeoff power.	From table in §33.77(e): Water. At least 4 percent of engine airflow by weight. Speed of foreign object: Sucked in. Engine operation: Flight idle, acceleration, takeoff, deceleration. Ingestion: For 3 minutes each at idle and takeoff, and during acceleration and deceleration in spray to simulate rain.	**No incremental cost.**
(b) Engines for airplanes (subsonic or supersonic). It must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden and continuing encounters with the certification standand concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down (rollback), surge, stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.	From table in (e): Water: At least 4 percent of engine airflow by weight. Speed of foreign object: sucked in. Engine operation: flight idle, accerlation, takeoff, deceleration. Ingestion: for 3 minute each at idle and takeoff, and during acceleration and deceleration in spray to simulate rain.	**Three manufactures interviewed. incremental cost = $250,000-$500,000+ (per certification), but cost for derivative type certs would be lower (approximately $50,000 per certification). Negligible incremental manufacturing or operating cost.** **Test procedures established in AC.**

Proposed	Current	Comments
(c) For supersonic engines. Three hailstones shall be ingested at supersonic cruise velocity. The hailstone size shall correspond to the lowest supersonic cruise altitude expected, given that these hailstones vary linearly in diameter from 1-inch (25 mm) at 35,000 ft (10,500 m) to 1/4-inch (6 mm) at 60,000 ft (18,000 m). These hailstones shall be aimed at the critical engine face area. Alternatively, ingestion of these hailstones may be performed at subsonic velocities with larger hailstones to give equivalent kinetic energy. Ingestion of these hailstones may not cause unacceptable mechanical damage or unacceptable power or thrust loss after ingestion.	From table in (e): Hail (0.8 to 0.9 specific gravity) For supersonic engines (in addition): 3 hailstones each having a diameter equal to that in a straight line variation from 1 inch at 35,000 feet to 0.25 inch at 60,000 feet using diameter corresponding to the lowest supersonic cruise altitude expected. Speed of foreign object: Supersonic cruise velocity. Alternatively, use subsonic velocities with larger hailstones to give equivalent kinetic energy. Engine operation: Maximum cruise. Ingestion: Aimed at critical engine face area.	**No incremental cost.**
(d) For an engine that incorporates a protection device, demonstration of the water and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), (c), and (d) of this section, may be waived wholly or in part if it is shown that-- (1) The subject water constituents are of a size that will not pass through the protection device; (2) The protective device will withstand the impact of the subject water constituents; and (3) The subject water constituents, stopped by the protective device, will not obstruct the flow of induction air into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be acceptable in paragraphs (a), (b), (c), and (d) of this section.	Similar to existing §33.77(d).	**No incremental cost.**

Appendix II: Proposed Rain/Hail Concentrations and Characteristics

Figures (not shown) and tables in proposed Appendix B to FAR Part 33 define the certification standards for rain and hail concentrations and size distributions. The tables are reproduced below:

Proposed Table B1--Certification Standard Atmospheric Rain Concentrations (LWC values at other altitudes may be determined by linear interpolation)

Altitude (feet)	LWC (grams/m^3)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

Proposed Table B2--Certification Standard Atmospheric Hail Concentrations (HWC values at other altitudes may be determined by linear interpolation)

Altitude (feet)	HWC (grams/m^3)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

Proposed Table B3--Certification Standard
Atmospheric Rain Droplet Size Distribution

Rain Droplet Diameter (mm)	Contribution to Total LWC (%)
0 - 0.49	0.00
0.50 - 0.99	2.25
1.00 - 1.49	8.75
1.50 - 1.99	16.25
2.00 - 2.49	19.00
2.50 - 2.99	17.75
3.00 - 3.49	13.50
3.50 - 3.99	9.50
4.00 - 4.49	6.00
4.50 - 4.99	3.00
5.00 - 5.49	2.00
5.50 - 5.99	1.25
6.00 - 6.49	0.50
6.50 - 7.00	0.25
TOTAL	100.00

Proposed Table B4--Certification Standard
Atmospheric Hailstone Size Distribution

Hailstone	Contribution to
Diameter (mm)	Total HWC (%)
0 - 4.9	0.00
5.0 - 9.9	17.00
10.0 - 14.9	25.00
15.0 - 19.9	22.50
20.0 - 24.9	16.00
25.0 - 29.9	9.75
30.0 - 34.9	4.75
35.0 - 39.9	2.50
40.0 - 44.9	1.50
45.0 - 49.9	0.75
50.0 - 55.0	0.25
TOTAL	100.00

Appendix III: Calculation of Departures for Large and Regional Air Carriers

Accident and injury rates contained in this regulatory analysis are based on domestic departures for large and small certificated air carriers. Large air carriers departures are defined as domestic scheduled and non-scheduled departures for major and national air carriers. Departure information was obtained from the Department of Transportation, Research and Special Program Administration's *Air Carrier Traffic Statistics Monthly*. An estimate of the number of departures per year per large-air-carrier airplane was computed by dividing 1992 total departures by the number of active airplanes for the same year (Table 2.4, *FAA Census of U.S. Civil Aircraft*). This evaluation assumes that all large air carrier departures were of turbine-engined airplanes.

"Other air carrier" departures were computed by adding domestic scheduled and non-scheduled departures for large, medium, and small regionals. These data were gotten from the latest *FAA Statistical Handbook of Aviation* (Table 6.17) and RSPA's *Air Carrier Traffic Statistics Monthly*. This evaluation assumes that 100 percent of large and medium regional departures were of turbine-engined airplanes. However, small regional departures were adjusted to account for the fact that many small commuters make use of piston-powered airplanes. Thus, the ratio of turbine- to piston-powered airplanes reported in operation by commuter air carriers and on-demand air taxis (Table 2.5, *Census of U.S. Civil Aircraft*) was used to estimate the proportion of turbine-engined airplane departures.

Table AIII.1--Scheduled and Nonscheduled Departures for Large and Other Air Carriers

	MAJORS Departures		NATIONALS Departures		Lg Air C	LARGE REGIONAL Departures		MED REGIONAL Departures		Estimated Sm Com Only	Estimated Regional Turbine
	Sch	Non-sch	Sch	Non-sch	Total	Sch	Non-sch	Sch	Non-sch	Total	Total
1992	5,428,655	12,256	776,891	138,496	6,356,298	267,111	41,710	4,897	34,993	1,819,178	2,167,889
1991	5,338,975	15,641	919,371	124,438	6,398,425	158,277	58,195	2,312	8,979	2,935,373	3,163,136
1990	5,614,130	18,147	886,594	111,313	6,630,184	78,063	64,082	3,530	15,059	2,993,680	3,154,414
1989	5,386,444	16,838	793,456	121,493	6,318,231	114,276	90,720	1,614	11,901	2,675,931	2,894,442
1988	5,047,590	10,945	1,113,891	98,977	6,271,403	236,497	94,130	192	11,538	2,547,099	2,889,456
1987	4,910,193	10,156	1,080,624	32,093	6,033,066	314,579	89,110	4,284	66,527	2,097,321	2,571,821
1986	4,306,504	8,225	1,393,735	45,488	5,753,952	484,871	83,565	18,832	15,596	1,939,880	2,542,744
1985	3,795,440	7,840	1,086,305	36,355	4,925,940	582,316	73,769	11,716	22,447	1,991,463	2,681,711
1984	3,658,914	12,456	1,052,274	30,486	4,754,130	347,287	74,915	173,177	12,100	1,763,715	2,371,194
1983	3,247,724	8,920	1,058,904	29,578	4,345,126	406,767	51,531	93,000	29,293	1,305,188	1,885,779
1982	3,117,595	8,930	1,053,181	28,381	4,208,087	282,796	42,223	316,289	30,293	1,160,224	1,831,825
1981	3,231,325	9,224	1,061,472	30,316	4,332,337	446,596	37,747	263,341	11,137	876,765	1,635,586
1980	3,581,649	13,225	1,017,195	40,570	4,652,639	357,728	29,105	174,926	12,784	753,546	1,328,089
1979	3,590,457	9,679	1,019,696	29,691	4,649,522	358,608	21,300	175,356	9,356	459,672	1,024,291
1978	3,348,922	10,573	951,100	32,436	4,343,031	334,484	23,269	163,560	10,221	329,066	860,600
1977	3,287,775	11,844	933,734	36,335	4,269,688	328,376	26,067	160,573	11,449	422,769	949,235
1976	3,209,388	9,189	911,472	28,189	4,158,238	320,547	20,223	156,745	8,883	315,712	822,109
1975	3,109,812	12,487	883,192	38,306	4,043,797	310,602	27,481	151,882	12,071	250,971	753,006
1974	3,105,725	12,428	882,032	38,126	4,038,312	310,194	27,352	151,682	12,014	244,438	745,679
Total	76,317,217	219,003	18,875,120	1,071,066	96,482,406	6,039,975	976,493	2,027,908	346,640	26,881,989	36,273,005

Date	Aircraft	Appendix IV: Summary of FAA/NTSB Accident Record	Srce		Casualties			
			1	2	F	S	M	N
11/12/75	B727-225	Raleigh, NC. (Excerpt from NTSB brief) "NTSB determines that the probable cause of the accident was an encounter with heavy rain and associated downdrafts and windshear during the final stages of landing when the airplane was less than 100 feet above the ground." (Excerpt from Airline Pilot's Association petition to NTSB) "...consideration should have been given to the effect the heavy rain had on the thrust output of the engines. Even a momentary thrust loss as the aircraft progressed through the downdraft and the associated 'wall of water' would have reduced the aircraft's ability to perform as the pilot intended and expected to perform...the instantaneous rainfall rate at [the time of the accident] approached 7 inches/hour, an intensity characteristic of the heaviest tropical downpour." Descent. Possible	x		0	4	4	131
04/04/77	DC-9	Rome, GA. (Excerpt from NTSB brief) "...the Safety Board concludes that the causal factors related to this accident are associated with the severe weather conditions that flight 242 encountered near Rome, Georgia, the extent of the flightcrew's knowledge of those conditions before the encounter, and the information about those conditions provided to the flightcrew. After the severe weather conditions were encountered and thrust from the engines was completely and permanently lost, an accident most probably was inevitable...the engine tests proved that rotational speed will be lost at low thrust settings if water is ingested at a rate greater than 14 percent water-to-air ratio." Descent.	x		62	22	1	na
01/29/80	Lockeed L1011	Tower reported to captain #1 engine on fire. Snow ingested into engine causing flameout, fire in tailpipe. Landing.		x	0	0	0	na
06/12/80	Swrngn SA-226	Valley, NE. (Excerpt from NTSB brief) "The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's continued flight into an area of severe thunderstorms, and the resultant precipitation induced flameout or loss of power of both engines at an altitude from which recovery could not be made...After the accident, a test was conducted to determine the effect of rainfall above 4 percent water-air ratio...Operation ceased when water quantities reached a 9.46 percent of engine airflow. This figure was more than twice the maximum certification level." Descent.	x		13	2	0	0
01/06/81	Swrngn SA 226 TC	Aircraft encountered ice. Left prop spinner ice was ingested in engine resulting in engine flameout. Test run OK. Descent.		x	0	0	0	na
01/07/81	Swrngn SA 226 TC	Right followed by left engine quit. Safe landing. Ice ingestion suspected. Approach.		x	0	0	0	na
01/13/82	Swrngn SA 226 TC	Engine flamed out on landing roll. Slush from runway blocked air and oil cooler inlets. Landing.		x	0	0	0	na
01/14/82	Mtsbsi MU-2B20	Engines flamed out on landing from slush on runway. Stopped, cleaned out engines, restarted, taxied in. Landing.		x	0	0	0	na

03/21/83	Swrngn SA 226 TC	Aircraft began to swerve on landing roll. Unable to correct due to engine flameout from heavy wet snow on runway. Landing.		x	0	0	0	na
03/21/83	Swrngn SA 226 TC	Aborted takeoff due to engine flameout. Slush and water found in engine. Airplane became stuck in slush and snow. Takeoff		x	0	0	0	na
12/28/83	Swrngn SA 226 TC	Engine flamed out on takeoff roll. Aborted. Slush on runway a possible factor. No engine damage. Takeoff.		x	0	0	0	na
04/29/84	B727	Compressor stall on takeoff roll. Ingested heavy wet snow and slush. Engine removed. Takeoff		x	0	0	0	na
04/29/84	Douglas DC-9-15	Both engines flamed out when nosewheel touched runway. Standing water and slush on runway. Both engines found OK. Landing.						
06/13/84	Beech 200	Both engines had intermittant power loss and flashes from exhaust. Requested lower altitude. May have been ice.		x	0	0	0	na
06/13/84	Douglas DC-9-31	During arrival, aircrew noted thunderstorms west and southwest of airport. Crew elected to continue and make an ILS approach. The VIS dropped to 1/4 mile with heavy rain and hail. As aircraft approached runway, VIP level 4 thunderstorm moved over the northern part of the airport. Controller provided wind info from the low level wind shear alert system, but used improper phraseology...At approximately 350' AGL, the aircraft encountered low clouds, heavy rain, hail and turbulence. The aircrew initiated a missed approach. Speed increased to 143 knots, then decreased to 119 knots. Captain believed the aircraft would not climb and elected to land. Aircraft touched downabout 2500' down the runway with the gear partially extended, then slid 3800' and went off runway.	x				10	46
02/05/85	Douglas DC-9-15	After landing, aircraft was parked on ramp for approximately 39 minutes to unload cargo. During that time, light freezing drizzle was falling, intermittently mixed with ice pellets and snow. The crew checked the aircraft surfaces from the cockpit and entry door, but observed no ice. Takeoff was normal until just after lift-off, then aircraft entered an uncommanded left roll and both engines compressors stalled. The aircraft touched down left of the runway on the tail skid and right wing tip...it then travelled another 2025' in a sweeping right arc, hitting 2 runway signs and came to rest with right pylon bent down. Investigation revealed a thin layer of ice would have been on wings, raising aicraft stall speed. When DC-9-15 aircraft stall, engines are susceptible to compressor stall.	x	x	0	2	0	na
02/13/85	Swrngn SA 226 TC	Right followed by left engine quit. Safe landing Ice ingestion suspected. Final approach.		x	0	0	0	na
12/10/85	Saab SF 340A	Flame out on left engine during descent with light ice. Restart accomplished. No malfunction or damage found. Descent.		x	0	0	0	na

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25, and 33

[Docket No. 28652; Notice No. 96–12]

RIN 2120–AF75

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes changes to the water and hail ingestion standards for aircraft turbine engines. This proposal addresses engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. This proposal also harmonizes these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). The proposed changes, if adopted, would establish one set of common requirements, thereby reducing the regulatory hardship on the United States and worldwide aviation industry, by eliminating the need for manufactures to comply with different sets of standards when seeking type certification from the Federal Aviation Administration (FAA) and JAA.

DATES: Comments to be submitted on or before November 7, 1996.

ADDRESSES: Comments on this notice may be delivered or mailed, in triplicate, to: Federal Aviation Administration, Office of the Chief Counsel, Attention: Rules Docket (AGC-200), Docket No. 28652, Room 915G, 800 Independence Avenue, SW., Washington, DC 20591. Comments submitted must be marked: "Docket No. 28652. Comments may also be sent electronically to the following Room 915G on weekdays, except Federal holidays, between 8:30 a.m. and 5:00 p.m.

FOR FURTHER INFORMATION CONTACT: Thomas Boudreau, Engine and Propeller Standards Staff, ANE–110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803–5229; telephone (617) 238–7117; fax (617) 238–7199.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Comments relating to the environmental, energy, federalism, or economic impact that might result from adopting the proposals in this notice are also invited. Substantive comments should be accompanied by cost estimates. Comments must identify the regulatory docket or notice number and be submitted in triplicate to the Rules Docket address specified above.

All comments received, as well as a report summarizing each substantive public contact with FAA personnel on this rulemaking, will be filed in the docket. The docket is available for public inspection before and after the comment closing date.

All comments received on or before the closing date will be considered by the Administrator before taking action on this proposed rulemaking. Late-filed comments will be considered to the extent practicable. The proposals contained in this notice may be changed in light of comments received.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must include a pre-addressed, stamped postcard on those comments on which the following statement is made: "Comments to Docket No. 28652." The postcard will be date stamped and mailed to the commenter.

Availability of NPRMs

An electronic copy of this document may be downloaded using a modem and suitable communications software from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703–321–3339), the **Federal Register's** electronic bulletin board service (telephone: 202–512–1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone: 202–267–5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the **Federal Register**'s webpage at http://www.access.gpo.gov/su_docs for access to recently published rulemaking documents.

Any person may obtain a copy of this NPRM by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM–1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267–9680. Communications must identify the notice number of this NPRM.

Person interested in being placed on the mailing list for future NPRM's should request from the above office a copy of Advisory Circular No. 11–2A, Notice of Proposed Rulemaking Distribution System, that describes the application procedure.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

Industry Study

In 1987 the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to part 33, if appropriate. AIA, working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of 14 CFR part 33 do not adequately address this threat.

