SUBPART E - POWERPLANT

Section 1. General

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Section 25.901 Installation.

a. **Rule Text.**

(a) For the purpose of this part, the airplane powerplant installation includes each component that --

(1) Is necessary for propulsion;

(2) Affects the control of the major propulsive units; or

(3) Affects the safety of the major propulsive units between normal inspections or overhauls.

(b) For each powerplant --

(1) The installation must comply with --

(i) The installation instructions provided under § 33.5 of this chapter; and

(ii) The applicable provisions of this subpart;

(2) The components of the installation must be constructed, arranged, and installed so as to ensure their continued safe operation between normal inspections or overhauls;

(3) The installation must be accessible for necessary inspections and maintenance; and

(4) The major components of the installation must be electrically bonded to the other parts of the airplane.

(c) For each powerplant and auxiliary power unit installation, it must be established that no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane except that the failure of structural elements need not be considered if the probability of such failure is extremely remote.

(d) Each auxiliary power unit installation must meet the applicable provisions of this subpart.

(Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-23, 35 FR 5676, April 8, 1970; Amdt. 25-40, 42 FR 15042, March 17, 1977; Amdt. 25-46, 43 FR 50597, Oct. 30, 1978)

b. **<u>Intent of Rule.</u>**

- **§ 25.901(a)** is intended to provide a functional definition of the term "powerplant installation" as applicable to Part 25.

- **§ 25.901(b)(1)(i)** is intended to provide for compatibility between the airplane and engine type design approvals.

- **§ 25.901(b)(1)(ii)** is intended to ensure that Subpart E regulations are applied as appropriate for the specific type of powerplant installation.

- **§ 25.901(b)(2)** is intended to require such preventative maintenance as is necessary to ensure that components of the powerplant installation do not cease safe functioning.

- **§ 25.901(b)(3)** is intended to ensure that the powerplant installation components are sufficiently accessible to permit the effective performance of those inspections and other maintenance actions necessary for continued airworthiness.

- **§ 25.901(b)(4)** is intended to prevent the existence of significant differences in electrical potential between major components of the powerplant installation and other portions of the airplane.

- **§ 25.901(c)** is intended to define, in general terms, the foreseeable failures that each powerplant and auxiliary power unit installation must be shown to safely accommodate.

- **§ 25.901(d)** is intended to ensure that those Subpart E provisions that are relevant to auxiliary power unit installations are applied to those installations.

c. **<u>Background.</u>**

(1) ***§ 25.901(a)(1), (2), and (3) Regulatory History:*** These sections originated from Section 400 of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). These sections of the rule were recodified from CAR 4b.400 without any substantive changes; they have not changed since that time.

(2) ***§ 25.901(b)(1)(i) Regulatory History:*** Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975) proposed a modification to this regulation. The following excerpt is from the preamble to Amendment 25-40 (42 FR

15042, March 17, 1977), which followed Notice 75-19 and adopted the rule as proposed; this excerpt provides additional guidance to the intent of the regulation.

> One commenter suggests that the installation instructions of proposed § 25.901(b)(1)(i) should be limited to those installation design parameters pertinent to the engine type certificate. The installation instructions provided under § 33.5 include only those parameters referred to by the commenter, and the FAA believes that a revision of the proposal is not needed.
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> Two commenters object to the use of the term “extremely remote” in proposed § 25.901(c) as not being clearly understood. The FAA believes the term is appropriate, since it has been used in other sections of the regulations, without administrative difficulty, to establish the consideration that must be given to the failure of structural components during the evaluation of the type design.
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> One commenter believes that the proposal would make § 25.1309 inapplicable to powerplant or APU installations. The FAA disagrees; § 25.1309 would continue to apply to powerplant and APU installations.
>
> Another commenter concurs with the proposal if, with respect to APU’s, it is limited to those approved for use in flight. The FAA does not believe the proposal should be so limited, since the failure or malfunction of an APU approved for use only on the ground could jeopardize safe operation on the ground and in flight.
>
> The proposal is adopted without substantive change.

This section of the rule has not changed since Amendment 25-40.

(3) ***§ 25.901(b)(1)(ii), (b)(2), (b)(3), and (b)(4) Regulatory History:*** These sections originated from Sections 400(a), (b), (c), and (d), respectively, of CAR 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). These sections were recodified from CAR 4b.400 without any substantive changes. They have not changed since that time.

(4) ***§ 25.901(c) Regulatory History:***

(a) This rule was first proposed in Notice of Proposed Rulemaking 68-18 (33 FR 11913, August 22, 1968). The proposed text of the rule at that time was as follows:

> It must be established by fault analysis, component tests, or simulated environmental tests, that no single failure or likely combination of failures of any powerplant system will jeopardize the safe operation of the airplane, except that failures of structural elements need not be considered when the probability of such failures is extremely remote.

The following excerpt is from the preamble to that Notice and provides the justification for the proposal:

> The present regulations do not specifically cover a fault analysis of the powerplant system. However, a rule similar to the requirements for the equipment systems is needed.

Amendment 25-23 (35 FR 5665, April 8, 1970) followed Notice 68-18. The following excerpt from the preamble to that Amendment provides more insight to the intent of the rule.

> One commenter objects to the proposal to add a new § 25.901(c) to require a powerplant installation fault analysis on the basis that the requirement is covered in the proposed amendment to § 25.1309. The FAA agrees that the requirement is adequately covered in § 25.1309 and the proposal has been changed to make it clear that compliance with § 25.1309 is required.

(b) Another revision to this section was proposed by Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975) to "provide for a higher degree of airplane engine compatibility." (Beyond this statement, the justification for the proposal is not clearly evident in the available materials from the public docket.) This was Proposal No. 737 of the FAA's 1974-75 Airworthiness Review Program. Unfortunately, most of the supporting materials from that program are not currently available in the public docket. However, in the Notice the FAA stated that "the proposal would delete the reference in the section *[i.e., § 25.901(c)]* to § 25.1309. That reference is not necessary since that section *(i.e., § 25.1309)* applies to the powerplant installation by its own terms." That FAA statement is supported by current FAA legal opinion that "both rules apply to powerplant installations unless they impose a mutually exclusive requirement, then the more specific rule [*i.e., § 25.901(c)]* would take precedence." These facts notwithstanding, application of § 25.1309 to powerplant installations over the last 20 years has been very limited and controversial.

Amendment 25-40 (42 FR 15042, March 17, 1977) followed Notice 75-19 and adopted the rule as proposed. The rule text that was adopted at that time has not changed since that time.

(5) ***§ 25.901(d) Regulatory History:*** This section was first proposed for addition into the regulations by Notice of Proposed Rulemaking 75-31 (40 FR 29419, July 11, 1975) to "make it clear that Subpart E of Part 25 contains provisions applicable to APU installations." (This was Proposal No. 736 of the FAA's 1974-75 Airworthiness Review Program.) Amendment 25-46 (43 FR 50597, October 30,1978) followed Notice 75-31 and adopted the rule as proposed. This rule has not changed since Amendment 25-46.

NOTE: Concerning Auxiliary Power Units (APU): There has been a good deal of confusion regarding which Subpart E rules should apply to the APU installation. The FAA has successfully applied other regulations such as § 25.903(d)(1) to APU installations. The counterpart requirements in the JAR select regulations from throughout Subpart E and provide them in a separate Subpart. The FAA has agreed that this helps clarify what regulations apply to APU's and affords the opportunity to modify regulatory materials that should be different for an APU and a main engine. Work is currently underway within the Powerplant Installation Harmonization Working Group (PPIHWG) of the Aviation Rulemaking Advisory Committee (ARAC) to develop a proposed set of harmonized regulations specifically applicable to APU installations.

d. **Policy/Compliance Methods.** The following general policy and compliance methodologies have been used to demonstrate compliance with the subparagraphs of § 25.901. In addition, where applicable, unique or special issues associated with each subparagraph have been identified.

(1) ***§ 25.901 (a):*** The powerplant installation of a transport category airplane typically includes the components that make up the:

- main engines (and propellers);
- gear boxes;
- engine oil and fuel systems;
- engine related controls and indications;
- engine nacelles/cowling including inlets, exhaust nozzles, core cowls, fan cowls, etc.;
- engine struts/pylons;
- engine fire protection systems;
- engine icing protection systems;
- engine bleed air systems; and
- airplane fuel systems including fuel feed systems, refuel/defuel systems, fuel transfer systems, fuel jettison systems, fuel system controls and indications; etc.

In addition, while those components that are part of an engine or propeller type design certificated under Parts 33 or 35 are considered part of the powerplant installation, any finding of compliance with Part 25 requirements should take maximum advantage of the relevant findings made in support of Part 33 or 35 compliance.

(2) ***§ 25.901(b)(1)(i):*** A proposed powerplant installation must be compatible with all engine installation instructions and limitations delineated in any FAA-approved or -accepted source, such as the Engine Type Certification Data Sheet, the engine manufacturer's installation drawings, engine manufacturer's installation manuals, or other engine type design data.

Some interdependencies between proposed Part 25 type designs and the conditions of the related Part 33 type design approvals have not been recognized in time to avoid significant incompatibility problems. Some examples of this problem are:

- In one certification project, the maximum operating altitude proposed for an aircraft was above that for which the engine was designed. This incompatibility was not recognized until engine operating problems were experienced during aircraft certification flight testing.

- In another project, the minimum in-flight idle approved for an aircraft was below that used during some engine certification icing tests. This incompatibility was not recognized until engine operating problems were experienced in service.

As is evident by these examples, care must be taken to identify and accommodate within the powerplant installation design all engine certification dependencies, both those that are explicitly identified in approved or accepted engine installation instruction and those that are implicit in the conditions under which the engine was found compliant with Part 33.

(3) ***§ 25.901(b)(1)(ii):*** Provisions of Subpart E are applicable to all types of powerplant installations, unless explicitly limited to a specific type of installation or portion thereof. For example, § 25.901(b)(2) is applicable to <u>any</u> installation, while § 25.903(a)(1) is explicitly limited to installation of a "turbine engine."

(4) ***§ 25.901(b)(2):*** Methods of compliance include:

- reviews of drawings, schematics, system descriptions, and safety analyses;
- mock-up inspections;
- laboratory and aircraft testing;
- comparison with the service experience on similar designs; and
- comparison with accepted design standards.

For some components, such as the integrated circuits used in modern avionics, there is no practicable means to ensure the continued operation of each individual component. In such cases where individual components cannot be inspected for impending failure, overhauled, or otherwise prevented from failing, the intent of this requirement can be met by "ensuring continued safe operation" at an assembly or functional level rather than at the individual component level. In other words, preventative maintenance is not required for individual components provided that, when they fail, other components will ensure the continued safe operation of the engine until these failures can be detected and eliminated.

(5) ***§ 25.901(b)(3):*** No specific type design guidance currently exists concerning this subparagraph. However, it is especially important to demonstrate compliance with § 25.901(b)(3) by means of mock-up inspections or certification ground tests for inspections and/or maintenance tasks that are crucial for ensuring compliance with § 25.901(c).

(6) ***§ 25.901(b)(4):*** Components of the powerplant installation must be electrically bonded to each other and to related (mating) portions of the airframe such that no significant differences in electrical potential can develop.

High intensity radiated fields (HIRF), lightning, electromagnetic interference (EMI), hot short, and electrostatic charge protection issues must be considered. Bonding the powerplant installation components can help to protect them during exposures to electromagnetic fields, lightning strikes, electrical power shorts, or generators of electrostatic charge. However, selecting the bonding methods and characteristics that best protects all components is a design decision that must take into account the specific type design features and requirements, anticipated exposures to the sources of electrical differentials, necessary instructions for continued airworthiness, etc.

In some cases, higher bonding resistances/impedances may be advantageous to reduce or redirect currents, while in other cases, lower bonding resistances/impedances are needed to keep the voltage down or distribute currents. Also, the types of bonding that are effective for low frequency or low power threats may not be effective for high frequency or high power threats, and visa versa. Typical bonding resistances are on the order of 1 ohm. However, effective electrostatic "bleed-off" can occur through a bonding resistance of 1 mega-ohm, while low voltage electronics may require bonding better than 100 mili-ohms to protect them from the effects of a lightning strike. Consequently, given the proposed bonding scheme, the effects of foreseeable electrical differentials between adjacent components should be assessed and found to not create an unsafe condition. This can be done:

- by similarity to previous designs;
- through a dedicated assessment for § 25.901(b)(4);
- as part of related compliance assessments such as those performed to demonstrate compliance with § 25.581, § 25.901(c), § 25.954, § 25.1316, etc.; or
- any combination thereof.

Additional issues that must be considered include fuel system ignition source isolation, can be found in Advisory Circular (AC) 25-8, "Auxiliary Fuel System Installations" [which is incorporated in total into this Mega-AC under Section 25.952]. Section 6 (Ignition Source Isolation Evaluation) of that AC provides guidance regarding:

- system electrical bonding,
- bonding for lightning protection, and
- electrostatic considerations.

Reticulated polyurethane safety foam has been used in applications where fuel tanks have been installed in the engine uncontained failure impact area. In one application, a fuel tank explosion occurred when the electrostatic charge from the foam in one portion of the tank is believed to have discharged and caused an explosion in a portion of the tank that did not contain the foam. Post-incident analysis indicated that other fuel tank explosions had occurred in airplanes equipped with this type of foam. A new, more conductive foam has been developed to eliminate this problem. The foam selected for a particular application should be consistent with the desired overall fuel tank conductivity.

Bonding and grounding of equipment containing electrical power must be given special attention both from the standpoint of normal operation and under anticipated failure conditions [see discussion, below, under § 25.901(c)].

(7) ***§ 25.901(c):*** Section 25.901(c) is intended to provide an overall safety assessment of the powerplant installation. It is intended to augment rather than replace other, more specific applicable Part 25 design and performance standards for transport category airplanes. When assessing the potential hazards to the aircraft caused by the powerplant installation, the effects of an engine case rupture, uncontained engine rotor failure, engine case burnthrough, and propeller debris release are excluded from § 25.901(c). The effects and rates of these failures are minimized by compliance with Part 33 ("Airworthiness Standards: Aircraft Engines"); Part 35 ("Airworthiness Standards: Propellers"); § 25.903(d)(1) ("Engines"); § 25.905(d) ("Propellers"); and § 25.1193 ("Cowling and nacelle skin"). Furthermore, the effects of encountering environmental threats or other operating conditions more severe than those for which the aircraft is certified (such as volcanic ash or operation above placard speeds) need not be considered in the § 25.901(c) compliance process. However, if a failure or malfunction can affect the subsequent environmental qualification or other operational capability of the installation, this effect should be accounted for in the § 25.901(c) assessment.

Compliance with § 25.901(c) may be shown by a System Safety Assessment (SSA) substantiated by appropriate testing and/or comparable service experience. Such an assessment may range from a simple report that offers descriptive details associated with a failure condition, interprets test results, compares two similar systems, or offers other qualitative information; to a detailed failure analysis that may include estimated numerical probabilities. The depth and scope of an acceptable SSA depends on:

- the complexity and criticality of the functions performed by the system(s) under consideration,
- the severity of related failure conditions,
- the uniqueness of the design and extent of relevant service experience,
- the number and complexity of the identified causal failure scenarios, and
- the detectability of contributing failures.

Historically, the use of a "bottom-up single failure analysis," such as a Failure Modes and Effects Analysis (FMEA), has been a popular safety assessment method with many applicants. Wherever the effects of a failure are found to be operationally "latent," then the effects of the "next worst" failure are assessed. In this approach, the "probable combinations of failures" are assumed only to be a single latent failure plus "the next worst" failure. When assessing the failure effects of a simple mechanical, hydromechanical, or electrical system, where independence from the effects of failures elsewhere in the aircraft can be assumed, this can be an effective and relatively simple means of assuring that the design is adequately "fail-safe." However, as the integration and diversity of functions and technologies in the subject design increase, particularly when digital avionics are involved, the resulting increases in complexity, interdependence, and parts count make this "latents-plus-one" assumption about the "probable combinations of failure" questionable. Consequently, to ensure that the design is "fail-safe" for a sufficient number of co-existing failures, probability methods are typically necessary.

Formal § 25.901(c) policy is currently under development (as an Advisory Circular) within the Aviation Rulemaking Advisory Committee (ARAC) Powerplant Installation Harmonization Working Group (PPIHWG). In the interim, the basic concepts and techniques delineated in AC 25.1309-1A can be used to perform a system safety assessment to support compliance with § 25.901(c), provided the following is recognized:

- When predicting the probability of a given failure condition, the effects of failure rate deviations will tend to cancel each other for any contributing multiple failure case. Therefore, the use of component "average" reliability (i.e., MTBF) for these calculations is reasonable. However, this is not the case for contributing single failures. Any consideration of using probability to accept a possible single failure must be based on a confidence that the "minimum" anticipated reliability of the subject component is controlled and will not dominate the probability of the given failure condition. That is, the "minimum" time between contributing single failures should be much less than the "mean" time between the most probable contributing multiple failure case.

- An analysis is only as accurate as the data, assumptions, and techniques used to conduct it. Consequently, the underlying assumptions, data, and analytic techniques should be identified and justified to ensure that the conclusions of the analysis are valid. Variability may be inherent in elements such as failure modes, failure effects, failure rates, failure probability distribution functions, failure exposure times, failure detection methods, fault independence, limitation of analytical methods, processes, and assumptions. The justification of the assumptions made with respect to the above items should be an integral part of the analysis. Assumptions can be validated by using experience with identical or similar systems or components with due allowance made for differences of design, duty cycle and environment. Where it is not possible to fully justify the adequacy of the safety analysis and where data or assumptions are critical to the acceptability of the failure condition, extra conservatism should be built into either the analysis or the design. Alternatively, any uncertainty in the data and assumptions should be evaluated to the degree necessary to demonstrate that the analysis conclusions are insensitive to that uncertainty.

- The term “probable” does not have the same meaning in § 25.901(c) and AC 25.1309-1A. The term “probable” in § 25.901(c) means “foreseeable” or (in AC 25.1309-1A terms) “not extremely improbable.” And

- § 25.901(c) has typically only been used to regulate those failures that are potentially “catastrophic” without significant crew error. That is to say, the term “jeopardize” can be taken to include all of the § 25.1309(b) “catastrophic failure conditions” and some (approximately the upper half) of the “hazardous/severe major failure conditions.” Furthermore, § 25.901(c) has not been used to regulate any failure conditions of lower severity (i.e., “major”/“minor”/no effect).

In carrying out the SSA for the powerplant installation for § 25.901(c), the results of the engine (and propeller) failure analyses (reference § 33.28 and § 33.75) should be used as inputs for those powerplant failure effects that can have an impact on the aircraft. However, the SSA undertaken in response to Part 33 and Part 35 may not address all the potential effects that an engine and propeller as installed may have on the aircraft. For those failure conditions covered by analysis under Part 33 and/or Part 35, and for which the installation has no effect on the conclusions derived from these analyses, no additional analyses will be required to demonstrate compliance to § 25.901(c).

The effects of structural failures on the powerplant installation, and vice versa, should be carefully considered when conducting system safety assessments The powerplant installation must be shown to comply with § 25.901(c) following structural failures that are anticipated to occur within the fleet life of the airplane type. Since the probability of a given structural failure is normally considered “remote,” consideration of structural failures is normally limited to potentially “hazardous” and “catastrophic” failure conditions. This should be part of the assessment of the **causes** of the powerplant installation failure condition. Examples of structural failures that have been of concern in previous powerplant installations are:

- thrust reverser restraining load path failure that may cause a catastrophic inadvertent deployment;
- throttle quadrant framing or mounting failure that causes loss of control of multiple engines; and
- structural failures in an avionics rack or related mounting that cause loss of multiple, otherwise independent, powerplant functions/components/systems.

Any effect of powerplant installation failures that could influence the suitability of affected structures, should be identified during the § 25.901(c) assessment and accounted for when demonstrating compliance with the requirements of Part 25, Subpart C (“Structure”) and D (“Design and Construction”). This should be part of the assessment of the **effects** of powerplant installation failure conditions. Some examples of historical interdependencies between powerplant installations and structures include:

- fuel system failures that cause excessive fuel load imbalance;
- fuel vent, refueling, or feed system failures that cause abnormal internal fuel tank pressures;
- engine failures that cause excessive loads/vibration; and
- powerplant installation failures that expose structures to extreme temperatures or corrosive material.

[Society of Aeronautical Engineers (SAE) Documents ARP 4754 and 4761 provide some additional useful guidance as to how safety assessments should be performed.]

Some important considerations that are sometimes overlooked in § 25.901(c) analyses are:

- the effects of failures on the continued environmental qualification (e.g., HIRF, lightning, explosion-proof capability, vibration, etc.) of the powerplant installation;
- failure of dedicated safeguards (e.g., firewalls, overspeed governers, containment rings, warning means, etc.);
- the effects of failures on the probability of subsequent failures. That is, the potential for "cascading failure" effects. For example if one of two load paths fail, the remaining load path may see much greater stress and hence may now have a greater probability of failure than before the first load path failed;
- the potential for common mode failures due to common susceptibility and/or exposure to a common threat;
- the effects of systems failures on structures and structural failures on systems; and
- the effect of air data. fuel system, and other aircraft system faults on engine systems and visa versa.

The following guidance discusses some of the typical topics included in a § 25.901(c) system safety assessment:

A. Undetected Thrust Loss and its Effect on Aircraft Safety. The assessment should include an evaluation of the failure of components and systems that could cause an undetected thrust loss, except those covered by the traditional average-to-minimum engine assessment. In determining the criticality of undetected thrust losses from a system design and installation perspective, the following should be considered:

- magnitude of the thrust loss*,
- direction of thrust,
- phase of flight, and

- impact of the thrust loss on aircraft safety.

*(*Although it is common for safety analyses to consider the total loss of one engine's thrust, a small undetected thrust loss that persists from the point of takeoff power set could have a more significant impact on the accelerate/stop distances and takeoff flight path/obstacle clearance capability than a detectable single engine total loss of thrust failure condition at V_1)*

In addition, the level at which any thrust loss becomes detectable should be validated. This validation is typically influenced by:

- impact on aircraft performance and handling,
- resultant changes in powerplant indications,
- instrument accuracy and visibility,
- environmental and operating conditions,
- relevant crew procedures and capabilities, etc.

Less than 3% thrust loss on any one engine, and up to 3% on all engines, generally has been accepted as not having any significant adverse effect on safety. A 10% thrust asymmetry or a symmetric 20% thrust loss may be considered detectable.

B. Detected Thrust Loss. While detectable engine thrust losses can range in magnitude from 3% to 100% of total aircraft thrust, the total loss of useful thrust (in-flight shutdown/IFSD) of one or more engines usually has the largest impact on aircraft capabilities and engine-dependent systems. Furthermore, single and multiple engine IFSD's tend to be the dominant thrust loss-related failure conditions for most powerplant installations. In light of this, the guidance in this AC focuses on the IFSD failure conditions. The applicant must consider other engine thrust loss failure conditions, as well, if they are anticipated to occur more often due to different failures, or if they are more severe than the related IFSD failure condition.

1. ***Single Engine IFSD***. The effects of any single engine thrust loss failure condition, including IFSD, on aircraft performance, controllability, maneuverability, and crew workload are accepted as meeting the intent of § 25.901(c) if compliance is also demonstrated with:

   - § 25.111 ("Takeoff path"),
   - § 25.121 ("Climb: one-engine-inoperative"), and
   - § 25.143 ("Controllability and Maneuverability -- General").

   Nevertheless, the effects of an IFSD on other aircraft systems or in combination with other conditions also must be assessed as part of showing compliance with § 25.901(c)/§ 25.1309. In this case, it should be noted that a single engine IFSD can result from any number of single failures, and that the rate of IFSD's range from approximately $1x10^{-4}$ to $1x10^{-5}$ per engine flight hour. This rate includes all failures within a typical powerplant installation that affect one -- and only one -- engine. Those failures within a typical powerplant that can affect more than one engine are described below.

If an estimate of the IFSD rate is required for a specific turbine engine installation, any one of the following methods are suitable for the purposes of complying with § 25.901(c)/§ 25.1309(b):

- Estimate the IFSD rate based on service experience of similar powerplant installations;

- Perform a bottom-up reliability analysis using service, test, and any other relevant experience with similar components and/or technologies to predict component failure modes and rates; or
- Use a conservative value of $1x10^{-4}$ per flight hour.

If an estimate of the percentage of these IFSD's for which the engine is restartable is required, the estimate should be based on relevant service experience.

The use of the default values delineated above is limited to traditional turbine engine installations. However, the other methods listed above are acceptable for estimating the IFSD rates and restartability for other types of engines, such as reciprocating engines or some totally new type of engine or unusual powerplant installation with features such as a novel fuel feed system. In the case of new or novel components, significant non-service experience may be required to validate the reliability predictions. This is typically attained through test and/or technology transfer analysis.

Related issues that should be noted here are:

- Section 25.901(b)(2) sets an additional standard for installed engine reliability. That regulation is intended to ensure that all technologically feasible and economically practical means are used to ensure the continued safe operation of the powerplant installation between inspections and overhauls.

- The effectiveness of compliance with § 25.111, § 25.121 and § 25.143 in meeting the intent of § 25.901(c) for single engine thrust loss is dependent on the accuracy of the human factors assessment of the crew's ability to take appropriate corrective action. For the purposes of compliance with § 25.901(c) in this area, it may be assumed that the crew will take the corrective actions called for in the airplane flight manual procedures and associated approved training.

2. ***Multiple Engine IFSD***. The guidance in AC 25.1309-1A provides for a catastrophic failure condition to exceed 1×10^{-9} per hour under certain conditions (i.e., well-proven design and construction techniques, and a predicted overall airplane level rate of catastrophic failures within historically-accepted service experience). Typical engine IFSD rates have been part of this historically-accepted service experience, and these IFSD rates are continuously improving. However, typical engine IFSD rates may not meet the AC 25.1309-1A condition that calls for 1×10^{-9} per hour for a catastrophic multiple engine IFSD.

Current typical turbine engine IFSD rates, and the resulting possibility of multiple independent IFSD's leading to a critical power loss, are considered acceptable for compliance with § 25.901(c) without quantitative assessment. Therefore, there is no need to calculate the overall airplane level risk of catastrophic failure, even though the probability of a catastrophic failure condition due to multiple engine IFSD's may exceed 1×10^{-9}. Nevertheless, some combinations of failures within aircraft systems common to multiple engines may cause a catastrophic multiple engine thrust loss. These should be assessed to ensure that they meet the extremely improbable criteria. Systems to be considered include:

- fuel system,
- air data system,
- electrical power system,
- throttle assembly,
- engine indication systems, etc.

The means of compliance described above is only valid for turbine engines, and for engines that can demonstrate equivalent reliability to turbine engines, using the means outlined in Section 6.a. of this AC. The approach to demonstrating equivalent reliability should be discussed early in the program with the certifying authority on a case-by-case basis.

C. <u>Automatic Takeoff Thrust Control System.</u> Part 25, Appendix I ["Installation of an Automatic Takeoff Thrust Control System (ATTCS)"], specifies the minimum reliability levels for these automatic systems. In addition to showing compliance with these reliability levels for certain combinations of failures, other failure conditions that can arise as a result of introducing such a system must be shown to comply with § 25.901(c).