Engine Harmonization Effort

the FAA is committed to undertaking and supporting harmonization of standards in part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. The partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which where considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards. This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On November 7, 1995, the TAEIG recommended to the FAA that it proceed with rulemaking and associated advisory material even though one manufacturer has expressed reservations. This NPRM and associated advisory material reflects the ARAC recommendations.

Disposition of Objections

One manufacturer participating in the EHWG has expressed reservations with the proposal. The reservations focused on the degree of conservatism built into the assumptions regarding weather statistics. These reservations include concerns about a bias in the hail characterization towards geographical areas of extremely high hailstorm probabilities and with an apparent rounding up of the hail threat definition from 8/3 g/m³ to 10 g/m³. The manufacturer also expressed concern regarding the lack of standardized test procedures and analytical methods for compliance within the industry.

During the early phase of defining the environmental threat, for both rain and hail, engineering judgment suggested that expressing rain water content (RWC) and hail water content (HWC) as a function of a joint probability was an appropriate method. That joint probability is the product of the prior probability of a storm occurring at a given point and the conditional probability of a given water concentration value occurring within that storm. Given the potential for a pilot to avoid a storm and the ability for an engine to recover sufficiently for continued safe flight, a joint probability of 10^{-8} was determined adequate for establishing the certification standards for rain and hail. Accounting for hail shaft exposure times, the hail threat levels could vary from 8.7 g/m³ to 10.2 g/m³. The choice of 10 g/m³ was agreed to by the EHWG as the certification standard that would be suitable for all applications. It was not simply a round up. Admittedly, the only credible hail data available was for high hail probability areas in North America and Europe. While these data may not represent the average world environment, they do represent areas of high commercial air traffic through which aircraft equipped with turbine engines normally operate.

The EHWG also consider the proposal and the associated harmonization activity to be an effective method of reaching a more uniform method for compliance by manufacturers. That activity has already fostered a significant sharing of knowledge on the subject.

Current Requirements

The current water and large hailstone ingestion standards are valid tests for addressing permanent mechanical damage resulting from such ingestions. However, they do not adequately address engine power-loss and instability effects, such as run down and flameout at lower than takeoff-rated power settings for turbine engines installed on airplanes.

The EHWG concluded that, with respect to power-loss and instability effects, the current water ingestion standard is adequate for turbine engines installed on rotorcraft (turboshaft engines) as an alternative to the new rain and hail ingestion standards. The EHWG reached this conclusion after it had reviewed the service experience of rotorcraft turbine engines and could not find an inservice event that would indicate that the current water ingestion standard are inadequate for that application. There are differences between rotorcraft and airplanes that help to explain the differences in the service experience of rotorcraft turbine engines versus other turbine engines. Rotorcraft turbine engines operate at higher power settings during descent than turbine engines installed on airplanes. Also, rotorcraft operate at lower flight speeds than airplanes. The combination of higher engine power and lower flight speed significantly reduces the water concentration amplification effects on rotorcraft turbine engines. Therefore, the proposed new rain and hail ingestion standards apply to all turbine engines, while a harmonized version of a four percent water to engine airflow by weight ingestion standard is proposed as an alternative for turbine engines installed on rotorcraft.

General Discussion of the Proposals

Section 23.901(d)(2), § 23.903(a)(2) and § 25.903(a)(2)

The proposed amendments would revise § 23.903(a)(2) and § 25.903(a)(2) to be consistent with the proposed part 33 changes. Additionally, proposed § 23.901(d)(2) would replace the current text with new text requiring each turbine engine installation to be constructed and arranged not to jeopardize compliance of the engine with § 23.903(a)(2). This would ensure that the installed engine retains the acceptable rain, hail, ice, and bird ingestion capabilities established for the uninstalled engine under § 23.903(a)(2).

Section 33.77

The proposed amendments would remove the large hailstone ingestion standards now specified in § 33.77 (c) and (e), and place them in new § 33.78 (a)(1) and (c). The proposal would also harmonize the four percent water to engine airflow by weight ingestion standard, currently specified in § 33.77 (c) and (e), and place it in new § 33.78(b) as an alternative standard for rotorcraft turbine engines to the proposed new rain and hail ingestion standards. New water and hail ingestion standards for all turbine engines would be introduced in new § 33.78(a)(2). All rain and hail ingestion standards would then be found in one section, as in the current JAR–E.

The intent of the current water ingestion standard is to address a number of concerns including power-loss, instability, and the potential hazardous effects of water associated with case contraction. As stated previously, there have been numerous power-loss and instability events on airplane turbine engines since the standard was promulgated (39 FR 35463, October 1, 1974). The need to better address power-loss and instability effects at lower than takeoff-rated power settings led to the proposed new standards for all turbine engines (new § 33.78(a)(2)). Collectively, the proposed new standards and the proposed changes as contained in new § 33.78 (a)(2) and (b) also better address potential concerns associated with case contractions on turbine engines since they are based on a more thorough understanding of the in-flight effects of rain and hail ingestion.

Section 33.78

The proposed § 33.78 would consolidate all harmonized rain and hail ingestion standards for turbine engines, and the corresponding harmonized acceptance criteria, into a single section. The proposal also introduces new rain and hail ingestion standards for turbine engines to address the power-loss and instability phenomena identified by AIA and AECMA.

Currently, part 33 and JAR–E have different acceptance criteria for the water and large hailstone ingestion standards. In general, part 33 does not permit any sustained power or thrust loss after the ingestion, while JAR–E permits some power or thrust loss and some minimal amount of mechanical damage. The EHWG determined, however, that the current FAA post ingestion power loss criterion does not consider thrust and power loss variabilities, such as inherent measurement inaccuracies. Therefore, allowing some measured power or thrust loss would be reasonable but must not reduce the level of safety intended by these requirements.

The EHWG concluded that sufficient airplane performance margins exist to permit sustained post ingestion power or thrust losses up to 3 percent at any value of the power or thrust setting parameter. Variabilities and uncertainties associated with thrust and power measurements could conceivably result in upwards of a 3 percent power or thrust measurement error. Therefore, measured post ingestion power or thrust losses up to 3 percent are acceptable and do not represent a reduction in the level of safety provided by current FAA water and large hailstone ingestion standards. However, measured post ingestion power or thrust losses greater than 3 percent, at any value of the primary power or thrust setting parameter, can only be accepted when supported by appropriate airplane performance assessments.

The EHWG also discussed levels of acceptable engine performance degradation that might be experienced as a result of certification testing. This degradation is a power or thrust reduction when pre-test and post test comparisons are made at any given values of the engine manufacturer's normal performance parameters other than the primary power or thrust setting parameter. This power or thrust degradation must not affect the measured power or thrust of the engine at any value of the primary power or thrust setting parameters, but would tend to reduce the available gas path temperature margin of the engine after the test. It is the judgment of the EHWG, based on certification and development test experience, that current and future technology engines should be capable of demonstrating less than 10 percent engine performance degradation from a single hail or rain ingestion event. Some members of the EHWG believe that values greater than 10 percent can be safely accommodated, but consensus could not be obtained in defining this uppermost value. The EHWG accepted the 10 percent value as a compromise certification standard for future use in the context of rain and hail ingestion testing. In the event that future certification tests result in engine performance degradations that exceed 10 percent, the actual demonstrated level must be evaluated for acceptability against the criterion of aircraft safety.

The proposed new rain and hail ingestion standards to address the power loss and instability phenomena refer to a proposed new FAR part 33 appendix for a definition of maximum concentrations of rain and hail in the atmosphere. It is expected that a combination of tests and analyses would be needed to demonstrate compliance. Therefore, this proposal allows for various means of compliance.

Allowing various means of compliance has distinct advantages. The variables associated with an ingestion event are best addressed through a combination of tests and analyses. Also, it is anticipated that further insight into the phenomenon of rain and hail ingestion would be gained through the development of these various compliance methods. Finally, the EHWG believes that applicants would develop compliance methods which minimize the cost impact.

Rain and hail ingestion standards embodied in this rule represent an extremely remote probability of encounter (1×10^{-8}). They are based on current assessments of atmospheric and meteorological conditions and aircraft engine service experience. Both the FAA and the JAA agree that the need for revised standards should be considered as additional service and atmospheric data warrant.

Appendix B

Proposed Appendix B defines the certification standard atmospheric concentrations of rain and hail. These values were derived through detailed meteorological surveys and statistical analyses and represent an extremely remote aircraft encounter.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1990 (44 U.S.C. 3501 *et seq.*), there are no requirements for information collection associated with this proposed rule.

International Compatibility

The FAA has reviewed corresponding International Civil Aviation Organization international standards and recommended practices and Joint Aviation Authorities requirements and has identified no difference in these proposed amendments and the foreign regulations.

Regulatory Evaluation Summary

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) Would generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) would not have a significant impact on a substantial number of small entities; and (4) would not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Incremental Certification Costs

The proposed rule would permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods would most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment would likely be the most costly. Incremental cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for airplane turbine engines would be approximately $667,000; this includes $300,000 in additional engineering hours, and $367,000 for the prorated share of the cost of a test facility.

Incremental Manufacturing and Operating Costs

Predicting the rule's effect on manufacturing costs is complicated by design/cost tradeoffs, the large number of permutations of modifications that could achieve the desired result, and because engine design takes place in the context of constant technological change. Based on discussions with industry representatives, the FAA expects that, once rain/hail centrifuging and engine cycle models are established, compliance would be accomplished through design modifications that would have little impact on manufacturing costs. Such design features may affect: (1) fan blade/propeller, (2) spinner/nose cone, (3) bypass splitter, (4) engine bleeds, (5) accessory loads, (6) variable stator scheduling, and (7) fuel control. Similarly, the FAA expects that the rule would have a negligible effect on operating costs (again, based on discussions with industry representatives).

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of FAA and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the proposed rule, as summarized below. However, the following summary should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. The historical record shows that many accidents (not included in the following benefit estimates) were caused by other forms of water such as snow and graupel. It is possible that the aircraft in some of these cases would have benefited from the proposed rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

Benefits of Prevented Aircraft Damage

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the proposed rule. These classifications are: (1) Large air carrier aircraft (major and national air carriers), and (2) other air carrier aircraft (large regional, medium regional, commuter, and other small certificated air carriers).

An examination of accident records for the period 1975–90, indicates that, in the absence of the proposed rule, the probability of a hull loss due to a water induced loss of engine power is 0.0104 per million airplane departures for large air carriers, and 0.0276 per million airplane departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the proposed standards would reduce the accident rate by two orders of magnitude. That is, the rule is expected to be 99 percent effective in reducing water ingestion accidents. FAA estimates that the annual average benefits per airplane from prevented aircraft damage would be approximately $337 and $97 for large air carriers and other air carriers, respectively.

Benefits of Prevent Injuries and Fatalities

Using projections from the FAA Aviation Forecast, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61 percent. The average regional airplane is assumed to have 30 seats and a load factor of 51 percent. The estimated distribution of fatal, serious, and minor injuries is derived from the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane would be $3,062 for operations by large air carriers and $706 for operations by other air carriers.

Benefit-Cost Analysis

The benefits and costs of the proposed rule are compared for two representative engine certifications using the following assumptions: (1) For each certification, 50 engines are produced per year for 10 years (500 engines), (2) incremental certification costs are incurred in year "0", (3) engine production begins in year "3", (4) the first engines enter service in year "4", (5) each engine is retired after 10 years, (6) the discount rate is 7 percent. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the airplane accident rate) this analysis assumes that each airplane has two engines.

For each airplane/engine type, the annual benefit per aircraft is the sum of the expected property and casualty benefits. The total benefit for each type certification, then, is the product of the per aircraft annual benefit and the number of aircraft in service summed over the life of the engines. Thus, for representative type certifications, discounted lifecycle benefits would be approximately $3.7 million and $0.8 million for operations by large air carriers and other air carriers, respectively.

FAA finds that the rule would be cost-beneficial. Under conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage would exceed discounted costs by a factor ranging from 5.5 ($3,661,084/$667,000) for operations by large air carriers to 1.3 ($864,696/$667,000) for operations by other air carriers.

Harmonization Benefits

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act (RFA) of 1980 was enacted by Congress to ensure that small entities are not unnecessarily or disproportionately burdened by Government regulations. The RFA requires a Regulatory Flexibility Analysis if a rule is expected to have a "significant economic impact on a substantial number of small entities." Based on the standards and thresholds specified in implementing FAA Order 2100.14A, Regulatory Flexibility Criteria and Guidance, the FAA has determined that the rule would not have a significant impact on a substantial number of small manufacturers or operators because no turbine engine manufacturer is a "small entity" as defined in the order.

International Trade Impact Assessment

The rule would have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine engines in the U.S.

Federalism Implications

The regulations proposed herein would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this proposal would not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Conclusion

For the reasons discussed above, including the findings in the Regulatory Flexibility Determination and the International Trade Impact Analysis, the FAA has determined that this proposed regulation is not significant under Executive Order 12866. In addition, the FAA certifies that this proposal, if adopted, would not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act. This proposal is not considered significant under DOT Regulatory Policies and Procedures (44 FR 11034, February 26, 1979). An initial regulatory evaluation of the proposal, including a Regulatory Flexibility Determination and Trade Impact Analysis, has been placed in the docket. A copy may be obtained by contacting the person identified under FOR FURTHER INFORMATION CONTACT.

List of Subjects in 14 CFR Parts 23, 25, and 33

Air transportation, Aircraft, Aviation safety, Safety.

The Proposed Amendment

In consideration of the foregoing, the Federal Aviation Administration proposes to amend parts 23, 25, and 33 of the Federal Aviation Regulations (14 CFR part 23, 14 CFR part 25, and 14 CFR part 33) as follows:

PART 23—AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

§ 23.901 Installation.

* * * * *

(d) * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

* * * * *

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

§ 23.903 Engines.

(a) * * *

(2) Each turbine engine must either—

(i) Comply with § 33.77 and § 33.78 of this chapter for an airplane for which application for type certification is made on or after [Insert effective date of final rule]; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, and must have a foreign object ingestion service history that has not resulted in any unsafe condition for an airplane for which application for type certification was made before [Insert effective date of final rule]; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467; October 1, 1974.

* * * * *

PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

§ 25.903 Engines.

(a) * * *

(2) Each turbine engine must either—

(i) Comply with § 33.77 and § 33.78 of this chapter for an airplane for which application for type certification is made on or after [Insert effective date of final rule]; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, and must have a foreign object ingestion service history that has not resulted in any unsafe condition for an airplane for which application for type certification was made before [Insert effective date of final rule]; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467; October 1, 1974.

* * * * *

PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

§ 33.77 Foreign object ingestion.

* * * * *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

* * * * *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

Foreign object	Test quantity	Speed of foreign object	Engine operation	Ingestion
Birds:				
3-ounce size	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1½-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.

Foreign object	Test quantity	Speed of foreign object	Engine operation	Ingestion
1½-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
4-pound size	One, if it can enter the inlet	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes.	Maximum cruise	Aimed at critical area.
		Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Takeoff	Aimed at critical area.
Ice	Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in	Maximum cruise	To simulate a continuous maximum icing encounter at 25°F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) *All engines.* (1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum rough air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet fact area. The hailstone number and size shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet area of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 20-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet area more than 100 square inches (0.0645 square meters).

(2) Except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability during any three minute continuous period in rain and during any 30 second continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) *Engines for rotocraft.* As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotocraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) Continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) Continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) Continuation of the rain ingestion during subsequent rapid deceleration to takeoff power.

(c) *Engines for supersonic airplanes.* In addition to complying with paragraph (a)(1) of this section, a separate test for supersonic airplane engines only, shall be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain or hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject water constituents; and

(3) The subject water constituents, stopped by the protective device, will not obstruct the flow of induction air

into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

Appendix B to Part 33—Certification Standard Atmospheric Concentrations of Rain and Hail

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hailstones fabricated from ice to simulate hail conditions, the use of water droplets and hailstones having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hailstone, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

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FIGURE B1 - Illustration of Rain and Hail Threats. Certification concentrations are obtained using Tables B1 and B2.

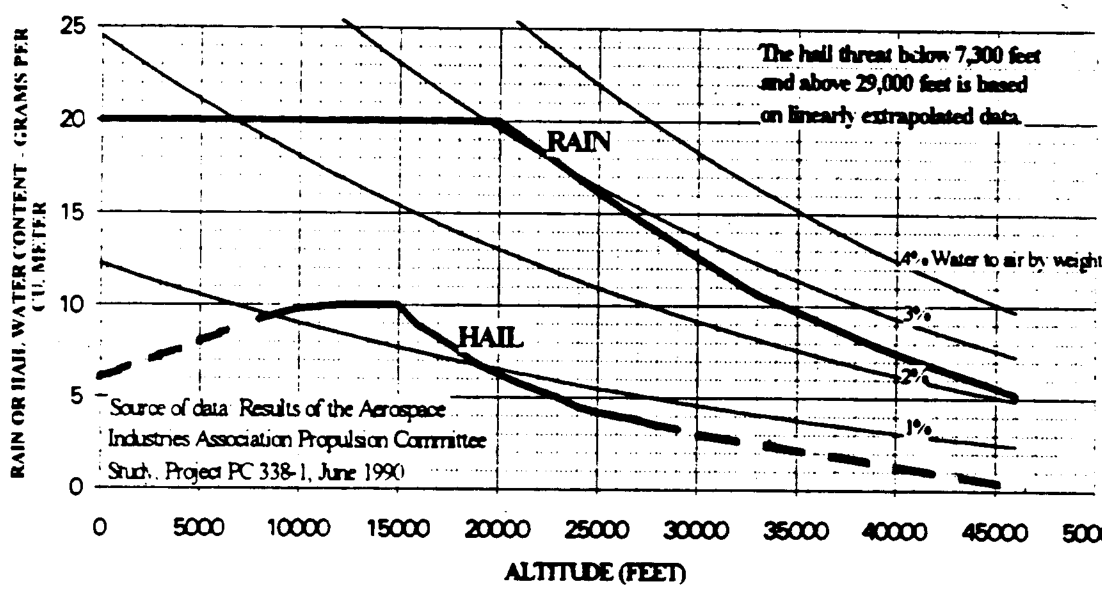

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TABLE B1.—CERTIFICATION STANDARD ATMOSPHERIC RAIN CONCENTRATIONS

Altitude (feet)	Rain water content (RWC) (gramswater/ meter³ air)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

RWC values at other altitudes may be determined by linear interpolation.

Note: Source of data—Results of the Aerospace Industries Association (AIA) Propulsion Committee Study, Project PC 338-1, June 1990.

TABLE B2.—CERTIFICATION STANDARD ATMOSPHERIC HAIL CONCENTRATIONS

Altitude (feet)	Hail water content (HWC) (grams water / meter³ air)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

HWC values at other altitudes may be determined by linear interpolation. The hail threat below 7,300 feet and above 29,000 feet is based on linearly extrapolated data.

Note: Source of data—Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project (PC 338-1, June 1990.

TABLE B3.—CERTIFICATION STANDARD ATMOSPHERIC RAIN DROPLET SIZE DISTRIBUTION

Rain droplet diameter (mm)	Contribution to total LWC (%)
0-0.49	0
0.50-0.99	2.25
1.00-1.49	8.75
1.50-1.99	16.25
2.00-2.49	19.00
2.50-2.99	17.75
3.00-3.49	13.50
3.50-3.99	9.50
4.00-4.49	6.00
4.50-4.99	3.00
5.00-5.49	2.00
5.50-5.99	1.25
6.00-6.49	0.50
6.50-7.00	0.25
Total	100.00

Median diameter of rain droplets is 2.66 mm

Note: Source of data—Results of the Aerospace Industry Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B4.—CERTIFICATION STANDARD ATMOSPHERIC HAILSTONE SIZE DISTRIBUTION

Hailstone diameter (mm)	Contribution to total HWC (%)
0.4.9	0
5.0-9.9	17.00
10.0-14.9	25.00
15.0-19.9	22.50
20.0-24.9	16.00
25.0-29.9	9.75
30.0-34.9	4.75
35.0-39.9	2.50
40.0-44.9	1.50
45.0-49.9	0.75
50.0-55.0	0.25
Total	100.00

Median diameter of hailstones is 16 mm.

Note: Source of data—Results of the Aerospace Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

Issued in Washington, DC on August 2, 1996.

Elizabeth Yoest,

Acting Director, Aircraft Certification Services.

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[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25 and 33

[Docket No. 28652; Amendment Nos. 23-53, 25-95, and 33-19]

RIN 2120-AF75

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: These amendments establish revisions to the Federal Aviation Administration's certification standards for rain and hail ingestion for aircraft turbine engines. These amendments address engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. These amendments also generally harmonize these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). These amendments establish nearly uniform standards for engines certified in the United States under 14 CFR part 33 and in the JAA countries under Joint Airworthiness Requirements-Engines (JAR-E), thereby simplifying the certification of engine designs by the FAA and the JAA.

EFFECTIVE DATE: April 30, 1998

FOR FURTHER INFORMATION CONTACT: John Fisher, Engine and Propeller Standards Staff, ANE-110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803-5229; telephone (781) 238-7149; fax (781) 238-7199.

SUPPLEMENTARY INFORMATION

Availability of Final Rules

An electronic copy of this document may be downloaded, using a modem and suitable communications software, from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703-321-3339), the **Federal Register's** electronic bulletin board service (2002-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone 202-267-5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the **Federal Register's** web page at http://www.access.gpo.gov/su_ docs for access to recently published rulemaking documents.

Any person may obtain a copy of this final rule by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-9680. Communications must identify the amendment number or document number of this final rule.

Persons interested in being placed on the mailing list for future notices of proposed rulemaking and final rulemaking should request from the above office a copy of Advisory Circular No. 11-2A, Notices of Proposed Rulemaking Distribution System, that describes the application procedure.

Small Entity Inquiries

The Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA) requires the FAA to report inquiries from small entities concerning information on, and advice about, compliance with statutes and regulations within the FAA's jurisdiction, including interpretation and application of the law to specific sets of facts supplied by a small entity.

If you are a small entity and have a question, contact your local FAA official. If you do not know how to contact your local FAA official, you may contact Charlene Brown, Program Analyst Staff, Office of Rulemaking, ARM-27, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, 1-888-551-1594. Internet users can find additional information on SBREFA in the "Quick Jump" section of the FAA's web page at http://www.faa.gov and may send electronic inquiries to the following internet address: 9-AWA-SBEFA@faa.dot.gov.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

Industry Study

In 1987, the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. Consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to part 33, if appropriate. AIA,

working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of 14 CFR part 33 do not adequately address this threat.

Engine Harmonization Effort

The FAA is committed to undertaking and supporting harmonization of standards in part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and Propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. This partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which were considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards. This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On November 7, 1995, the TAEIG recommended to the FAA that it proceed

with rulemaking and associated advisory material even though one manufacturer expressed reservations. The FAA published a notice of proposed rulemaking on August 9, 1996 (61 FR 41688). This rule and associated advisory material reflect the ARAC recommendations.

Discussion of Comments

All interested persons have been afforded an opportunity to participate in this rulemaking, and due consideration has been given to all comments received. The commenters represent domestic and foreign industry, and foreign airworthiness authorities. Five commenters provided the FAA with comments to the NPRM.

Four commenters expressed concern with the proposed wording for §§ 23.903 and 25.903. The commenters state that the proposal could result in retroactive requirements imposed on certain engines already type certificated. Three of the four commenters further state that this part of the proposal represents a significant departure from the proposal submitted to the FAA by ARAC.

The FAA agrees. It was not the intent of the FAA to retroactively impose the new requirements on an engine design already type certificated unless service history indicates that an unsafe condition is present. The FAA has changed the wording for §§ 23.903 and 25.903 back to that originally proposed by the ARAC .

All five commenters found a number of typographical errors and suggested some editorial changes. One notable typographical error appeared in the "Disposition of Comments" section of the preamble of the proposal. When addressing a concern that the hail threat definition was apparently rounded up to 10 g/m^3 , the value 8/3 g/m^3 was incorrect and should have been written as 8.7 g/m^3.

The FAA also agrees to the other recommendations by the commenters and the following grammatical corrections and changes to § 33.78 and Appendix B have been made to this rule:

Section 33.78(a)(1): "Critical inlet fact area" has been changed to "Critical inlet face area" and the last sentence revised to read, "The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:".

Section 33.78(a)(1)(ii): The term "one 20-inch" has been changed to "one 2-inch".

Section 33.78(a)(2): The following has been added to the beginning of the paragraph, "In addition to complying with paragraph (a)(1) of this section and", and a comma has been added immediately following the phrase "or loss of acceleration and deceleration capability".

Section 33.78(b)(4): "deceleration" has been replaced with "acceleration".

Appendix B, Table B3: "Contribution to total LWC (%)" has been changed to "Contribution to total RWC (%)".

Appendix B, Table B4: The term "0.4.9" has been changed to "0-4.9", and "hailstone" has been replaced with "hail" in the title, column heading, and footnote.

One commenter provided an additional clarifying statement with respect to the hail threat level variations obtained from the Industry Study. Given an extremely remote encounter probability and a typical thirty second exposure to severe hail, the assessed hail threat level varies from 8.7 g/m^3 to 10.2 g/m^3, depending upon the airspeed of the aircraft traversing the hail shaft.

The FAA agrees with the commenter's additional explanation of the assessed hail threat variation. However, the discussion of the Industry Study in the proposal is technically correct.

One commenter states the need for advisory material to accompany the rule to clarify various terms and criteria contained in the rule.

The FAA agrees. An extensive advisory circular (AC) was drafted providing explanation of the various terms and criteria contained in the rule. The FAA issued a notice of availability of proposed AC and request for comments on September 5, 1996 (61 FR 46893). Further information regarding this AC can be obtained by contacting the FAA at the address specified under "FOR FURTHER INFORMATION CONTACT:".

One commenter suggested changes to the preamble discussion regarding power loss and performance degradation. The commenter did not suggest nor imply that any changes to the proposed rule were needed. The FAA need not address those comments since they do not affect the meaning of these regulations.

One commenter states that the criterion of no flameout contained in § 33.78(a)(2) and § 33.78(b) was excessive. The commenter further states that many engines are equipped with automatic re-ignition systems that would ensure quick recovery from a flameout.

The FAA disagrees. Automatic re-ignition systems can facilitate quick recovery from a flameout as a result of a momentary ingestion, such as an ice shed. However, the rain and hail ingestion threats addressed by the new standards are not momentary, and have been defined for purposes of certification testing as 30 seconds duration for hail and 3 minutes duration for rain. Once flameout occurs under these conditions, it is unlikely that the engine will be capable of recovery until the ingestion of rain or hail ceases, with or

without an automatic re-ignition system. Also, for actual encounters of severe rain and hail, it is likely that the engine will continue to ingest water, at lower concentrations, after exiting the area of severe rain or hail. The effect of this ingested water is to lower the starting capability of the engine. Therefore, if an airplane encounters severe rain or hail with installed engines that are susceptible to flameout, the airplane will be susceptible to an all engine out, forced landing. For these reasons, demonstrating tolerance to flameout under conditions of extreme rain and hail is a primary objective of the new standards.

One commenter states that the acceptance criteria for rain and hail ingestion contained in § 33.78(a)(2) and § 33.78(b) appeared to be more stringent than the acceptance for ice ingestion. The commenter believes that the acceptance criteria for rain and hail ingestion should be less stringent than for ice ingestion, since ice ingestion is a more common occurrence than hail ingestion.

The FAA concurs with the commenter that the stringency of acceptance criteria should be proportional to the occurrence rate of the threat being assessed. However, the FAA disagrees with the commenter’s view that the acceptance criteria for rain and hail ingestion are more stringent than for ice ingestion. Some amount of sustained power or thrust loss is permitted following testing to the new rain and hail ingestion standards, but no power or thrust loss is permitted following an ice ingestion test. Also, the FAA would accept momentary but recoverable surges and stalls encountered while testing to the new rain and hail ingestion standards, but has not historically accepted momentary surges and stalls following an ice ingestion test. Flameout, run down, continued or non-recoverable surge or stall, and loss of acceleration and deceleration are unacceptable conditions for rain, hail and ice ingestion.

Finally, the FAA has made the following minor editorial changes to better align this rule with recent changes to the JAA's requirements. These changes do not affect the scope of the rule or change the intent of these sections.

Section 33.78(a)(1): The phrase "maximum true air speed" replaces the phrase "maximum rough air speed", and the phrase "operating in rough air" is added following the words "representative aircraft".

Section 33.78(a)(1)(i) and (ii): The word "area" is changed to read "areas".

Section 33.78(c): In the first sentence the phrase "complying with paragraph (a)(1) of this section" is changed to read "complying with paragraphs (a)(1) and (a)(2) of this section.

Appendix B: The word "hailstones" is changed to read "hail" in the introductory paragraph and also in Table B4.

After careful review of all the comments, the FAA has determined that air safety and the public interest require the adoption of the rule with the changes described.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d), there are no information collection requirements associated with this final rule.

Regulatory Evaluation Summary

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to

assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) will generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) will not have a significant impact on a substantial number of small entities; and (4) will not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Incremental costs

The proposed rule will permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods will most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment will likely be the most costly. Incremental certification cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for an airplane turbine engine design will be approximately $627,000-- this includes $300,000 in additional engineering hours, and $327,000 for the prorated share of the cost of a test facility.

Based on statements from industry, the FAA expects that, once Rain/Hail centrifuging and engine cycle models are established, compliance will be accomplished through design modifications that will have little impact on manufacturing costs. Such design features may affect: 1) fan blade/propeller, 2) spinner/nose cone, 3) bypass splitter, 4) engine bleeds, 5) accessory loads, 6)

variable stator scheduling, and 7) fuel control. Similarly, the FAA expects that the rule will have a negligible effect on operating costs.

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of the FAA accident/incident database system and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the subject rule. However, what follows should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. Accident/incident records show that many events (not included in the benefit estimates that follow) were caused by other forms of water such as snow and graupel. It is possible that some of these cases would have benefited from the subject rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large

aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the subject rule. These classifications are: 1) large air carrier aircraft (operated by major and national air carriers), and 2) other air carrier aircraft (operated by large regional, medium regional, commuter, and other small certificated air carriers). An examination of accident records for the 20-year period 1975-1994 indicates that, in the absence of the subject rule, the probability of a hull loss due to a water induced loss of engine power is 0.0094 per million departures for large air carriers, and 0.0249 per million departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the revised water ingestion standards will reduce the rate of engine power loss events by two orders of magnitude. This analysis assumes that the rule’s effect on the accident rate will be proportionately equal to the rule’s effect on the event rate.

Using projections from the FAA Aviation Forecast, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61%. The average regional air carrier airplane is assumed to have 30 seats and a load factor of 51%. The estimated distribution of fatal, serious, and minor injuries is based on the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane will be $3,360 for large air carriers and $618 for other air carriers.

Benefits and Costs Analysis

The benefits and costs of the rule are compared for two representative engine certifications: 1) An engine designed for operation on a large jet transport (corresponding to the "large air carrier" category described earlier), and 2) an engine designed for operation on a regional transport (corresponding to the "other air carrier" category).

For each certification, the following assumptions apply: 1) 50 engines are produced per year for 10 years (500 total engines produced per certification), 2) incremental certification costs are incurred in the year 2000, 3) engine production begins in the year 2002, 4) the first engines enter service in the year 2003, 5) each engine is retired after 10 years, 6) the discount rate is 7%. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the aircraft accident rate) this analysis assumes that each aircraft has two engines.

Under the assumptions enumerated above, total lifecycle benefits for a representative engine designed for operation on a large airplane equal

approximately $9.3 million or $3.5 million at present value (1997 dollars). Total lifecycle benefits for a representative engine designed for operation on a regional airplane equal to approximately $1.8 million or $0.7 million at present value.

This analysis postulates that incremental certification costs for both representative engine designs are the same. As discussed above, incremental costs are approximately $627,000 or $512,000 at present value.

FAA finds that the rule would be cost-beneficial. Under very conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage will exceed costs by a ratio ranging from 6.9 to 1 for large air carriers to 1.3 to 1 for other air carriers.

<u>Harmonization Benefits</u>

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 establishes "as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation." To achieve that principle, the Act requires agencies to solicit and consider flexible regulatory proposals and to explain the rationale for their actions. The Act covers a wide range of small entities, including small businesses, not-for-profit organizations and small governmental jurisdictions.

Agencies must perform an analysis to determine whether a rule will have a significant economic impact on a substantial number of small entities; if the determination is that it will, the agency must prepare a regulatory flexibility analysis (RFA).

However, if after an analysis for a proposed or final rule, an agency determines that a rule is not expected to have a significant economic impact on a substantial number of small entities, § 605(b) of the 1980 act provides that the head of the agency may so certify. The certification must include a statement providing the factual basis for this determination, and the reasoning should be clear.

The FAA conducted the required preliminary analysis of this proposal and determined that it would not have a significant economic impact on a substantial number of small entities. That determination was published in the Federal Register on August 9, 1996 as part of the Notice of Proposed Rulemaking. No comments were received regarding the economic analysis of the rule. No substantial changes were made in the final rule from the proposed rule, and estimated costs were not significantly modified. Accordingly, pursuant to the Regulatory Flexibility Act, 5 U.S.C. § 605(b), the Federal Aviation Administration certifies that this rule will not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment

The rule will have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine

engines in the U.S. Generally, this rule harmonizes FAA requirements with existing and proposed JAA requirements.

Federalism Implication

The regulations will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this rule will not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (The Act), enacted as Pub. L. 104-4 on March 22, 1995, requires each federal agency, to the extent permitted by law, to prepare a written assessment of the effects of any federal mandate in a proposed or final agency rule that may result in the expenditure by state, local, and tribal governments, in the aggregate, or by the private sector, of $100 million or more (adjusted annually for inflation) in any one year. Section 204(A) of The Act, 2 U.S.C. 1534(A), requires the federal agency to develop an effective process to permit timely input by elected officers (or their designees) of state, local, and tribal governments on a proposed "significant intergovernmental mandate". A "significant intergovernmental mandate" under The Act is any provision in a federal agency regulation that will impose an enforceable duty upon state, local, and tribal governments, in the aggregate, of $100 million (adjusted annually for inflation) in any one year. Section 203 of The Act, 2 U.S.C. 1533, which supplements section 204(A), provides that before establishing any regulatory requirements that might significantly or uniquely affect small governments, the agency shall have developed a plan

that, among other things, provides for notice to potentially affected small governments, if any, and for a meaningful and timely opportunity to provide input in the development of regulatory proposals**.**

The FAA determines that this rule does not contain a significant intergovernmental or private sector mandate as defined by the act.