D. <u>Thrust Management Systems.</u> A System Safety Assessment is essential for any airplane system that aids the crew in managing engine thrust (i.e., computing target engine ratings, commanding engine thrust levels, etc.). As a minimum, the criticality and failure hazard classification must be assessed. The system criticality will depend on:

- the range of thrust management errors it could cause,
- the likelihood that the crew will detect these errors and take appropriate corrective action, and
- the severity of the effects of these errors with and without crew intervention.

The hazard classification will depend on the most severe effects anticipated from any system. The need for more in-depth analysis will depend upon the systems complexity, novelty, initial failure hazard classification, relationship to other aircraft systems, etc.

Automated thrust management features, such as autothrottles and target rating displays, traditionally have been certified on the basis that they are only conveniences to reduce crew workload and do not relieve the crew of any responsibility for assuring proper thrust management. In some cases, malfunctions of these systems can be considered to be minor, at most.

However, for this to be valid, even when the crew is no longer directly involved in performing a given thrust management function, the crew must be provided with information concerning unsafe system operating conditions to enable them to take appropriate corrective action. Consequently, when demonstrating compliance with § 25.901(c), failures within any automated thrust management feature which, if not detected and properly accommodated by crew action, could create a catastrophe should be either:

- considered a catastrophic failure condition when demonstrating compliance with § 25.1309(b)/§ 25.901(c); or
- considered an unsafe system operating condition when demonstrating compliance with the warning requirements of § 25.1309(c).

E. Thrust Reversers. Compliance with § 25.933(a) ("Reversing systems") provides demonstration of compliance with § 25.901(c) for the thrust reverser in-flight deployment failure conditions. A standard § 25.901(c) System Safety Assessment should be performed for any other thrust reverser-related failure conditions.

(8) ***§ 25.901(d)*:** Each auxiliary power unit (APU) installation must meet the applicable provisions of this subpart. The ARAC Powerplant Installation Harmonization Working Group is currently developing a new Subpart to be added to 14 CFR part 25 that will make it clear what regulations apply to APU's, and should provide guidance for sections that apply to APU's. General policy regarding specific sections relating to APU's is contained within the guidance of this AC. Special issues concerning the APU installation follow:

APU Noise Substantiation:

If an APU is added to an airplane after the original certification, noise tests may be necessary under the provisions of § 21.93(b)(1) and (2). An "acoustical change" is defined as any change that may increase the noise level by 0.1 EPNdB or more. If the APU is approved for in-flight operation, it must be in operation when the noise tests are conducted in compliance with Part 36, C36.9(b). A limitation in the Aircraft Flight Manual (AFM) to prohibit the use of an in-flight operable APU during certain segments of the flight for noise reasons only, is not acceptable. If a limitation in the AFM to restrict all in-flight APU operation is required to satisfy Part 36 requirements, the limitation must be for all segments of flight unless an emergency is declared that requires APU in-flight operation. Furthermore, a placard stating the prohibition against the use of the APU in flight, except for emergency conditions, must be installed in the cockpit.

e. **References.**

(1) Civil Air Regulations 4b, December 31, 1953.

(2) Amendment 25-23 (35 FR 5676, April 8, 1970).

(3) Amendment 25-40 (42 FR 15042, March 17, 1977).

(4) Amendment 25-46 (43 FR 50597, October 30, 1978).

(5) Advisory Circular 25.1309-1A, “System Design Analysis,” June 21, 1988.

(6) Advisory Circular 25.1329-1A, “Automatic Pilot System Approval,” July 8, 1968.

(7) Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4754, “Certification Considerations for Highly Integrated or Complex Aircraft Systems”

(8) SAE ARP 4761, “Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment”

Section 25.903 Engines.

a. **Rule Text.**

(a) Engine type certificate.

(1) Each engine must have a type certificate and must meet the applicable requirements of part 34 of this chapter.

(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.

(b) Engine isolation. The powerplants must be arranged and isolated from each other to allow operation, in at least one configuration, so that the failure or malfunction of any engine, or of any system that can affect the engine, will not --

(1) Prevent the continued safe operation of the remaining engines; or

(2) Require immediate action by any crewmember for continued safe operation.

(c) Control of engine rotation. There must be means for stopping the rotation of any engine individually in flight, except that, for turbine engine installations, the means for stopping the rotation of any engine need be provided only where continued rotation could jeopardize the safety of the airplane. Each component of the stopping and restarting system on the engine side of the firewall that might be exposed to fire must be at least fire-resistant. If hydraulic propeller feathering systems are used for this purpose, the feathering lines must be at least fire resistant under the operating conditions that may be expected to exist during feathering.

(d) Turbine engine installations. For turbine engine installations -

(1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case.

(2) The powerplant systems associated with engine control devices, systems, and instrumentation, must be designed to give reasonable assurance that those engine operating limitations that adversely affect turbine rotor structural integrity will not be exceeded in service.

(e) Restart capability.

(1) Means to restart any engine in flight must be provided.

(2) An altitude and airspeed envelope must be established for in-flight engine restarting, and each engine must have a restart capability within that envelope.

(3) For turbine engine powered airplanes, if the minimum windmilling speed of the engines, following the in-flight shutdown of all engines, is insufficient to provide the necessary electrical power for engine ignition, a power source independent of the engine-driven electrical power generating system must be provided to permit in-flight engine ignition for restarting.

(f) Auxiliary power unit. Each auxiliary power unit must be approved or meet the requirements of the category for its intended use.

(Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-23, 35 FR 5676, April 8, 1970; Amdt. 25-40, 42 FR 15042, March 17, 1977; Amdt. 25-57, 49 FR 6848, Feb. 23, 1984; Amdt. 25-72, 55 FR 29784, July 20, 1990; Amdt. 25-73, 55 FR 32861, August 10, 1990)

b. **Intent of Rule.**

(1) The intent of this rule can be separated into 5 distinct subjects that are covered by each of the subparagraphs:

Subparagraph (a)	Engine type certificate
Subparagraph (b)	Engine isolation
Subparagraph (c)	Control of engine rotation
Subparagraph (d)	Turbine engine installations
Subparagraph (e)	Restart capability

Details on each of the 5 subparagraphs of this section will be discussed separately, as follows.

(2) It must be noted that the current FAA interpretation of "powerplant components" includes engines and propellers and their parts, appurtenances, and accessories that are furnished by the engine or propeller manufacturer, and all other components of the powerplant installation that are furnished by the airplane manufacturer. Examples of the former may include fuel pumps, lines, valves, etc.; examples of the latter may include main inlet, auxiliary inlet doors (take-off doors), heat-exchangers, lines to provide cabin cooling, etc. [reference Civil Air Regulations (Civil Aeronautics Manual) 4b, "Airplane Airworthiness Transport Categories,," Federal Aviation Agency, May 1, 1960.]

c. **References** (for all parts of this section).

(1) Civil Air Regulations 4b, December 31, 1953; including Civil Air Regulations 4b, “Airplane Airworthiness Transport Categories,” Federal Aviation Agency, May 1, 1960.

(2) Amendment 25-23 (35 FR 5676, April 8, 1970).

(3) Amendment 25-40 (42 FR 15042, March 17, 1977).

(4) Amendment 25-46 (43 FR 50597, Oct. 30, 1978).

(5) Advisory Circular 20-128, “Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures,” March 9, 1988.

(6) Advisory Circular 20-128A, “Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failures,” March 25, 1997.

(7) Advisory Circular 20-135, “Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria,” February 15, 1990.

(8) Advisory Circular 120-42A, “Extended Range Operation with Two-Engine Airplanes (ETOPS),” December 30, 1988.

(9) FAA Order 8110.11, “Design Considerations for Minimizing Damage Caused by Uncontained Aircraft Turbine Engine Rotor Failures,” November 19, 1975.

<u>Section 25.903(a) Engine type certificate.</u>

a. **<u>Text.</u>**

(a) <u>Engine type certificate</u>.

(1) Each engine must have a type certificate and must meet the applicable requirements of part 34 of this chapter.

(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.

b. **<u>Intent of Subparagraph.</u>** The intent of this subparagraph is self-explanatory.

c. **<u>Background</u>.** The regulatory history shows that § 25.903(a) originated from Section 401 of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.401 without any substantive changes.

d. **<u>Policy/Compliance Methods</u>**. While there is no official written general policy on this portion of the regulations, current FAA interpretation of this section requires mutual compliance with the engine manufacturer's engine installation drawing, installation manual and the specific operating instructions. Non-compliance with the engine manufacturer's installation requirements can invalidate the type certification status of the engine, rendering the engine in non-compliance with § 25.903(a)(1).

Furthermore, it must be noted that regardless of the "credit" given to engines that have demonstrated compliance with § 33.77, or that have satisfactory service experience in similar installations, mandatory foreign object ingestion/foreign object damage (FOI/FOD) inspections or dedicated FOI/FOD tests during Type Inspection Approval (TIA) flight testing on all installations, including APU's should be conducted. In addition, compliance with Part 34, or its equivalent Special Regulation (SFAR) 27-5, should be identified on the engine type certificate.

(See Appendix – "Powerplant Installations Special Topics" for more detailed information regarding the "Engine/Airplane Regulatory Interface.")

Section 25.903(b) Engine isolation.

a. **Text.**

(b) Engine isolation. The powerplants must be arranged and isolated from each other to allow operation, in at least one configuration, so that the failure or malfunction of any engine, or of any system that can affect the engine, will not --

(1) Prevent the continued safe operation of the remaining engines; or

(2) Require immediate action by any crewmember for continued safe operation.

b. **Intent of Subparagraph.** As explained in the "Background" section, below, the intent of § 25.903(b)(1) is to ensure that, during any one flight, any initial failure condition that could prevent the continued safe operation of one engine, will not prevent the continued safe operation of multiple engines. The intent of 25.903(b)(2) is to ensure that, when demonstrating compliance with § 25.903(b)(1), no unrealistic credit is taken for crew intervention.

c. **Background.** The regulatory history shows that § 25.903(b) originated from Section 401(b) of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.401(b) without any substantive changes, and has remained essentially unchanged since that time.

When CAR 4b was promulgated, a "system" was typically considered a collection of components arranged in a "single string" series to perform a specific "function." Failures or malfunctions in multiple "systems" during any one flight were not normally considered under the CAR 4b "fail-safe" concept. CAR 4b did however require that the applicant take into account any failures expected to be present at the initiation of the flight (e.g., latent failures), plus the failure or malfunction of any single "system" during that flight. Consequently, when CAR 4b.401(b) referred to the "failure or malfunction" of "any system," this was intended to cover any single "functional failure" that could affect an engine. Hence, the historical interpretation that the intent of § 25.903(b) was to cover only the initial functional failure or malfunction during any one flight. Later rules [such as § 25.1309(b) and § 25.901(c)] extended the "fail-safe" concept to the possibility of multiple failures within multiple systems during any one flight. Consequently, the potential for multiple functional failures to affect multiple engines is covered by § 25.901(c), not § 25.903(b).

d. **<u>Policy/Compliance Methods</u>.** Compliance with § 25.903(b) is often demonstrated in the same System Safety Assessments (SSA) that are used to demonstrate compliance with § 25.901(c) and § 25.1309. While the same general safety assessment guidance is relevant to both § 25.901(c) and § 25.903(b), the following specific guidance should also be taken into account for § 25.903(b) compliance:

(1) The single failure prohibition in § 25.901(c) is at the "component failure" level, while the single failure prohibition in § 25.903(b) is at the system or "functional failure" level.

(2) Credit cannot be given for any crew actions that increase the workload beyond that which has been established in accordance with Part 25, § 25.1523 and Appendix D.

(3) Any operating condition where the next single system failure or malfunction will prevent the continued safe operation of multiple engines is an unsafe system operating condition for the purposes of compliance with § 25.1309(c).

(4) Any claim that a possible failure mode is not anticipated to occur and, hence, need not be considered when finding compliance with § 25.903(b) (e.g., bulk fuel contamination, failure of primary structural elements, etc.), should be identified and justified to the certification authority early in a type certification program.

Section 25.903(c) Control of engine rotation.

a. **Text.**

(c) Control of engine rotation. There must be means for stopping the rotation of any engine individually in flight, except that, for turbine engine installations, the means for stopping the rotation of any engine need be provided only where continued rotation could jeopardize the safety of the airplane. Each component of the stopping and restarting system on the engine side of the firewall that might be exposed to fire must be at least fire-resistant. If hydraulic propeller feathering systems are used for this purpose, the feathering lines must be at least fire resistant under the operating conditions that may be expected to exist during feathering.

b. **Intent of Subparagraph.** The intent of this requirement is to ensure that a continued rotation of an engine does not jeopardize continued safe flight and landing.

c. **Background.**

(1) The regulatory history shows that § 25.903(c) originated from Section 401(c) of the Civil Air Regulations (CAR) 4b, December 31, 1953. That paragraph included a requirement to provide a means to stop and restart the rotation of any engine during flight. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.401(c) without any substantive changes.

(2) Notice of Proposed Rulemaking 68-18 (33 FR 11913, August 22, 1968) proposed to delete the requirement to restart rotation. The preamble to the Notice contained a discussion of the proposed revision as follows:

> Section 25.903(c) requires engines to have means for stopping and restarting engine rotation, but turbine engines need not comply with this rule if continued engine rotation would not jeopardize the safety of the airplane. The purpose of the original rule was to provide restart capability for reciprocating engines, and the rule was subsequently amended to include turbine engines.
>
> Successful compliance with this rule requires mutual compliance with Section 25.903(e) and 25.1585 (a)(3) for airstart/relight requirements. The rule is not clear with respect to the restart of any engine, due in part to the fact that the restart and stopping means for both types of engines are covered in the same sentence. Notwithstanding the language in the rule, the FAA is not aware of any transport category airplane with engines that do not have a restart capability. Such a capability is necessary during operational training and could be paramount during precautionary or inadvertent engine shutdown. Although engine-out performance is required in other rules, non-use of an engine, inadvertently shutdown, reduces generally the overall safety otherwise provided

> with the full engine performance designed for the airplane. The proposal would clarify the rule regarding the restarting of any engine, and would set the requirement for stopping engine rotation in a separate sentence."

Amendment 25-23 (35 FR 5665, April 8, 1970) followed Notice 68-18 and adopted the revision.

c. **Policy/Compliance Methods,**

(1) ***Demonstrating Compliance:*** Acceptable methods of compliance and, in certain cases "required compliance methods," include drawing and schematic review together with compliance (mock-up) inspections, system descriptions, fail safe analysis, and ground and flight testing. The applicant must supply system functioning and test proposals that address each design provision cited in this subpart and Subparts B, F and G.

Consideration can be given to compliance by design similarity and service experience on an applicant's approved existing design on other model aircraft.

Review of the original guidance in CAR 4b.401 provides an understanding of factors that should be considered in showing compliance with this regulation. This original guidance was stated as follows:

> *(a) If means are not provided to completely stop the rotation of turbine engines, it should be shown that continued rotation, either windmilling or controlled, or a shutdown turbine engine will not cause:*
>
> *(1) Powerplant (including engine and accessories) structural damage which will adversely affect other engines or the aircraft structure;*
>
> *(2) Flammable fluid to be pumped into a fire or onto an ignition source; or*
>
> *(3) A vibration mode which adversely affect the aerodynamic or structural integrity of the airplane.*
>
> *(b) Feathered propellers, brakes, doors, or other means used to control turbine engine rotation need not produce a complete stop of engine rotation under all flight conditions unless continued rotation will result in any of the conditions set forth in paragraph (a) of this section.*
>
> *(c) If engine induction air duct doors, or shaft, or other types of brakes are provided to control engine rotation, no single fault or failure of the system controlling engine rotation should cause the inadvertent travel of the doors toward the closed position or the inadvertent energizing of braking means, unless compensating features are provided to ensure that engine failure or a critical operating condition will not occur. (effective August 15, 1957)"*

More recent turbine engines typically have not required incorporation of a stopping means to meet this regulation, as engines have been shown to windmill without creating a hazard to the airplane. However, one in-service event on an aircraft equipped with an engine with wide chord fan blades highlighted the need to consider possible interactions between the airplane and engine due to engine imbalance. The degree to which engine imbalance may create a hazard is dependent upon:

- natural frequencies of the structure,
- the driving force (amount of blade loss, loss-of-centerline due to failure of the shaft bearings or shaft support structure, including collateral damage), and
- the windmill rotational speed of the engine.

With the introduction of wide chord fan blades and propeller fans, imbalance loads have resulted in larger relative imbalances, and slower windmilling speeds that are closer to the airframe natural frequencies; it also has resulted in the need to evaluate the effects of engine imbalance on the airplane. Therefore, compliance with this regulation requires the applicant to show that no hazard exists during uncontrolled rotation of a damaged engine. The effects of engine imbalance on airplane structure, systems, and flight crew ability to operate the airplane must all be considered.

Compliance data must include analysis of the engine rotor unbalance loads / frequencies from maximum operating RPM down to windmilling RPM, and also must include investigation of rotor unbalance loads/frequencies in the windmilling RPM range. This investigation should include both:

- the initial transient loading before and during engine deceleration following a fan blade loss or loss-of-centerline event, and
- the sustained loading resulting from sustained operation at windmill rotational speeds for the maximum diversion time expected or established for this airplane.

(2) ***Engine Imbalance/Control of Engine Rotation***: The current available guidance on this subject is provided in the following excerpt from a FAA Generic Issue Paper. [***NOTE***: This subject has been tasked to an ARAC committee for harmonization. The guidance shown below may be modified eventually by this group. The local FAA office should be contacted for the latest guidance regarding this subject.]

STATEMENT OF ISSUE. Service experience has shown that engine blade and bearing mechanical or structural failures may lead to high imbalance and vibratory loads in the airframe and engine. These vibratory loads may cause damage to primary structure and critical systems. Furthermore, vibrations on the flight deck may create a problem for the flight crew in flying the airplane. The criteria contained in this Issue Paper are specifically directed at the effects of sustained vibrations resulting from the failed engine, both before spool down and during the subsequent windmilling event. The dynamic transient loads occurring as a result of engine seizure and deceleration are not covered by this Issue Paper.

BACKGROUND. The vibratory loads resulting from the separation of a fan blade has traditionally been regarded as insignificant relative to other portions of the design load spectrum for the airplane. However, the progression to larger fan diameters and fewer blades with larger chords has changed the significance of engine structural failures that result in an imbalanced rotating shaft. This condition is further exacerbated by the fact that the fans will continue to windmill in the imbalance condition following engine shut down. Although current rules require provisions to stop the windmilling rotor if it could jeopardize safe flight, these fans are practically impossible to stop in flight.

The loss of a fan blade, and the subsequent damage to other rotating parts of the fan and engine, may induce significant structural loads and vibration throughout the airframe that may damage primary structure, including, but not limited to, the engine mounts, nacelles, and wing, as well as critical equipment mounted on the engine or airframe. Also, the effect of flight deck vibration on displays and equipment is of significance to the crew's ability to make critical decisions regarding the shut down of the damaged engine and to carry out other operations during the remainder of the flight.

Several recent in-service events have shown that failures of the shaft bearings and shaft support structure have also resulted in sustained high vibratory loads. These vibratory loads from the loss-of-centerline condition produce vibratory loading similar to the sustained imbalance loads resulting from fan blade loss.

Experience has demonstrated that there are two sustained imbalance conditions that may effect safe flight: the high power condition and the windmilling condition. The high power imbalance condition may result just after blade failure but before the engine is shut down or otherwise spools down. This case usually involves losing a smaller portion of a single blade and lasting several seconds. In some cases it has caused difficulty in reading instruments that may have aided in determining which engine was damaged, and the extent of the damage.

The windmilling imbalance condition results from loss of centerline support or loss of a fan blade along with additional collateral damage. This case may last until the airplane completes its diversion flight, which could be several hours.

FAA POSITION. It must be shown by a combination of tests and analyses that, after partial or complete loss of an engine fan blade, including ensuing damage to other parts of the engine, or loss of centerline shaft support, the [Model] airplane is capable of continued safe flight and landing.

The evaluation must show, that before spool down and during continued operation at windmilling engine rotational speeds, the engine induced vibrations will not cause damage to either the primary structure of the airplane, or to critical equipment that would jeopardize continued safe flight and landing. The degree of flight deck vibration must not prevent the flight crew from operating the airplane in a safe manner. This includes the ability to read and accomplish checklist procedures. This evaluation must consider the effects on continued safe flight and landing from the possible damage to primary structure, including, but not limited to, engine mounts, inlets, nacelles, wing, and flight control surfaces, as well as critical equipment (including connectors) mounted on the engine or airframe. For the windmilling condition, the evaluation must cover the expected diversion time for the airplane.

A. ACCEPTABLE MEANS OF COMPLIANCE – BLADE LOSS

1. Windmilling blade loss conditions: 100 percent of the resulting imbalance (including all collateral damage) shown in tests of a single release of a turbine, compressor, or fan blade at redline speed (as usually conducted for compliance to § 33.94). This level of imbalance is described in the following criteria as an imbalance design fraction (IDF) of 1.0. With an IDF of 1.0, two separate conditions are defined for application of the subsequent criteria which are developed consistent with the combined probability of occurrence of the imbalance level and the diversion times.

   (a) A diversion of duration equal to the maximum diversion time established for the airplane, but that need not exceed three hours.

   (b) A one hour diversion.

2. Airplane loads and flight phases: Loads on the airplane components should be determined by dynamic analysis. The analysis should take into account unsteady aerodynamic characteristics and all significant structural degrees of freedom including rigid body modes. The vibration loads should be determined for the significant phases of the diversion profiles described in 1(a) and 1(b) above. The significant phases are:

   (a) initial phase during which the pilot establishes a cruise condition;

   (b) the cruise condition;

   (c) the descent phase; and

   (d) the approach to landing phase.

   The flight phases may be further divided to account for variation in aerodynamic and other parameters. The calculated loads parameters should include the accelerations needed to define the vibration environment for the systems and flight deck evaluations.

3. Strength criteria.

   (a) The primary airframe structure should be shown capable of sustaining the flight and windmilling vibration loads combinations defined in (i), (ii) and (iii) below.

      (i) The peak vibration loads for each significant flight phases 2(a) and 2(c) combined with appropriate 1g flight loads. These loads are to be considered limit loads, and a factor of safety of 1.375 shall be applied.

      (ii) The peak vibration loads for the approach to landing phase described in 2(d) combined with 1g flight loads and incremental loads corresponding to a positive limit symmetrical balanced maneuvering load factor of 0.15g. These loads are to be considered as limit loads and a factor of safety of 1.375 shall be applied.

      (iii) The vibration loads for the cruise phase described in 2(b) combined with appropriate 1g flight loads and 70% of the flight maneuver loads and, separately, 40% of the limit gust velocity of § 25.341 as specified at V_C up to the maximum likely operational speed following the event. These loads are to be considered ultimate loads.

(b) In selecting material strength properties for the static strength analysis, the requirements of section 25.613 apply.

4. Assessment of structural endurance. Requirements for fatigue and damage tolerance evaluations are summarized in **Table 4-1**, below. Both conditions 1(a) and 1(b) above should be evaluated. The criteria provide two different levels of structural endurance capability for these conditions. The criteria for condition 1(a) are set to ensure at least a 50 percent probability of preventing a structural component failure and the criteria for condition 1(b) are set to ensure at least a 95 percent probability of preventing a structural component failure.

For multiple load path "fail-safe" structure, where it can be shown by observation, analysis, and/or test that a load path failure, or partial failure in crack arrest structure, will be detected by general visual inspection prior to the failure of the remaining structure, either a fatigue analysis per 4(a) or damage tolerance analysis per 4(b) may be performed to demonstrate structural endurance capability. All other structure should be shown to have capability using only the damage tolerance approach of 4(b).

(a) Fatigue analysis. Where a fatigue analysis is used for substantiation of multiple load path "fail-safe" structure, the total fatigue damage accrued during the well phase and the windmilling phase should be considered. The analysis should be conducted considering the following:

(i) For the well phase, the fatigue damage should be calculated using an approved load spectrum (such as used in satisfying the requirements of § 25.571) for one design service goal (DSG). Average material properties may be used.

(ii) For the windmilling phase, fatigue damage should be calculated for the diversion profiles using a mission that envelopes the Airplane Flight Manual (AFM) recommended operations, accounting for transient exposure to peak vibrations as well as the more sustained exposures to vibrations (i.e., flight phases 2(a) to 2(d) above). Average material properties may be used.

(iii) For each component the accumulated fatigue damage due to 4(a)(i) and 4(a)(ii) multiplied by an appropriate factor (if any) specified in Table 4.1 should be shown to be less than or equal to the fatigue damage to failure of the component.

(b) Damage tolerance analysis. Where a damage tolerance approach is used to establish the structural endurance, the airplane should be shown to have adequate residual strength during the specified diversion time. The extent of damage for residual strength should be established taking into account growth from an initial flaw during the well phase followed by growth during the windmilling phase. The analysis should be conducted considering the following:

(i) The size of the initial flaw should be equivalent to a manufacturing quality flaw associated with a 95% probability of existence with 95% confidence (95/95).

(ii) For the well phase, crack growth should be calculated starting from the initial flaw defined in 4(b)(i) using an approved load spectrum (such as used in satisfying the requirements of § 25.571) for one design life goal. Average material properties may be used.

(iii) For the windmilling phase, crack growth should be calculated for the diversion profile starting from the crack length calculated in 4(b)(ii) using a mission that envelopes the AFM recommended operation accounting for transient exposure to peak vibrations as well as the more sustained exposures to vibrations (i.e., flight phases 2(a) to 2(d) above). Average material properties may be used.

(iv) The residual strength for the structure with damage equal to the crack length calculated in 4(b)(iii) should be shown capable of sustaining the combined loading conditions defined in 3(a) with a factor of safety of 1.0.

TABLE 4.1 - Fatigue and Damage Tolerance

	Condition	1a	1b
	Imbalance Design Fraction (IDF)	1.0	1.0
	Diversion time	The maximum expected diversion[6]	A 60 min. diversion
Fatigue Analysis[1,2] (average material properties)	Well case	Damage for 1 DSG	Damage for 1 DSG
	Windmilling case	Damage due to the maximum expected diversion time[6] under a 1.0 IDF imbalance condition	Damage due to 60 minutes diversion under a 1.0 IDF imbalance condition.
	Criteria	Demonstrate no failure[7] under the total damage (unfactored) due to the well case and the windmilling case.	Demonstrate no failure[7] under twice the total damage due to the well case and the windmilling case.
Damage Tolerance[1,2] (average material properties)	Well case[3]	Manufacturing quality flaw[5] (MQF) grown for 1/2 DSG	Manufacturing quality flaw[5] (MQF) grown for 1 DSG
	Windmilling case[4]	Additional crack growth for a 180 minute diversion with an IDF = 1.0	Additional crack growth for 60 minute diversion with an IDF = 1.0
	Criteria	Positive margin of safety with residual strength loads specified in 3a for the final crack length	Positive margin of safety with residual strength loads specified in 3a for the final crack length

Notes:

1 *The analysis method that may be used is described in section 4.0*

2 *Load spectrum to be used for the analysis is the same load spectrum qualified for use in showing compliance to § 25.571 augmented with windmilling loads as appropriate.*

3 *Windmilling case is to be demonstrated following application of the well case spectrum loads.*

4 *The initial flaw for damage tolerance analysis of the windmilling case need not be greater than the flaw size determined as the detectable flaw size plus growth under well case spectrum loads for one inspection period for mandated inspections.*

5 *MQF is the manufacturing quality flaw associated with 95/95 probability of existence. (Reference - 'Verification of Methods For Damage Tolerance Evaluation of Aircraft Structures to FAA Requirements', Tom Swift FAA, 12th International Committee on Aeronautical Fatigue, 25 May 1983, Figures 42, and 43.)*

6 *Maximum diversion time for condition 1a is the maximum diversion time established for the airplane, but need not exceed 180 minutes.*

7 *The allowable cycles to failure may be used in the damage calculations.*

5. Systems integrity. It must be shown systems required for continued safe flight and landing after a blade-out event will withstand the vibratory environment defined for the windmilling condition for the load levels and diversion times described above. This assessment need not consider the possible effects of potentially inoperative instruments or equipment.