List of Subjects in 14 CFR Parts 23, 25 and 33

Air transportation, Aircraft, Aviation safety, Safety.

Adoption of the Amendments

In consideration of the foregoing, the Federal Aviation Administration amends 14 CFR parts 23, 25, and 33 as follows:

PART 23 - AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

§ 23.901 Installation.

*** * * * ***

(d) * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

* * * * *

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

§ 23.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

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PART 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

§ 25.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

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PART 33 - AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

§ 33.77 Foreign object ingestion.

* * * * *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

* * * * *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

FOREIGN OBJECT	TEST QUANTITY	SPEED OF FOREIGN OBJECT	ENGINE OPERATION	INGESTION
BIRDS:				
3-Ounce size	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1-1/2-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
1-1/2-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
4-pound size	One, if it can enter the inlet.	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes. Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Maximum cruise Takeoff	Aimed at critical area. Aimed at critical area.
ICE :				
Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in.		Maximum cruise	To simulate a continuous maximum icing encounter at 25°F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) <u>All engines.</u>

(1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum true air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft operating in rough air, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet areas of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 2-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet areas of more than 100 square inches (0.0645 square meters).

(2) In addition to complying with paragraph (a)(1) of this section and except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability, during any three minute continuous period in rain and during any 30 second

continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) Engines for rotorcraft. As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotorcraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) Continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) Continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) Continuation of the rain ingestion during subsequent rapid acceleration to takeoff power.

(c) Engines for supersonic airplanes. In addition to complying with paragraphs (a)(1) and (a)(2) of this section, a separate test for supersonic airplane engines only, shall

be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain and hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject rain and hail constituents; and

(3) The subject of rain and hail constituents, stopped by the protection device, will not obstruct the flow of induction air into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

APPENDIX B TO PART 33--CERTIFICATION STANDARD ATMOSPHERIC CONCENTRATIONS OF RAIN AND HAIL

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hail fabricated from ice to simulate hail conditions, the use of water droplets and hail having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hail, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

FIGURE B1 - Illustration of Rain and Hail Threats. Certification concentrations are obtained using Tables B1 and B2.

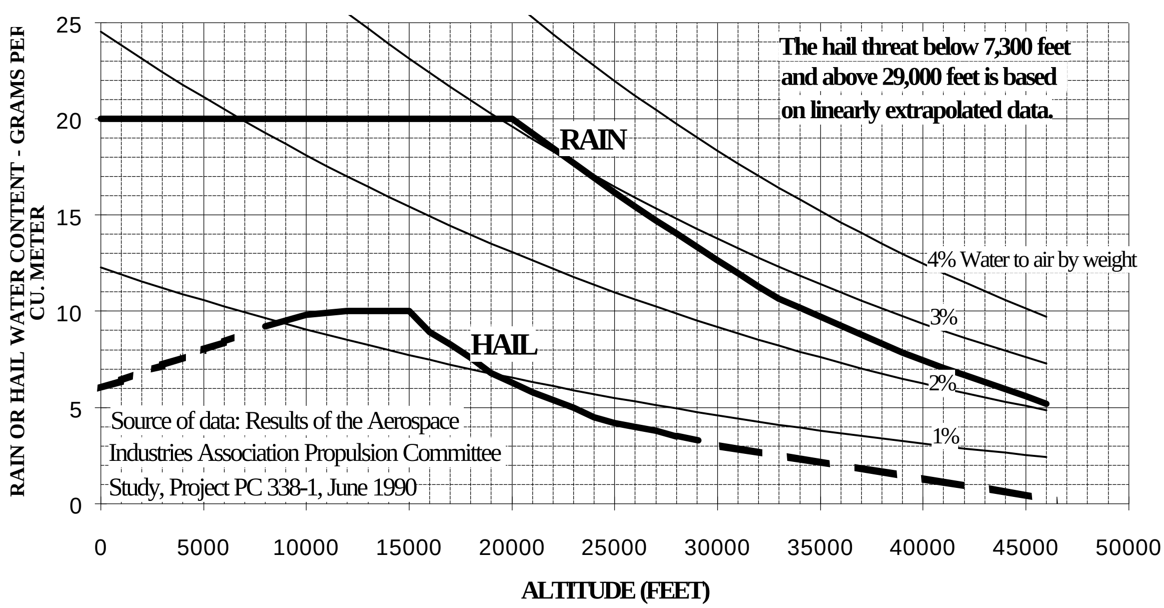


TABLE B1

CERTIFICATION STANDARD ATMOSPHERIC RAIN CONCENTRATIONS

Altitude (feet)	Rain Water Content (RWC) (grams water / meter^3 air)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

RWC values at other altitudes may be determined by linear interpolation.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee Study, Project PC 338-1, June 1990.

TABLE B2

CERTIFICATION STANDARD ATMOSPHERIC HAIL CONCENTRATIONS

Altitude (feet)	Hail Water Content (HWC) (grams water / meter^3 air)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

HWC values at other altitudes may be determined by linear interpolation. The hail threat below 7,300 feet and above 29,000 feet is based on linearly extrapolated data.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B3

CERTIFICATION STANDARD ATMOSPHERIC RAIN DROPLET SIZE DISTRIBUTION

Rain Droplet Diameter (mm)	Contribution to total RWC (%)
0 - 0.49	0
0.50 - 0.99	2.25
1.00 - 1.49	8.75
1.50 - 1.99	16.25
2.00 - 2.49	19.00
2.50 - 2.99	17.75
3.00 - 3.49	13.50
3.50 - 3.99	9.50
4.00 - 4.49	6.00
4.50 - 4.99	3.00
5.00 - 5.49	2.00
5.50 - 5.99	1.25
6.00 - 6.49	0.50
6.50 - 7.00	0.25
TOTAL	100.00

Median diameter of rain droplets is 2.66 mm

Note: Source of data - Results of the Aerospace Industry Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B4

CERTIFICATION STANDARD ATMOSPHERIC HAIL SIZE DISTRIBUTION

Hail Diameter (mm)	Contribution to total HWC (%)
0 - 4.9	0
5.0 - 9.9	17.00
10.0 - 14.9	25.00
15.0 - 19.9	22.50
20.0 - 24.9	16.00
25.0 - 29.9	9.75
30.0 - 34.9	4.75
35.0 - 39.9	2.50
40.0 - 44.9	1.50
45.0 - 49.9	0.75
50.0 - 55.0	0.25
TOTAL	100.00

Median diameter of hail is 16 mm

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

Issued in Washington, DC on March 20, 1998.

/signed by

Jane F. Garvey
Administrator

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25 and 33

[Docket No. 28652; Amendment Nos. 23-53, 25-95, and 33-19]

RIN 2120-AF75

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: These amendments establish revisions to the Federal Aviation Administration's certification standards for rain and hail ingestion for aircraft turbine engines. These amendments address engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. These amendments also generally harmonize these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). These amendments establish nearly uniform standards for engines certified in the United States under 14 CFR part 33 and in the JAA countries under Joint Airworthiness Requirements-Engines (JAR-E), thereby simplifying the certification of engine designs by the FAA and the JAA.

EFFECTIVE DATE: April 30, 1998

FOR FURTHER INFORMATION CONTACT: John Fisher, Engine and Propeller Standards Staff, ANE-110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803-5229; telephone (781) 238-7149; fax (781) 238-7199.

SUPPLEMENTARY INFORMATION

Availability of Final Rules

An electronic copy of this document may be downloaded, using a modem and suitable communications software, from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703-321-3339), the **Federal Register's** electronic bulletin board service (2002-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone 202-267-5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the **Federal Register's** web page at http://www.access.gpo.gov/su_ docs for access to recently published rulemaking documents.

Any person may obtain a copy of this final rule by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-9680. Communications must identify the amendment number or document number of this final rule.

Persons interested in being placed on the mailing list for future notices of proposed rulemaking and final rulemaking should request from the above office a copy of Advisory Circular No. 11-2A, Notices of Proposed Rulemaking Distribution System, that describes the application procedure.

Small Entity Inquiries

The Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA) requires the FAA to report inquiries from small entities concerning information on, and advice about, compliance with statutes and regulations within the FAA's jurisdiction, including interpretation and application of the law to specific sets of facts supplied by a small entity.

If you are a small entity and have a question, contact your local FAA official. If you do not know how to contact your local FAA official, you may contact Charlene Brown, Program Analyst Staff, Office of Rulemaking, ARM-27, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, 1-888-551-1594. Internet users can find additional information on SBREFA in the "Quick Jump" section of the FAA's web page at http://www.faa.gov and may send electronic inquiries to the following internet address: 9-AWA-SBEFA@faa.dot.gov.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

Industry Study

In 1987, the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. Consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to part 33, if appropriate. AIA,

working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of 14 CFR part 33 do not adequately address this threat.

Engine Harmonization Effort

The FAA is committed to undertaking and supporting harmonization of standards in part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and Propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. This partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which were considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards. This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On November 7, 1995, the TAEIG recommended to the FAA that it proceed

with rulemaking and associated advisory material even though one manufacturer expressed reservations. The FAA published a notice of proposed rulemaking on August 9, 1996 (61 FR 41688). This rule and associated advisory material reflect the ARAC recommendations.

Discussion of Comments

All interested persons have been afforded an opportunity to participate in this rulemaking, and due consideration has been given to all comments received. The commenters represent domestic and foreign industry, and foreign airworthiness authorities. Five commenters provided the FAA with comments to the NPRM.

Four commenters expressed concern with the proposed wording for §§ 23.903 and 25.903. The commenters state that the proposal could result in retroactive requirements imposed on certain engines already type certificated. Three of the four commenters further state that this part of the proposal represents a significant departure from the proposal submitted to the FAA by ARAC.

The FAA agrees. It was not the intent of the FAA to retroactively impose the new requirements on an engine design already type certificated unless service history indicates that an unsafe condition is present. The FAA has changed the wording for §§ 23.903 and 25.903 back to that originally proposed by the ARAC .

All five commenters found a number of typographical errors and suggested some editorial changes. One notable typographical error appeared in the "Disposition of Comments" section of the preamble of the proposal. When addressing a concern that the hail threat definition was apparently rounded up to 10 g/m^3 , the value 8/3 g/m^3 was incorrect and should have been written as 8.7 g/m^3.

The FAA also agrees to the other recommendations by the commenters and the following grammatical corrections and changes to § 33.78 and Appendix B have been made to this rule:

Section 33.78(a)(1): "Critical inlet fact area" has been changed to "Critical inlet face area" and the last sentence revised to read, "The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:".

Section 33.78(a)(1)(ii): The term "one 20-inch" has been changed to "one 2-inch".

Section 33.78(a)(2): The following has been added to the beginning of the paragraph, "In addition to complying with paragraph (a)(1) of this section and", and a comma has been added immediately following the phrase "or loss of acceleration and deceleration capability".

Section 33.78(b)(4): "deceleration" has been replaced with "acceleration".

Appendix B, Table B3: "Contribution to total LWC (%)" has been changed to "Contribution to total RWC (%)".

Appendix B, Table B4: The term "0.4.9" has been changed to "0-4.9", and "hailstone" has been replaced with "hail" in the title, column heading, and footnote.

One commenter provided an additional clarifying statement with respect to the hail threat level variations obtained from the Industry Study. Given an extremely remote encounter probability and a typical thirty second exposure to severe hail, the assessed hail threat level varies from 8.7 g/m^3 to 10.2 g/m^3, depending upon the airspeed of the aircraft traversing the hail shaft.

The FAA agrees with the commenter's additional explanation of the assessed hail threat variation. However, the discussion of the Industry Study in the proposal is technically correct.

One commenter states the need for advisory material to accompany the rule to clarify various terms and criteria contained in the rule.

The FAA agrees. An extensive advisory circular (AC) was drafted providing explanation of the various terms and criteria contained in the rule. The FAA issued a notice of availability of proposed AC and request for comments on September 5, 1996 (61 FR 46893). Further information regarding this AC can be obtained by contacting the FAA at the address specified under "FOR FURTHER INFORMATION CONTACT:".

One commenter suggested changes to the preamble discussion regarding power loss and performance degradation. The commenter did not suggest nor imply that any changes to the proposed rule were needed. The FAA need not address those comments since they do not affect the meaning of these regulations.

One commenter states that the criterion of no flameout contained in § 33.78(a)(2) and § 33.78(b) was excessive. The commenter further states that many engines are equipped with automatic re-ignition systems that would ensure quick recovery from a flameout.

The FAA disagrees. Automatic re-ignition systems can facilitate quick recovery from a flameout as a result of a momentary ingestion, such as an ice shed. However, the rain and hail ingestion threats addressed by the new standards are not momentary, and have been defined for purposes of certification testing as 30 seconds duration for hail and 3 minutes duration for rain. Once flameout occurs under these conditions, it is unlikely that the engine will be capable of recovery until the ingestion of rain or hail ceases, with or

without an automatic re-ignition system. Also, for actual encounters of severe rain and hail, it is likely that the engine will continue to ingest water, at lower concentrations, after exiting the area of severe rain or hail. The effect of this ingested water is to lower the starting capability of the engine. Therefore, if an airplane encounters severe rain or hail with installed engines that are susceptible to flameout, the airplane will be susceptible to an all engine out, forced landing. For these reasons, demonstrating tolerance to flameout under conditions of extreme rain and hail is a primary objective of the new standards.

One commenter states that the acceptance criteria for rain and hail ingestion contained in § 33.78(a)(2) and § 33.78(b) appeared to be more stringent than the acceptance for ice ingestion. The commenter believes that the acceptance criteria for rain and hail ingestion should be less stringent than for ice ingestion, since ice ingestion is a more common occurrence than hail ingestion.

The FAA concurs with the commenter that the stringency of acceptance criteria should be proportional to the occurrence rate of the threat being assessed. However, the FAA disagrees with the commenter's view that the acceptance criteria for rain and hail ingestion are more stringent than for ice ingestion. Some amount of sustained power or thrust loss is permitted following testing to the new rain and hail ingestion standards, but no power or thrust loss is permitted following an ice ingestion test. Also, the FAA would accept momentary but recoverable surges and stalls encountered while testing to the new rain and hail ingestion standards, but has not historically accepted momentary surges and stalls following an ice ingestion test. Flameout, run down, continued or non-recoverable surge or stall, and loss of acceleration and deceleration are unacceptable conditions for rain, hail and ice ingestion.

Finally, the FAA has made the following minor editorial changes to better align this rule with recent changes to the JAA's requirements. These changes do not affect the scope of the rule or change the intent of these sections.

Section 33.78(a)(1): The phrase "maximum true air speed" replaces the phrase "maximum rough air speed", and the phrase "operating in rough air" is added following the words "representative aircraft".

Section 33.78(a)(1)(i) and (ii): The word "area" is changed to read "areas".

Section 33.78(c): In the first sentence the phrase "complying with paragraph (a)(1) of this section" is changed to read "complying with paragraphs (a)(1) and (a)(2) of this section.

Appendix B: The word "hailstones" is changed to read "hail" in the introductory paragraph and also in Table B4.

After careful review of all the comments, the FAA has determined that air safety and the public interest require the adoption of the rule with the changes described.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d), there are no information collection requirements associated with this final rule.

Regulatory Evaluation Summary

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to

assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) will generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) will not have a significant impact on a substantial number of small entities; and (4) will not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Incremental costs

The proposed rule will permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods will most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment will likely be the most costly. Incremental certification cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for an airplane turbine engine design will be approximately $627,000-- this includes $300,000 in additional engineering hours, and $327,000 for the prorated share of the cost of a test facility.

Based on statements from industry, the FAA expects that, once Rain/Hail centrifuging and engine cycle models are established, compliance will be accomplished through design modifications that will have little impact on manufacturing costs. Such design features may affect: 1) fan blade/propeller, 2) spinner/nose cone, 3) bypass splitter, 4) engine bleeds, 5) accessory loads, 6)

variable stator scheduling, and 7) fuel control. Similarly, the FAA expects that the rule will have a negligible effect on operating costs.

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of the FAA accident/incident database system and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the subject rule. However, what follows should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. Accident/incident records show that many events (not included in the benefit estimates that follow) were caused by other forms of water such as snow and graupel. It is possible that some of these cases would have benefited from the subject rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large

aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the subject rule. These classifications are: 1) large air carrier aircraft (operated by major and national air carriers), and 2) other air carrier aircraft (operated by large regional, medium regional, commuter, and other small certificated air carriers). An examination of accident records for the 20-year period 1975-1994 indicates that, in the absence of the subject rule, the probability of a hull loss due to a water induced loss of engine power is 0.0094 per million departures for large air carriers, and 0.0249 per million departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the revised water ingestion standards will reduce the rate of engine power loss events by two orders of magnitude. This analysis assumes that the rule’s effect on the accident rate will be proportionately equal to the rule’s effect on the event rate.

Using projections from the FAA Aviation Forecast, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61%. The average regional air carrier airplane is assumed to have 30 seats and a load factor of 51%. The estimated distribution of fatal, serious, and minor injuries is based on the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane will be $3,360 for large air carriers and $618 for other air carriers.

Benefits and Costs Analysis

The benefits and costs of the rule are compared for two representative engine certifications: 1) An engine designed for operation on a large jet transport (corresponding to the "large air carrier" category described earlier), and 2) an engine designed for operation on a regional transport (corresponding to the "other air carrier" category).

For each certification, the following assumptions apply: 1) 50 engines are produced per year for 10 years (500 total engines produced per certification), 2) incremental certification costs are incurred in the year 2000, 3) engine production begins in the year 2002, 4) the first engines enter service in the year 2003, 5) each engine is retired after 10 years, 6) the discount rate is 7%. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the aircraft accident rate) this analysis assumes that each aircraft has two engines.

Under the assumptions enumerated above, total lifecycle benefits for a representative engine designed for operation on a large airplane equal

approximately $9.3 million or $3.5 million at present value (1997 dollars). Total lifecycle benefits for a representative engine designed for operation on a regional airplane equal to approximately $1.8 million or $0.7 million at present value.

This analysis postulates that incremental certification costs for both representative engine designs are the same. As discussed above, incremental costs are approximately $627,000 or $512,000 at present value.

FAA finds that the rule would be cost-beneficial. Under very conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage will exceed costs by a ratio ranging from 6.9 to 1 for large air carriers to 1.3 to 1 for other air carriers.

<u>Harmonization Benefits</u>

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 establishes "as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation." To achieve that principle, the Act requires agencies to solicit and consider flexible regulatory proposals and to explain the rationale for their actions. The Act covers a wide range of small entities, including small businesses, not-for-profit organizations and small governmental jurisdictions.

Agencies must perform an analysis to determine whether a rule will have a significant economic impact on a substantial number of small entities; if the determination is that it will, the agency must prepare a regulatory flexibility analysis (RFA).

However, if after an analysis for a proposed or final rule, an agency determines that a rule is not expected to have a significant economic impact on a substantial number of small entities, § 605(b) of the 1980 act provides that the head of the agency may so certify. The certification must include a statement providing the factual basis for this determination, and the reasoning should be clear.

The FAA conducted the required preliminary analysis of this proposal and determined that it would not have a significant economic impact on a substantial number of small entities. That determination was published in the Federal Register on August 9, 1996 as part of the Notice of Proposed Rulemaking. No comments were received regarding the economic analysis of the rule. No substantial changes were made in the final rule from the proposed rule, and estimated costs were not significantly modified. Accordingly, pursuant to the Regulatory Flexibility Act, 5 U.S.C. § 605(b), the Federal Aviation Administration certifies that this rule will not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment

The rule will have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine

engines in the U.S. Generally, this rule harmonizes FAA requirements with existing and proposed JAA requirements.

Federalism Implication

The regulations will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this rule will not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (The Act), enacted as Pub. L. 104-4 on March 22, 1995, requires each federal agency, to the extent permitted by law, to prepare a written assessment of the effects of any federal mandate in a proposed or final agency rule that may result in the expenditure by state, local, and tribal governments, in the aggregate, or by the private sector, of $100 million or more (adjusted annually for inflation) in any one year. Section 204(A) of The Act, 2 U.S.C. 1534(A), requires the federal agency to develop an effective process to permit timely input by elected officers (or their designees) of state, local, and tribal governments on a proposed "significant intergovernmental mandate". A "significant intergovernmental mandate" under The Act is any provision in a federal agency regulation that will impose an enforceable duty upon state, local, and tribal governments, in the aggregate, of $100 million (adjusted annually for inflation) in any one year. Section 203 of The Act, 2 U.S.C. 1533, which supplements section 204(A), provides that before establishing any regulatory requirements that might significantly or uniquely affect small governments, the agency shall have developed a plan

that, among other things, provides for notice to potentially affected small governments, if any, and for a meaningful and timely opportunity to provide input in the development of regulatory proposals**.**

The FAA determines that this rule does not contain a significant intergovernmental or private sector mandate as defined by the act.

List of Subjects in 14 CFR Parts 23, 25 and 33

Air transportation, Aircraft, Aviation safety, Safety.

Adoption of the Amendments

In consideration of the foregoing, the Federal Aviation Administration amends 14 CFR parts 23, 25, and 33 as follows:

PART 23 - AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

§ 23.901 Installation.

*** * * * ***

(d) * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

* * * * *

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

§ 23.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

*** * * * ***

PART 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

§ 25.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

* * * * *

PART 33 - AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

§ 33.77 Foreign object ingestion.

* * * * *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

* * * * *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

FOREIGN OBJECT	TEST QUANTITY	SPEED OF FOREIGN OBJECT	ENGINE OPERATI ON	INGESTION
BIRDS:				
3-Ounce size	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1-1/2-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
1-1/2-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
4-pound size	One, if it can enter the inlet.	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes. Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Maximum cruise Takeoff	Aimed at critical area. Aimed at critical area.
ICE :				
Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in.		Maximum cruise	To simulate a continuous maximum icing encounter at 25^{o}F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) <u>All engines.</u>

(1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum true air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft operating in rough air, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet areas of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 2-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet areas of more than 100 square inches (0.0645 square meters).

(2) In addition to complying with paragraph (a)(1) of this section and except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability, during any three minute continuous period in rain and during any 30 second

continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) Engines for rotorcraft. As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotorcraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) Continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) Continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) Continuation of the rain ingestion during subsequent rapid acceleration to takeoff power.

(c) Engines for supersonic airplanes. In addition to complying with paragraphs (a)(1) and (a)(2) of this section, a separate test for supersonic airplane engines only, shall

be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain and hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject rain and hail constituents; and

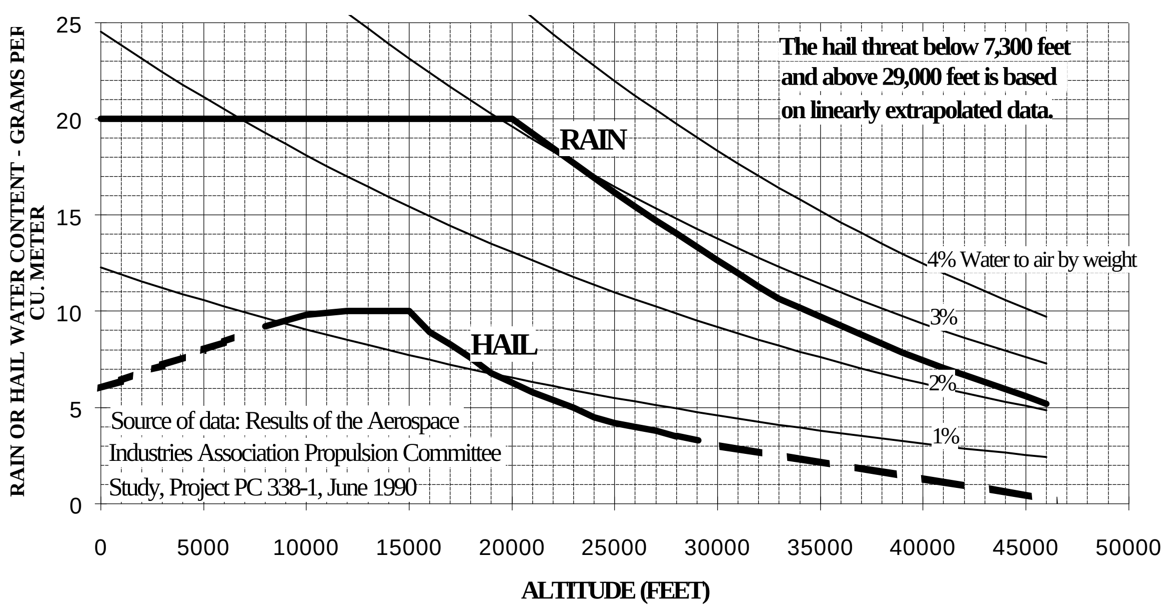
(3) The subject of rain and hail constituents, stopped by the protection device, will not obstruct the flow of induction air into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

APPENDIX B TO PART 33--CERTIFICATION STANDARD ATMOSPHERIC CONCENTRATIONS OF RAIN AND HAIL

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hail fabricated from ice to simulate hail conditions, the use of water droplets and hail having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hail, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

FIGURE B1 - Illustration of Rain and Hail Threats. Certification concentrations are obtained using Tables B1 and B2.



<u>TABLE B1</u>

CERTIFICATION STANDARD ATMOSPHERIC RAIN CONCENTRATIONS

Altitude (feet)	Rain Water Content (RWC) (grams water / meter^3 air)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

RWC values at other altitudes may be determined by linear interpolation.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee Study, Project PC 338-1, June 1990.

TABLE B2

CERTIFICATION STANDARD ATMOSPHERIC HAIL CONCENTRATIONS

Altitude (feet)	Hail Water Content (HWC) (grams water / meter^3 air)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

HWC values at other altitudes may be determined by linear interpolation. The hail threat below 7,300 feet and above 29,000 feet is based on linearly extrapolated data.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B3

CERTIFICATION STANDARD ATMOSPHERIC RAIN DROPLET SIZE DISTRIBUTION

Rain Droplet Diameter (mm)	Contribution to total RWC (%)
0 - 0.49	0
0.50 - 0.99	2.25
1.00 - 1.49	8.75
1.50 - 1.99	16.25
2.00 - 2.49	19.00
2.50 - 2.99	17.75
3.00 - 3.49	13.50
3.50 - 3.99	9.50
4.00 - 4.49	6.00
4.50 - 4.99	3.00
5.00 - 5.49	2.00
5.50 - 5.99	1.25
6.00 - 6.49	0.50
6.50 - 7.00	0.25
TOTAL	100.00

Median diameter of rain droplets is 2.66 mm

Note: Source of data - Results of the Aerospace Industry Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B4

CERTIFICATION STANDARD ATMOSPHERIC HAIL SIZE DISTRIBUTION

Hail Diameter (mm)	Contribution to total HWC (%)
0 - 4.9	0
5.0 - 9.9	17.00
10.0 - 14.9	25.00
15.0 - 19.9	22.50
20.0 - 24.9	16.00
25.0 - 29.9	9.75
30.0 - 34.9	4.75
35.0 - 39.9	2.50
40.0 - 44.9	1.50
45.0 - 49.9	0.75
50.0 - 55.0	0.25
TOTAL	100.00

Median diameter of hail is 16 mm

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

Issued in Washington, DC on March 20, 1998.

/signed by

Jane F. Garvey
Administrator

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25, and 33

[Docket No. 28652; Notice No. 96–12]

RIN 2120–AF75

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration, DOT.

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This document proposes changes to the water and hail ingestion standards for aircraft turbine engines. This proposal addresses engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. This proposal also harmonizes these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). The proposed changes, if adopted, would establish one set of common requirements, thereby reducing the regulatory hardship on the United States and worldwide aviation industry, by eliminating the need for manufactures to comply with different sets of standards when seeking type certification from the Federal Aviation Administration (FAA) and JAA.

DATES: Comments to be submitted on or before November 7, 1996.

ADDRESSES: Comments on this notice may be delivered or mailed, in triplicate, to: Federal Aviation Administration, Office of the Chief Counsel, Attention: Rules Docket (AGC-200), Docket No. 28652, Room 915G, 800 Independence Avenue, SW., Washington, DC 20591. Comments submitted must be marked: "Docket No. 28652. Comments may also be sent electronically to the following Room 915G on weekdays, except Federal holidays, between 8:30 a.m. and 5:00 p.m.

FOR FURTHER INFORMATION CONTACT: Thomas Boudreau, Engine and Propeller Standards Staff, ANE–110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803–5229; telephone (617) 238–7117; fax (617) 238–7199.

SUPPLEMENTARY INFORMATION:

Comments Invited

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Comments relating to the environmental, energy, federalism, or economic impact that might result from adopting the proposals in this notice are also invited. Substantive comments should be accompanied by cost estimates. Comments must identify the regulatory docket or notice number and be submitted in triplicate to the Rules Docket address specified above.

All comments received, as well as a report summarizing each substantive public contact with FAA personnel on this rulemaking, will be filed in the docket. The docket is available for public inspection before and after the comment closing date.

All comments received on or before the closing date will be considered by the Administrator before taking action on this proposed rulemaking. Late-filed comments will be considered to the extent practicable. The proposals contained in this notice may be changed in light of comments received.

Commenters wishing the FAA to acknowledge receipt of their comments submitted in response to this notice must include a pre-addressed, stamped postcard on those comments on which the following statement is made: "Comments to Docket No. 28652." The postcard will be date stamped and mailed to the commenter.

Availability of NPRMs

An electronic copy of this document may be downloaded using a modem and suitable communications software from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703–321–3339), the **Federal Register's** electronic bulletin board service (telephone: 202–512–1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone: 202–267–5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the **Federal Register**'s webpage at http://www.access.gpo.gov/su_docs for access to recently published rulemaking documents.

Any person may obtain a copy of this NPRM by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM–1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267–9680. Communications must identify the notice number of this NPRM.

Person interested in being placed on the mailing list for future NPRM's should request from the above office a copy of Advisory Circular No. 11–2A, Notice of Proposed Rulemaking Distribution System, that describes the application procedure.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

Industry Study

In 1987 the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to part 33, if appropriate. AIA, working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of 14 CFR part 33 do not adequately address this threat.

Engine Harmonization Effort

the FAA is committed to undertaking and supporting harmonization of standards in part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. The partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which where considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards. This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On November 7, 1995, the TAEIG recommended to the FAA that it proceed with rulemaking and associated advisory material even though one manufacturer has expressed reservations. This NPRM and associated advisory material reflects the ARAC recommendations.

Disposition of Objections

One manufacturer participating in the EHWG has expressed reservations with the proposal. The reservations focused on the degree of conservatism built into the assumptions regarding weather statistics. These reservations include concerns about a bias in the hail characterization towards geographical areas of extremely high hailstorm probabilities and with an apparent rounding up of the hail threat definition from 8/3 g/m^3 to 10 g/m^3. The manufacturer also expressed concern regarding the lack of standardized test procedures and analytical methods for compliance within the industry.

During the early phase of defining the environmental threat, for both rain and hail, engineering judgment suggested that expressing rain water content (RWC) and hail water content (HWC) as a function of a joint probability was an appropriate method. That joint probability is the product of the prior probability of a storm occurring at a given point and the conditional probability of a given water concentration value occurring within that storm. Given the potential for a pilot to avoid a storm and the ability for an engine to recover sufficiently for continued safe flight, a joint probability of 10^{-8} was determined adequate for establishing the certification standards for rain and hail. Accounting for hail shaft exposure times, the hail threat levels could vary from 8.7 g/m^3 to 10.2 g/m^3. The choice of 10 g/m^3 was agreed to by the EHWG as the certification standard that would be suitable for all applications. It was not simply a round up. Admittedly, the only credible hail data available was for high hail probability areas in North America and Europe. While these data may not represent the average world environment, they do represent areas of high commercial air traffic through which aircraft equipped with turbine engines normally operate.

The EHWG also consider the proposal and the associated harmonization activity to be an effective method of reaching a more uniform method for compliance by manufacturers. That activity has already fostered a significant sharing of knowledge on the subject.

Current Requirements

The current water and large hailstone ingestion standards are valid tests for addressing permanent mechanical damage resulting from such ingestions. However, they do not adequately address engine power-loss and instability effects, such as run down and flameout at lower than takeoff-rated power settings for turbine engines installed on airplanes.

The EHWG concluded that, with respect to power-loss and instability effects, the current water ingestion standard is adequate for turbine engines installed on rotorcraft (turboshaft engines) as an alternative to the new rain and hail ingestion standards. The EHWG reached this conclusion after it had reviewed the service experience of rotorcraft turbine engines and could not find an inservice event that would indicate that the current water ingestion standard are inadequate for that application. There are differences between rotorcraft and airplanes that help to explain the differences in the service experience of rotorcraft turbine engines versus other turbine engines. Rotorcraft turbine engines operate at higher power settings during descent than turbine engines installed on airplanes. Also, rotorcraft operate at lower flight speeds than airplanes. The combination of higher engine power and lower flight speed significantly reduces the water concentration amplification effects on rotorcraft turbine engines. Therefore, the proposed new rain and hail ingestion standards apply to all turbine engines, while a harmonized version of a four percent water to engine airflow by weight ingestion standard is proposed as an alternative for turbine engines installed on rotorcraft.