   The initial flight environmental conditions are to be assumed as night, instrument meteorological conditions (IMC) enroute to nearest alternate airport, and approach landing minimum of 300 -3/4 or RVR 4000 or better.

6. Flight crew response. For the windmilling condition described above, the degree of flight deck vibration shall not jeopardize the flight crew's ability to continue to operate the airplane in a safe manner during any [all] phases of flight.

B. ACCEPTABLE MEANS OF COMPLIANCE – LOSS OF CENTERLINE.

To evaluate the loss of shaft centerline condition, the low pressure (LP) rotor system should be analyzed with each bearing removed, one at a time, with the initial imbalance consistent with the airborne vibration monitor (AVM) advisory level. The analysis should include the maximum operating LP rotor speed (assumed bearing failure speed), spool down, and windmilling speed regions. The effect of gravity, inlet steady air load, and significant rotor to stator rubs and gaps should be included. If the analysis or experience indicates that secondary damage such as additional mass loss, secondary bearing overload, permanent shaft deformation, or other structural changes affecting the system dynamics occur during the event, the model should be revised to account for these additional effects. The objective of the analysis is to show that the loads produced by the loss-of-centerline event are less than the loads produced by the blade loss event.

C. ACCEPTABLE MEANS OF COMPLIANCE HIGH POWER CONDITION

Assume an imbalance condition equivalent to 50 percent of one blade at cruise rotor speed considered to last for 20 seconds. It must be shown that attitude, airspeed, and altimeter indications will withstand the vibratory environment of the high power condition and operate accurately in that environment. Adequate cues must be available to readily determine which engine is damaged. This is forecast to be a high frequency, low amplitude vibration condition of short duration, and thus, strength and structural endurance need not be considered for this condition.

Section 25.903(d) Turbine engine installations.

a. **Text.**

(d) Turbine engine installations. For turbine engine installations -

(1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case.

(2) The powerplant systems associated with engine control devices, systems, and instrumentation, must be designed to give reasonable assurance that those engine operating limitations that adversely affect turbine rotor structural integrity will not be exceeded in service.

b. **Intent of Subparagraph.** The intent of this subparagraph is to ensure that practical design precautions are taken such that hazards to the airplane are minimized following an uncontained engine failure. It requires design features to protect structure, systems, and components that would be adversely affected by the heat and pressure conditions resulting from an engine case burn-through.

c. **Background.**

(1) The regulatory history shows that § 25.903(d) originated from Section 401(d) of the Civil Air Regulations (CAR) 4b, December 31, 1953. That paragraph required that the engine installation "*include a means of protection such that the occurrence of rotor blade failure in any engine will not affect the operation of the remaining engines or jeopardize the continued safe operation of the airplane* . . ." [CAR 4b.401(e) included a requirement for minimizing the probability of jeopardizing the safety of the airplane in the event of an uncontained turbine rotor failure, unless the engine type certificate specified that exceedance of rotor limits could not occur in service.] Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.401(d) without any substantive changes.

(2) Notice of Proposed Rulemaking 68-18 (33 FR 11913, August 22, 1968) proposed to delete the requirement for the engine installer to provide a means of protection from the effects of blade failure. The following excerpt from the preamble to the Notice discusses the reasoning behind the proposed revision:

> The engine rotor blade containment requirement of § 25.903(d) is redundant, since § 25.903(a) requires each engine to be type certificated under Part 33 and § 33.19 requires rotor blade containment as a condition for engine certification. The proposal would delete that portion of § 25.903(d) pertaining to rotor blade failure considerations.

> Also, all engines certificated to the requirements of § 33.27 must have (a) turbine rotors capable of withstanding damage inducing factors and (b) control devices, systems, and instrumentation that will preserve the engine rotor structural integrity. Since all certificated engines must incorporate turbine rotors capable of withstanding damage inducing factors, the proposal would delete this requirement from § 25.903(d)(1).
>
> However, the requirement of § 25.903(d)(2) pertaining to control devices, systems, and instrumentation to protect the engine is still necessary in some installations to provide such protection as a result of installation features. In addition, even though § 33.27 contains specific requirements to minimize the probability of turbine rotor failure, turbine and compressor rotors have failed in service. Engine fires have burned through the engine case with torch-like effectiveness. These failures were due to maintenance factors, engine defects due to service uses, material defects, and to some extent, design deficiencies. The incidents have not caused catastrophic damage because of the basic engine location in under-wing pods. However, the present rules do not preclude engine locations in other areas of an airplane where severe damage is more likely to be caused by engine failures. The proposal would permit flexibility in the design of engine installations and, at the same time, it would minimize any hazards to flight safety.

Amendment 25-23 (35 FR 5665, April 8, 1970) followed Notice 68-18 and adopted the proposed revision. At the same time, § 33.19 was amended to require the engine manufacturer to provide blade containment. The following excerpt from the preamble to Amendment 25-23, provides additional guidance:

> The purpose of the proposed amendment to § 25.903(d) is to ensure that, for turbine engine installations, design precautions are taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating in the engine which burns through the engine case. Comments were received objecting to the proposed words *"design precautions to minimize hazards to the airplane"* in that they would be subject to interpretation. However, this wording is contained in the current regulations and no change to these words or their meaning is intended. Another comment stated that containment precautions and engine integrity should be the engine manufacturer's responsibility and covered under Part 33. The FAA does not agree. Service experience has shown that additional safeguards in the installation of the engine is necessary over and above those provided by Part 33 to minimize hazards resulting from engine rotor failure or engine case burn-through.

c. **Policy/Compliance Methods.** Acceptable methods of compliance, and in certain cases "required compliance methods," include drawing and schematic review together with compliance (mock-up) inspections, system descriptions, fail safe analysis, ground and flight test. Flight testing involves demonstration of safe flight and landing with (simulated) damaged systems and controls and external airflow tuft studies of nacelle strut-airframe boundary layer conditions. The applicant must supply system functioning and test proposals that address each design provision cited in this subpart.

Consideration can be given to compliance by design similarity and service experience on applicants approved existing design on other model aircraft.

The FAA has issued guidance for compliance with this paragraph in:

- FAA Order 8110.11, "Design Considerations for Minimizing Damage Caused by Uncontained Aircraft Turbine Engine Rotor Failures," November 19, 1975.
- Advisory Circular 20-128A, "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Bald Failures," March 25, 1997.*
- Advisory Circular 20-135, "Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria," February 15, 1990.

**Advisory Circular (AC) 20-128A contains the most recent guidance regarding minimization of damage to the airplane from uncontained engine and APU failure. The AC is a product of an ARAC harmonization committee. Additional guidance regarding APU's is provided below.*

(1) ***Considerations for Auxiliary Power Units (Generic Issue Papers):*** Guidance provided in Advisory Circular 20-128A has been further clarified as described in the following excerpts from two FAA Generic Issue Papers generated for this purpose. The first Issue Paper provides guidance for APU's that were qualified under the TSO as meeting the "rotor integrity option" (explained below). The second Issue Paper provides guidance for APU's that were qualified under the "containment option."

ISSUE PAPER #1
CONSIDERATIONS FOR PREVENTING HAZARDS CAUSED BY UNCONTAINED APU FAILURE (ROTOR INTEGRITY-QUALIFIED APU'S)

Statement of Issue. In a recent certification meeting, the FAA became aware that [*an aircraft company*] intends to install a [*model*] APU in their new [*model*] airplane. This APU will be qualified under the "Rotor Integrity" provisions (containment of rotor blades only) of Technical Standard Order (TSO) C77a. The intent of this Issue Paper (IP) is to review and clarify APU compliance with § 25.903(d)(1) and the corresponding guidance material described in Advisory Circular (AC) 20-128, "Design Considerations For Minimizing Hazards Caused By Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures."

Background. In order to better understand the Part 25 uncontained APU rotor compliance methodology outlined within this IP, clarification on how the APU is initially tested and qualified by the APU manufacturer prior to airplane installation is first needed. U.S. APU manufacturers qualify their products per the minimum performance standard set by FAA Technical Standard Order (TSO) C77a, "Gas Turbine Auxiliary Power Units." Within the TSO-C77a qualification process, the APU manufacturer is given two options for meeting rotor or rotor blade containment standards. The APU manufacturer must meet one of the following TSO options:

- The TSO *Rotor Integrity* Option involves conducting a functional test of the APU's speed and temperature limiting devices, an overspeed and over temperature test to demonstrate rotor overstress margin, and a demonstration of rotor blade containment capability. The rotor blade containment test is conducted on the most critical stage blade at a high APU (>100%) rotor speed defined in the TSO.

- The TSO *Rotor Containment Demonstration* Option involves demonstrating that the APU is capable of containing a tri-hub rotor burst of the most critical APU stage at a high APU (>100%) rotor speed defined in the TSO.

Independent of the TSO option chosen by the APU manufacturer, service history has shown that uncontained APU rotor failures do occur. However, these uncontained failures occur more frequently and produce higher energy fragments on APU's qualified under the Rotor Integrity Option than under the Rotor Containment Option.

Service experience has also shown that some APU radial turbine failures produced fragments, having significant energy, which were expelled at angles up to 35 degrees from the plane of rotation. Additionally, some APU rotor failures resulted in large rotor segments being liberated through the tailpipe (axial failure). For axial failures that result in a hazard to the airplane, the FAA has given credit for installation of devices that are designed to stop large rotor pieces from progressing down the tailpipe. These scenarios should be considered in the APU failure model for APU installations near critical aircraft items such as control cables, pressure bulkheads, fuel tanks and lines, electrical power feeder cables, or fire protection equipment.

Airplane protection from hazardous consequences caused by damage from APU rotor failures is considered technically (and economically) feasible for APU's. Typically, this level of safety can be accomplished by:

- Installation of an APU where no critical airplane structure, components, or systems are located within the rotorburst zone as defined by AC 20-128. This approach is valid independent of whether the installed APU has demonstrated compliance with the rotor containment or rotor integrity provisions of the TSO.

Or

- Installation of an APU which has demonstrated containment per the TSO requirements. For this case, shielding of critical airplane structure and components within the rotorburst zone must only consider smaller secondary fragments which may contain approximately 1% of the total rotor stage energy (secondary fragment size and energy provided by APU manufacturer). Airplane shielding evaluation for these secondary fragments can be based on analysis and shielding credit can be taken for APU fire walls.

Or

- Installation of an APU which has met the rotor integrity requirements of the TSO. For this case, shielding of all critical airplane structure and components within the rotorburst zone must consider maximum energy from the most critical 1/3 disk segment. Airplane shields and mounts must substantiated by actual test data using 1/3 rotor disk at speeds defined by Section 7.10 of TSO-C77a.

Independent of the compliance method chosen above, a full APU rotorburst hazard analysis is required to show compliance with § 25.903(d)(1). For APU installations where no critical airplane structure, components, or systems are located within the rotorburst zone, the required hazard analysis need only consists of a layout drawing showing the relationship between the APU burst zone and the nearest critical components or structure. For compliance options 2) and 3), an extensive airplane hazard analysis (identification of potential hazards caused by an APU uncontained failure) as outlined in AC 20-128 for engines and APU's is required.

In addition to the design precautions required to minimize the hazards of rotor failures required by § 25.903(d)(1), both § 25.901 and § 25.1461(d) require measures be taken to prevent any APU disc, blades or secondary failures, irrespective of any APU TSO certification containment declaration, from causing damage to critical systems that would jeopardize continued safe operation of the airplane. Previously accepted methods for minimizing the hazards following an uncontained APU failure are described within AC 20-128. These methods include separation, isolation, redundancy, and additional shielding.

Another APU failure concern relates to the ground deicing of an airplane with the APU operating. In at least one case, deicing fluid entered the APU inlet, causing an APU overspeed that ultimately resulted in an uncontained failure and significant airplane structural damage. Because the deicing fluid entering the APU inlet acts like an uncontrolled additional fuel source, APU overspeed protection devices which reduce fuel flow are deemed ineffective. In addition, the APU containment rings (if applicable), which are designed and tested to function during tri-hub failures up to approximately 110% of maximum rotorspeed, may not be fully effective in containing debris at energies associated with rotorspeeds levels (130+%) attained during deicing fluid ingestion events.

In addressing the ground deicing condition, some applicants have chosen to design (i.e., fluid diverters or dams) and locate their APU inlet in order to minimize the risk of deicing fluid (or any other flammable fluid) ingestion in combination with operational warnings. Other applicants have chosen to use a limitation to prohibit the operation of the APU during ground deicing. Operational warnings (i.e., Do not spray deicing fluid into APU inlet) by themselves, have not been shown to be fully effective. Applicants should address this condition by either inlet design considerations in combination with operational warnings or by prohibiting APU operation during ground deicing via an Airplane Flight Manual Limitation.

FAA Position: Many factors have caused uncontained failures of APU's that have been approved utilizing the "rotor integrity" provisions of TSO-C77a. Installation of an uncontained APU in close proximity to critical systems and structure, without consideration of the consequences of an uncontained failure could compromise the level of safety of this airplane type. Therefore, the FAA has concluded that identification of these critical components, within the plane of rotor(s) rotation identified in AC 20-128, will be required to determine if the level of safety needed for Part 25 certification has been achieved.

For installation of an APU that has met the rotor integrity requirements of TSO-C77a, the APU uncontained rotor failure analysis should:

(a) Consider the effects of rotor failure and the resultant safety implications on any critical aircraft systems or structure that may be affected. In addition to the normal evaluation, the installer also needs to address any hazard to the airplane associated with APU debris exiting the tailpipe (up to and including a complete rotor where applicable).

(b) Base additional shielding requirements on the analysis. For this analysis, the 1/3 rotor size, energy, and angular trajectory should be supplied by the APU manufacturer.

(c) The adequacy of airplane shielding (including airframe shielding mounts shall be demonstrated and validated by full scale testing using the most critical 1/3 disk segment (as defined by AC 20-128) at energy levels equivalent to those defined in section 7.10 of TSO-C77a.

Previously accepted methods for minimizing the hazards following an uncontained APU failure are described within AC 20-128. These methods include separation, isolation, redundancy, and additional shielding. Airplane shielding requirements vary pending whether the APU has been demonstrated to contain a tri-hub failure or not. Variables for substantiation of any airplane shielding include assumed rotor fragment size, energy, and spread angle. Additionally, [Generic] Airplane Company should propose a method to address potential hazards associated APU operation during airplane ground deicing.

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ISSUE PAPER #2
CONSIDERATIONS FOR PREVENTING HAZARDS CAUSED BY UNCONTAINED APU FAILURE (ROTOR CONTAINMENT-QUALIFIED APU'S)

Statement of Issue. In a recent certification meeting, the FAA became aware that [*an aircraft company*] intends to install a [*model*] APU in their new [*model*] airplane. This APU will be qualified under the "Rotor Containment Demonstration" provisions of Technical Standard Order (TSO) C77a. The intent of this Issue Paper (IP) is to review and clarify APU compliance with § 25.903(d)(1) and the corresponding guidance material described in Advisory Circular (AC) 20-128, "Design Considerations For Minimizing Hazards Caused By Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures."

Background. In order to better understand the Part 25 uncontained APU rotor compliance methodology outlined within this IP, clarification on how the APU is initially tested and qualified by the APU manufacturer prior to airplane installation is first needed. U.S. APU manufacturers qualify their products per the minimum performance standard set by FAA Technical Standard Order (TSO) C77a, "Gas Turbine Auxiliary Power Units." Within the TSO-C77a qualification process, the APU manufacturer is given two options for meeting rotor or rotor blade containment standards. The APU manufacturer must meet one of the following TSO options:

- The TSO *Rotor Integrity* Option involves conducting a functional test of the APU's speed and temperature limiting devices, an overspeed and over temperature test to demonstrate rotor overstress margin, and a demonstration of rotor blade containment capability. The rotor blade containment test is conducted on the most critical stage blade at a high APU (>100%) rotor speed defined in the TSO.

- The TSO *Rotor Containment Demonstration* Option involves demonstrating that the APU is capable of containing a tri-hub rotor burst of the most critical APU stage at a high APU (>100%) rotor speed defined in the TSO.

Independent of the TSO option chosen by the APU manufacturer, service history has shown that uncontained APU rotor failures do occur. However, these uncontained failures occur more frequently and produce higher energy fragments on APU's qualified under the Rotor Integrity Option than under the Rotor Containment Option.

For APU's like the [*Model,*] which have demonstrated tri-hub containment during a TSO-C77a rotor containment tests, such measures have not always proven fully successful in the field. This stems from a number of unforeseen conditions, such as:

- containment ring deflection or roll at time of hub failure,
- embrittlement of the containment ring structure,
- erroneous design conclusions regarding the identification of critical stages,
- overspeed failures above 110%, and
- non-repeatability of internal energy transfer paths due to different hub fracture mechanics (bi-hub failures) than that required in the TSO or other certification criteria.

The majority of these uncontained failures have occurred at rotor speeds between 100% and 137%.

Service experience has also shown that some APU radial turbine failures produced fragments, having significant energy, which were expelled at angles up to 35 degrees from the plane of rotation. Additionally, some APU rotor failures resulted in rotor debris missing a containment ring or large rotor segments being liberated through the tailpipe (axial failure). For axial failures that result in a hazard to the airplane, the FAA has given credit for installation of devices that are designed to stop large rotor pieces from progressing down the tailpipe. These scenarios should be considered in the APU failure model for APU installations near critical aircraft items such as control cables, pressure bulkheads, fuel tanks and lines, electrical power feeder cables, or fire protection equipment.

Airplane protection from hazardous consequences caused by damage from APU rotor failures is considered technically (and economically) feasible for APU's. Typically, this level of safety can be accomplished by:

- Installation of an APU where no critical airplane structure, components, or systems are located within the rotorburst zone as defined by AC 20-128. This approach is valid independent of whether the installed APU has demonstrated compliance with the rotor containment or rotor integrity provisions of the TSO.

Or

- Installation of an APU which has demonstrated containment per the TSO requirements. For this case, shielding of critical airplane structure and components within the rotorburst zone must only consider smaller secondary fragments which may contain approximately 1% of the total rotor stage energy (secondary fragment size and energy provided by APU manufacturer). Airplane shielding evaluation for these secondary fragments can be based on analysis and shielding credit can be taken for APU fire walls.

Or

- Installation of an APU which has met the rotor integrity requirements of the TSO. For this case, shielding of all critical airplane structure and components within the rotorburst zone must consider maximum energy from the most critical 1/3 disk segment. Airplane shields and mounts must substantiated by actual test data using 1/3 rotor disk at speeds defined by Section 7.10 of TSO-C77a.

Independent of the compliance method chosen above, a full APU rotorburst hazard analysis is required to show compliance with § 25.903(d)(1). For APU installations where no critical airplane structure, components, or systems are located within the rotorburst zone, the required hazard analysis need only consists of a layout drawing showing the relationship between the APU burst zone and the nearest critical components or structure. For compliance options 2) and 3), an extensive airplane hazard analysis (identification of potential hazards caused by an APU uncontained failure) as outlined in AC 20-128 for engines and APU's is required.

In addition to the design precautions required to minimize the hazards of rotor failures required by § 25.903(d)(1), both § 25.901 and § 25.1461(d) require that measures be taken to prevent any APU disc, blades, or secondary failures (irrespective of any APU TSO certification containment declaration) from causing damage to critical systems that would jeopardize continued safe operation of the airplane. Previously accepted methods for minimizing the hazards following an uncontained APU failure are described within AC 20-128. These methods include separation, isolation, redundancy, and additional shielding.

Another APU failure concern relates to the ground deicing of an airplane with the APU operating. In at least two cases, deicing fluid entered the APU inlet, causing an APU overspeed that ultimately resulted in an uncontained failure and significant airplane structural damage. Because the deicing fluid entering the APU inlet acts like an uncontrolled additional fuel source, APU overspeed protection devices which reduce fuel flow are deemed ineffective. In addition, the APU containment rings (if applicable), which are designed and tested to function during tri-hub failures up to approximately 110% of maximum rotorspeed, may not be fully effective in containing debris at energies associated with rotorspeeds levels (130+%) attained during deicing fluid ingestion events.

In addressing the ground deicing condition, some applicants have chosen to design (i.e., fluid diverters or dams) and locate their APU inlet in order to minimize the risk of deicing fluid (or any other flammable fluid) ingestion in combination with operational warnings. Other applicants have chosen to use a limitation to prohibit the operation of the APU during ground deicing. Operational warnings (i.e., Do not spray deicing fluid into APU inlet) by themselves, have not been shown to be fully effective. Applicants should address this condition by either inlet design considerations in combination with operational warnings or by prohibiting APU operation during ground deicing via an Airplane Flight Manual Limitation.

FAA Position. Many factors have caused rotor failures of APU's that have been approved utilizing the "rotor containment" provisions of TSO-C77a. Installation of an APU in close proximity to any critical systems and structure (including pressure bulkheads and fuel tanks), without consideration of the consequences of an uncontained failure could compromise the level of safety of this airplane type. Therefore, the FAA has concluded that identification of these critical components, within the plane of rotor(s) rotation identified in AC 20-128, will be required to determine if the level of safety needed for Part 25 certification has been achieved.

For installation of an APU that has met the rotor containment requirements of TSO-C77a, the APU uncontained rotor failure analysis should:

- Consider the effects of rotor failure and the resultant safety implications on any critical aircraft systems or structure that may be affected. In addition to the normal evaluation, the installer also needs to address any hazard to the airplane associated with APU debris exiting the tailpipe (up to and including a complete rotor where applicable).

- Base additional airplane shielding requirements on small secondary APU rotor fragments which contain 1% of the total rotational energy of the critical stage. For this analysis, the fragment size, energy level, and angular trajectory should be supplied by the APU manufacturer.

- The adequacy of airplane shielding (including airframe shielding mounts) may be substantiated by test or validated analysis. Shielding provided by the APU firewall or enclosure may eliminate or significantly reduce the need for additional shielding.

Previously accepted methods for minimizing the hazards following an uncontained APU failure are described within AC 20-128. These methods include separation, isolation, redundancy, and additional shielding. Airplane shielding requirements vary pending whether the APU has been demonstrated to contain a tri-hub failure or not. Variables for substantiation of any airplane shielding include assumed rotor fragment size, energy, and spread angle. Additionally, [Generic] Aircraft Company should propose a method to address potential hazards associated APU operation during airplane ground deicing.

(2) ***Application of § 25.903 vs. § 25.1461 to APU's:*** Guidance provided in AC 20-128A, regarding application of § 25.1461 to APU's, supersedes previous guidance issued in a FAA memorandum, dated January 29, 1992. However the memorandum provides useful background relating to application of these regulations to APU's and the following excerpt is provided below:

The FAA's Engine Rotorburst Team is currently in the process of revising AC 20-128, "Design Precautions for Minimizing Hazards to Aircraft from Uncontained Turbine Engine & Auxiliary Power Unit Rotor & Fan Blade Failures." The team has asked the FAA to determine the rotor non-containment regulatory standards that are applicable to Auxiliary Power Unit (APU) installations. This information will be included in the revised AC.

The FAA has conducted an extensive research of the regulatory history concerning § 25.903(d)(1) and § 25.1461. It is not evident that APU rotor non-containment was addressed during either of these rulemaking processes. As a result, neither rule, by itself, is adequate for all APU installation situations.

There is evidence, however, in the regulatory history supporting Amendment 25-46 (1978) which adopted § 25.901(d) regarding APU regulatory applicability, that the "powerplant community" recognized that APU's were reaching the size of small turbine engines and needed to be treated as such. As early as 1967, FAA Order 8110.4 recognized that these units should be given the same installation considerations as the prime mover. In 1981, the FAA published the draft AC "Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Blade Failures," which described methods of compliance under the provisions of § 25.903(d).

Although Amendment 25-41 (1977), which introduced § 25.1461, does not specifically address APU's, APU's have been considered "equipment" under the airworthiness regulations because they do not receive a Part 33 certificate. Section § 25.1461 pertains to equipment containing high energy rotors. The provisions of § 25.1461(c) provide rotor non-containment criteria that supplement, or could be used to replace, that of Technical Standard Order C77. The provisions of § 25.1461(d) allow philosophy similar to that imposed by § 25.903(d)(1) to be used.

The Transport Standards Staff [*of the FAA's Transport Airplane Directorate*] recommends that both the provisions of § 25.1461 and § 25.903(d)(1) be applicable for transport airplane APU installation criteria. Subsections § 25.1461(b) and (c) supplement the TSO rotor non-containment criteria. Subsection § 25.1461 (d) provides criteria similar to that of § 25.903(d)(1). Since compliance with only subsection (b), (c), or (d) of § 25.1461 is required, the applicant's choice of compliance route will dictate the degree that the provisions of § 25.903(d)(1) will have been met. For example:

1) If an APU were located where a non-contained rotor failure was potentially catastrophic, compliance with § 25.1461(c) (by use of shielding incorporated into the APU or the installation) would be required to minimize the hazard.

2) If an APU were located where rotor failure did not endanger the occupants or adversely affect continued safe flight, compliance with § 25.1461(d) would satisfy the requirements of § 25.903(d)(1) for an APU installation.

The AC should include a detailed discussion of means to demonstrate compliance to § 25.1461. The discussion should clearly state that :

- if the rotor integrity/containment provisions of § 25.1461(b) are used, the full provisions of § 25.903(d)(1) apply;

- if the containment provisions of § 25.1461(c) are used (as noted in the example above), installation rotor containment testing of all rotors may be required.

The compliance guidelines should include details of the types of failure modes that have previously occurred on APU rotors that have resulted in non-containment incidents.

(3) ***Engine Case Burnthrough:*** The following excerpt from an internal FAA memorandum provides guidance on compliance with engine case burnthrough requirements:

Background. :Fire that results from an engine case burnthrough is localized but extremely intense. The flame temperature is approximately 3500 Degrees Fahrenheit at a high velocity (depending on the engine pressure ratio). This high velocity and high temperature flame has the potential to severely damage all components and structures in the flame path. The fire has penetrated engine firewalls in some instances before the engine could be shut down.

A considerable effort is being expended by the FAA and industry to develop a barrier material that can resist the high temperature and high pressure effect of this type of fire; but none of the materials tested to date show promise to resist the full effects of such burnthrough fires for more than a short period of time. R&D effort is continuing, however. The ultimate objective of the R&D is to develop a barrier material that will provide the same degree of protection against fire as our current firewall materials - 15 minutes at actual installation fire conditions, both temperature and pressure.

To ensure that new airplane engine installations can safely cope with burnthrough type fire effects, we believe the following design factors should be taken into account:

(a) Airflow Over the Engine Case.

A high velocity and large amount of airflow or fan flow over the combustion case can serve as an effective deterrent to burnthrough damage in the installation.