General Discussion of the Proposals

Section 23.901(d)(2), § 23.903(a)(2) and § 25.903(a)(2)

The proposed amendments would revise § 23.903(a)(2) and § 25.903(a)(2) to be consistent with the proposed part 33 changes. Additionally, proposed § 23.901(d)(2) would replace the current text with new text requiring each turbine engine installation to be constructed and arranged not to jeopardize compliance of the engine with § 23.903(a)(2). This would ensure that the installed engine retains the acceptable rain, hail, ice, and bird ingestion capabilities established for the uninstalled engine under § 23.903(a)(2).

Section 33.77

The proposed amendments would remove the large hailstone ingestion standards now specified in § 33.77 (c) and (e), and place them in new § 33.78 (a)(1) and (c). The proposal would also harmonize the four percent water to engine airflow by weight ingestion standard, currently specified in § 33.77 (c) and (e), and place it in new § 33.78(b) as an alternative standard for rotorcraft turbine engines to the proposed new rain and hail ingestion standards. New water and hail ingestion standards for all turbine engines would be introduced in new § 33.78(a)(2). All rain and hail ingestion standards would then be found in one section, as in the current JAR–E.

The intent of the current water ingestion standard is to address a number of concerns including power-loss, instability, and the potential hazardous effects of water associated with case contraction. As stated previously, there have been numerous power-loss and instability events on airplane turbine engines since the standard was promulgated (39 FR 35463, October 1, 1974). The need to better address power-loss and instability effects at lower than takeoff-rated power settings led to the proposed new standards for all turbine engines (new § 33.78(a)(2)). Collectively, the proposed new standards and the proposed changes as contained in new § 33.78 (a)(2) and (b) also better address potential concerns associated with case contractions on turbine engines since they are based on a more thorough understanding of the in-flight effects of rain and hail ingestion.

Section 33.78

The proposed § 33.78 would consolidate all harmonized rain and hail ingestion standards for turbine engines, and the corresponding harmonized acceptance criteria, into a single section. The proposal also introduces new rain and hail ingestion standards for turbine engines to address the power-loss and instability phenomena identified by AIA and AECMA.

Currently, part 33 and JAR–E have different acceptance criteria for the water and large hailstone ingestion standards. In general, part 33 does not permit any sustained power or thrust loss after the ingestion, while JAR–E permits some power or thrust loss and some minimal amount of mechanical damage. The EHWG determined, however, that the current FAA post ingestion power loss criterion does not consider thrust and power loss variabilities, such as inherent measurement inaccuracies. Therefore, allowing some measured power or thrust loss would be reasonable but must not reduce the level of safety intended by these requirements.

The EHWG concluded that sufficient airplane performance margins exist to permit sustained post ingestion power or thrust losses up to 3 percent at any value of the power or thrust setting parameter. Variabilities and uncertainties associated with thrust and power measurements could conceivably result in upwards of a 3 percent power or thrust measurement error. Therefore, measured post ingestion power or thrust losses up to 3 percent are acceptable and do not represent a reduction in the level of safety provided by current FAA water and large hailstone ingestion standards. However, measured post ingestion power or thrust losses greater than 3 percent, at any value of the primary power or thrust setting parameter, can only be accepted when supported by appropriate airplane performance assessments.

The EHWG also discussed levels of acceptable engine performance degradation that might be experienced as a result of certification testing. This degradation is a power or thrust reduction when pre-test and post test comparisons are made at any given values of the engine manufacturer's normal performance parameters other than the primary power or thrust setting parameter. This power or thrust degradation must not affect the measured power or thrust of the engine at any value of the primary power or thrust setting parameters, but would tend to reduce the available gas path temperature margin of the engine after the test. It is the judgment of the EHWG, based on certification and development test experience, that current and future technology engines should be capable of demonstrating less than 10 percent engine performance degradation from a single hail or rain ingestion event. Some members of the EHWG believe that values greater than 10 percent can be safely accommodated, but consensus could not be obtained in defining this uppermost value. The EHWG accepted the 10 percent value as a compromise certification standard for future use in the context of rain and hail ingestion testing. In the event that future certification tests result in engine performance degradations that exceed 10 percent, the actual demonstrated level must be evaluated for acceptability against the criterion of aircraft safety.

The proposed new rain and hail ingestion standards to address the power loss and instability phenomena refer to a proposed new FAR part 33 appendix for a definition of maximum concentrations of rain and hail in the atmosphere. It is expected that a combination of tests and analyses would be needed to demonstrate compliance. Therefore, this proposal allows for various means of compliance.

Allowing various means of compliance has distinct advantages. The variables associated with an ingestion event are best addressed through a combination of tests and analyses. Also, it is anticipated that further insight into the phenomenon of rain and hail ingestion would be gained through the development of these various compliance methods. Finally, the EHWG believes that applicants would develop compliance methods which minimize the cost impact.

Rain and hail ingestion standards embodied in this rule represent an extremely remote probability of encounter (1×10^{-8}). They are based on current assessments of atmospheric and meteorological conditions and aircraft engine service experience. Both the FAA and the JAA agree that the need for revised standards should be considered as additional service and atmospheric data warrant.

Appendix B

Proposed Appendix B defines the certification standard atmospheric concentrations of rain and hail. These values were derived through detailed meteorological surveys and statistical analyses and represent an extremely remote aircraft encounter.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1990 (44 U.S.C. 3501 *et seq.*), there are no requirements for information collection associated with this proposed rule.

International Compatibility

The FAA has reviewed corresponding International Civil Aviation Organization international standards and recommended practices and Joint Aviation Authorities requirements and has identified no difference in these proposed amendments and the foreign regulations.

Regulatory Evaluation Summary

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) Would generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) would not have a significant impact on a substantial number of small entities; and (4) would not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Incremental Certification Costs

The proposed rule would permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods would most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment would likely be the most costly. Incremental cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for airplane turbine engines would be approximately $667,000; this includes $300,000 in additional engineering hours, and $367,000 for the prorated share of the cost of a test facility.

Incremental Manufacturing and Operating Costs

Predicting the rule's effect on manufacturing costs is complicated by design/cost tradeoffs, the large number of permutations of modifications that could achieve the desired result, and because engine design takes place in the context of constant technological change. Based on discussions with industry representatives, the FAA expects that, once rain/hail centrifuging and engine cycle models are established, compliance would be accomplished through design modifications that would have little impact on manufacturing costs. Such design features may affect: (1) fan blade/propeller, (2) spinner/nose cone, (3) bypass splitter, (4) engine bleeds, (5) accessory loads, (6) variable stator scheduling, and (7) fuel control. Similarly, the FAA expects that the rule would have a negligible effect on operating costs (again, based on discussions with industry representatives).

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of FAA and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the proposed rule, as summarized below. However, the following summary should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. The historical record shows that many accidents (not included in the following benefit estimates) were caused by other forms of water such as snow and graupel. It is possible that the aircraft in some of these cases would have benefited from the proposed rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

Benefits of Prevented Aircraft Damage

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the proposed rule. These classifications are: (1) Large air carrier aircraft (major and national air carriers), and (2) other air carrier aircraft (large regional, medium regional, commuter, and other small certificated air carriers).

An examination of accident records for the period 1975–90, indicates that, in the absence of the proposed rule, the probability of a hull loss due to a water induced loss of engine power is 0.0104 per million airplane departures for large air carriers, and 0.0276 per million airplane departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the proposed standards would reduce the accident rate by two orders of magnitude. That is, the rule is expected to be 99 percent effective in reducing water ingestion accidents. FAA estimates that the annual average benefits per airplane from prevented aircraft damage would be approximately $337 and $97 for large air carriers and other air carriers, respectively.

Benefits of Prevent Injuries and Fatalities

Using projections from the FAA Aviation Forecast, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61 percent. The average regional airplane is assumed to have 30 seats and a load factor of 51 percent. The estimated distribution of fatal, serious, and minor injuries is derived from the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane would be $3,062 for operations by large air carriers and $706 for operations by other air carriers.

Benefit-Cost Analysis

The benefits and costs of the proposed rule are compared for two representative engine certifications using the following assumptions: (1) For each certification, 50 engines are produced per year for 10 years (500 engines), (2) incremental certification costs are incurred in year "0", (3) engine production begins in year "3", (4) the first engines enter service in year "4", (5) each engine is retired after 10 years, (6) the discount rate is 7 percent. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the airplane accident rate) this analysis assumes that each airplane has two engines.

For each airplane/engine type, the annual benefit per aircraft is the sum of the expected property and casualty benefits. The total benefit for each type certification, then, is the product of the per aircraft annual benefit and the number of aircraft in service summed over the life of the engines. Thus, for representative type certifications, discounted lifecycle benefits would be approximately $3.7 million and $0.8 million for operations by large air carriers and other air carriers, respectively.

FAA finds that the rule would be cost-beneficial. Under conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage would exceed discounted costs by a factor ranging from 5.5 ($3,661,084/$667,000) for operations by large air carriers to 1.3 ($864,696/$667,000) for operations by other air carriers.

Harmonization Benefits

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act (RFA) of 1980 was enacted by Congress to ensure that small entities are not unnecessarily or disproportionately burdened by Government regulations. The RFA requires a Regulatory Flexibility Analysis if a rule is expected to have a "significant economic impact on a substantial number of small entities." Based on the standards and thresholds specified in implementing FAA Order 2100.14A, Regulatory Flexibility Criteria and Guidance, the FAA has determined that the rule would not have a significant impact on a substantial number of small manufacturers or operators because no turbine engine manufacturer is a "small entity" as defined in the order.

International Trade Impact Assessment

The rule would have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine engines in the U.S.

Federalism Implications

The regulations proposed herein would not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this proposal would not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Conclusion

For the reasons discussed above, including the findings in the Regulatory Flexibility Determination and the International Trade Impact Analysis, the FAA has determined that this proposed regulation is not significant under Executive Order 12866. In addition, the FAA certifies that this proposal, if adopted, would not have a significant economic impact, positive or negative, on a substantial number of small entities under the criteria of the Regulatory Flexibility Act. This proposal is not considered significant under DOT Regulatory Policies and Procedures (44 FR 11034, February 26, 1979). An initial regulatory evaluation of the proposal, including a Regulatory Flexibility Determination and Trade Impact Analysis, has been placed in the docket. A copy may be obtained by contacting the person identified under FOR FURTHER INFORMATION CONTACT.

List of Subjects in 14 CFR Parts 23, 25, and 33

Air transportation, Aircraft, Aviation safety, Safety.

The Proposed Amendment

In consideration of the foregoing, the Federal Aviation Administration proposes to amend parts 23, 25, and 33 of the Federal Aviation Regulations (14 CFR part 23, 14 CFR part 25, and 14 CFR part 33) as follows:

PART 23—AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

§ 23.901 Installation.

* * * * *

(d) * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

* * * * *

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

§ 23.903 Engines.

(a) * * *

(2) Each turbine engine must either—

(i) Comply with § 33.77 and § 33.78 of this chapter for an airplane for which application for type certification is made on or after [Insert effective date of final rule]; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, and must have a foreign object ingestion service history that has not resulted in any unsafe condition for an airplane for which application for type certification was made before [Insert effective date of final rule]; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467; October 1, 1974.

* * * * *

PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

§ 25.903 Engines.

(a) * * *

(2) Each turbine engine must either—

(i) Comply with § 33.77 and § 33.78 of this chapter for an airplane for which application for type certification is made on or after [Insert effective date of final rule]; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, and must have a foreign object ingestion service history that has not resulted in any unsafe condition for an airplane for which application for type certification was made before [Insert effective date of final rule]; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467; October 1, 1974.

* * * * *

PART 33—AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701, 44702, 44704.

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

§ 33.77 Foreign object ingestion.

* * * * *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

* * * * *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

Foreign object	Test quantity	Speed of foreign object	Engine operation	Ingestion
Birds:				
3-ounce size	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1½-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.

Foreign object	Test quantity	Speed of foreign object	Engine operation	Ingestion
1½-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
4-pound size	One, if it can enter the inlet	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes.	Maximum cruise	Aimed at critical area.
		Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Takeoff	Aimed at critical area.
Ice	Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in	Maximum cruise	To simulate a continuous maximum icing encounter at 25°F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) *All engines.* (1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum rough air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet fact area. The hailstone number and size shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet area of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 20-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet area more than 100 square inches (0.0645 square meters).

(2) Except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability during any three minute continuous period in rain and during any 30 second continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) *Engines for rotocraft.* As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotocraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) Continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) Continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) Continuation of the rain ingestion during subsequent rapid deceleration to takeoff power.

(c) *Engines for supersonic airplanes.* In addition to complying with paragraph (a)(1) of this section, a separate test for supersonic airplane engines only, shall be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain or hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject water constituents; and

(3) The subject water constituents, stopped by the protective device, will not obstruct the flow of induction air

into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

Appendix B to Part 33—Certification Standard Atmospheric Concentrations of Rain and Hail

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hailstones fabricated from ice to simulate hail conditions, the use of water droplets and hailstones having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hailstone, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

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FIGURE B1 - Illustration of Rain and Hail Threats. Certification concentrations are obtained using Tables B1 and B2.

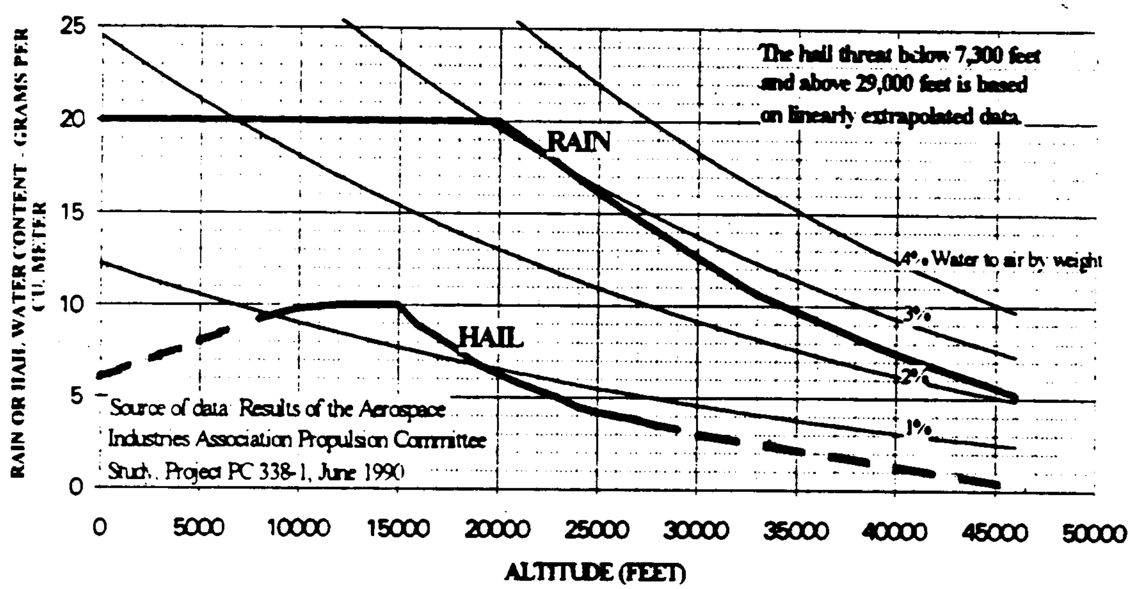

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TABLE B1.—CERTIFICATION STANDARD ATMOSPHERIC RAIN CONCENTRATIONS

Altitude (feet)	Rain water content (RWC) (gramswater/ meter^3 air)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

RWC values at other altitudes may be determined by linear interpolation.

Note: Source of data—Results of the Aerospace Industries Association (AIA) Propulsion Committee Study, Project PC 338–1, June 1990.

TABLE B2.—CERTIFICATION STANDARD ATMOSPHERIC HAIL CONCENTRATIONS

Altitude (feet)	Hail water content (HWC) (grams water / meter^3 air)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

HWC values at other altitudes may be determined by linear interpolation. The hail threat below 7,300 feet and above 29,000 feet is based on linearly extrapolated data.

Note: Source of data—Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project (PC 338–1, June 1990.

TABLE B3.—CERTIFICATION STANDARD ATMOSPHERIC RAIN DROPLET SIZE DISTRIBUTION

Rain droplet diameter (mm)	Contribution to total LWC (%)
0–0.49	0
0.50–0.99	2.25
1.00–1.49	8.75
1.50–1.99	16.25
2.00–2.49	19.00
2.50–2.99	17.75
3.00–3.49	13.50
3.50–3.99	9.50
4.00–4.49	6.00
4.50–4.99	3.00
5.00–5.49	2.00
5.50–5.99	1.25
6.00–6.49	0.50
6.50–7.00	0.25
Total	100.00

Median diameter of rain droplets is 2.66 mm

Note: Source of data—Results of the Aerospace Industry Association (AIA) Propulsion Committee (PC) Study, Project PC 338–1, June 1990.

TABLE B4.—CERTIFICATION STANDARD ATMOSPHERIC HAILSTONE SIZE DISTRIBUTION

Hailstone diameter (mm)	Contribution to total HWC (%)
0.4.9	0
5.0–9.9	17.00
10.0–14.9	25.00
15.0–19.9	22.50
20.0–24.9	16.00
25.0–29.9	9.75
30.0–34.9	4.75
35.0–39.9	2.50
40.0–44.9	1.50
45.0–49.9	0.75
50.0–55.0	0.25
Total	100.00

Median diameter of hailstones is 16 mm.