(b) Location of Components & Systems

A determination should be made that no hazard to the airplane will occur as the result of the failure of systems or components within the powerplant installation in the path of combustion case burnthrough flames

(c) Fire Detector Systems

In view of the hazardous nature of burnthrough type fires, it is extremely important to rapidly detect the occurrence. Specific attention should be given to the placement of detectors to ensure that these fires are quickly detected. Also, specific detector coverage should be provided for areas where a burnthrough can penetrate the firewall. The detector should be designed such that if an intense fire severs the detector element or associated wiring the detector provides an immediate fire warning.

(d) Firewall Penetrations

> When it is determined that a burnthrough can penetrate the airplane firewall, the hazard to airplane structure and systems on the remote side of the firewall should be assessed. It should be established that any structure or systems on the remote side of the firewall in the path of the burnthrough can withstand the burnthrough flame for a minimum of 5 minutes, or that the structure and systems are located so as to be capable of withstanding the resulting heat and pressure at that point. This would ensure the time necessary to detect and initiate action to control the fire produced.

The considerations discussed above reflect some current concepts that were developed into a more comprehensive description of an acceptable means of compliance for § 25.903(d). This material is also provided within Advisory Circular 20-135, “Powerplant Installation and Propulsion System Component Fire Protection Test Methods, Standards, and Criteria” (page 12).

Section 25.903(e) Restart Capability.

a. **Text.**

(e) Restart capability.

(1) Means to restart any engine in flight must be provided.

(2) An altitude and airspeed envelope must be established for in-flight engine restarting, and each engine must have a restart capability within that envelope.

(3) For turbine engine powered airplanes, if the minimum windmilling speed of the engines, following the in-flight shutdown of all engines, is insufficient to provide the necessary electrical power for engine ignition, a power source independent of the engine-driven electrical power generating system must be provided to permit in-flight engine ignition for restarting.

b. **Intent of Subparagraph.** The intent of this requirement is to ensure that the engine, airplane, and related starting and powerplant systems are designed to provide normal single-engine restart capability and engine(s) restart capability under the conditions of § 25.1351(d). Additionally, compliance with § 25.903(e) will establish the procedural information and data needed to restart engines in flight for the purpose of complying with § 25.1585(a)(3).

c. **Background.**

(1) The regulatory history shows that § 25.903(a) originated from Section 401(c) of the Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.401 without any substantive changes.

(2) The original CAR 401(c) required: "*Means shall be provided for individually stopping and starting the rotation of any engine in flight* . . ." Notice of Proposed Rulemaking 75-19 (40 FR 21866, 19, 1975) proposed an amendment to create a new paragraph "§ 25.903(e), Engine Restart," that would consolidate all restart requirements. The explanation for the proposal was given in the preamble of the Notice as follows:

> The proposal would delete the requirement that certain components of the engine restarting system be fire resistant since the need for such components after a fire is questionable. However, a means to restart any engine in flight when there has been no fire would continue to be required.

> In addition, although § 25.1585(a)(3) requires that the Airplane Flight Manual contain recommended procedures for restarting turbine engines in flight, there exists no specific requirement for establishing the conditions of altitude and airspeed for which restarting capability must exist. The proposal would add such a requirement and would editorially revise § 25.903 for clarity.
>
> The proposal would ensure that a source of ignition energy for in-flight engine restarting exists in the event of loss of combustion in all engines during flight."

Amendment 25-40 (42 FR 15034, March 17, 1977) followed Notice 75-19 and adopted the proposed revisions. The following excerpt from the preamble to that Amendment provides additional insight into the intent of this regulation:

> One commenter recommends revising proposed § 25.903(e)(2) to require only the establishment of an envelope that defines the in-flight restart capability. The FAA disagrees, since this recommendation would not explicitly require restart capability, which was the intent of the proposal and which the FAA believes is essential for safe operation.
>
> Another commenter questions the deletion of the fire-resistant requirement for engine restarting from current § 25.903(c). The FAA believes, due to the very limited use of an engine after a fire in the engine, that the benefits of requiring the components of the restarting system to be fire-resistant are slight. The FAA, thus, can no longer justify this requirement.
>
> One commenter does not concur with proposed § 25.903(e)(3) because it provides for ignition but not for rotational capability sufficient for an engine start. *[FAA response:]* The proposal, however ,was not intended to require a power source for rotation where windmilling speeds are too low for restarting. The proposal would provide the necessary electrical power for engine ignition whether or not the windmilling speed was adequate for an engine start. The proposal is accepted `without substantive change.

d. **<u>Policy/Compliance Methods.</u>**

(1) Acceptable methods of compliance, and in certain cases "required compliance methods," include drawing and schematic review together with compliance (mock-up) inspections, system descriptions, fail safe analysis, ground test, and flight test. Flight testing involves development of an engine air start envelope and engine starting procedures for compliance with §§ 25.903(e), 25.1353(d), and 25.1585(a)(3). The applicant must supply system functioning and test proposals that address each design provision cited in these regulations.

Although this section was intended to require a restart capability following loss of power from all engines, the regulation does not specify a minimum restart capability. The following excerpt from an FAA Generic Issue Paper provides guidance regarding compliance methods for this regulation. This regulation is the subject of a harmonization effort under ARAC and additional guidance will likely evolve through this process.

(2) ***Engine Restart Requirements.*** The following excerpt from an FAA Generic Issue Paper provides current guidance on engine restart requirements:

Statement of Issue: The [*Model*] airplane is powered by [*two/three/four turboprop/turbofan*] engines incorporating high bypass turbine engine technology. The engine restart requirements following loss of all engine power have not been specifically addressed in the transport category airworthiness regulations. The level of engine design technology that existed at the time Part 25 was promulgated provided adequate all-engine restart capability and specific regulatory requirements were not needed. The introduction of high bypass ratio engine technology, free power turbine type engines, and related electronic engine control and combustor technology that affords improved fuel efficiency and lower emissions has, in some cases, reduced the capability of the engine to be restarted. The latest generation of high bypass ratio turbofan and turbopropeller engine designs apparently exacerbates this tendency and are therefore novel and unique with respect to the engine designs that provided a basis for the existing regulations. A [*model*] airplane Special Condition is needed to maintain the level of safety that was envisioned by the current airworthiness regulations.

Background: Since the introduction of turbopropeller and turbofan engines into commercial service, newer technology high bypass ratio engines have been developed which improve fuel efficiency. High bypass ratio engines generally require increased airspeed to provide sufficient windmilling rotational energy for restarting. The bypass ratio of the engines when the existing Part 25 standards were developed was approximately 1 and the engine “windmill” relight capability covered nearly the entire airspeed and altitude operational envelope.

Many of the turbopropeller engines incorporated electrical starters for restart and assurance that electrical power for the starter and engine ignition were all that was needed to address the all engine out condition. Many of today’s larger turboprop engines do not incorporate electrical starters due to the high electrical power requirements and resultant weight needed for these systems. In addition many of today’s new technology turbofan and turbopropeller airplanes have significantly less “windmill” restart capability. These engines, typically with pneumatic starters, require “assists” from a pneumatic source, such as another operable engine or an in-flight operable Auxiliary Power Unit (APU), in order to conduct a restart over a large portion of the airplane operating envelope. Engine manufacturers recognize the need to maintain an adequate “windmill” relight envelope and have incorporated features into their engine designs such as improved fuel scheduling and compressor bleeds to maintain engine “windmill” restart capabilities. The degree that these features compensate for the engine’s lack of restart capability has yet to be demonstrated.

A significant number of incidents of all-engine flameouts or shutdowns on transport category airplanes have occurred over the last decade. These have occurred for a number of reasons including fuel mismanagement, loss of electrical power, crew error, fuel contamination, mis-trimming of engine idle setting, selection of propeller pitch in the beta range, fuel nozzle coking, volcanic ash encounters, or inclement weather. The need for regulatory criteria addressing all-engine restart capability is now evident. The FAA has considered all-engine power loss in other regulatory standards such as § 25.671(d), which requires that “the airplane must be designed to be controllable if all engines fail.”

Discussion: The following guidelines are provided as background information regarding the restart conditions. Compliance with these conditions must be substantiated by flight test. The test conditions including the initial altitude, airspeed, engine temperature, and engine rotor speed should be established based on an evaluation to determine what conditions are critical. This evaluation should address the restart of an undamaged engine for at least the following conditions: for airplanes with electrical driven fuel pumps, suction feed windmill relight at the maximum suction feed relight altitude (or restart altitude as determined under § 25.1351); flameout of all engines due to volcanic ash, inclement weather, fuel mismanagement, or fuel contamination. The following are examples of conditions that the FAA believes are critical. (Actual flight test conditions will be established following review of the results of the evaluation noted above):

In the event of an all-engine flameout or shutdown during the takeoff/climb portion of the flight, it should be possible to restore engine power when the fuel source is restored to the engine. The test sequence would include shutoff of the fuel supply to the test engine, (with the engine initially at a relatively high power setting (Maximum Climb Power or higher)), followed by restoration of fuel supply to the engine. The test engine should accelerate to the previous power setting after a brief shutdown. The duration of the fuel shutdown may last up to 15 seconds, and will be based upon an evaluation of pilot response times as determined by a review of human factors considerations (inherent or dedicated cockpit indications of the engine failure) and systems response times. This test is intended to demonstrate an acceptable level of safety in the event of a "common cause" total thrust loss (i.e., crew error, unrecoverable compressor stall, etc.) at a combination of high engine power, low airplane speed (V_2+10 kts) and altitude. The engine and airplane systems associated with engine starting should not preclude restart capability during these conditions. (In one instance the engine control was configured such that restart could only be initiated following engine spool down to idle).

In the event of an all-engine flameout that occurs at high altitude, it should be possible to restart those engines required to maintain level flight or restart all but one of the engines and produce Maximum Continuous Thrust/Power (MCT/MCP) by an altitude of 15000 feet. This will ensure adequate terrain clearance for a majority of the flight paths that the model airplane will encounter. The test engine should be at a stabilized rotor speed and temperature representative of an all engine out descent from the maximum certified altitude to a point within the flight envelope where restart is probable. An evaluation of the ability of the crew to determine clear progression of engine restart should be conducted.

In the event of an all-engine flameout or shutdown that occurs below 20,000 feet, at any airspeed greater than the minimum flaps-up "holding speed" and with the engines at stabilized windmill speed, it should be possible to restart the engines and arrest the airplane descent within a total altitude loss of 5000 feet. The altitude loss should be measured from the point at which engine restart procedures are initiated. This is intended to provide an acceptable level of safety in the event of a "common cause" thrust loss at a combination of low engine power, moderate to low altitudes, and moderate airspeeds (typical holding pattern). Subparagraph (c) of the Special Condition is not intended to require that engines be restarted at any speed within the flight envelope below an altitude of 20,000 feet. It is intended to ensure that, from any point within the normal airspeed envelope, the airplane can be accelerated/decelerated (if necessary) to a flight condition whereby a successful all engine restart can be accomplished. However, engine restart should be accomplished prior to exceeding an airspeed of 300 knots. In addition, the test should evaluate the ability of the crew to identify an all-engine loss of power and to determine clear progression of engine restart so that premature termination of the restart attempt is not likely. Credit for engine failure recognition and "Auto Restart" design features may be used to ameliorate the ability to demonstrate engine restart from certain low airspeed/low altitude flight conditions.

The engine restart envelope included in the Airplane Flight Manual should include a "core windmill relight envelope" developed in a manner consistent with the current policy which allows both a maximum 90 second (from start initiation to idle) restart time and a 30 second ignition time. A larger envelope that includes appropriately labeled longer restart times may be allowed if it can be shown that indication of a clear progression of engine start is provided to the flight crew. (Clear progression of start is needed because flight crews have terminated relight attempts because it was unclear that the start was progressing normally). The AFM should also include those procedures needed for an immediate restart, "cold" engine restart from windmilling conditions, and normal engine restart from windmilling conditions. "Assisted" and "unassisted" regions of engine envelope restart should be appropriately labeled. If the airplane must be accelerated to a specific airspeed within the envelope to achieve relight, procedures that minimize altitude loss while maximizing the likelihood of successful restart should be provided.

If it is determined that power assisted relight is required and an APU is utilized to provide power assisted restart, the need for a minimum demonstrated APU start reliability (validated by flight test) or operation of the APU within critical portions of the flight envelope will be evaluated. A minimum APU start reliability of 95 percent is acceptable assuming that the start probability is substantiated by actual in-flight start testing (specifically following cold-soak cruise conditions, two relight attempts allowed) with a minimum of a two APU's used to develop the start reliability data base.

To ensure that the APU start reliability does not fall below the certified value when the airplane is operated in service, an APU maintenance program should be defined by the applicant. From this maintenance program, certification maintenance requirements will be considered by the FAA to maintain the long-term APU start reliability. In addition, Master Minimum Equipment List (MMEL) dispatch considerations with the APU inoperative will have to be evaluated by the FAA Aircraft Evaluations Group (AEG).

If start cartridges are proposed, the capability for at least two start attempts of each engine should be provided.

FAA Position. The FAA has evaluated the service history of the existing transport category airplane fleet and determined that the model engine design features are novel and unique with respect to those design features that are the basis for the existing airworthiness regulations and that the regulatory provisions shown below are necessary to provide an adequate level of safety. Therefore, the following is issued with the proposed restart conditions :

In addition to the engine restart provisions of § 25.903(e) of the Federal Aviation Regulations the following criteria apply:

The means to restart engines, while in-flight, following flameout or in-flight shutdown of all engines, must be substantiated by flight test. The means must provide all-engine restart capability for the airplane in the following situations:

Immediately following an all-engine power loss at high torque or power settings.

Following loss of all-engine power at maximum cruise altitude conditions. In demonstrating compliance with this condition, the engines must be initially "windmilling" and, prior to descending below 15,000 feet altitude using procedures recommended by the manufacturer for restarting, either

- all but one engine must be restarted and accelerated to Maximum Continuous Thrust/Power (MCT/MCP), or
- the engine(s) must be restarted, and the necessary thrust/power achieved, to enable the airplane to maintain level flight.

From any initial airspeed within the normal flight envelope below an altitude of 20,000 feet. In demonstrating compliance with this condition, the test engine(s) must be initially "windmilling" and prior to an airplane altitude loss of 5,000 feet (or an altitude loss shown by the applicant not to preclude continued safe flight and landing), either

- all but one engine must be restarted and produce Maximum Continuous Thrust/Power (MCT/MCP), or
- the engine(s) must be restarted, and the necessary thrust/power achieved, to enable the airplane to maintain level flight.

The criteria defined in paragraph (b) and (c) above includes consideration of a typical one-engine inoperative scenario and allows airplanes, which have maximum one-engine-inoperative altitudes below 15,000 feet altitude, to exceed the maximum height loss allowed for engine restart and arrest of airplane descent. These airplanes are allowed to slowly drift down to the one-engine-inoperative ceiling provided that all but one of the engines are restarted and accelerated to MCT/MCP prior to reaching the specified altitude floor or allowable height loss.

(3) ***Auto Relight Logic/Digital Control Systems:*** The following excerpts come from a letter that the FAA received and the FAA's response to it. These documents concern auto-relight logic in digital control systems of modern high bypass ratio turbofan engines and associated Aircraft Flight Manual revisions:

<u>From a Letter Submitted to the FAA:</u>

The proliferation of auto-relight logic in digital control systems of modern high bypass ratio turbofan engines has prompted one airplane manufacturer to propose Aircraft Flight Manual revisions which delete the traditional recommendations to utilize continuous ignition in certain operating conditions (e.g., takeoff, landing and during exposure to heavy precipitation). This recent philosophical change has resulted in our receipt of a request by [*an Aircraft Certification Office*] to examine this issue with the engine manufacturers and provide our position and recommendations as soon as practical.

As an initial perspective, we consider that selection of continuous ignition in various operating conditions, as suggested above, is a pilot's prerogative as a measure of good practice and conservatism, and is not a mandatory action with respect to the engine/aircraft type certification basis. Nevertheless, recommendations to select continuous ignition stem from a logical philosophy to utilize an available resource which is otherwise dormant, to preclude a potential power loss in an adverse and unforeseeable situation which transcends the severity of engine certification testing (e.g., ingestion testing and water-entrained fuel testing). In this context, therefore, it is prudent to retain the recommendation to utilize an ignition system during critical phases, and the focus of the issue becomes whether an auto-relight system can be expected to arrest a flameout/ spooldown as effectively and reliably as that possible with continuous ignition.

With respect to our request for your consideration of the viability of reliance upon auto-relight logic in lieu of using continuous ignition, please consider the impact of the recently redefined inclement weather threat, and such variables as the lapse associated with actual or impending flameout recognition, ignition system capacitance timing and spark-rate factors, rotor spooldown effects after flameout, transient stability factors, and others, as appropriate, when formulating your recommendations.'

The FAA response included the following:

1. The speed-range covered by the words "normal and emergency operation within the range of operating limitations of the airplane and the engine" in § 25.939(a) is considered, in general, to be from VDF/MDF down to VS, stick pusher actuation, horn/light barrier, or extreme buffet, whichever occurs at the highest speed.

2. We believe that some relaxation [of the use of continuous ignition] may be justified at the higher altitudes where takeoffs and landings are not performed. (We are considering establishing an altitude above the maximum altitude scheduled for takeoff and landing plus 3,000 feet but not less than 15,000 feet.) In the case of non-damaging adverse engine characteristics, such as flame-out or stall/surge from which the engine can be easily restarted or restabilized without excessive loss in altitude, we believe that it would be acceptable for the minimum speed to be above the stall speed as long as an adequate warning (§ 25.207(c)) is provided to the pilot to avoid such adverse characteristics. In the case of potentially damaging adverse characteristics such as stall/surge leading to engine overtemperatures, overspeed, or exceedance of other engine limits; excessive loss of altitude to the restart the engine; or a hazard to the crew or passengers and continued safe flight, we believe that demonstration to Vs is not necessary if an adequate and redundant barrier is provided alone with adequate warning.

3. We believe that there should be at least a 7 percent speed margin above the minimum airspeed for safe engine operation or above the speed at which the redundant barrier is activated. We would not consider a minimum speed limitation, by itself, in the Airplane Flight Manual, to be an acceptable warning means in any case.

Section 25.903(f) Auxiliary power unit.

a. **Text.**

(f) Auxiliary power unit. Each auxiliary power unit must be approved or meet the requirements of the category for its intended use.

b. **Intent of Subparagraph.** The intent of this requirement is self-evident.

c. **Background.** The regulatory history shows that § 25.903(f) was first proposed in Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984). The explanation given for proposing this requirement was to . " . . *present the requirement for APU qualification in § 25.901 along with the analogous requirement for propulsion engine certification*." Amendment 25-72 (55 FR 29756, July 20, 1990) followed Notice 84-21 and adopted the proposal. The following excerpt from the preamble to the Amendment contains a discussion of the comments received, which may provide additional insight into the rule's intent.

> One commenter supports the change proposed to clarify the present requirement for qualification of the auxiliary power unit (APU). Another opposes the proposed § 25.903(f) as being ambiguous and failing to clearly state the requirement or intent of the rule. In lieu of stating that each APU must be approved, the commenter proposes a requirement that the APU be " . . . certified to TSO-C77 or FAA approved Equivalent. As noted in the explanation for Proposal 53, the term "approved," when used in Part 25 in this context, means that the product must comply with an applicable Technical Standard Order (TSO) or, in lieu thereof, be approved in conjunction with the type certification process for the airplane on which it is to be installed. Because TSO-C77 is the TSO applicable to an APU, the proposed use of the term "approved" meets the intent of the commenter's proposal. It is also noted that the term "certified" (or the related term "certificated") is a misnomer with respect to products authorized under the TSO system. The commenter also proposes adding the parenthetical expression "essential or non-essential" following the word "category;" however, it does not appear that this addition would add clarity to the rule. Accordingly, § 25.903(f) is added as proposed.

d. **Policy/Compliance Methods.** While there is no official general policy on this portion of the regulations, Advisory Circular (AC) 120-42A, "Extended Range Operation with Two-Engine Airplanes (ETOPS)," does provide guidance on auxiliary power unit data collection for ETOPS-approved airplanes.

Section 25.904 Automatic takeoff thrust control system (ATTCS).

a. **Rule Text.**

Each applicant seeking approval for installation of an engine power control system that automatically resets the power or thrust on the operating engine(s) when any engine fails during the takeoff must comply with the requirements of Appendix I of this part.

(Amdt. 25-62, 52 FR 43156, Nov. 9, 1987)

b. **Intent of Rule.** This rule provides new airplane and equipment airworthiness standards for the installation of an automatic takeoff thrust control system (ATTCS) on Part 25 transport category airplanes.

c. **Background.**

(1) The initial types of "regulatory" actions related to ATTCS systems began with the issuance of Special Conditions for this new-technology equipment. The development of ATTCS Special Conditions began in the latter part of 1976. At that time, several airplane manufacturers were known to be interested in such a system or had made application for approval of such a system. The "Policy/Compliance Methods" section, below, contains more details on the history, background, description, and guidance in pertinent Special Conditions relevant to ATTCS installations in transport category airplanes.

(2) This rule was originally proposed in Notice of Proposed Rulemaking 84-4 (49 FR 18240, April 27, 1984). Notice 84-4A (49 FR 29410, July 20, 1984) was published a short time later to allow additional time for public comment. The proposal was finally adopted in its current form by Amendment 25-62 (52 FR 43152, November 9, 1987). The following excerpt from the preamble to that Amendment provides additional guidance and summarizes the comments received in response to the Notice(s):

> The requirements adopted by this amendment incorporate into Part 25 the substance of the Special Conditions that have been developed and issued to date. Future applicants who wish to install an ATTCS system will have appropriate rules for designing their systems without the need to go through the Special Condition development process. As in the Special Conditions, the amendment herein:
>
> - specifies limits on the maximum thrust increment that can be applied to the operating engines by the ATTCS system;
> - prescribes ATTCS system reliability;
> - requires system status monitoring;
> - requires provisions for manual selection of the maximum takeoff thrust approved, for the airplane;

- prohibits approval of the ATTCS system design if the automatic or manual application of maximum takeoff thrust would result in exceeding engine operating limits; and
- requires an independent engine failure warning indication if the inherent operating characteristics of the airplane do not provide a clear warning to the crew.

In addition, a “critical time interval” definition is included to provide a uniform and acceptable basis for probability calculations.

. . .

One commenter expresses concern about § 25.904 being sufficiently flexible to allow future flight management systems and performance management systems to be expanded to manage the takeoff functions an ATTCS now performs. A system designed to perform ATTCS and other functions during the takeoff would be acceptable if it can be shown to comply with both the requirements of this amendment and the requirements for those other functions. The same commenter recommends that the FAA devise a more objective criterion than the “arbitrary” 10 percent limit. The commenter believes the proposed paragraphs I25.4(b) and (c) may be sufficient by themselves.

In the Special Conditions, the FAA adopted the value based on a review of the impact that “reduced thrust” operations had on runway-critical takeoffs. A 10 percent value was determined to be a straightforward and acceptable decrement from a safety standpoint in limiting both runway critical takeoffs and degradation of all-engine climb performance factors that are not addressed by paragraphs I25.4(b) and (c).

Several commenters recommend expanding the scope of the proposed standards to include such additional maneuvers as:

- takeoffs using reduced and derated thrust,
- thrust reductions during initial climb, and
- approach climb performance and go-around maneuvers.

The FAA has not restricted ATTCS operations where airplane performance is based on an approved “derate” rating which has corresponding engine and airplane limits approved for use under all weight, altitude and temperature (WAT) conditions. However, the FAA has not allowed the reduced thrust (assumed temperature or weight decrement method) operations to be combined with ATTCS because the resulting flight procedures would increase the pilot workload by creating an infinite number of initial all-engine and engine-failed thrust settings. The increased workload could lead to performance computation errors, and create confusion for the crew’s workload during a critical high workload engine failure situation. Operationally, noise abatement procedures have already created another set of thrust settings, which must be monitored and set. The combination would substantially increase exposure to performance limiting conditions, and this clearly would not be equivalent to current regulations, which are based on a single thrust setting for takeoff). In regard to ATTCS credit for approach climb and go-around maneuvers, current regulations preclude a higher thrust for the approach climb [§ 25.121(d)] than for the landing climb (§ 25.119). The workload required for the flightcrew to monitor and select from multiple in-flight thrust settings in the event of an engine failure during a critical point in the approach, landing, or go-around operation is excessive. Therefore, the FAA does not agree that the scope of the amendment should be changed to include the use of ATTCS for anything except the takeoff phase.

Two commenters request that paragraph I25.1(b) be revised by deleting the phrase "*. . . without requiring any action by the crew to increase thrust or power*." One commenter thinks the phrase is misleading because several requirements of Part 25 must be met at the maximum takeoff thrust irrespective of whether action by the crew is necessary to obtain such thrust. The other commenter states that all the design and flight requirements must be met with the maximum power attained after ATTCS advance occurs and accelerate-stop distances, all engine takeoff, etc., must be accomplished with the power actually available. The phrase "*without requiring any action by the crew* . . ." was originally inserted into the previous Special Conditions for the purpose of emphasizing that the ATTCS must automatically function to insert the thrust increment if an engine fails during the critical time portion of the takeoff. The ATTCS is required to perform automatically without pilot assistance to demonstrate compliance and to be consistent with the requirements of § 25.111(c)(4). The inclusion of this requirement in the rule makes it clear that the system design must not require any pilot action in order to achieve a level of safety that would otherwise be required by Part 25. Amendment 25-54 adopted October 14, 1980, amended § 25.111(c)(4) by specifying that no change in thrust requiring pilot action could be necessary until the airplane is 400 feet above the surface. Since that section applies also to airplanes equipped with an ATTCS, the requirement could be deleted as being redundant, but it is retained to emphasize the automatic feature required in all ATTCS systems presented for approval.

d. **Policy/Compliance Methods.**

(1) ***Addressing ATTCS Installations by Use of Special Conditions***. The history of the initial development of ATTCS Special Conditions began in the latter part of 1976. At that time, several airplane manufacturers were known to be interested in such a system or had made application for approval of such a system. There were no regulations existing at that time, however, that were applicable to this specific system, however. In light of this, it was necessary to address the ATTCS installations via issuance of Special Conditions.

With an ATTCS installed, takeoffs would normally be made with all-engine thrust set at less than the maximum certificated takeoff thrust approved for the airplane. The ATTCS actuates in the event of an engine failure during takeoff to automatically apply maximum takeoff thrust to the remaining operating engine(s). An airplane with such a system installed would have a number of novel and unusual design features that are not presently addressed by the regulations. As such, § 21.16 and § 21.101 of Part 21 require that Special Conditions be developed and compliance with the Special Conditions be demonstrated. Special Conditions were, therefore, developed for each applicant requesting approval of an ATTCS installation to cover the change in the airplane type design. Note that the term "thrust" is used throughout this discussion even though the normal nomenclature for turbojet is thrust and for turbopropeller is power. No distinction is made in the discussion and "thrust" is used for both.

In November 1977, proposed Special Conditions for an ATTCS for any two- or three-engine turbine-powered transport category airplane were developed and sent to interested aviation groups and various foreign civil aviation authorities for review and comment. Comments were reviewed, and the Special Conditions were revised and sent out for comment in May 1978 and again in November 1978. The FAA, industry, and foreign aviation safety authorities participated in the development of the Special Conditions. As a result of this effort, essentially identical Special Conditions were issued to all applicants.

The following excerpt comes from FAA's comments submitted to a Notice of Proposed Amendment (NPA) developed by the European Joint Aviation Authorities. It provides insight into the FAA's policy regarding ATTCS installations, and clarifies the FAA's current position with regard to conducting ATTCS (APR) and "reduced thrust" operations:

> The basis for this [*NPA*] is the Special Conditions developed for several ATTCS designs. The ATTCS installed and approved on those airplane models involved a relatively simple electromechanical system integrated with the engines hydromechanical fuel control unit and was designed to increase the thrust a fixed amount. The system was designed to increase thrust only and no other systems or functions beyond the ATTCS could be interfaced with the ATTCS uptrim function, nor could the ATTCS be adversely affected if other systems malfunctioned or failed.
>
> Since certification of the original ATTCS, however, a number of others have been approved that were required to comply with the same Special Conditions issued for the earlier ATTCS designs. Some of the more recent ATTCS configurations installed on some of the latest model turbofan and turbopropeller airplanes have been considerably more complex than the ATTCS approved for the airplane. These systems interface with the latest designed engine electronic fuel control units (ECU) which use microprocessors and digital computers. The electronic controls command fuel flows for a range of thrust from about 50 percent to full rated thrust in some installations and facilitates the ATTCS 10 percent increment which can be a software program within the basic electronic fuel control configuration. Additionally, these electrical or electronic engine controls interface with and are integrated with, in some installations, other critical or essential engine and airplane systems such as autofeathering, autothrottles and in some instances reverser thrust control systems and surge, stall and overspeed protection.
>
> These interfaces and integrated features make the ECU complex in design and difficult to evaluate in light of the performance and other pertinent design criteria used to find compliance with the Special Conditions and the applicable airworthiness regulations. However, the FAA considers the ATTCS installation an optional appliance, and it is not an item necessary for the basic airplane certification. **Therefore, the FAA policy on ATTCS is that, regardless of whether the airplane is ATTCS equipped or not, the airplane must be found to comply with the applicable regulations on its own merits and where an ATTCS is installed and integrated the basic airplane airworthiness must not be compromised by the ATTCS installation, and the ATTCS must comply with the requirements of the proposed amendment.** This means that the isolation, separation and fail safe concepts in §§ 25.901 and 25.903 must be satisfied regardless of the depth or complexity of the integrated electrical or

electronic fuel controls and other critical or essential airplane systems. The FAA considers the fail-safe means for these ATTCS applications to be a fail-fixed condition in that the design of the ECU's would not cause a downtrim or reduce installed engine thrust by a significant amount.

> *"Aircraft equipped with Automatic Takeoff Thrust Control Systems (ATTCS) will require instrument markings for <u>both</u> the normal and maximum (ATTCS operating) takeoff rating limits, The normal takeoff rating limit should be marked with a red radial. The maximum takeoff rating limit should be marked with a dashed red radial and an offset yellow arc placed between the red radials, provided there is sufficient space. As stated previously, a wedge-shaped red radial may be used instead of a dashed red radial on small dial faces."*

By marking and observing the normal takeoff rating limit, adequate takeoff+APR redline margin is ensured should it be needed during an engine-out takeoff when extra power is applied automatically.

At a June 8, 1994, meeting, the FAA agreed to research its files to determine whether the above interpretation of I25.5(b)(2) was consistent with the original intent, as well as with previous applications, of this requirement. Our records show that, for ATTCS systems installed on airplanes with engine limiters, a means other than the power levers may be used to obtain the maximum rated power. Although the background material that introduced this exception into the requirements does not address the all-engines-operating condition, the system for which the "other means" exception was written would not have allowed the maximum rated power to be obtained with all-engines-operating through the use of the power levers alone. Several similar installations have also been approved. Therefore, we find that the ATTCS design on the airplane is consistent with the original intent of I25.5(b)(2) and with past ATTCS approvals.

The applicant requested approval of the currently proposed CPR system under the existing part 25 requirements of the Federal Aviation Regulations based on the similarity of this system to the ATTCS systems used on other transport category airplanes. The current proposal is such that the CPR power rating cannot be obtained unless a toggle switch is moved to the CPR position. If the pilot neglects to take this action, an action that would be unique to this airplane, the airplane cannot meet the performance level contained in the Airplane Flight Manual. The existing ATTCS requirements in part 25 of the regulations require an automatic increase in engine power when an engine fails and the requirements were promulgated under the premise that ATTCS was to be used only in conjunction with takeoff thrust.

Therefore, we do not consider the currently proposed CPR system to comply with the intent of existing applicable Part 25 requirements and cannot approve your request for performance credit. This reasoning and our position on the currently proposed CPR system were reviewed during a meeting with the airplane manufacturer and its supplier.

The FAA does not concur that APR system operations and "reduced thrust operations using the assumed temperature method" should be integrated. The FAA previously had a policy wherein automatic takeoff thrust control system operations were separate from "reduced thrust" operations, such that when conducting "reduced thrust" takeoffs, the ATTCS was disarmed. We have recently reviewed this policy and have concluded that with certain restrictions, ATTCS may be "armed" when scheduling "reduced thrust" takeoff operations.

We now accept that the operator may arm the ATTCS during "reduced thrust," takeoffs; however, no performance or weight credit is to be allowed. Furthermore, the applicant or operator must demonstrate that the airplane does not have adverse handling or controllability characteristics and the operating engine(s) must not exhibit adverse operating characteristics or exceed operating limits (in the event an engine fails or there is loss of power on an engine which causes the ATTCS to function) during the takeoff. Also, the AFM must furnish information, instructions and procedures, as required regarding the peculiarities of normal and abnormal operations when scheduling reduced thrust operations and an "armed" ATTCS together.

ATTCS system installed on the "full throttle engines" of the airplane contains an electronic fuel controller and thrust limiters which automatically limit thrust and prevent engine operating limits from being exceeded under conditions with full throttle employed. In the event of an engine failure, a signal from the ATTCS is transmitted to the limiters for the maximum thrust. In the event of an ATTCS failure with engine failure, the crew would be required to activate an override switch to obtain the maximum thrust. Because of this design feature where the pilot must move his hand off the throttle to activate the maximum thrust available, the agency has determined that the Special Condition ordinarily issued to other aircraft under item 5(b)(2) should be modified to provide that such activation is permitted providing that the means to increase thrust is located on or forward of the power levers, is easily operated by either pilot, and meets the requirement of Section 25.777

(2) Requirements for the installation of an ATTCS were incorporated into Part 25, appendix I, by Amendment 25-62 (52 FR 43156, November 9, 1987). The following text comes from Appendix I; it provides definitions for an ATTCS system, and additional performance and system reliability requirements for the installation of an ATTCS system:

I25.1 General.

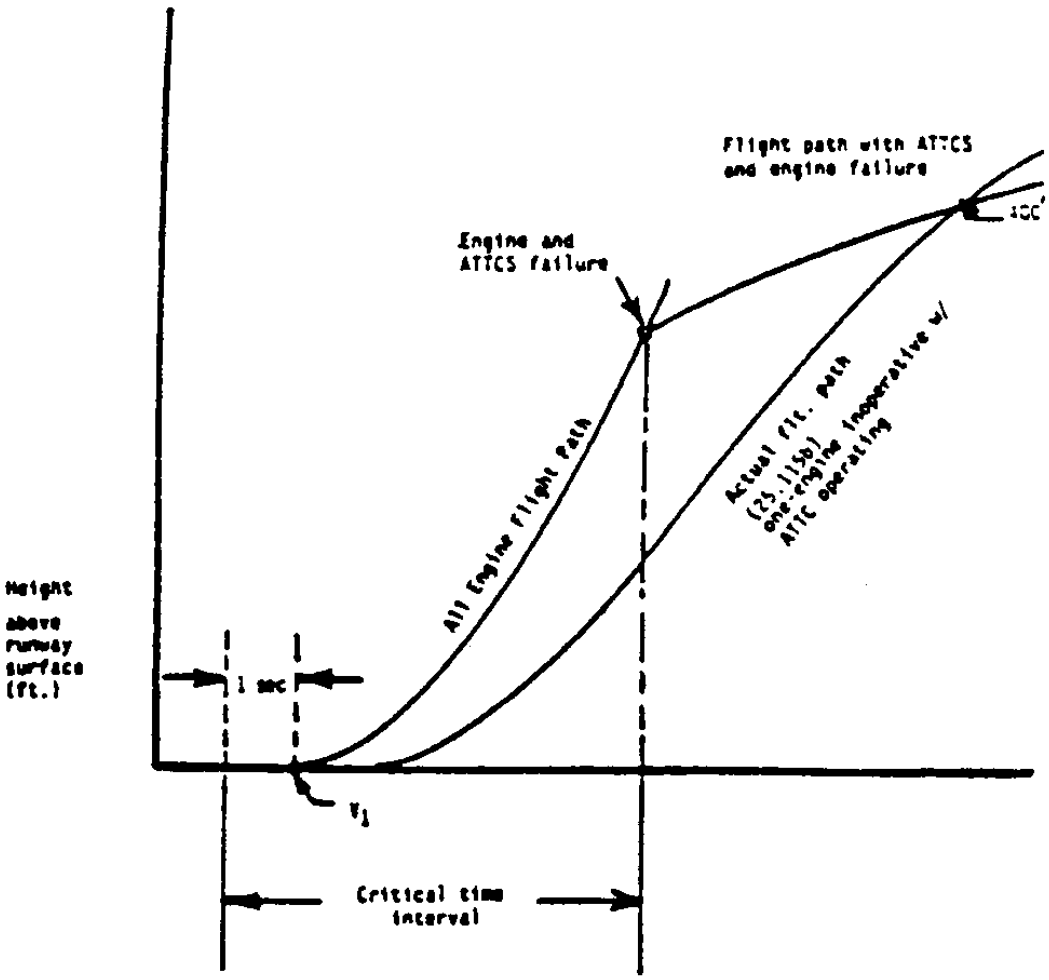
(a) This appendix specifies additional requirements for installation of an engine power control system that automatically resets thrust or power on operating engine(s) in the event of any one engine failure during takeoff.

(b) With the ATTCS and associated systems functioning normally as designed, all applicable requirements of Part 25, except as provided in this appendix, must be met without requiring any action by the crew to increase thrust or power.

I25.2 Definitions.

(a) Automatic Takeoff Thrust Control System (ATTCS). An ATTCS is defined as the entire automatic system used on takeoff, including all devices, both mechanical and electrical, that sense engine failure, transmit signals, actuate fuel controls or power levers or increase engine power by other means on operating engines to achieve scheduled thrust or power increases, and furnish cockpit information on system operation.

(b) Critical Time Interval. When conducting an ATTCS takeoff, the critical time interval is between V 1 minus 1 second and a point on the minimum performance, all-engine flight path where, assuming a simultaneous occurrence of an engine and ATTCS failure, the resulting minimum flight path thereafter intersects the Part 25 required actual flight path at no less than 400 feet above the takeoff surface. This time interval is shown in the following illustration:



I25.3 Performance and System Reliability Requirements. The applicant must comply with the performance and ATTCS reliability requirements as follows:

(a) An ATTCS failure or a combination of failures in the ATTCS during the critical time interval:

(1) Shall not prevent the insertion of the maximum approved takeoff thrust or power, or must be shown to be an improbable event.

(2) Shall not result in a significant loss or reduction in thrust or power, or must be shown to be an extremely improbable event.

(b) The concurrent existence of an ATTCS failure and an engine failure during the critical time interval must be shown to be extremely improbable.

(c) All applicable performance requirements of Part 25 must be met with an engine failure occurring at the most critical point during takeoff with the ATTCS system functioning.

I25.4 Thrust Setting. The initial takeoff thrust or power setting on each engine at the beginning of the takeoff roll may not be less than any of the following:

(a) Ninety (90) percent of the thrust or power set by the ATTCS (the maximum takeoff thrust or power approved for the airplane under existing ambient conditions);

(b) That required to permit normal operation of all safety-related systems and equipment dependent upon engine thrust or power lever position; or

(c) That shown to be free of hazardous engine response characteristics when thrust or power is advanced from the initial takeoff thrust or power to the maximum approved takeoff thrust or power.

I25.5 Powerplant Controls.

(a) In addition to the requirements of 25.1141, no single failure or malfunction, or probable combination thereof, of the ATTCS, including associated systems, may cause the failure of any powerplant function necessary for safety.

(b) The ATTCS must be designed to:

(1) Apply thrust or power on the operating engine(s), following any one engine failure during takeoff, to achieve the maximum approved takeoff thrust or power without exceeding engine operating limits;

(2) Permit manual decrease or increase in thrust or power up to the maximum takeoff thrust or power approved for the airplane under existing conditions through the use of the power lever. For airplanes equipped with limiters that automatically prevent engine operating limits from being exceeded under existing ambient conditions, other means may be used to increase the thrust or power in the event of an ATTCS failure provided the means is located on or forward of the power levers; is easily identified and operated under all operating conditions by a single action of either pilot with the hand that is normally used to actuate

the power levers; and meets the requirements o §§ 25.777(a), (b), and (c);

(3) Provide a means to verify to the flightcrew before takeoff that the ATTCS is in a condition to operate; and

(4) Provide a means for the flightcrew to deactivate the automatic function. This means must be designed to prevent inadvertent deactivation.

I25.6 <u>Powerplant Instruments</u>. In addition to the requirements of § 25.1305:

(a) A means must be provided to indicate when the ATTCS is in the armed or ready condition; and

(b) If the inherent flight characteristics of the airplane do not provide adequate warning that an engine has failed, a warning system that is independent of the ATTCS must be provided to give the pilot a clear warning of any engine failure during takeoff.

(2) ***ATTCS for Go-Around Special Condition:*** The following material is from a final Special Condition (60 FR 10483, February 27, 1995) on an airplane model that features an "Automatic Takeoff Thrust Control System." The text of this Special Condition reads as follows:

Accordingly, pursuant to the authority delegated to me by the Administrator, the following Special Conditions are issued as part of the type certification basis for a model airplane.

(a) **General**: An ATTCS is defined as the entire automatic system, including all devices, both mechanical and electrical, that sense engine failure, transmit signals, actuate fuel controls or power levers, or increase engine power by other means on operating engines to achieve scheduled thrust or power increases and furnish cockpit information on system operation.

(b) **Automatic takeoff thrust control system (ATTCS).** The engine power control system that automatically resets the power or thrust on the operating engine (following engine failure during the approach for landing) must comply with the following requirements:

(1) <u>Performance and System Reliability Requirements</u>. The probability analysis must include consideration of ATTCS failure occurring after the time at which the flightcrew last verifies that the ATTCS is in a condition to operate until the beginning of the critical time interval.

(2) <u>Thrust Setting</u>. The initial takeoff thrust set on each engine at the beginning of the takeoff roll or go-around may not be less than:

(i) Ninety (90) percent of the thrust level set by the ATTCS (the maximum takeoff thrust or power approved for the airplane under existing ambient conditions);

(ii) That required to permit normal operation of all safety-related systems and equipment dependent upon engine thrust or power lever position; or

(iii) That shown to be free of hazardous engine response characteristics when thrust is advanced from the initial takeoff thrust or power to the maximum approved takeoff thrust or power.

(3) Powerplant Controls. In addition to the requirements of Section 25.1141, no single failure or malfunction, or probable combination thereof, of the ATTCS, including associated systems, may cause the failure of any powerplant function necessary for safety. The ATTCS must be designed to:

(i) Apply thrust or power on the operating engine(s), following any one engine failure during takeoff or go-around, to achieve the maximum approved takeoff thrust or power without exceeding engine operating limits; and

(ii) Provide a means to verify to the flightcrew before takeoff and before beginning an approach for landing that the ATTCS is in a condition to operate.

(c) **Critical Time Interval.** The definition of the Critical Time Interval in Appendix I, Section I25.2(b) shall be expanded to include the following:

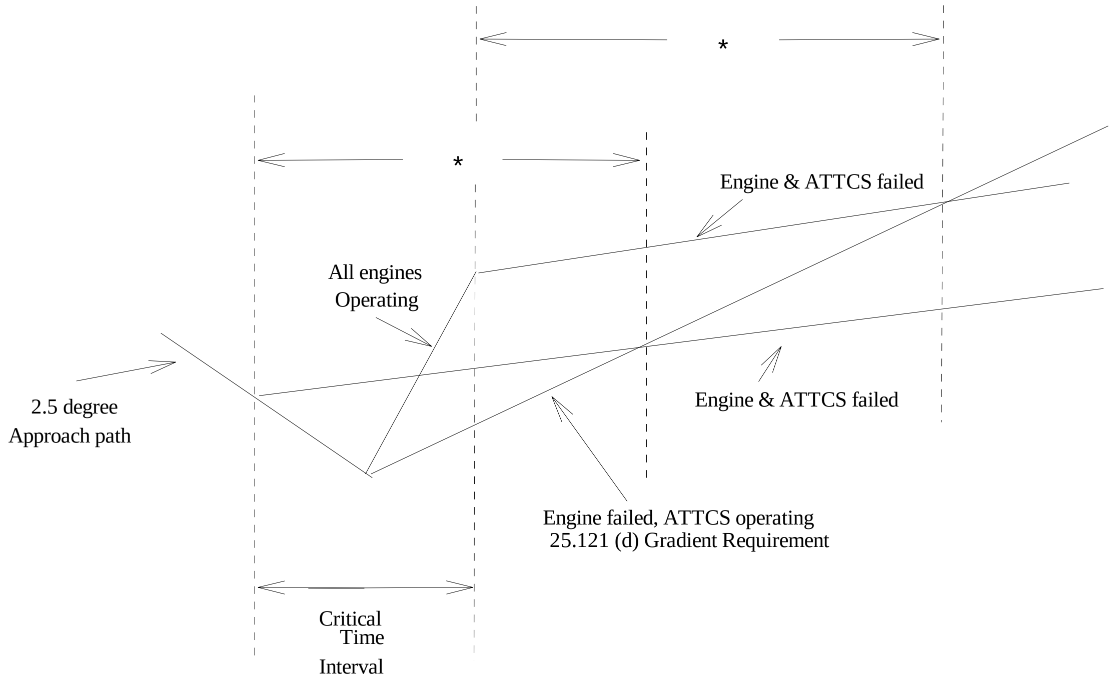
(1) When conducting an approach for landing using ATTCS, the critical time interval is defined as follows:

(i) The critical time interval begins at a point on a 2.5 degree approach glide path from which, assuming a simultaneous engine and ATTCS failure, the resulting approach climb flight path intersects a flight path originating at a later point on the same approach path corresponding to the Part 25 one-engine-inoperative approach climb gradient. The period of time from the point of simultaneous engine and ATTCS failure to the intersection of these flight paths must be no shorter than the time interval used in evaluating the critical time interval for takeoff beginning from the point of simultaneous engine and ATTCS failure and ending upon reaching a height of 400 feet.

(ii) The critical time interval ends at the point on a minimum performance, all-engines-operating go-around flight path from which, assuming a simultaneous engine and ATTCS failure, the resulting minimum approach climb flight path intersects a flight path corresponding to the Part 25 minimum one-engine-inoperative approach climb gradient. The all-engines-operating go-around flight path and the Part 25 one-engine-inoperative approach climb gradient flight path originate from a common point on a 2.5 degree approach path. The period of time from the point of simultaneous engine and ATTCS failure to the intersection of these flight paths must be no shorter than the time interval used in evaluating the critical time interval for the takeoff beginning from the point of simultaneous engine and ATTCS failure and ending upon reaching a height of 400 feet.

(2) The critical time interval must be determined at the altitude resulting in the longest critical time interval for which one-engine-inoperative approach climb performance data are presented in the Airplane Flight Manual.

(3) The critical time interval is illustrated in the following figure:



*\ *The engine and ATTCS failed time interval must be no shorter than the time interval from the point of simultaneous engine and ATTCS failure to a height of 400 feet used to comply with I25.2(b) for ATTCS use during takeoff.*

e. **References.**

(1) Amendment 25-62 (52 FR 43152, November 9, 1987).

(2) Notice of Proposed Special Conditions: **". . .** Automatic Takeoff Thrust Control System," [Docket No. NM-103, Notice No. SC-94-4-NM), (59 FR 46673, December 16, 1994].

Section 25.905 Propellers.

a. **Rule Text.**

(a) Each propeller must have a type certificate.

(b) Engine power and propeller shaft rotational speed may not exceed the limits for which the propeller is certificated.

(c) Each component of the propeller blade pitch control system must meet the requirements of § 35.42 of this chapter.

(d) Design precautions must be taken to minimize the hazards to the airplane in the event a propeller blade fails or is released by a hub failure. The hazards which must be considered include damage to structure and vital systems due to impact of a failed or released blade and the unbalance created by such failure or release.

(Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-54, 45 FR 60173, Sept. 11, 1980; Amdt. 25-57, 49 FR 6848, Feb. 23, 1984; Amdt. 25-72, 55 FR 29784, July 20, 1990)

b. **Intent of Rule.** The intent of this rule is to address damage from released propeller blades in the same manner as damage from uncontained engine debris, which is addressed under the provisions of § 25.903(d).

c. **Background.** Amendment 25-72 (55 FR 29756, 20, 1990) deleted the requirement to address damage from a failed propeller blade under the discrete damage evaluation criteria defined in § 25.571. The propeller damage considerations under the provisions of § 25.571(e)(2), as amended by Amendment 25-45 (43 FR 46238, October 5, 1978), required consideration of damage only to structure. Amendment 25-72 created a new subparagraph, § 25.905(d), that broadened the scope of protecting the airplane from propeller impact damage. That regulation addresses not only structural damage, but also impact damage to vital systems and damage due to engine unbalance resulting from the loss of a propeller blade. Accountability for propeller damage was removed from the damage tolerance regulation [§ 25.571(e)(2)] because it was determined that it is not practicable to ensure structural integrity following failure of the large propeller blades in use today. Previously, exemptions were routinely granted for certification of propeller-driven airplanes.

The FAA did, however, determine that it was both technically feasible and economically justifiable to require the airplane manufacturers to minimize the hazard from propeller blade/hub failures. Section § 25.905(d) then was added in its current form.

d. **Policy/Compliance Methods.** The following excerpt is from an FAA memorandum, dated July 28, 1993, which provides an example of FAA policy for compliance with Amendment 25-72, specifically with § 25.905(d):

> Techniques defined in Advisory Circular 20-128 ("Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures") for minimizing the hazards following an uncontained rotor failure are also applicable when minimizing damage from propeller blades. These techniques include:
>
> - separation of critical systems,
> - isolation of functions,
> - redundancy of function, and/or
> - shielding.
>
> Section 4(g) of the AC defines the area that is likely to be impacted by uncontained engine debris. The impact area that should be considered for propeller blades varies with the propeller design. The impact zone that should be considered for traditional "straight" propeller blades is based on a spread angle of ± 5 degrees. Propeller blades of new technology engines under development, such as unducted fans that have blades with helical contours, have experienced blade failures with trajectories up to 25 degrees forward of the plane of rotation. Based on this information the impact area for airplanes with non-standard blades should be evaluated on an individual basis. The applicant should establish the impact area based on test, analysis, or both. Data from propellers with similar physical and operating characteristics may be used to establish the impact area.
>
> The policy noted above is applicable to new type certificates and amended or supplemental type certificates where the provisions of § 21.101 dictate that later regulations be used. Furthermore, type certification bases that had included the provisions of § 25.571(e)(2), as amended by Amendment 25-45, would now substitute as the certification bases the provisions of § 25.905(d), as amended by Amendment 25-72, as the certification bases, thus eliminating the need for an exemption from § 25.571(e)(2).

e. **References.**

(1) Amendment 25-54 (45 FR 60173, September 11, 1980).

(2) Amendment 25-57 (49 FR 6848, February 23, 1984).

(3) Amendment 25-72 (55 FR 29784, July 20, 1990).

(4) Advisory Circular 20-128, "Design Considerations for Minimizing Hazards caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures" March 9, 1988.

(5) Advisory Circular 20-128A, "Design Considerations for Minimizing Hazards caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor and Fan Blade Failures" March 25, 1997.

Section 25.907 Propeller Vibration.

a. **Rule Text.**

(a) The magnitude of the propeller blade vibration stresses under any normal condition of operation must be determined by actual measurement or by comparison with similar installations for which these measurements have been made.

(b) The determined vibration stresses may not exceed values that have been shown to be safe for continuous operation.

b. **Intent of Rule.** The intent of this rule is self-evident.

c. **Background.**

(1) Regulatory history shows that this rule originated from Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b without any substantive changes and has survived with no further changes since that time.

(2) Notice of Proposed Rulemaking 66-44 (31 FR 16790. December 31, 1966), proposed to revise the regulations to add a new § 25.906 that would require data to be provided for the propeller vibration evaluation. Amendment 25-11 (32 FR 6906, May 5, 1967) followed Notice 64-44 and withdrew the proposal. The following excerpt from the preamble to Amendment 25-11 contains the disposition of the comments submitted to the proposal and provides further insight into intent of this regulation:

> Proposed new §§ 23.906, 25.906, 27.906, and 29.906 are withdrawn. These proposed sections would have required the applicant for an aircraft type certificate to obtain, from the engine and propeller manufacturer, all vibration information that those manufacturers can supply to show compliance with the vibration requirements for aircraft.
>
> One industry commenter states that the proposed rule is unnecessary since § 21.21(b) requires, for an aircraft, that no feature or characteristic make it unsafe for the category in which certification is requested. Another industry commenter states that the proposal is not stringent enough. The FAA will continue in the future, as it has in the past, to administer § 21.21(b) to require the use of engine and propeller vibration data to account for vibration conditions that result from the combination of specific engines, propellers, and airframes, where such investigation is necessary for safety. It is believed, however, that the possible kinds and sources of adequate vibration data are too numerous to be adequately covered in a specific, enforceable standard at this time.
>
> . . .

Propeller blade stress can occur due to:

- abnormally rough operating engines,
- unfavorable angles of air inflow,
- insufficient clearance between blade tip and fuselage/wing or between adjacent propeller discs of rotation,
- engine overspeeding,
- unequal air flow distribution through the propeller disc; and
- propeller operating speed at or near structural resonant frequency.

As an example, variations in the angularity of air flow as it enters the propeller rotational plane can produce high cyclic aerodynamic loads. Any angularity present (which can be caused by yaw or pitch movement of the airplane) will cause a variation in propeller blade lift per revolution. During each revolution, a specific blade segment will experience a cyclic change in lift (blade lift minimum through lift maximum returning to lift minimum). This variation in blade lift induces blade bending vibration which has a frequency equal to propeller rotational speed (denoted as a first order vibration mode). In addition, blade tip interference effects can also induce a similar vibration mode (also first order). Other sources can produce higher order vibrational modes. Regardless of the source, excessive blade stress limits life and may ultimately result in blade failure.

d. **Policy/Compliance Methods**. An aircraft propeller that incorporates metal/composite blades or other highly stressed components is subjected to vibratory stresses under many different operating conditions of the aircraft, both while in flight and while on the ground. The forces causing propeller blade vibration stresses are divided into two general categories:

- Those forces created and transmitted internally from the engine to the propeller, and
- Those forces produced aerodynamically and transmitted by the air to the propeller blades directly.