Note: Source of data—Results of the Aerospace Association (AIA) Propulsion Committee (PC) Study, Project PC 338–1, June 1990.

Issued in Washington, DC on August 2, 1996.

Elizabeth Yoest,

Acting Director, Aircraft Certification Services.

[FR Doc. 96–20265 Filed 8–8–96; 8:45 am]

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[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Parts 23, 25 and 33

[Docket No. 28652; Amendment Nos. 23-53, 25-95, and 33-19]

RIN 2120-AF75

Airworthiness Standards; Rain and Hail Ingestion Standards

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final rule.

SUMMARY: These amendments establish revisions to the Federal Aviation Administration's certification standards for rain and hail ingestion for aircraft turbine engines. These amendments address engine power-loss and instability phenomena attributed to operation in extreme rain or hail that are not adequately addressed by current requirements. These amendments also generally harmonize these standards with rain and hail ingestion standards being amended by the Joint Aviation Authorities (JAA). These amendments establish nearly uniform standards for engines certified in the United States under 14 CFR part 33 and in the JAA countries under Joint Airworthiness Requirements-Engines (JAR-E), thereby simplifying the certification of engine designs by the FAA and the JAA.

EFFECTIVE DATE: April 30, 1998

FOR FURTHER INFORMATION CONTACT: John Fisher, Engine and Propeller Standards Staff, ANE-110, Engine and Propeller Directorate, Aircraft Certification Service, FAA, New England Region, 12 New England Executive Park, Burlington, Massachusetts 01803-5229; telephone (781) 238-7149; fax (781) 238-7199.

SUPPLEMENTARY INFORMATION

Availability of Final Rules

An electronic copy of this document may be downloaded, using a modem and suitable communications software, from the FAA regulations section of the Fedworld electronic bulletin board service (telephone: 703-321-3339), the **Federal Register's** electronic bulletin board service (2002-512-1661), or the FAA's Aviation Rulemaking Advisory Committee Bulletin Board service (telephone 202-267-5948).

Internet users may reach the FAA's web page at http://www.faa.gov or the **Federal Register's** web page at http://www.access.gpo.gov/su_ docs for access to recently published rulemaking documents.

Any person may obtain a copy of this final rule by submitting a request to the Federal Aviation Administration, Office of Rulemaking, ARM-1, 800 Independence Avenue, SW., Washington, DC 20591, or by calling (202) 267-9680. Communications must identify the amendment number or document number of this final rule.

Persons interested in being placed on the mailing list for future notices of proposed rulemaking and final rulemaking should request from the above office a copy of Advisory Circular No. 11-2A, Notices of Proposed Rulemaking Distribution System, that describes the application procedure.

Small Entity Inquiries

The Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA) requires the FAA to report inquiries from small entities concerning information on, and advice about, compliance with statutes and regulations within the FAA's jurisdiction, including interpretation and application of the law to specific sets of facts supplied by a small entity.

If you are a small entity and have a question, contact your local FAA official. If you do not know how to contact your local FAA official, you may contact Charlene Brown, Program Analyst Staff, Office of Rulemaking, ARM-27, Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, 1-888-551-1594. Internet users can find additional information on SBREFA in the "Quick Jump" section of the FAA's web page at http://www.faa.gov and may send electronic inquiries to the following internet address: 9-AWA-SBEFA@faa.dot.gov.

Background

Statement of the Problem

There have been a number of multiple turbine engine power-loss and instability events, forced landings, and accidents attributed to operating airplanes in extreme rain or hail. Investigations have revealed that ambient rain or hail concentrations can be amplified significantly through the turbine engine core at high flight speeds and low engine power conditions. Rain or hail through the turbine engine core may degrade compressor stability, combustor flameout margin, and fuel control run down margin. Ingestion of extreme quantities of rain or hail through the engine core may ultimately produce a number of engine anomalies, including surging, power loss, and engine flameout.

Industry Study

In 1987, the Aerospace Industries Association (AIA) initiated a study of natural icing effects on high bypass ratio (HBR) turbofan engines that concentrated primarily on the mechanical damage aspects of icing encounters. It was discovered during that study that separate power-loss and instability phenomena existed that were not related to mechanical damage. Consequently, in 1988 another AIA study was initiated to determine the magnitude of these threats and to recommend changes to part 33, if appropriate. AIA,

working with the Association Europeenne des Constructeurs de Materiel Aerospatial (AECMA), concluded that a potential flight safety threat exists for turbine engines installed on airplanes operating in extreme rain and hail. Further, the study concluded that the current water and hail ingestion standards of 14 CFR part 33 do not adequately address this threat.

Engine Harmonization Effort

The FAA is committed to undertaking and supporting harmonization of standards in part 33 with those in Joint Aviation Requirements-Engines (JAR-E). In August 1989, as a result of that commitment, the FAA Engine and Propeller Directorate participated in a meeting with the Joint Aviation Authorities (JAA), AIA, and AECMA. The purpose of the meeting was to establish a philosophy, guidelines, and a working relationship regarding the resolution of issues arising from standards that need harmonization, including the adoption of new standards when needed. All parties agreed to work in partnership to address jointly the harmonization task. This partnership was later expanded to include the airworthiness authority of Canada, Transport Canada.

This partnership identified seven items which were considered the most critical to the initial harmonization effort. New rain and hail ingestion standards are an item on this list of seven items and, therefore, represent a critical harmonization effort.

Aviation Rulemaking Advisory Committee Project

In December 1992, the FAA requested the Aviation Rulemaking Advisory Committee (ARAC) to evaluate the need for new rain and hail ingestion standards. This task, in turn, was assigned to the Engine Harmonization Working Group (EHWG) of the Transport Airplane and Engine Issues Group (TAEIG) on December 11, 1992 (57 FR 58840). On November 7, 1995, the TAEIG recommended to the FAA that it proceed

with rulemaking and associated advisory material even though one manufacturer expressed reservations. The FAA published a notice of proposed rulemaking on August 9, 1996 (61 FR 41688). This rule and associated advisory material reflect the ARAC recommendations.

Discussion of Comments

All interested persons have been afforded an opportunity to participate in this rulemaking, and due consideration has been given to all comments received. The commenters represent domestic and foreign industry, and foreign airworthiness authorities. Five commenters provided the FAA with comments to the NPRM.

Four commenters expressed concern with the proposed wording for §§ 23.903 and 25.903. The commenters state that the proposal could result in retroactive requirements imposed on certain engines already type certificated. Three of the four commenters further state that this part of the proposal represents a significant departure from the proposal submitted to the FAA by ARAC.

The FAA agrees. It was not the intent of the FAA to retroactively impose the new requirements on an engine design already type certificated unless service history indicates that an unsafe condition is present. The FAA has changed the wording for §§ 23.903 and 25.903 back to that originally proposed by the ARAC .

All five commenters found a number of typographical errors and suggested some editorial changes. One notable typographical error appeared in the "Disposition of Comments" section of the preamble of the proposal. When addressing a concern that the hail threat definition was apparently rounded up to 10 g/m^3 , the value 8/3 g/m^3 was incorrect and should have been written as 8.7 g/m^3.

The FAA also agrees to the other recommendations by the commenters and the following grammatical corrections and changes to § 33.78 and Appendix B have been made to this rule:

Section 33.78(a)(1): "Critical inlet fact area" has been changed to "Critical inlet face area" and the last sentence revised to read, "The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:".

Section 33.78(a)(1)(ii): The term "one 20-inch" has been changed to "one 2-inch".

Section 33.78(a)(2): The following has been added to the beginning of the paragraph, "In addition to complying with paragraph (a)(1) of this section and", and a comma has been added immediately following the phrase "or loss of acceleration and deceleration capability".

Section 33.78(b)(4): "deceleration" has been replaced with "acceleration".

Appendix B, Table B3: "Contribution to total LWC (%)" has been changed to "Contribution to total RWC (%)".

Appendix B, Table B4: The term "0.4.9" has been changed to "0-4.9", and "hailstone" has been replaced with "hail" in the title, column heading, and footnote.

One commenter provided an additional clarifying statement with respect to the hail threat level variations obtained from the Industry Study. Given an extremely remote encounter probability and a typical thirty second exposure to severe hail, the assessed hail threat level varies from 8.7 g/m^3 to 10.2 g/m^3, depending upon the airspeed of the aircraft traversing the hail shaft.

The FAA agrees with the commenter’s additional explanation of the assessed hail threat variation. However, the discussion of the Industry Study in the proposal is technically correct.

One commenter states the need for advisory material to accompany the rule to clarify various terms and criteria contained in the rule.

The FAA agrees. An extensive advisory circular (AC) was drafted providing explanation of the various terms and criteria contained in the rule. The FAA issued a notice of availability of proposed AC and request for comments on September 5, 1996 (61 FR 46893). Further information regarding this AC can be obtained by contacting the FAA at the address specified under “FOR FURTHER INFORMATION CONTACT:”.

One commenter suggested changes to the preamble discussion regarding power loss and performance degradation. The commenter did not suggest nor imply that any changes to the proposed rule were needed. The FAA need not address those comments since they do not affect the meaning of these regulations.

One commenter states that the criterion of no flameout contained in § 33.78(a)(2) and § 33.78(b) was excessive. The commenter further states that many engines are equipped with automatic re-ignition systems that would ensure quick recovery from a flameout.

The FAA disagrees. Automatic re-ignition systems can facilitate quick recovery from a flameout as a result of a momentary ingestion, such as an ice shed. However, the rain and hail ingestion threats addressed by the new standards are not momentary, and have been defined for purposes of certification testing as 30 seconds duration for hail and 3 minutes duration for rain. Once flameout occurs under these conditions, it is unlikely that the engine will be capable of recovery until the ingestion of rain or hail ceases, with or

without an automatic re-ignition system. Also, for actual encounters of severe rain and hail, it is likely that the engine will continue to ingest water, at lower concentrations, after exiting the area of severe rain or hail. The effect of this ingested water is to lower the starting capability of the engine. Therefore, if an airplane encounters severe rain or hail with installed engines that are susceptible to flameout, the airplane will be susceptible to an all engine out, forced landing. For these reasons, demonstrating tolerance to flameout under conditions of extreme rain and hail is a primary objective of the new standards.

One commenter states that the acceptance criteria for rain and hail ingestion contained in § 33.78(a)(2) and § 33.78(b) appeared to be more stringent than the acceptance for ice ingestion. The commenter believes that the acceptance criteria for rain and hail ingestion should be less stringent than for ice ingestion, since ice ingestion is a more common occurrence than hail ingestion.

The FAA concurs with the commenter that the stringency of acceptance criteria should be proportional to the occurrence rate of the threat being assessed. However, the FAA disagrees with the commenter's view that the acceptance criteria for rain and hail ingestion are more stringent than for ice ingestion. Some amount of sustained power or thrust loss is permitted following testing to the new rain and hail ingestion standards, but no power or thrust loss is permitted following an ice ingestion test. Also, the FAA would accept momentary but recoverable surges and stalls encountered while testing to the new rain and hail ingestion standards, but has not historically accepted momentary surges and stalls following an ice ingestion test. Flameout, run down, continued or non-recoverable surge or stall, and loss of acceleration and deceleration are unacceptable conditions for rain, hail and ice ingestion.

Finally, the FAA has made the following minor editorial changes to better align this rule with recent changes to the JAA's requirements. These changes do not affect the scope of the rule or change the intent of these sections.

Section 33.78(a)(1): The phrase "maximum true air speed" replaces the phrase "maximum rough air speed", and the phrase "operating in rough air" is added following the words "representative aircraft".

Section 33.78(a)(1)(i) and (ii): The word "area" is changed to read "areas".

Section 33.78(c): In the first sentence the phrase "complying with paragraph (a)(1) of this section" is changed to read "complying with paragraphs (a)(1) and (a)(2) of this section.

Appendix B: The word "hailstones" is changed to read "hail" in the introductory paragraph and also in Table B4.

After careful review of all the comments, the FAA has determined that air safety and the public interest require the adoption of the rule with the changes described.

Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1995 (44 U.S.C. 3507(d), there are no information collection requirements associated with this final rule.

Regulatory Evaluation Summary

Proposed changes to Federal regulations must undergo several economic analyses. First, Executive Order 12866 directs that each Federal agency shall propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs. Second, the Regulatory Flexibility Act of 1980 requires agencies to analyze the economic effect of regulatory changes on small entities. Third, the Office of Management and Budget directs agencies to

assess the effects of regulatory changes on international trade. In conducting these analyses, the FAA has determined that this rule: (1) will generate benefits that justify its costs and is not a "significant regulatory action" as defined in the Executive Order; (2) is not significant as defined in DOT's Regulatory Policies and Procedures; (3) will not have a significant impact on a substantial number of small entities; and (4) will not constitute a barrier to international trade. These analyses, available in the docket, are summarized below.

Incremental costs

The proposed rule will permit a range of compliance options, thereby enabling manufacturers to select cost-minimizing approaches. Approaches that maximize the use of analytical methods will most likely be the least expensive means to demonstrate compliance, while approaches that rely primarily on engine testing in a simulated rain and hail environment will likely be the most costly. Incremental certification cost estimates supplied by industry varied depending on engine model and the testing method used.

FAA conservatively estimates that incremental certification costs for an airplane turbine engine design will be approximately $627,000-- this includes $300,000 in additional engineering hours, and $327,000 for the prorated share of the cost of a test facility.

Based on statements from industry, the FAA expects that, once Rain/Hail centrifuging and engine cycle models are established, compliance will be accomplished through design modifications that will have little impact on manufacturing costs. Such design features may affect: 1) fan blade/propeller, 2) spinner/nose cone, 3) bypass splitter, 4) engine bleeds, 5) accessory loads, 6)

variable stator scheduling, and 7) fuel control. Similarly, the FAA expects that the rule will have a negligible effect on operating costs.

Expected Benefits

Rain or hail related in-flight engine shutdowns are rare occurrences. This is due, in large part, to the high quality of meteorological data available to ground controllers and pilots, and to well established weather avoidance procedures. However, while such events are infrequent, they pose a serious hazard because they typically occur during a critical phase of flight where recovery is difficult or impossible.

An examination of the FAA accident/incident database system and National Transportation Safety Board (NTSB) records revealed two accidents that were the result of inflight engine shutdowns or rundowns caused by excessive water ingestion. In each case, the aircraft was in the descent phase of flight. These accidents form the basis of the expected benefits of the subject rule. However, what follows should be considered a conservative estimate of the rule's potential benefits for three reasons.

First, the rule should have the effect of increasing turbine engine water ingestion tolerance regardless of the source of water. Accident/incident records show that many events (not included in the benefit estimates that follow) were caused by other forms of water such as snow and graupel. It is possible that some of these cases would have benefited from the subject rule.

Second, several other incidents, while not resulting in a crash, nevertheless had catastrophic potential. This potential could be exacerbated by the development of more efficient turbofan powerplants which have permitted large

aircraft designs incorporating fewer engines. An industry study identified seven events (not recorded in either the FAA or NTSB databases) in which rain and/or hail affected two or more engines and resulted in an inflight shutdown of at least one engine.

Third, heavy rain and hail are often accompanied by severe turbulence and windshear. While recovery from a water induced engine shutdown is frequently successful, the ability to maintain engine power during an encounter with an unexpected downdraft could be crucial to avoiding a crash.

The available accident and aircraft usage data suggest the categories that are used to classify the benefits of the subject rule. These classifications are: 1) large air carrier aircraft (operated by major and national air carriers), and 2) other air carrier aircraft (operated by large regional, medium regional, commuter, and other small certificated air carriers). An examination of accident records for the 20-year period 1975-1994 indicates that, in the absence of the subject rule, the probability of a hull loss due to a water induced loss of engine power is 0.0094 per million departures for large air carriers, and 0.0249 per million departures for other air carriers.

The calculation of the rule's benefits, then, depends on the degree to which the rule can reduce this risk. According to industry representatives, compliance with the revised water ingestion standards will reduce the rate of engine power loss events by two orders of magnitude. This analysis assumes that the rule’s effect on the accident rate will be proportionately equal to the rule’s effect on the event rate.

Using projections from the FAA Aviation Forecast, this analysis assumes that the average large air carrier airplane has 168 seats and a load factor of 61%. The average regional air carrier airplane is assumed to have 30 seats and a load factor of 51%. The estimated distribution of fatal, serious, and minor injuries is based on the actual distribution of casualties in the accidents cited above. On the basis of these assumptions, FAA estimates the annual benefits of prevented casualties per airplane will be $3,360 for large air carriers and $618 for other air carriers.

Benefits and Costs Analysis

The benefits and costs of the rule are compared for two representative engine certifications: 1) An engine designed for operation on a large jet transport (corresponding to the "large air carrier" category described earlier), and 2) an engine designed for operation on a regional transport (corresponding to the "other air carrier" category).