Because the vibration exciting forces acting on a propeller are very complex and the responsive propeller vibrational characteristics are equally complex, it has proven difficult to arrive at any satisfactory method of computing the overall vibrational reaction of a propeller for a given aircraft-engine installation. For these reasons, it has become necessary to measure the propeller vibration response under all normal operating conditions of the aircraft since serious propeller fatigue failures can result if the vibration stresses are not held within safe limits established by the propeller manufacturer.

Compliance with § 25.907 has historically been demonstrated through testing and, if applicable, by service experience. Advisory Circular 20-66, “Vibration Evaluation of Aircraft Propellers,” dated January 29, 1970, provides guidance for demonstrating compliance. Typically, the propeller manufacturer specifies the level of acceptable stress for continuous operation. If compliance is demonstrated through testing, the propeller is instrumented and a flight test conducted. Conditions should be selected that represent the entire ground and flight envelope and include variations in wind (direction and speed during static and taxi airplane operation), propeller angle of attack, and airplane and propeller operating speed representative of that which will be experienced in service.

If compliance is demonstrated through service experience, the referenced configuration must be sufficiently close to the propeller installation for which certification is sought and the measured stress levels must be acceptable per the propeller blade manufacturer.

e. **References.**

(1) Civil Air Regulations 4b, December 31, 1953.

(2) Amendment 25-AD (29 FR 18289, December 24, 1964).

(3) "Aircraft Propeller Handbook," ANC-9, September 1956.

(4) Advisory Circular 20-66, "Vibration Evaluation of Aircraft Propellers," January 29, 1970.

Section 25.925 Propeller clearance.

a. **Rule Text.**

Unless smaller clearances are substantiated, propeller clearances with the airplane at maximum weight, with the most adverse center of gravity, and with the propeller in the most adverse pitch position, may not be less than the following:

(a) Ground clearance. There must be a clearance of at least seven inches(for each airplane with nose wheel landing gear) or nine inches(for each airplane with tail wheel landing gear) between each propeller and the ground with the landing gear statically deflected and in the level takeoff, or taxiing attitude, whichever is most critical. In addition, there must be positive clearance between the propeller and the ground when in the level takeoff attitude with the critical tire(s) completely deflated and the corresponding landing gear strut bottomed.

(b) Water clearance. There must be a clearance of at least 18 inches between each propeller and the water, unless compliance with § 25.239(a) can be shown with a lesser clearance.

(c) Structural clearance. There must be --

(1) At least one inch radial clearance between the blade tips and the airplane structure, plus any additional radial clearance necessary to prevent harmful vibration;

(2) At least one-half inch longitudinal clearance between the propeller blades or cuffs and stationary parts of the airplane; and

(3) Positive clearance between other rotating parts of the propeller or spinner and stationary parts of the airplane.

(Amdt. 25-72, 55 FR 29784, July 20, 1990)

b. **Intent of Rule.** The purpose of this rule is to provide guidance and define minimum levels of clearance between the propeller and other rotating parts of the engine and the airplane, and the ground plane (level surface, i.e., ground, water, etc.). In order to minimize the necessary test conditions required to demonstrate compliance, specific airplane and propeller configurations were established and clearly stated in the this rule.

c. **Background.**

(1) This rule originated from Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b without any substantive changes.

(2) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984), proposed a minor modification of the rule, specifically to clarify that the requirements include dual-wheel airplanes. Amendment. 25-72 (55 FR 29784. July 20, 1990), followed Notice 84-21 and adopted the proposal.

d. **Policy/Compliance Methods.** FAA policy on this topic has been limited to establishing the necessary test configurations that demonstrate compliance. Compliance has been demonstrated through a series of ground and flight testing. Compliance is demonstrated through testing at airplane maximum weight, most adverse center of gravity, and propeller in the most adverse pitch position.

e. **References.**

(1) Civil Air Regulations 4b, December 31, 1953.

(2) Amendment 25-AD (29 FR 18289, December 24, 1964).

(3) Amendment 25-72 (55 FR 29784, July 20, 1990.)

(4) “Aircraft Propeller Handbook,” ANC-9, September 1956.

Section 25.929 Propeller deicing.

a. **Rule Text.**

(a) For airplanes intended for use where icing may be expected, there must be a means to prevent or remove hazardous ice accumulation on propellers or on accessories where ice accumulation would jeopardize engine performance.

(b) If combustible fluid is used for propeller deicing, § 25.1181 through § 25.1185 and § 25.1189 apply.

b. **Intent of Rule.** The intent of this rule is self-evident.

c. **Background.** This rule originated from Civil Air Regulations (CAR) 4b, December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b without any substantive changes. This rule was recodified from CAR 4b without any substantive changes, and has survived with no further change since that time.

d. **Policy/Compliance Methods.** FAA policy on this topic has been limited to issues regarding the use of combustible fluids for deicing:

- specifying limits on the presence of these fluids relative to designated powerplant fire protection zones,
- provision for fluid shutoff ,and
- proper design to eliminate any possible draining of fluid into a designated fire zone.

Historically, compliance has been demonstrated by testing. A typical fluid type propeller deicing test would be carried out as follows:

- If the propellers are equipped with fluid type deicers, the flow test should be conducted starting with a full tank of fluid and operated at maximum flow for a 15-minute timed period.
- The operation should be checked at all engine speeds and powers.
- The tank should be refilled to determine the amount of fluid used after the airplane has landed.

Similar testing would be accomplished for an electrical deicer or use of an adhesive depressant.

Some system description and testing information for propeller electrical deicing and fluid anti-icing systems is contained Advisory Circular 65-12A, "Airframe and Powerplant Mechanics Powerplant Handbook."

e. **References.**

(1) Civil Air Regulations 4b, December 31, 1953.

(2) Amendment 25-AD (29 FR 18289, December 24, 1964).

(3) Advisory Circular 65-12A, "Airframe and Powerplant Mechanics Powerplant Handbook," April 12, 1976.

Section 25.933 Reversing systems.

a. **Rule Text.**

(a) For turbojet reversing systems --

(1) Each system intended for ground operation only must be designed so that during any reversal in flight the engine will produce no more than flight idle thrust. In addition, it must be shown by analysis or test, or both, that --

(i) Each operable reverser can be restored to the forward thrust position; and

(ii) The airplane is capable of continued safe flight and landing under any possible position of the thrust reverser.

(2) Each system intended for in-flight use must be designed so that no unsafe condition will result during normal operation of the system, or from any failure(or reasonably likely combination of failures) of the reversing system, under any anticipated condition of operation of the airplane including ground operation. Failure of structural elements need not be considered if the probability of this kind of failure is extremely remote.

(3) Each system must have means to prevent the engine from producing more than idle thrust when the reversing system malfunctions, except that it may produce any greater forward thrust that is shown to allow directional control to be maintained, with aerodynamic means alone, under the most critical reversing condition expected in operation.

(b) For propeller reversing systems --

(1) Each system intended for ground operation only must be designed so that no single failure (or reasonably likely combination of failures) or malfunction of the system will result in unwanted reverse thrust under any expected operating condition. Failure of structural elements need not be considered if this kind of failure is extremely remote.

(2) Compliance with this section may be shown by failure analysis or testing, or both, for propeller systems that allow propeller blades to move from the flight low-pitch position to a position that is substantially less than that at the normal flight low-pitch position. The analysis may include or be supported by the analysis made to show compliance with the requirements of § 35.21 of this chapter for the propeller and associated installation components.

(Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-11, 32 FR 6912, May 5, 1967; Amdt. 25-38, 41 FR 55466, Dec. 20, 1976; Amdt. 25-40, 42 FR 15042, Mar. 17, 1977; Amdt. 25-72, 55 FR 29784, July 20, 1990)

b. **Intent of Rule.** The intent of this rule is to ensure that airplane type design precautions are taken to accommodate or preclude known potentially unsafe thrust reversal system operating and failure modes. .

c. **Background.**

(1) Civil Air Regulations (CAR) 4b, Amendment 1, December 31, 1953, introduced Section 407, "Propeller reversing systems," into the regulations, which read as follows

> *The propeller reversing system, if installed, shall be such that no single failure or malfunctioning of the system during normal or emergency operation will result in unwanted travel of the propeller blades to a position substantially below the normal flight low-pitch stop. Failure of structural elements need not be considered if occurrence of such failure is expected to be extremely remote.*

(2) CAR 4b, Amendment 11, August 24, 1959, extended the "fail-safe" concept to all types of thrust reversing systems intended for ground and/or in-flight use. This was included in Sections 4b.407 (a) and (b). Propeller systems was expanded into a new Section 4b.407-1.

(3) Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the Civil Air Regulations. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). The rule was recodified from CAR 4b without any substantive changes.

(4) Notice of Proposed Rulemaking 65-43, (31 FR 93, January 5, 1966) proposed to add § 25.933(d), which would prohibit any turbine engine thrust reverser from allowing unwanted forward thrust. That proposal was based on hazardous incidents involving loss of directional control of turbojet-powered airplanes on the ground; these incidents were caused by thrust reverser malfunctions that allowed forward thrust to be developed by one engine while the remaining engines produced reverse thrust.

Amendment 25-11 (32 FR 6906, May 5, 1967) followed Notice 65-43 and adopted the proposal. The following excerpt is from the preamble of that Amendment:

> The notice proposed to amend § 25.933 to require that each turbojet reversing system must have means to prevent the engine from producing more than "idle forward thrust" when the reversing controls are set for reverse but the reversing system is not in the reverse position.
>
> Two commenters state that the limitation to "idle forward thrust" would impede reverser design unnecessarily, and suggest that maintenance of directional control during reverser malfunction should be the only test for compliance. The

Administrator agrees that safety does not require a limitation to any specific thrust value if directional control can, in fact, be maintained. The approach recommended by industry is therefore allowed, by exception, in this amendment.

However, in adopting the industry approach, it must be pointed out that safety requires that directional control capabilities be investigated under the most critical conditions expected in operation. Safety also requires that such control be maintained with aerodynamic means alone, since rapid diagnosis of a reverser malfunction and timely correction by use of thrust controls, cannot be assumed when a reverser fails at the most critical condition. Dependence, even partial dependence, on other non-aerodynamic means of control such as differential use of brakes, is also not consistent with safety under the most critical conditions in which reverser malfunction could occur, Section 25.933 is revised to reflect these factors.

(4) Clarifications to § 25.933(b) were proposed during the 1974-75 Airworthiness Review Program, which is referenced within Notice of Proposed Rulemaking 75-10 (40 FR 10802, March 7, 1975). The following excerpt is from that document:
:

Proposal No. 268 of Airworthiness Review; § 25.933(b).]

In § 25.933(b), insert the words "as well as ground use" after "in-flight use."

Justification: To clarify the word "in-flight" and to be sure ground operation is included. . . . The proposal would make clear that ground operations of the airplane must be considered in complying with § 25.933(b).

No unfavorable comments were received on this proposal to amend § 25.933(b). Accordingly, the proposal is adopted without substantive change.

The Rule: Reversing systems.

> *Reversing systems intended for ground operation-only must be designed so that no single failure or malfunction of the system will result in unwanted reverse thrust under any expected operating condition. Failure of structural elements need not be considered if the probability of this kind of failure is extremely remote.*
>
> *Turbojet reversing systems intended for in-flight use must be designed so that no unsafe condition will result during normal operation of the system, or from any failure (or reasonably likely combination of failures) of the reversing system, under any anticipated condition of operation of the airplane including ground operation. Failure of structural elements need not be considered if the probability of this kind of failure is extremely remote.*

Compliance with this section may be shown by failure analysis, testing, or both, for propeller systems that allow propeller blades to move from the flight low-pitch position to a position that is substantially less than that at the normal flight low-pitch stop position. The analysis may include or be supported by the analysis made to show compliance with the requirements of § 35.21 for the propeller and associated installation components.

Each turbojet reversing system must have means to prevent the engine from producing more than idle forward thrust when the reversing system malfunctions, except that it may produce any greater forward thrust that is shown to allow directional control to be maintained, with aerodynamic means alone, under the most critical reversing condition expected in operation.

Amendment 25-38 (41 FR 55454, December 20, 1976) followed Notice 75-10 and adopted the proposal without substantive change.

(5) Changes to §§ 25.933(a)(1) and (d) were also proposed in the 1974-75 Airworthiness Review Program:

<u>Proposal 739 and 182</u>

[*Revise*] paragraph (a) to read as follows:

(a) Reversing systems intended for ground operation only must be designed so that no single failure or malfunction of the system will result in unwanted reverse thrust under any expected operating condition.

It must be shown by analysis or tests (including model and component tests and simulated environmental tests), or both, that unwanted deployment of a critical engine reverser under normal operating conditions will not prevent continued safe flight and landing of the airplane.

It must be established by flight and ground tests --

(i) That the airplane can be safely landed and stopped with a critical engine reverser deployed. If special operating procedures are required, they must be included in the Airplane Flight Manual.

(ii) That an undamaged operable reverser can be safely restored to a forward thrust position using flight conditions and procedures selected by the applicant. These conditions and procedures must be included in the Airplane Flight Manual. Failure of structural elements need not be considered if the probability of this kind of failure is extremely remote.

[*Revise*] paragraph (d)(1) to read as follows:

The thrust reversing system shall have means to automatically retard the power control to a low thrust position in the event of inadvertent actuation of a thrust reverser caused by a malfunction in the reversing system. In addition, a throttle interlock in the thrust reversing system shall be provided to prevent application of thrust greater than forward idle thrust when the thrust reverser is not in the position of reverse thrust, except that a higher forward thrust level will be acceptable at the reverse interlock if it is shown that directional control of the airplane can be maintained under the most critical reversing condition with a malfunction of a reverser. If the engine power control is of the unidirectional type, the thrust reversing system must be designed so that no single failure or malfunction of any of the systems during normal or emergency operations results in an asymmetric thrust condition that cannot be controlled by aerodynamic means and pilot corrective action. The pilot corrective action may be assumed to be initiated at the time maximum *yawing velocity is reached, but not earlier than two seconds after the reverser malfunction. The magnitude of the corrective action may be based on the control forces specified in § 25.397(b) except lower forces may be assumed where it is shown by analysis or test that these forces can control the yaw and roll resulting from the prescribed reverser malfunction.*

Justification: The thrust reverser airworthiness and safety design standards presently existing in part 25 have been found to be inadequate to cover the high thrust engines being installed in the current transport airplanes. There are also many smaller high speed business jets being retrofitted with reverser systems. Both the retrofit reverser aspects and the high thrust consequences call for special analyses and designs to prevent catastrophic flight situations from developing and to safely handle the inadvertent in-flight thrust reversal anywhere within the normal airplane operating envelope.

A review of the past operating history of airplane engine thrust reverser indicates that fail-safe design features in the reverser systems do not always prevent unwanted deployment in flight. Many of these unwanted deployments are not caused by deficiencies in design but can be attributed to maintenance omissions, wear and other like factors that cannot be completely accounted for in the original design and over which the manufacturer generally has no control even when comprehensive maintenance programs are established. Since the existing reverser design standards are inadequate, it is felt that it is incumbent on the airplane manufacturers to investigate the effects of various types of failures either by analysis and or flight and ground tests, as well as establishing operating limitations and incorporating safety features so that catastrophic situations do not develop from unwanted deployment in flight or on the ground.

Amendment 25-40 (42 FR 15034, March 17, 1977) followed Notice 75-10. The following excerpt from the preamble to that Amendment provides further insight into the intent of this regulation.

Several commenters believe that the reference in proposed § 25 933(a) to engine idle forward thrust is misleading and that the word “forward” should be deleted. One commenter suggests the word “reverse” be used instead of “forward.” However, the direction of the thrust produced by the engine is not pertinent to the proposal. The resultant thrust is controlled by the reverser position. Therefore, the word “forward” is deleted.

One of the commenters believes that the allowable engine thrust setting should be stated as a percent of maximum, or in terms of aircraft performance. The commenter suggests that “flight idle” be used in place of “idle.” The proposal was intended to require the engine thrust to be reduced to the thrust produced at idle in flight and the proposal has been revised to specify flight idle.

The same commenter believes that the proposal could be interpreted to include the malfunction of all reversers and an unlimited combination of failure modes. The proposed lead-in to paragraph (a) is revised to make it clear that consideration must be given to each reverser, but only one reversal at time.

Another commenter recommends that the proposal be revised to require the prevention of inadvertent thrust reversal in flight. The FAA disagrees. Section 25.1155 currently requires consideration of inadvertent operation for each reverse thrust control.

A commenter states that present § 25.993(d) covers the proposal. The FAA does not agree. Proposed § 25.933(a) would apply to all cases of in-flight thrust reversal of a reverser intended for ground operation only. Section 25.933(d) on the other hand applies only to malfunctions of the thrust reverser system that effect directional control.

Another commenter suggests that the word “condition” at the end of the proposed paragraph (a)(2) should be changed to “position.” The FAA agrees that the significant status of the reverser is its position and the proposal is revised accordingly.

Finally, a commenter states that, in view of the requirements in § 25.1155, proposed § 25.933(a) should be limited to systems failures. The FAA disagrees. The consequence of an in-flight thrust reversal is the same whether the reversal results form malfunction or the control is moved to the reverse position. Both situations have occurred in service and need consideration. The commenter also suggested replacing “possible” by “probable” in a proposed § 25.933(a)(2) because “possible” does not define the limit of failure analysis or test configuration that has to be considered. However, the FAA believes that any degree of deployment of the reverser should be considered.

(6) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984), proposed another revision of this section

Unwanted deployments of thrust reversing systems that were designed only for ground operation have occurred in flight on turbojet powered airplanes, sometimes with catastrophic results. Section 25.933 currently requires an applicant to show that the reverser can be restored to the forward flight position or that the airplane is capable of continued safe flight and landing under any possible position of the thrust reverser. An unwanted, in-flight deployment is generally accompanied by damage to the reversing system due to the dynamic nature of the deployment, particularly at high speed. Although it might be possible to demonstrate that an undamaged reverser could be restored to the forward thrust position, there is no assurance that the reverser could be restored following and actual unwanted, in-flight deployment due to the possibility of unpredictable damage.

It is, therefore, essential that the airplane be capable of continued safe flight and landing with any possible position of the reverser. Conversely, it is also essential that an operable reverser be restored to the forward thrust position whenever possible. The word “or” would, therefore be replaced with the word “and” to require showing that the reverser can be restored to the forward thrust position, if undamaged, and that the airplane is capable of continued safe flight and landing under any possible position of the thrust reverser.

In addition, § 25.933 would be changed to clarify the applicability of the requirements of this section to other types of reversing systems, such as reversible pitch propellers.

Amendment 25-72 (55 FR 29756, July 20, 1990) followed Notice 84-21 and adopted the proposal (in part). The following excerpt is from the preamble to the Amendment and provides insight into the intent of these changes:

As [proposed in the Notice], the applicant would have to show that the reverser can be restored to the forward thrust position, if undamaged, and that the airplane is capable of continued safe flight and landing under any possible position of the thrust reverser.

Three commenters believe that this proposed requirement is unnecessary. One of the three commenters further speculates that safe flight cannot be ensured should a reverser be deployed at liftoff. The FAA does not concur that showing both conditions is unnecessary. As discussed in Notice 84-21, an unwanted, in-flight deployment is generally accompanied by damage to the reversing system due to the dynamic nature of the deployment, particularly at high speed. Although it might be demonstrated that an undamaged reverser could be restored to the forward thrust position, there is not assurance that the reverser could be restored in an actual unwanted, in-flight deployment due to the possibility of unpredictable damage. It is therefore, essential that the airplane be capable of continued safe flight and landing under any possible position of the thrust reverser. Conversely, it is also essential that an operable reverser be restored to the forward thrust position whenever possible. The FAA is aware of at least four incidents in which the thrust reversers of transport category airplanes could not be restowed following unwanted, in-flight deployment. Each of the airplanes involved was landed safely with the reverser unstowed, because it had the capability for making a safe landing under such circumstances. Notwithstanding the option provided by current § 25.933(a), the manufacturers of transport category airplanes have recognized the need to show that the airplanes can be landed safely under these circumstances. The manufacturers of most, if not all, transport category, turbojet-powered airplanes certificated under Part 25 have demonstrated this capability. The commenter's speculation that safe flight cannot be ensured in the event a reverser is deployed at lift off is inconsistent with past certification experience.

The capability of restowing an undamaged reverser in flight is considered to be equal in importance to having the capability for safe landing with an unstowed reversed. In-flight deployment of a reverser designed only for ground operation generally results in drag, buffeting, and possibly hazardous aerodynamic loads. Although initially undamaged, a deployed reverser may sustain damage from prolonged exposure to such buffeting and aerodynamic loads. It is, therefore, essential that a deployed reverser be restowed whenever possible so that the airplane can resume normal, hazard-free operation.

One commenter suggests that § 25.933(a)(1) should read *" . . .during inadvertent or deliberate reversal . . ."* in lieu of *" . . .during any reversal . . ."* The FAA does not consider that this change would serve any purpose because any reversal is either inadvertent or deliberate.

Another commenter suggests that § 25.933(a)(1) should contain the provision "if undamaged" for consistency with the explanation given in Notice 84-21. This change is also considered unnecessary because the requirement pertains to each operable reverser.

. . . [S]everal commenters believe that the proposed use of the term "extremely improbable" would actually result in a change in the level of safety and present and additional burden. This aspect of the proposal, therefore, withdrawn for further study.

> One commenter suggests that § 25.933(a)(1) and (3) should refer to " . . .producing no more than reverse . . ." in lieu of " . . .producing no more than idle . . ." In addition to this suggested change being beyond the scope of the notice, the FAA does not agree with the change because it would represent a significant degradation in the established level of safety.

d. **Policy/Compliance Methods.** Following an accident involving a two-engine airplane with wing-mounted high bypass engines, the FAA initiated a safety review of the transport airplane fleet to determine if an unsafe condition existed on the thrust reverser systems of previously certificated transport category airplanes. The Aerospace Industries of America (AIA) assisted the FAA in gathering data from unwanted thrust reverser deployments, and developing criteria for assessing the transport fleet. This information was published in a document titled, "Criteria for Assessing Turbojet Thrust Reverser Safety," that was initially released April 15, 1992, and revised June 1, 1994. In summary, the criteria allowed the use of controllability or reliability for showing that no unsafe condition existed. Manufacturers with wing mounted high bypass engines found that insufficient data existed to demonstrate controllability and, therefore, provided necessary analyses and modification to meet the reliability criteria. Manufacturers of airplanes with aft fuselage-mounted engines utilized in-service deployment data and developed a methodology for showing adequate control authority following an unwanted deployment. This methodology was published in a report "Thrust Reverser Task Force Group IV Airplanes," dated June 30, 1993.

Based on findings from the safety assessment, the FAA determined that the method for showing "controllability" used on previous certifications did not ensure that the airplane was, in fact, controllable. The FAA developed new criteria for showing controllability that has been applied to recent certification projects where the applicant has chosen to directly comply with the regulation (see the excerpt from FAA Issue Paper below). These criteria also defined minimum reliability required to address the takeoff to 1,500 ft. phase of flight where, in the opinion of the FAA, controllability cannot be adequately ensured.

Based on the difficulty in demonstrating direct compliance, many applicants have requested a finding of equivalent safety under the provisions of § 21.21. Approaches have included using reliability and, in some cases, demonstrating controllability during certain phases of flight and reliability for the remainder of the flight envelope. Development of revised criteria for assessing thrust reverser systems has been tasked to an ARAC committee. Amendment of § 25.933 and issuance of an AC is expected. Until the ARAC group completes these tasks, FAA guidance regarding current compliance methodologies is found in Generic Issue Papers, excerpts from which are included below.

Several recent applications have requested approval of thrust reverser systems that have utilized thrust reverser control systems where the mechanical interlock in the thrust reverser throttle control is deleted. These systems do not provide the traditional tactile feedback to the flight crew that the reverser has failed to deployed.

(1) ***Compliance via Equivalent Level of Safety.*** This issue has been addressed as discussed in the excerpt from a FAA Issue paper, below, which provides guidance on a finding of equivalent level of safety:

> **Statement of Issue:** The [*model*] airplane does not meet an applicable airworthiness requirement [§ 25.933(a)(1)(ii)] which states: "The airplane is capable of continued safe flight and landing under any possible position of the thrust reverser." Therefore, in accordance with the provisions of § 21.21(b)(1), a type certificate cannot be issued for the [*model*] airplane unless the airworthiness provision not complied with is compensated for by factors that provide an equivalent level of safety.
>
> **Background**: In response to the FAA [*model*] airplane Issue Paper P-6, "In-flight Thrust Reverser Deployment Demonstration," the manufacturer has declared that the [model] airplane will not demonstrate compliance with the subject rule. However, the manufacturer contends that the [*model*] airplane thrust reverser design protects against in-flight reverser deployment to an extent which provides a level of safety equivalent to that provided by direct compliance with the rule. Compliance with § 25.933(a)(1)(ii) is intended to completely eliminate all risk of catastrophic in-flight reverser deployment from normal operation. Under § 25.933(a)(1)(ii), any residual risk of catastrophic in-flight reverser deployment would be limited to scenarios involving unusual aircraft configurations, abnormal flight conditions, or inappropriate flight crew actions. Therefore, any design intended to provide an equivalent level of safety to the subject rule must limit the residual risk of catastrophic in-flight reverser deployment to a similar level.
>
> In general, the catastrophic risks from other aircraft system hazards are identified and managed through compliance with § 25.1309(b)(1). Therefore, compliance with this standard by the means delineated in the related Advisory Circular 25.1309-1A should be part of any equivalent safety finding utilizing probability that a catastrophic in-flight deployment will not occur. However, as documented in the docket justification for the subject § 25.933 rule:
>
>> "A review of the past operating history of airplane engine thrust reversers indicates that fail-safe design features in the reverser systems do not always prevent unwanted deployment in flight. Many of these unwanted deployments are not caused by deficiencies in design but can be attributed to maintenance omissions, wear and other factors that cannot be completely accounted for in the original design and over which the manufacturer generally has no control even when comprehensive maintenance programs are established.
>
> This perspective has been re-enforced by a recent AIA/FAA review of transport service history which indicates that many of the reverser in-flight deployment incidents involved inadequate maintenance or improper operations. Other factors, such as uncontained engine failure, unanticipated system failure modes and effects, and inadequate manufacturing quality, have also played a role in in-service deployment incidents.
>
> Therefore, in addition to the traditional reliability predictions provided in demonstrating compliance with § 25.1309, any equivalent safety finding to § 25.933 will require that the influences which could render that prediction invalid be identified, and acceptable means for managing these influences, be defined. To this end, compensating design assurance and continued airworthiness

features must be provided for FAA Aircraft Certification approval which, as a minimum, address:

(1) Justification for any assumptions made in the System Safety Analysis (SSA) including:

(a) rationale for failure modes considered;

(b) failure effects determination and verification methods;

(c) criteria for assuring the completeness of any top down analysis *(e.g., dependency diagrams, fault tree analysis (FTA), etc.)*;

(d) rationale for failure rate data source applicability including consideration of relative design and manufacturing standards as well as the installation environment;

(e) methods by which failures will be detected, isolated and eliminated prior to the assumed exposure times *(e.g., exposure time may be justified by providing reference traceability to an FMEA that provides the resultant detection means, the MMEL or MRB documents that set the detection interval, and the Trouble Shooting and/or Maintenance Procedures that set the effective interval required to isolate and eliminate the fault)*.; and

(f) verification of any fault independence assumptions *(e.g., independence between all failure conditions contributing to any FTA "and gate")*.

When providing these justifications, the effects of other systems that have physical, zonal, or functional interfaces with the reverser must be taken into account *(i.e., failures within the airplane hydraulic, ECS or electrical systems may be significant to the SSA. Also engine uncontained failure or fire may have a significant impact on the integrity of the thrust reverser and must be addressed.)*

(2) All applicable lessons learned from the collective fleet experience delineated in Appendix A of the "Criteria for Assessing Transport Turbojet Fleet Thrust Reverser System Safety," including:

(a) providing protection from inadvertent crew actuation;

(b) validating the accuracy and effectiveness of flight deck design and crew procedures as they relate to reverser operation and failure modes;

(c) limiting reliance on use of aerodynamic means to keep the reverser stowed;

(d) minimizing of and justification for any latent failures (this should include latency due to faults which are "made latent" either due to loss of the detection means or due to the fault being intermittent);

(e) providing system contamination tolerance;

(f) validating maintainability, both in the design and procedures. This validation should include at least verification that the system and procedures support the SSA assumptions, are tolerant to anticipated human errors, and that any critical procedures are highlighted for consideration as required inspection items *(e.g., if under some anticipated dispatch conditions an improperly performed reverser lock-out procedure could leave the reverser without any active* *restraint, depending on the potential for miss-maintenance, this procedure may need to be independently witnessed by an approved inspector.)*

(g) providing protection from common mode failure sources such as environmental conditions, engine uncontained failure, and fire.

(3) Means to monitor and report in-service experience relative to thrust reverser system safety, and effectively respond to any conditions that may invalidate this equivalent safety finding.

FAA position: The manufacturer has declared that the [*model*] airplane will not demonstrate compliance with the subject rule. Therefore, the manufacturer must demonstrate that the [*model*] airplane is protected against catastrophic in-flight reverser deployment to an extent which provides a level of safety equivalent to that provided by direct compliance with the rule. This demonstration must include at least:

(1) A rigorous qualitative safety analysis to show that no single failure or malfunction, regardless of the probability, can result in a catastrophic in-flight reverser deployment. In addition to the traditional Failure Modes and Effects Analysis (FMEA), a top down analysis, at least to the assembly level, should be performed to ensure that any obscure single failure modes are identified.

(2) An average risk analysis in accordance with Advisory Circular 25.1309-1A which predicts that catastrophic in-flight reverser deployment will not occur in the fleet life of the [model] airplane;

(3) A specific risk analysis which predicts that at the beginning of each flight the aircraft will continue to meet the “no single failure” criteria of analysis #1 above and that the risk of catastrophic in-flight deployment is less than $1X10^{-6}$ / flt.hr.. This analysis is only required if the design can have contributory faults present for more than one flight. This analysis must consider any aircraft configuration (including latent faults) anticipated to occur in the fleet life of the airplane type which is not proposed to be precluded from dispatch by the MMEL. For the purpose of this analysis a configuration whose probability of occurrence is greater than $1X10^{-8}$ must be assumed to occur unless a lower total fleet exposure time can be justified by prescribing either production or utilization limits. This analysis provide a previously unavailable tool to assist in the assessment of MMEL and MRB proposals.

(4) Verification that the influences which could render these predictions invalid have been identified and acceptable means for managing these influences throughout the fleet life of the [model] airplane have been defined and implemented.

(2) ***Compliance via Demonstration of Airplane Controllability:***

(b) The following excerpt is from a FAA memorandum that provides guidance on a method of compliance via a demonstration of airplane controllability:

The following memo is provided in response to your request for policy regarding the section § 25.933 requirement to demonstrate controllability following in-flight thrust reverser deployment. This policy is applicable to new, amended, and supplemental type certificates with engines mounted on the empennage.

As you are aware, based on information from an accident, the FAA has been working with industry to develop a standard for evaluating the safety of the existing transport category fleet following inadvertent thrust reverser deployment. This standard is contained in document "Criteria for Assessing Turbojet Thrust Reverser Safety," that was released April 15, 1992. During review of airplane service history following thrust reverser deployment it was determined that the effects of the thrust reverser plume on airplane controllability for engines mounted on the empennage were distinctly different. The tail mounted engine configurations were therefore grouped together and named Group Four. The committee prepared and submitted a report to the FAA containing analysis of Group Four controllability.

The FAA has also been evaluating the adequacy of the existing regulation and the certification test methods (applicable to new TC's, amended TC's, and STC's) used to show compliance to the existing regulation. Based upon our recent understanding of the effects of thrust reverser deployment on airplane controllability, direct compliance to § 25.933 would require extensive testing and/or analysis to show that the airplane is controllable within the normal flight envelope. Policy applicable to airplanes with empennage mounted engines should be as follows:

a) Demonstration of controllability should be conducted at representative points within the normal flight envelope. Critical conditions will vary with airplane type and must be determined on an individual basis. Previous policy focused on demonstration of controllability at low speeds where less control margin exists, ie. the return landing capability following deployment at high speed. The engine deceleration to idle following inadvertent deployment was assumed to be rapid enough to have a negligible effect. The need for additional flight testing at higher speeds and/or engine power levels should be determined based on analysis of the effects of the reverser plume on adjacent empennage control surfaces. The effects of buffet should be considered. Previous service history provided by the applicant on airplanes with similar aerodynamic/reverser configurations should be taken into consideration when determining the need for high speed/high engine power flight test data.

b) Airplane controllability immediately following takeoff and prior to landing may not be possible on most airplane types. Therefore, airplanes that cannot demonstrate controllability following thrust reverser deployment during these flight phases must show that the likelihood of deployment is extremely improbable. (i.e., the reverser system must be shown to have a failure rate no greater than 1×10^{-9} for this exposure time.)

c) Based on the service history of reverser systems, indication of reverser system position (unlock) should be annunciated to the flight crew in a graphic manner prior to takeoff.

d) Structural analysis must be conducted to show that inadvertent deployment at the worst case condition of airspeed (usually at high speed (V_{mo}/M_{mo})), altitude, and engine power will not result in structural damage to any principle structural elements as defined in Advisory Circular 25.571 ["Damage Tolerance and Fatigue Evaluation of Structure"]. Damage to the reverser system is allowed, provided the reverser does not depart the airplane and controllability is demonstrated with the airplane configured with likely damage.

The FAA is recommending that the reliability assessment team be utilized to assist in answering any questions your office may have in evaluating reliability assessments for the takeoff and landing phases of flight.

(b) Additional guidance on compliance via demonstration of airplane controllability is given in the following excerpt from an internal FAA memorandum.

The purpose of this memorandum is to formalize existing policy regarding airplane controllability and performance requirements for certification of thrust reverser systems under the provisions of § 25.933. This memorandum is in response to a request by [*an FAA Office*] for formal issuance of additional policy for use in certification of thrust reverser systems. The request for additional policy was prompted by issues that evolved during several recent certification projects where the applicant opted to demonstrate compliance with the controllability requirements of § 25.933.

Background: On July 18, 1994, the FAA issued a memorandum containing policy information regarding in-flight thrust reverser deployment. This policy was later incorporated into a FAA Generic Issue Paper dated, June 22, 1995, that was transmitted to each Aircraft Certification Office via a memorandum dated, June 30, 1995. As this policy was applied during recent certification projects, it became apparent that additional guidance was required to ensure continued safe flight and landing following an inadvertent thrust reverser deployment. The previously-issued policy referenced the document titled, " Criteria for Assessing Transport Turbojet Fleet Thrust Reverser System Safety," Revision A, dated June 1, 1994, which required evaluation of airplane performance with a deployed thrust reverser. However, that specific criteria was developed to assess the safety of the existing fleet of turbojet airplanes and was not intended to provide the entire basis for satisfying § 25.933(a)(2) for a new or amended type certificated model.

The attached policy is based on the premise that higher performance standards should be applied to airplanes where thrust reverser system reliability is lower. For example, if thrust reverser system safety assessment showed that the probability of an unwanted deployment was more frequent than $1x10^{-7}$ (similar to the rate of an engine failure) it was determined that the airplane would be required to show compliance with all performance requirements of Part 25, Subpart B, with the reverser deployed.

The policy within the attached "Generic Issue Paper" is applicable to new, amended, and supplemental type certificates and where new or significantly modified engine and reverser system installations have been incorporated.

Generic Issue Paper

Statement of Issue: Aircraft plans to show compliance with § 25.933 of the Federal Aviation Regulations (FAR) for the [*model*] airplane by demonstrating the capability for continued safe flight and landing of the airplane following in-flight deployment of a thrust reverser. Recent service experience indicates that demonstration of compliance with § 25.933 requires consideration of additional factors not previously evaluated during certification of earlier [*aircraft models]*. This Issue Paper describes factors that must be considered in demonstrating compliance with § 25.933.

Background: The [*model*] airplane is configured as follows, as given in the airplane configuration material presented to the Aircraft Certification Office (such information includes engine location, thrust reverser type, etc.).

Compliance with § 25.933 following an in-flight thrust reverser deployment has traditionally been shown by a limited flight demonstration, and an analysis that indicated that the demonstrated controllability could be extrapolated to cover the normal flight envelope of the subject airplane. Following a transport airplane accident involving an airplane where this "traditional" demonstration had been conducted, the FAA revised its policy and, in concert with industry, developed a criteria document for re-assessment of in-service airplanes that was distributed to all airframe manufacturers on April 15, 1992. The criteria was revised and is now contained in the document "Criteria for Assessing Turbojet Fleet Thrust Reverser System Safety," revision A, dated June 1, 1994. Please note that it was not envisioned that the criteria document, by itself, would be used to demonstrate compliance with § 25.933 for new or amended type designs.

During review of airplane in-flight thrust reverser deployment incidents, a committee made up of industry and FAA team members determined that thrust reverser plume effects on airplane controllability for airplanes with the engines mounted on the aft fuselage were distinctly different. The tail-mounted engine configurations were therefore grouped together and referred to as Group IV. The committee developed criteria to apply a uniform comparison to all airplanes proposed to be classified as Group IV airplanes. Manufacturers submitted airplane thrust and geometrical data, and the results of a controllability algorithm for their own airplanes. The group prepared an analysis of the effects of an inadvertent thrust reverser deployment on Group IV airplanes controllability and that report has been accepted by the FAA. Each manufacturer was also required to individually address minimum reliability and airplane performance requirements defined within the fleet assessment criteria document.

Since issuance of the fleet assessment document one additional accident occurred as a result of a thrust reverser deployment. The overall service history now shows that three accidents have resulted from insufficient airplane performance following an unwanted reverser deployment. In one case the reverser was not restowed and the airplane circled with wings level while losing altitude. In the second case two reversers deployed during the takeoff which again resulted in a wings level accident. The third case resulted from an unwanted deployment during takeoff where additional power was applied by the pilot to the engine that was in the reverse thrust position. Based upon the service history and regulatory history, it is apparent that both airplane controllability and performance following an unwanted reverser deployment must be shown in demonstrating compliance to § 25.933.

The intent of § 25.933 to provide for continued safe flight and landing following an unwanted reverser deployment requires that airplane performance be considered in any compliance demonstration. Although no specific performance criteria is defined within Amendment 25-72, the intent to require continued safe flight and landing with a thrust reverser in the deployed position anywhere within the operational flight profile is clearly stated. The discussion also clearly shows that it was intended that continued safe flight should be required following a deployment during the takeoff phase of flight.

Subpart B of Part 25 defines airplane performance requirements. Section 25.143 defines failure conditions for minimum airplane controllability and maneuverability. These failure conditions include: “sudden failure of the critical engine” and, “For airplanes with three or more engines, the sudden failure of the second critical engine when the airplane is en route, approach, or landing and is trimmed with the critical engine inoperative; and configuration changes, including deployment or retraction of deceleration devices.” Section 25.121 Climb: One-engine -inoperative, defines minimum airplane climb performance for engine failure conditions.

Although Subpart B provides airplane performance criteria for engine failure conditions, these criteria have not specifically been applied in showing continued safe flight and landing following an unwanted thrust reverser deployment. The airplane performance requirements contained in Subpart B typically have been applied to engine failure conditions which occur at a historical occurrence rate of up to 1 per 10^{-5} airplane flight hours. Thrust reverser deployment, with subsequent inability to restow the thrust reverser, has not been considered to occur at a frequency that would support a requirement for demonstrating full airplane performance with a reverser deployed. However service experience, and the preamble to Amendment 25-72 of § 25.933, indicates that restowing of a thrust reverser is not always possible because of damage to the reverser following the deployment. Therefore, the controllability and performance assessments must include consideration of a reverser that remains in the deployed position.

FAA Position: The Transport Airplane Directorate has evaluated the intent of the current requirements within § 25.933 and the certification test methods (applicable to new type certificate, amended type certificate and supplemental type certificate projects) used to show compliance to the existing regulation. Based upon our recent understanding of the potential effects of thrust reverser deployment on airplane controllability, direct compliance to § 25.933 would require extensive flight testing and/or analysis to show that the airplane is controllable within the normal flight envelope. The FAA policy applicable to airplanes with aft fuselage mounted engines is as follows:

(a) A flight test demonstration of controllability should be conducted at, or near, critical points within the normal flight envelope. The degree of investigation of critical conditions will vary with airplane type and must be determined on an individual basis. Previous policy focused on demonstration of controllability at low flight speeds where it was presumed that less control margin existed. The high speed conditions were usually not considered to be critical since the engine deceleration to idle following inadvertent deployment was assumed to be rapid, airplane control surface effectiveness was high, and therefore the reverser plume was assumed to have a negligible effect on airplane control. The need for additional flight testing at higher speeds and/or engine power levels should be determined based on analysis of the effects of the reverser plume on adjacent empennage control surfaces. The effects of buffet should be considered. Previous service history provided by the applicant on airplanes with similar aerodynamic/reverser configurations should be taken into consideration when determining the need for high speed/high engine power flight test data. Determination of whether the airplane is controllable should be based upon the Cooper Harper rating system as described within the national policy reference noted at the beginning of this Issue Paper.

(b) Airplane controllability during an inadvertent thrust reverser deployment immediately following takeoff and just prior to touchdown may not be possible on most airplane types. Therefore, airplanes that cannot demonstrate controllability following thrust reverser deployment during these flight phases must show that the likelihood of inadvertent deployment is extremely improbable. (i.e., Analysis per Appendix C, of revision A to the Thrust Reverser Safety Assessment document must show that the inadvertent deployment rate is no greater than 1×10^{-9} for this exposure time.)

(c) Based on the service history provided in fleet safety assessment criteria document, compliance with the § 25.1305 requirement to provide indication of reverser system position (unlock) should be reviewed to ensure that reverser unlock is annunciated to the flight crew in a graphic manner. Evaluation of the annunciation means should be made by human factors and cockpit annunciation specialists. The preflight checklist should also be reviewed to ensure the airplane will not be dispatched with a reverser unlock indication. As described within Appendix C, if dispatch with a reverser locked out is proposed for MMEL operation, the lock out procedure should be a required inspection item.

(d) Inadvertent deployment of the thrust reverser at any speed up to Vc, and at likely thrust settings, must not result in loads or buffeting on the airframe that would damage the primary structure. Damage to the thrust reverser is allowed and departure of parts of the reverser from the airplane may be allowed during inadvertent extension for certain configurations where it can be shown that the departure trajectory clears other primary structures and does not present any hazard to the airplane.

(e) The following criteria defines minimum airplane performance (range and climb) necessary to demonstrate continued safe flight and landing following an unwanted thrust reverser deployment.

Airplane performance should be shown under the following conditions:

i) Critical thrust reverser jammed in the fully deployed position.

ii) Engine with reverser deployed may be shut down or set at a power setting selected by the applicant that is consistent with the AFM procedure.

iii) Unless otherwise stated, airplane weight equal to the maximum takeoff weight minus fuel burn associated with each condition.:

Consideration must also be given to the performance degradation associated with continued flight with a reverser deployed. The aircraft must be shown to have sufficient climb performance following a deployment at some point during the takeoff path to be able to safely return for a landing. This determination involves consideration of the reliability up to this point and the climb capability with the reverser deployed. For example, if a rigorous safety analysis shows an in-flight deployment up to approximately 1500 feet AGL is extremely improbable, then no further climb performance substantiation is required. Lacking this analysis, an evaluation of airplane performance addressing height of deployment, resulting climb capability and effect on the net flight path is required. Furthermore, if in-flight reverser deployment anywhere along the Operational Flight Profile would be limiting on the critical fuel scenario or other route restrictions, this must be taken into account to ensure continued safe flight and landing at a suitable airport using the manufacturer's recommended procedures contained in the AFM.

(3) ***Thrust Reverser Control Interlock Design***: The following discussion is based upon issues that evolved during a certification project where the propulsion system included a thrust reverser control interlock design. These issues were subsequently documented within a FAA Issue Paper:

Statement of Issue: The model thrust reverser throttle control system has significant design differences from that of most current installations on transport category airplanes. Specifically, the mechanical interlock in the thrust reverser throttle control is deleted. The purpose of the interlock is to limit the movement of the each throttle lever to reverse idle until the thrust reverser is in its fully deployed position. On the model, the mechanical interlock has been eliminated and its function is accomplished by the engine's full authority digital electronic control (FADEC) system. Without the mechanical interlock, the thrust reverser throttle control system will not provide tactile cues to the pilot during landing rollout that one reverser has failed to deploy. Lack of this tactile cue to the pilot can lead to an asymmetric thrust condition with maximum reverse thrust on one engine and forward idle on the other engine.

Background: Most transport category airplanes provide a mechanical interlock on the thrust reverser lever to prevent the pilot from moving the engine throttle past the idle reverse position until the thrust reversers are fully deployed. This tactile cue minimizes the amount of asymmetric thrust since the pilot will immediately detect a reverser failure and take corrective action accordingly. The airplane design allows the pilot to move the throttle levers to full reverse and the FADEC on each engine will schedule the reverse engine power level as a function of thrust reverser sleeve or bucket position. Therefore, the only cue to the pilot that the reverser has failed to deploy is a cockpit indicator. Furthermore, a maximum asymmetric thrust condition may exist prior to pilot recognition of the failure indication. Although the effects of asymmetric thrust on the airplane's direction control may be somewhat minimized by the close to centerline engine configuration of the airplane, the issue of directional control still needs to be addressed.

FAA experience with airplanes which have similar thrust reverser control designs has shown that independent of the approved reverser deployment procedure (i.e., engine accelerated only after cockpit indication) , flight crews have pulled to full (high power) reverse prior to touchdown and let the system sequentially deploy the reverser and increase power during the landing rollout. The FAA believes that the flight crews conduct this unauthorized procedure in order to get to maximum reverse power as early as possible during the landing rollout, and thus minimize the landing distance.

FAA Position: In order to show compliance with the referenced regulatory requirements, [*airplane company*] must address the operational effects, including human factors considerations, of having one thrust reverser fail inoperative (without prior crew awareness). Additionally, the [*airplane* *company*] will need to demonstrate by actual tests and analysis that expected flight crew response and airplane controllability are acceptable, considering the range of runway surface properties (dry, wet, ice, snow, slush, etc.) expected to be encountered in service. The effects of a latent thrust reverser failure during landing rollout must be shown to not jeopardize continued safe airplane operation.

Included in this substantiation should be an adequate number of controllability tests with asymmetric reverse thrust. These tests should simulate the unforeseen failure of a single reverser to deploy, and demonstrate the crew's ability to recognize the asymmetry, independent of the attention getting lights, and maintain control of the airplane for the remainder of the landing rollout. Test procedures should include a normal landing, deployment of a single reverser to the maximum available reverse thrust (to simulate the failure of a single reverser to deploy), and recognition of the asymmetry by cues other than the attention getting lights, or other artificial means (i.e., deviation from runway centerline, or some other appropriate, repeatable cue.). Recognition times (denoted by first pilot response to the asymmetry) should be documented and compared with the prescribed all-engine reverser procedure.) If, upon FAA review, recognition times are deemed excessive, then a performance field length penalty based on a factor (multiple) of the demonstrated recognition time will be assessed.

(4) ***Airplanes Without Thrust Reversers:*** Although the installation of thrust reversers is not explicitly required by the Federal Aviation Regulations, this design feature has been present on nearly all transport category airplanes since the beginning of the jet transport age. The FAA believes that the current level of safety of the revenue passenger large transport airplane fleet has been established with airplanes having thrust reversers. There have also been numerous regulatory reviews of the operating and certification rules in which variables such as contaminated runways were not specifically accounted for because of the safety margin provided by reverse thrust. New certification rules in work specifically recognize the contribution of reverse thrust.

Of primary concern is the airplane's stopping capability on wet and contaminated runways. On slippery runways, wheel brakes lose much of their effectiveness for stopping the airplane. Thrust reversers provide effective means, independent of the condition of the runway, to enhance airplane stopping performance. On very slippery runways (e.g., icy runways), thrust reversers may provide the major portion of an airplane's stopping capability.

In several cases, the FAA has required performance penalties be applied to transport category airplanes when their thrust reversers were pinned in the closed position to prevent inadvertent thrust reverser deployments in flight. In these cases, the FAA, while mandating the thrust reverser inoperative, believed that the thrust reverser did contribute to the current level of safety of airplane performance. Therefore, when thrust reversers were not available the stopping performance of the airplane on a contaminated runway was penalized to compensate.

The following excerpts are from Final Special Condition, No. 25-NAM-131 (62 FR 45523, August 28, 1997), applicable to an airplane that required performance penalties for certification of the airplane without thrust reversers.

> **Background.** The *[airplane]* is a 50 passenger, pressurized, low-winged, ``T'' tailed, transport category airplane with retractable tricycle type landing gear. The airplane is powered by two high bypass ratio turbofan engines mounted on the aft fuselage, which are controlled by a Full Authority Digital Engine Control (FADEC). The cockpit will include a complete set of Electronic Flight Instrumentation and Engine Indication and Crew Alerting Systems (EFIS and EICAS).
>
> The *[airplane manufacturer]* has proposed to certificate and market the *[airplane]* with thrust reversers as optional equipment. Thrust reversers have been shown to play a significant role in reducing accelerate-stop distances on wet and contaminated runways and have contributed to the transport category airplane fleet's accelerate-stop safety record. The establishment of the transport category airplane safety record, with regard to accelerate-stop and landing overruns, is tied to the availability of auxiliary braking means that are independent of wheel-brake, tire, and runway surface interaction.
>
> The model airplane will have an unusual design feature which is the lack of incorporation of thrust reversers as standard equipment.
>
> **Discussion of Comments.** All commenters state the Special Conditions are inappropriate since thrust reversers are not required for Part 25 certification and Part 25 airplanes not equipped with thrust reversers have exhibited the same level of safety as those with thrust reversers. The FAA does not contest the fact that Part 25 does not require thrust reversers. With regard to the level of safety issue, it is obvious that the additional braking provided by reverse thrust will always improve safety, and the amount of that improvement will increase with decreasing runway surface friction. The only accelerate-stop performance information required to be in the Airplane Flight Manual (AFM) by the current Part 25 airworthiness regulations is based on a dry runway surface; these dry runway accelerate-stop distances may (and will) be used with no adjustments for takeoffs made on wet and contaminated runways. This could be of critical importance for an airplane the size of the airplane, which in all likelihood will see a sizable number of operations on relatively short runways, thus increasing the probability of its being dry runway takeoff or landing field length-limited.
>
> One commenter states that the main consideration of the Special Conditions is that the non-inclusion of thrust reversers is classified as an unusual design feature because the airplane is intended for operation in Part 121-type commercial service. Consequently, the commenter states the Special Conditions are not appropriate under Part 25 since the certification basis is independent of the rules an airplane might be operated under. The FAA does not agree with the commenter's statement. The overall operational safety of an airplane is as much the concern of the Aircraft Certification Service of the FAA as it is the Flight Standards Service, particularly where aircraft performance is a consideration since it is the Aircraft Certification Service personnel who witness the flight testing and approve the resulting Airplane Flight Manual performance that scheduled operations will be based on.
>
> Similarly, another commenter states that if performance credit is of established benefit in Part 121-type commercial operations, the appropriate rule to require

thrust reversers would be under Part 121 and not the certification rules (i.e., Part 25). The FAA questions the use of the term ``performance credit'' since no performance credit has been given in the past, as discussed in the preceding paragraph. The FAA understands this comment to mean if thrust reversers have provided benefits in Part 121-type operations, then any rule to require their installation should be proposed under Part 121. The FAA disagrees with this comment. The FAA's job is to ensure the safety of the traveling public; whether that is done through the Aircraft Certification Service or the Flight Standards Service is irrelevant in this case. As discussed in the notice of proposed Special Conditions, the thrust reverser issue is addressed in this context because the FAA has found that airplane manufacturer's type certificate application presents a novel or unusual design feature for which the applicable airworthiness standards do not provide adequate safety standards. In accordance with 14 CFR § 21.16, Special Conditions are the appropriate mechanism for dealing with such issues.

One commenter states that if the FAA considers the increased stopping benefit provided by thrust reversers as substantiation (sic) for requiring their installation, then performance credit should be granted for their use. The FAA has for many years gone on record as being opposed to granting general performance credit for the use of thrust reversers. One of the primary reasons for this position is that thrust reversers provided some compensation for the minimal amount of conservatism assumed in determining the accelerate-stop distances that takeoffs will be predicated on. Rejected takeoff accident data indicate that pilots do not always recognize and respond to a failure condition at or near V_1 in the time period assumed in calculating the AFM accelerate-stop distances. The FAA has proposed to grant performance credit for thrust reversers in the determination of accelerate-stop distances on wet runways, provided the stopping distances are based on the associated reduced wheel-brake stopping force available and certain reliability and controllability criteria are met.

One commenter notes that the proposed Special Conditions do not address the Master Minimum Equipment List (MMEL) allowance for airplanes to have thrust reversers rendered inoperative, and that the FAA did not consider the economic implications of this issue. The FAA does not consider this to be a relevant argument against requiring the installation of thrust reversers on the airplane. The MMEL allowance referred to by the commenter is classified as Level C which, among other things, places a 10-day limitation on the thrust reversers being inoperative. The 10-day limitation is, in part, based on the probability of occurrence of a situation in which the additional braking force provided by reverse thrust would be beneficial.

One commenter states that the inclusion of a proposed rule (i.e., NPRM 93-8) as a certification requirement was not appropriate. A related comment from another commenter noted that FAA's Aircraft Certification Service management has stated the FAA would not invoke unadopted regulations or policy on active certification programs. The FAA is not mandating compliance with the criteria of NPRM 93-8 as a certification requirement. The manufacturer has the option of installing thrust reversers on the airplane and determining accelerate-stop distances in accordance with Part 25 at the amendment level described in the type certification basis for the airplane. It should also be noted that in on going certification programs, the FAA routinely considers proposed rules as showing an equivalent level of safety to existing Part 25 regulations.

One commenter also states that NPRM 93-8 is not harmonized with the European Joint Aviation Authorities (JAA) requirements. This statement is incorrect. The criteria of NPRM 93-8 was developed in conjunction with the JAA; requirements identical to those of NPRM 93-8 can be found in the equivalent JAA Notice of Proposed Amendment.