For each certification, the following assumptions apply: 1) 50 engines are produced per year for 10 years (500 total engines produced per certification), 2) incremental certification costs are incurred in the year 2000, 3) engine production begins in the year 2002, 4) the first engines enter service in the year 2003, 5) each engine is retired after 10 years, 6) the discount rate is 7%. Also, in order to compare incremental engine costs with expected benefits (which are expressed in terms of the reduction in the aircraft accident rate) this analysis assumes that each aircraft has two engines.

Under the assumptions enumerated above, total lifecycle benefits for a representative engine designed for operation on a large airplane equal

approximately $9.3 million or $3.5 million at present value (1997 dollars). Total lifecycle benefits for a representative engine designed for operation on a regional airplane equal to approximately $1.8 million or $0.7 million at present value.

This analysis postulates that incremental certification costs for both representative engine designs are the same. As discussed above, incremental costs are approximately $627,000 or $512,000 at present value.

FAA finds that the rule would be cost-beneficial. Under very conservative production, service life, and incremental engine certification cost assumptions, the expected discounted benefits of prevented casualties and aircraft damage will exceed costs by a ratio ranging from 6.9 to 1 for large air carriers to 1.3 to 1 for other air carriers.

Harmonization Benefits

In addition to the benefits of increased safety, the rule harmonizes with JAR requirements, thus reducing costs associated with certificating aircraft turbine engines to differing airworthiness standards.

Regulatory Flexibility Determination

The Regulatory Flexibility Act of 1980 establishes "as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation." To achieve that principle, the Act requires agencies to solicit and consider flexible regulatory proposals and to explain the rationale for their actions. The Act covers a wide range of small entities, including small businesses, not-for-profit organizations and small governmental jurisdictions.

Agencies must perform an analysis to determine whether a rule will have a significant economic impact on a substantial number of small entities; if the determination is that it will, the agency must prepare a regulatory flexibility analysis (RFA).

However, if after an analysis for a proposed or final rule, an agency determines that a rule is not expected to have a significant economic impact on a substantial number of small entities, § 605(b) of the 1980 act provides that the head of the agency may so certify. The certification must include a statement providing the factual basis for this determination, and the reasoning should be clear.

The FAA conducted the required preliminary analysis of this proposal and determined that it would not have a significant economic impact on a substantial number of small entities. That determination was published in the Federal Register on August 9, 1996 as part of the Notice of Proposed Rulemaking. No comments were received regarding the economic analysis of the rule. No substantial changes were made in the final rule from the proposed rule, and estimated costs were not significantly modified. Accordingly, pursuant to the Regulatory Flexibility Act, 5 U.S.C. § 605(b), the Federal Aviation Administration certifies that this rule will not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment

The rule will have little or no effect on trade for either U.S. firms marketing turbine engines in foreign markets or foreign firms marketing turbine

engines in the U.S. Generally, this rule harmonizes FAA requirements with existing and proposed JAA requirements.

Federalism Implication

The regulations will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this rule will not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (The Act), enacted as Pub. L. 104-4 on March 22, 1995, requires each federal agency, to the extent permitted by law, to prepare a written assessment of the effects of any federal mandate in a proposed or final agency rule that may result in the expenditure by state, local, and tribal governments, in the aggregate, or by the private sector, of $100 million or more (adjusted annually for inflation) in any one year. Section 204(A) of The Act, 2 U.S.C. 1534(A), requires the federal agency to develop an effective process to permit timely input by elected officers (or their designees) of state, local, and tribal governments on a proposed "significant intergovernmental mandate". A "significant intergovernmental mandate" under The Act is any provision in a federal agency regulation that will impose an enforceable duty upon state, local, and tribal governments, in the aggregate, of $100 million (adjusted annually for inflation) in any one year. Section 203 of The Act, 2 U.S.C. 1533, which supplements section 204(A), provides that before establishing any regulatory requirements that might significantly or uniquely affect small governments, the agency shall have developed a plan

that, among other things, provides for notice to potentially affected small governments, if any, and for a meaningful and timely opportunity to provide input in the development of regulatory proposals**.**

The FAA determines that this rule does not contain a significant intergovernmental or private sector mandate as defined by the act.

List of Subjects in 14 CFR Parts 23, 25 and 33

Air transportation, Aircraft, Aviation safety, Safety.

Adoption of the Amendments

In consideration of the foregoing, the Federal Aviation Administration amends 14 CFR parts 23, 25, and 33 as follows:

PART 23 - AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES

1. The authority citation for part 23 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

2. Section 23.901 is amended by revising paragraph (d)(2) to read as follows:

§ 23.901 Installation.

*** * * * ***

(d) * * *

(2) Ensure that the capability of the installed engine to withstand the ingestion of rain, hail, ice, and birds into the engine inlet is not less than the capability established for the engine itself under § 23.903(a)(2).

* * * * *

3. Section 23.903 is amended by revising paragraph (a)(2) to read as follows:

§ 23.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

*** * * * ***

PART 25 - AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

4. The authority citation for part 25 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

5. Section 25.903 is amended by revising paragraph (a)(2) to read as follows:

§ 25.903 Engines.

(a) * * *

(2) Each turbine engine must either-

(i) Comply with § 33.77 and § 33.78 of this chapter in effect on April 30, 1998; or as subsequently amended; or

(ii) Comply with § 33.77 of this chapter in effect on October 31, 1974, or as subsequently amended prior to April 30, 1998, and must have a foreign object ingestion service history that has not resulted in any unsafe condition; or

(iii) Be shown to have a foreign object ingestion service history in similar installation locations which has not resulted in any unsafe condition.

Note: § 33.77 of this chapter in effect on October 31, 1974, was published in 14 CFR parts 1 to 59, Revised as of January 1, 1975. See 39 FR 35467, October 1, 1974.

* * * * *

PART 33 - AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES

6. The authority citation for part 33 continues to read as follows:

Authority: 49 U.S.C. 106(g), 40113, 44701-44702, 44704.

7. Section 33.77 is amended by revising paragraphs (c) and (e) to read as follows:

§ 33.77 Foreign object ingestion.

* * * * *

(c) Ingestion of ice under the conditions prescribed in paragraph (e) of this section, may not cause a sustained power or thrust loss or require the engine to be shut down.

* * * * *

(e) Compliance with paragraphs (a), (b), and (c) of this section must be shown by engine test under the following ingestion conditions:

FOREIGN OBJECT	TEST QUANTITY	SPEED OF FOREIGN OBJECT	ENGINE OPERATION	INGESTION
BIRDS:				
3-Ounce size	One for each 50 square inches of inlet area, or fraction thereof, up to a maximum of 16 birds. Three-ounce bird ingestion not required if a 1-1/2-pound bird will pass the inlet guide vanes into the rotor blades.	Liftoff speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
1-1/2-pound size	One for the first 300 square inches of inlet area, if it can enter the inlet, plus one for each additional 600 square inches of inlet area, or fraction, thereof up to a maximum of 8 birds.	Initial climb speed of typical aircraft.	Takeoff	In rapid sequence to simulate a flock encounter and aimed at selected critical areas.
4-pound size	One, if it can enter the inlet.	Maximum climb speed of typical aircraft, if the engine has inlet guide vanes. Liftoff speed of typical aircraft, if the engine does not have inlet guide vanes.	Maximum cruise Takeoff	Aimed at critical area. Aimed at critical area.
ICE :				
Maximum accumulation on a typical inlet cowl and engine face resulting from a 2-minute delay in actuating anti-icing system, or a slab of ice which is comparable in weight or thickness for that size engine.	Sucked in.		Maximum cruise	To simulate a continuous maximum icing encounter at 25^{o}F.

Note: The term "inlet area" as used in this section means the engine inlet projected area at the front face of the engine. It includes the projected area of any spinner or bullet nose that is provided.

8. Section 33.78 is added to part 33, to read as follows:

§ 33.78 Rain and hail ingestion.

(a) All engines.

(1) The ingestion of large hailstones (0.8 to 0.9 specific gravity) at the maximum true air speed, up to 15,000 feet (4,500 meters), associated with a representative aircraft operating in rough air, with the engine at maximum continuous power, may not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion, or require the engine to be shut down. One-half the number of hailstones shall be aimed randomly over the inlet face area and the other half aimed at the critical inlet face area. The hailstones shall be ingested in a rapid sequence to simulate a hailstone encounter and the number and size of the hailstones shall be determined as follows:

(i) One 1-inch (25 millimeters) diameter hailstone for engines with inlet areas of not more than 100 square inches (0.0645 square meters).

(ii) One 1-inch (25 millimeters) diameter and one 2-inch (50 millimeters) diameter hailstone for each 150 square inches (0.0968 square meters) of inlet area, or fraction thereof, for engines with inlet areas of more than 100 square inches (0.0645 square meters).

(2) In addition to complying with paragraph (a)(1) of this section and except as provided in paragraph (b) of this section, it must be shown that each engine is capable of acceptable operation throughout its specified operating envelope when subjected to sudden encounters with the certification standard concentrations of rain and hail, as defined in Appendix B to this part. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability, during any three minute continuous period in rain and during any 30 second

continuous period in hail. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power or thrust loss, or other adverse engine anomalies.

(b) Engines for rotorcraft. As an alternative to the requirements specified in paragraph (a)(2) of this section, for rotorcraft turbine engines only, it must be shown that each engine is capable of acceptable operation during and after the ingestion of rain with an overall ratio of water droplet flow to airflow, by weight, with a uniform distribution at the inlet plane, of at least four percent. Acceptable engine operation precludes flameout, run down, continued or non-recoverable surge or stall, or loss of acceleration and deceleration capability. It must also be shown after the ingestion that there is no unacceptable mechanical damage, unacceptable power loss, or other adverse engine anomalies. The rain ingestion must occur under the following static ground level conditions:

(1) A normal stabilization period at take-off power without rain ingestion, followed immediately by the suddenly commencing ingestion of rain for three minutes at takeoff power, then

(2) Continuation of the rain ingestion during subsequent rapid deceleration to minimum idle, then

(3) Continuation of the rain ingestion during three minutes at minimum idle power to be certified for flight operation, then

(4) Continuation of the rain ingestion during subsequent rapid acceleration to takeoff power.

(c) Engines for supersonic airplanes. In addition to complying with paragraphs (a)(1) and (a)(2) of this section, a separate test for supersonic airplane engines only, shall

be conducted with three hailstones ingested at supersonic cruise velocity. These hailstones shall be aimed at the engine's critical face area, and their ingestion must not cause unacceptable mechanical damage or unacceptable power or thrust loss after the ingestion or require the engine to be shut down. The size of these hailstones shall be determined from the linear variation in diameter from 1-inch (25 millimeters) at 35,000 feet (10,500 meters) to 1/4-inch (6 millimeters) at 60,000 feet (18,000 meters) using the diameter corresponding to the lowest expected supersonic cruise altitude. Alternatively, three larger hailstones may be ingested at subsonic velocities such that the kinetic energy of these larger hailstones is equivalent to the applicable supersonic ingestion conditions.

(d) For an engine that incorporates or requires the use of a protection device, demonstration of the rain and hail ingestion capabilities of the engine, as required in paragraphs (a), (b), and (c) of this section, may be waived wholly or in part by the Administrator if the applicant shows that:

(1) The subject rain and hail constituents are of a size that will not pass through the protection device;

(2) The protection device will withstand the impact of the subject rain and hail constituents; and

(3) The subject of rain and hail constituents, stopped by the protection device, will not obstruct the flow of induction air into the engine, resulting in damage, power or thrust loss, or other adverse engine anomalies in excess of what would be accepted in paragraphs (a), (b), and (c) of this section.

9. Appendix B is added to part 33, to read as follows:

APPENDIX B TO PART 33--CERTIFICATION STANDARD ATMOSPHERIC CONCENTRATIONS OF RAIN AND HAIL

Figure B1, Table B1, Table B2, Table B3, and Table B4 specify the atmospheric concentrations and size distributions of rain and hail for establishing certification, in accordance with the requirements of § 33.78(a)(2). In conducting tests, normally by spraying liquid water to simulate rain conditions and by delivering hail fabricated from ice to simulate hail conditions, the use of water droplets and hail having shapes, sizes and distributions of sizes other than those defined in this Appendix B, or the use of a single size or shape for each water droplet or hail, can be accepted, provided the applicant shows that the substitution does not reduce the severity of the test.

FIGURE B1 - Illustration of Rain and Hail Threats. Certification concentrations are obtained using Tables B1 and B2.

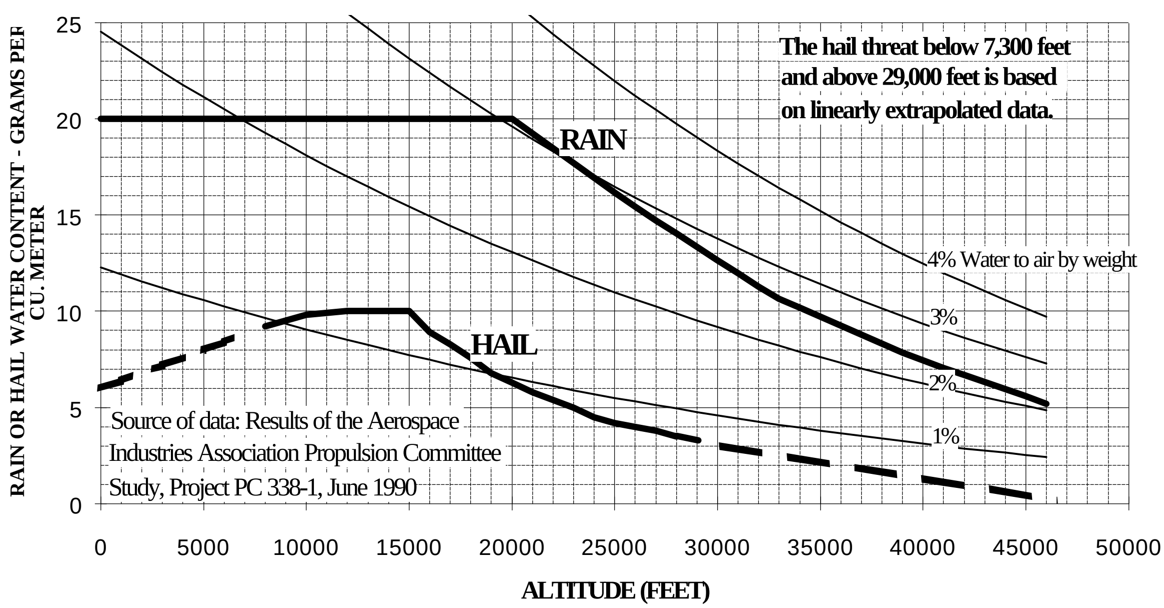

TABLE B1

CERTIFICATION STANDARD ATMOSPHERIC RAIN CONCENTRATIONS

Altitude (feet)	Rain Water Content (RWC) (grams water / meter^3 air)
0	20.0
20,000	20.0
26,300	15.2
32,700	10.8
39,300	7.7
46,000	5.2

RWC values at other altitudes may be determined by linear interpolation.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee Study, Project PC 338-1, June 1990.

TABLE B2

CERTIFICATION STANDARD ATMOSPHERIC HAIL CONCENTRATIONS

Altitude (feet)	Hail Water Content (HWC) (grams water / meter^3 air)
0	6.0
7,300	8.9
8,500	9.4
10,000	9.9
12,000	10.0
15,000	10.0
16,000	8.9
17,700	7.8
19,300	6.6
21,500	5.6
24,300	4.4
29,000	3.3
46,000	0.2

HWC values at other altitudes may be determined by linear interpolation. The hail threat below 7,300 feet and above 29,000 feet is based on linearly extrapolated data.

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B3

CERTIFICATION STANDARD ATMOSPHERIC RAIN DROPLET SIZE DISTRIBUTION

Rain Droplet Diameter (mm)	Contribution to total RWC (%)
0 - 0.49	0
0.50 - 0.99	2.25
1.00 - 1.49	8.75
1.50 - 1.99	16.25
2.00 - 2.49	19.00
2.50 - 2.99	17.75
3.00 - 3.49	13.50
3.50 - 3.99	9.50
4.00 - 4.49	6.00
4.50 - 4.99	3.00
5.00 - 5.49	2.00
5.50 - 5.99	1.25
6.00 - 6.49	0.50
6.50 - 7.00	0.25
TOTAL	100.00

Median diameter of rain droplets is 2.66 mm

Note: Source of data - Results of the Aerospace Industry Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

TABLE B4

CERTIFICATION STANDARD ATMOSPHERIC HAIL SIZE DISTRIBUTION

Hail Diameter (mm)	Contribution to total HWC (%)
0 - 4.9	0
5.0 - 9.9	17.00
10.0 - 14.9	25.00
15.0 - 19.9	22.50
20.0 - 24.9	16.00
25.0 - 29.9	9.75
30.0 - 34.9	4.75
35.0 - 39.9	2.50
40.0 - 44.9	1.50
45.0 - 49.9	0.75
50.0 - 55.0	0.25
TOTAL	100.00

Median diameter of hail is 16 mm

Note: Source of data - Results of the Aerospace Industries Association (AIA) Propulsion Committee (PC) Study, Project PC 338-1, June 1990.

Issued in Washington, DC on March 20, 1998.

/signed by

Jane F. Garvey
Administrator