One commenter requests the FAA submit this major change in certification philosophy to the appropriate regulatory/industry forum. The FAA discussed the philosophy embodied in Notice No. SC-96-7-NM with flight test specialists from several foreign civil airworthiness authorities during its development. The FAA is within its legal bounds by treating airplanes on a case-by-case basis with Special Conditions in accordance with Sec. 21.16. The FAA does not believe it is necessary to submit the certification philosophy embodied in Notice No. SC-96-7-NM to a regulatory/industry forum since the wet runway accelerate-stop criteria in NPRM 93-8, which gives performance credit for available reverse thrust on wet runways, will encourage manufacturers to incorporate thrust reversers as part of the basic design of their airplanes.

One commenter states that the FAA's contention that thrust reversers have played a significant role in the safety record of transport category airplanes is not supported by any form of factual information or data. The FAA disputes this commenter's position. A significant amount of testing has been conducted over the last 40 years that has repeatedly proven the increased benefit of reverse thrust as the runway surface condition deteriorates in terms of available wheel-braking force. It is obviously difficult to point at a particular rejected takeoff as an example since any successful field length-limited RTO that may have occurred on a wet or contaminated runway, whose takeoff weight was limited by a dry runway accelerate-stop distance, would not have been recorded. However, it stands to reason that the probability of such a case occurring would be very low without the additional braking force contribution provided by thrust reversers. As discussed above, these Special Conditions are applicable to the *[airplane].* Should the *[airplane manufacturer]* apply at a later date for a change to the type certificate to include another model incorporating the same novel or unusual design feature, the Special Conditions would apply to that model as well under the provisions of Sec. 21.101(a)(1).

Conclusion: This action affects only certain novel or unusual design features on one model of airplane. It is not a rule of general applicability, and it affects only the manufacturer who applied to the FAA for approval of these features on the airplane.

(5) ***Substantiation of Thrust Reverser Dynamic Loads:*** The following excerpt is from an internal FAA memorandum, dated November 10, 1982 and provides additional insight into the substantiation of thrust reverser dynamic loads.

The reverser loads resulting from reversing engine exhaust air would seem to be many times more severe than those added by landing or takeoff air speeds.

The in-flight deployment case throughout the envelope for ground operated-only reversers is strictly in the category of improbable failure and, therefore, not normal and not a load the reversers must be designed to sustain.

For reversers designed for in-flight deployment, the imposed flight loads are so dependent upon the airplane design, configuration, and speed/altitude envelope that any contrived flight values imposed as a § 33.97 test requirement would be of very doubtful validity.

For information, the dynamic loads environment that the reverser will be affected by are:

A. Reversers designed for ground use only.

1. *Normal reversing* - Used during landing rollout - up to maximum thrust use at normal landing ground speeds (100-150 knots).

2. *Refused Takeoff (RTO)* - Generally maximum reverse thrust obtainable at speeds up to V_1

3. *Inadvertent in-flight deployment* - By design [§ 25.933(a)] the engine thrust would be reduced to a flight idle level during the inadvertent reverser deployment. The deployment can occur at all flight speeds up to and including V_{MO}. Regardless of Part 33, an in-flight deployment and stow will be required during Part 25 certification.

B. Reversers designed for both in-flight and ground use.

1. *Normal (ground)* - Generally the same as for the “ground use only” design.

2. *Normal in-flight* - Reverser procedures for in-flight operation would be a function of the airplane requirements. The airspeeds and other requirements would have to be established by the airplane manufacturer, and defined at the time of Part 25 certification.

3. *RTO* - Same as for the “ground use only” designs.

4. *Inadvertent in-flight deployment* - Unless the normal in-flight use was designed for the V_{MO} condition then the dynamic loads at this speed must be evaluated with any aircraft limitations demonstrated in flight as part of Part 25 certification.

All elements of the reverser must withstand design limit loads and thermal effects without detrimental deformation. The design limit load is the maximum load normally authorized for aircraft operations. The reverser must be designed so it will not yield at limit loads or fail at ultimate loads. Ultimate loads are obtained by multiplying the design limit loads by a factor of safety (1.50). Structural strength should be verified by static testing. Any structural member failing in any test must be redesigned or reinforced and qualified by retesting. Acceptable sources of design data and properties of materials can be from MIL-MD8K-5, MIL-HDBK-17, etc, or from other sources acceptable to the FAA. It should to remembered, that a certified reverser design would have to be reviewed in its entirety when presented for installation on an airplane to be type certificated.

In addition to the determination of the dynamic and static loading for the reverser design, in contrast to your statement that the cycle test (loads) being the only requirement, there are a number of applicable sections to Part 33 that address design, construction and adequacy requirements, that must be included in the design to make it eligible for approval on an airplane. Other examples of required thrust reverser certification items include (as applicable) §§ 33.15, .17, .19, .21, .25, .61 through .67, .72, and .75. In particular, the thrust reverser components should require essentially the same level of verification as basic engine parts/accessories. The designers/certifiers should be aware of other applicable Part 25 requirements that appear in Subparts E, F, and G. The applicability of the Part 33 approval when compared with Part 25 should ensure that the "standards utilized are consistent with Part 25 usage."

Another impact that has to be considered is the accomplishment of a conformity inspection to approved drawings, and applicability at time of installation.

Considering only the dynamic loading requirements is not, in our opinion, all that is necessary of the applicant when he presents his reverser design for approval. That is a small part of the total task necessary for obtaining approval of the eventual installation on an airplane. We think these additional applicable requirements cannot be separated from the total design package that would be submitted for your evaluation. We consider that approving a reverser with the engine TC is a complex task and the cyclic test is not the only requirement the applicant must fill before we can approve his device.

We would strongly suggest you consider a pre-certification design review board setting as a standard procedure for such application. If an airplane certification program has been initiated, then the cognizant engine certification office, the airplane certification office and the applicant could convene and outline the total requirements the applicant must meet prior to going into the certification process.

(6) ***Backing Aircraft Using Reverse Thrust:***

(a) The following excerpts are from an internal FAA memorandum and provides additional insight into approval of the use of thrust reversers for airplane backing:

The Aircraft Certification Office procedures for assessing the safety aspects of backing aircraft using reverse thrust and the method of communicating the related status will be as follows:

1. If an application for reverse backing is received from an applicant and compliance with the related engine and airplane airworthiness requirements cannot be demonstrated, a limitation will be placed in the FAA approved Airplane Flight Manual prohibiting backing of the airplane using reverse thrust.

2. If an application for reverse backing has been received, and compliance with all related engine and airplane airworthiness requirements has been demonstrated, no Airplane Flight Manual limitation or qualifications will be included regarding backing of the airplane using reverse thrust.

3. If no application or request for approval is received from the applicant, a statement will be placed in the Normal Procedures section of the FAA approved Airplane Flight Manual indicating that compliance with the related airworthiness requirements for backing of the airplane using reverse thrust was not accomplished.

In each case the reverse backing procedures, such as crew manipulation of controls, effect of aft c.g., required ground crew, effect of ramp topography and adjacent structure, and other considerations will not be evaluated by engineering. Additionally, with regard to item 3, the airworthiness consideration would have to be addressed and satisfied by each operator. These conditions for approving the airplane procedures must be addressed by the responsible Flight Standards office and personnel.

(b) The following excerpts are from another internal FAA memorandum that provides additional guidance on the approval of thrust reversers for airplane backing

A new Part C, Paragraph 24, is being proposed which would prohibit the use of reverse thrust for taxiing an airplane except for those airplanes, airports, and gates specifically authorized.

A number of certificate holders have either begun to use or inquired about using, reverse thrust for taxiing. The aviation industry's interest in reverse taxi and technical discussions brought about due to this interest, indicate that the safety of the aircraft and the airport could be compromised if the use of reverse thrust for taxing were permitted without proper safeguards.

The FAA recognizes that a reverse taxi procedure could be safely utilized under certain circumstances at certain locations. In view of this, the certificate holder who desires to use a reverse taxi procedure must submit a proposal including a combination of information and operational tests which demonstrate the safe use of reverse thrust for taxing at specific airport gates.

Each proposal should show the following:

1. The Airplane Flight Manual (Limitations Section) does not contain a limitation for the use of reverse thrust for taxiing.

2. The certificate holder's operating manual contains information and procedures which are consistent with the aircraft and engine manufacturers' procedures with respect to taxiing with reverse thrust. This information should include, but not be limited to:

   a. engine operation parameters,

   b. use of flaps during taxiing,

   c. use of brakes,

   d. use of environmental systems,

   e. restoring of deployed reversers,

   f. steering during reverse taxiing, and

   g. cautions.

3. The certificate holder has a reverse taxi training program for both ground personnel and flightcrew stressing coordination between the two.

4. The certificate holder has advised the airport authority of its proposal to use reverse thrust for taxi.

5. The certificate holder provides enough ground personnel to ensure that the flightcrew is continuously aware of the airplane's position and progress through clearly understood visual and/or aural signals.

6. The certificate holder has developed a procedure which would prohibit movement of aircraft at adjacent gates during the reverse taxi procedures.

7. The certificate holder has developed an operational test which shows the safety of operating a specific type aircraft at a specific airport gate. When considering a specific gate for reverse thrust taxiing consideration should be given to the following areas individually and in combination with each other:

   a. Slope of the ramp. A ramp which slopes toward the terminal or other structure may require excessive thrust before the aircraft would move.

   b. Condition of the ramp. Obstructions such as bumps or drains could impede the airplane's motion.

   c. Proximity of structures such as terminals, jetways, or fueling facilities. Jet blast could cause damage to those even at a minimum thrust setting.

   d. Proximity to taxiways. Reverse thrust taxiing will not be authorized where the airplane would have to back into an active taxiway.

   e. Public protection.

   f. Potential for tipping the aircraft.

   g. Potential of foreign object damage to the engine.

   h. Maximum EPR for reverse taxi at the gate. If the aircraft will notback using this EPR, the procedure should be terminated.

Prior to authorizing a certificate holder to conduct operational tests, and prior to the issuance of any operations specifications authorizations, the POI will coordinate the proposed tests and authorizations with other appropriate FAA offices.

(c) The following excerpt is from an internal FAA memorandum dated July 16, 1981. It provides additional guidance on the use of thrust reversers for airplane backing.

The power-back procedure and the proposed airplane approval, as described in your letter, have been reviewed by the FAA. We do not concur with the airplane manufacturer's intent to accomplish an AFM change resulting in a general approval on the model airplane for reverse thrust taxiing.

Interest in the power-back operation is wide spread and many reservations have been expressed concerning an airline's proposal. A general approval should not be granted until such time as all areas of concern have been adequately addressed.

However, we do not believe the AFM Limitations Section should prohibit reverse thrust taxiing unless a specific or unique situation exists which would make it unusable. If such a procedure is to be used, such as a test case or to solve a unique problem at some location, evaluation and approval should be performed by the responsible FAA Regional Flight Standards-Office in conjunction with the Air Transportation Division, Washington, D.C. For the situation where the manufacturer desires a general approval for this procedure, normal procedures should be established by the manufacturer and included In the AFM Section III.

(d) The following excerpt is from a FAA Issue Paper, and has been applied to certification projects when approval of use of thrust reversers for backing has been requested.

Statement of Issue: The use of the airplane's thrust reversers to effect a reverse thrust backup from terminal gates, in lieu of a tug pushback, has come into popular usage for airplanes of this weight class. Use of thrust reversers for this purpose was not considered within the regulations and therefore an objective evaluation to establish that no unsafe condition has been created is required.

Discussion: Due to factors of economy, as they relate to personnel and equipment, numerous Transport Category airplane operators have requested and received FAA approval for the use of the reverse thrust system to effect a powered backup from terminal gates in lieu of using a tug for a pushback. Due to the current popularity of this type of operation, it is expected that FAA approval of this operation will be requested by the operators of the [model] series airplane.

Unlike the existing airplanes which utilize total airpath deflectors with the low bypass series engines, this model airplane will be equipped with the bypass engine employing a fan airstream reverser system. Typically, high bypass fan engine reversing systems display low effectiveness during powerback operations. Therefore, higher than idle power settings may be required to back the airplane. Excessive blade stresses may be incurred by the engines during such operation. In one instance an airplane tipped onto its tail when the brakes were applied to stop the airplane following use of the reversers to back the airplane.

FAA Position: The applicant must comply with engine and airplane airworthiness requirements to receive certification approval for reverse thrust backing operations. The following guidelines are recommended:

1. Both the airplane and engine manufacturer should determine the applicability of the maneuver and provide appropriate limitations for the procedure. They should include engine/power limits, maximum and minimum weights, limits, ramp slopes, use of brakes, weather conditions, and any other factors unique to the proposed operation.

   Note: It is not considered to be good practice to authorize the operation with snow, ice, or slush on the ramp or during periods of heavy rain.

2. All limitations and any normal or abnormal procedures should be incorporated into the AFM, including those procedures relating to the ground crew.

3. It should be determined that the powerplant remains free of detrimental effects such as Foreign Object Damage or bleed air contamination. Unusual engine cooling distortion characteristics, ingestion or exhaust gases and effects on engine mounted accessories should also be examined.

4. The environmental control system should be examined for contamination of the cabin/cockpit area.

Note: In one case it was determined that air conditioning packs should be off during this operation.

5. Taxi demonstrations should be conducted using procedures developed by the applicant. A recommended program would include at least two configurations; aft c.g. at maximum ramp weight and aft c.g. regardless of weight. The tests should be conducted to determine at least:

   a. Degree or potential for any aft pitching including affect on nose steering.

   b. Effect of inadvertent or emergency braking action.

   Note: This test is not necessary if the applicant performs an analysis showing the affect of braking when the airplane is in rearward motion.

   c. Adequate cockpit visibility and ground crew function.

   d. Adequacy of procedures including transition from reverse to forward thrust for arresting rearward motion.

   e. Thrust asymmetry.

   f. Failure of an engine to reverse or to recover forward thrust.

   g. The effects of lowered tire pressure, degree of ramp slope, wind, airport elevation, temperature, and airplane configuration, i.e., flap position.

Summary: In summary, the applicant has applied for reverse backing, and compliance with all related engine and airplane airworthiness requirements has been demonstrated. Therefore, no Airplane Flight Manual limitation or qualifications will be included regarding backing of the airplane using reverse thrust.

e. **References.**

(1) Civil Air Regulations (CAR) 4b, December 31, 1953

(2) Amendment 25-AD (29 FR 18289, December 24, 1964)

(3) Notice of Proposed Rulemaking 65-43 (31 FR 93, January 5, 1966)

(4) Amendment. 25-11 (32 FR 6912, May 5, 1967)

(5) Notice of Proposed Rulemaking 75-10 (40 FR 10802, March 7, 1975).

(6) Amendment 25-38 (41 FR 55466, December 20, 1976);

(7) Amendment 25-40 (42 FR 15042, Mar. 17, 1977).

(8) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984).

(9) Amendment 25-72 (55 FR 29784, July 20, 1990).

(10) Advisory Circular 25.1309-1A, “System Design Analysis,” June 21, 1988.

(11) FAA/AIA Report, “Criteria for Assessing Turbojet Thrust Reverser Safety,” April 15, 1992; and Amendment 1, June 1, 1994

(12) FAA Report, “Thrust Reverser Task Force Group IV Airplanes,” June 30, 1993.

Section 25.934 Turbojet engine thrust reverser system tests.

a. **Rule Text.**

Thrust reversers installed on turbojet engines must meet the requirements of § 33.97 of this chapter.

(Amdt. 25-23, 35 FR 5677, April 8, 1970)

b. **Intent of Rule.** The intent of the rule is self-evident.

c. **Background.** Section § 25.934 was initiated in Notice of Proposed Rulemaking 68-13 (33 FR 11913, August 22, 1968). The proposal was an effort to ensure that applicants requesting amended or supplemental (airplane) type certificates (STC) for new thrust reversers on already-certified engines and/or airframe combinations would have to complete the § 33.97 compatibility testing prior to Part 25 certification on the airplane. The following justification for the proposed rule was described in the preamble to the Notice:

> Part 25 does not require substantiation of turbojet engine thrust reverser systems which are not provided with and substantiated as part of the engine certification. The proposal would add a new section (§ 25.934) which would require all thrust reversers installed on turbojet engines to meet the requirements of § 33.97. This would ensure that the same testing requirements would apply to the airframe manufacturers, engine manufacturers, and all other applicants.

Amendment 25-23 (35 FR 5665, April 8, 1970) followed Notice 68-13 and adopted the proposal (without comment).

d. **Policy/Compliance Methods**.

(1) The following excerpts are from Advisory Circular (AC) 20-18A, "Qualification Testing of Turbojet Thrust Reversers." That AC specifically outlines acceptable compliance methods for the tests prescribed in Part 33. These Part 33 requirements are necessary for substantiating the thrust reverser endurance and functional properties, as well as operating compatibility, with the specific engine for which compliance is requested.

> **PURPOSE.** This circular discusses the requirements for the qualification of thrust reversers and sets forth an acceptable means of compliance with the tests prescribed in Federal Aviation Regulations, Part 33, when run under non-standard ambient air conditions.
>
> **BACKGROUND.** When conducting thrust reverser testing under ground static conditions with non-standard and varying atmospheric conditions, appreciable variations from standard rated severity levels may occur. The factors of actual thrust levels and engine exhaust gas temperature are of particular importance in this respect for reverser cyclic testing. In connection with a reverser substantiation program conducted under warm weather testing conditions, when

it is not feasible to attain maximum thrust, a question has arisen in regard to what minimum severity is required.

ACCEPTABLE MEANS OF COMPLIANCE. The following basis for complying with §§ 33.87 and 33.97, under non-standard ambient air testing conditions, is acceptable for a reverser unit:

A. The required 200 reverser operation cycles conducted should average no less than 100 percent of the specified maximum thrust conditions for maximum forward and maximum reverse. While some reverser operating cycles are acceptable with operation below the specified thrust values, to be credited the gas temperature should be maintained at least to the specified 100 percent value.

B. Test stand endurance operation may be supplemented by stress and load analyses, or by acceptable aircraft flight tests conducted which meet the foregoing test severity limits for the 200-cycle operation testing, and when at least one reverser is operated through the equivalent of a 150-hour endurance test with the cyclic testing.

C. For acceptable reliability, the reversers should be in a serviceable condition following the required testing.

D. Thrust reverser compatibility with the engine should be established on the basis of satisfactory engine and reverser performance during these tests, with no adverse effects on the engine.

(2) The following excerpts are from an internal FAA policy memorandum, dated December 11, 1986, which provides guidance on additional § 33.87 endurance testing clarification:

In 1974, the FAA experienced some difficulties in finding compliance with the thrust reverser regulations in part 25 and part 33, namely § 25.934 and § 33.97, and proposed some revisions to those sections which would improve the standards applicability and comprehension. An internal FAA review of the proposed changes occurred, but apparently no further action was taken.

Recently, these difficulties have come to our attention again. The problem concerns what is required of applicants who want approval for a retrofit thrust reversing system design and installation on a previously type certificated engine/airplane configuration, or a type certificated engine going on a new airplane. It appears some applicants have complied with different standards. The principal question has been whether compliance with § 33.87 (Engine 150-hour endurance test) must be demonstrated by actual tests when the thrust reverser is an “add-on” or retrofit design rather than a part of the basic engine type design and approved at the time the engine was certified.

Advisory Circular 20-18A, *Qualification Testing of Turbojet Engine Thrust Reversers*, outlines acceptable means of compliance with the tests prescribed in part 33 when run under non-standard ambient air conditions. The AC does not address the requirement for a so called “add-on” or retrofit configuration, and one interpretation is that regardless of whether a type certificated engine is involved or not, the reverser installation testing and certification program must include the 150-hour engine endurance test required by § 33.87.

The policy that has been used by us, and prior to that under the old regional concept, is to forego the extra 150-hour test (§ 33.87) when the engine/airplane configuration has a type certificated engine. When a thrust reverser is to be "added" or retrofitted as part of the aircraft certification, the thrust reverser installation must demonstrate that the engine operation and vibratory levels are not affected. Sufficient test instrumentation is required to provide substantiation data that the operation and vibratory characteristics of the engine are not changed, and the acceptance of this thrust reverser installation by the engine manufacturer should also be provided. It has not been the normal practice to require a repeat of the Part 33 150-hour endurance test of an "added" or retrofitted thrust reverser. The "extra" endurance test is not considered to provide useful data or enhance the assessment or investigation of the thrust reverser system design and installation reliability or airworthiness and results in an unnecessary burden on many of the applicants without a commensurate increase in the reliability and airworthiness of the reverser design and installation.

In regard to the other tests specified in § 33.97(a), FAA has accepted equivalent tests and other appropriate substantiation for showing compliance with §§ 33.83, 33.85, and 33.89. The service history on those reverser installations certified in this manner has been acceptable, and we do not believe the extra 150 hour endurance test would significantly improve the record."

e. **References.**

(1) Notice of Proposed Rulemaking 68-18 (33 FR 11913, August 22, 1968.)

(2) Amendment 25-23 (35 FR 5665, April 8, 1970).

(3) Advisory Circular 20-18A, "Qualification Testing of Turbojet Engine Thrust Reversers," March 16, 1966.

(4) Advisory Circular 33-2B, "Aircraft Engine Type Certification Handbook," June 30, 1993.

Section 25.937 Turbopropeller-drag limiting systems.

a. **Rule Text.**

Turbopropeller power airplane propeller-drag limiting systems must be designed so that no single failure or malfunction of any of the systems during normal or emergency operation results in propeller drag in excess of that for which the airplane was designed under § 25.367. Failure of structural elements of the drag limiting systems need not be considered if the probability of this kind of failure is extremely remote.

b. **Intent of Rule.** The intent of this rule is self-evident

c. **Background.**

(1) This requirement was originally proposed during the 1956 Annual Airworthiness Review. It was adopted as Section 408 of the Civil Air Regulations (CAR) 4b on July 8, 1957, as part of Amendment 4b-6. Justification for CAR 4b.408 in Amendment 4b-6 included the following discussion:

> A new provision is being added (section 4b.408) which requires, on turbopropeller installations, the consideration of the single failure safety criterion in the design of propeller-drag limiting systems such as negative torque control systems and other backup systems. This provision is not intended to require consideration of more than one component failure in any one of the systems at any given time, either during normal or emergency operation; investigation of all components, whether or not integral with the engine, is required.

Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the Civil Air Regulations. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). This rule was recodified from CAR 4b.408 without any substantive changes.

(2) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984) proposed a clarification of this rule to substitute current terminology , i.e., to use the word "improbable" in lieu of "remote." Amendment 25-72 (55 FR 29756, July 20, 1990) followed Notice 84-21 and formally withdrew the proposal for further study. The withdrawal action was taken due to the concerns of several commenters who considered that such a change would actually result in a change in the level of safety and an increased burden on the regulated industry.

d. **Policy/Compliance Methods.** There is no existing written policy or guidance on this subject.

e. **References.**

(1) Civil Air Regulations 4b, per Amendment 4b-7 (17 FR 11631, December 20, 1952).

(2) Amendment 4b-6 (22 F.R. 5562, July 16, 1957).

(3) Amendment 25-AD (29 FR 18289, December 24, 1964).

(4) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984).

(5) Amendment 25-72 (55 FR 29756, July 20, 1990).

Section 25.939 Turbine engine operating characteristics.

a. **Rule Text.**

(a) Turbine engine operating characteristics must be investigated in flight to determine that no adverse characteristics (such as stall, surge, or flameout) are present, to a hazardous degree, during normal and emergency operation within the range of operating limitations of the airplane and of the engine.

(b) [Reserved]

(c) The turbine engine air inlet system may not, as a result of air flow distortion during normal operation, cause vibration harmful to the engine.

(Amdt. 25-11, 32 FR 6912, May 5, 1967, as amended by Amdt. 25-40, 42 FR 15043, March 17, 1977)

b. **Intent of Rule.** The intent of this rule is to ensure that turbine engines (turbojet, turboprop, and turboshaft) and auxiliary power units (APU) on all transport category airplanes continue to operate safely during normal and emergency operation within the range of aerodynamic, propulsion, and structural operating limitations of the airplane and engine.

c. **Background**.

(1) This requirement was originally proposed during the 1957 Annual Airworthiness Review. In its original form, the requirement only addressed the engine operability conditions (surge, stall, and flameout) addressed by § 25.939(a), and did not directly address vibration caused by airflow distortion. As such, it was adopted as Section 409 of CAR 4b on April 15, 1958, as part of Amendment 4b-8.

(2) Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the Civil Air Regulations. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). CAR 4b.409 was recodified without any substantive changes via

(3) Notice of Proposed Rulemaking 65-43 (31 FR 93, January 5, 1966) proposed a new turbine engine installation vibration requirement. The proposal stated that, while turbine engine vibration is tested during Part 33 certification, a new § 25.939(c) requirement was needed to ensure that the engine installation and airframe effects (which could introduce airflow distortion) did not introduce any unforeseen engine vibration problems. Amendment 25-11 (32 FR 6906, May 5, 1967) followed Notice 65-43 and added §§ 25.939(b) and (c),containing negative acceleration and vibration requirements, respectively.

(4) Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975) proposed separating acceleration requirements from § 25.939. Amendment. 25-40 (42 FR 15034, March 17, 1977) followed Notice 75-19 and moved the negative acceleration requirement from § 25.939(b) to § 25. 943. The background and history of the negative acceleration requirements can be found in this Mega AC under the section pertaining to § 25.943.

d. **<u>Policy/Compliance Methods.</u>**

(1) Section 25.939(a) requires demonstration of acceptable engine operating characteristics during transient and steady state engine conditions at a variety of normal and non-normal airplane maneuvers. Compliance with this requirement is typically demonstrated by a series of ground and flight tests. In general, turbine engines and in-flight operable APU's should be stable in their operation and run free of adverse characteristics in the normal flight regime. However, certain adverse engine operating characteristics may be allowed in specific flight regimes if they do not present a hazardous condition. Therefore, acceptable compliance with § 25.939(a) has remained somewhat subjective, and Advisory Circular 25.939-1 ("Evaluating Turbine Engine Operating Characteristics") has been used to define the guidelines for acceptable engine operating characteristics (see below).

Section 25.939(c) requires demonstration that the engine or APU installation (i.e., inlet) cannot impose distortion or other effects which could cause the excess vibration (beyond the Part 33 certified limits) to any of the engine components (i.e., fan blades). Compliance with § 25.939(c) is historically demonstrated through a combination of analysis, wind tunnel, ground and flight testing.

(2) Current transport category airplane policy and compliance material for this section has been contained in Advisory Circular 25-939, "Evaluating Turbine Engine Operating Characteristics" May 2, 1986. However, with the publication of this Mega AC, that AC has been cancelled and its material has been incorporated below:

Advisory Circular 25.939-1

EVALUATING TURBINE ENGINE OPERATING CHARACTERISTICS

1. **PURPOSE.** This advisory circular (AC) provides guidelines for the evaluation of turbine engine (turbojet, turboprop, and turboshaft) operating characteristics for subsonic transport category airplanes. These guidelines describe a method of demonstrating compliance with the applicable airworthiness requirements. Like all advisory circular material these guidelines are not mandatory and do not constitute a regulation. They are derived from FAA experience in establishing compliance with the airworthiness requirements and represent the means and methods found to be acceptable by that experience. These guidelines may not be entirely applicable to all airplane designs. Each design should be examined to determine whether the suggested methods of evaluation are adequate or if other methods in addition to these may be appropriate.

2. **RELATED FEDERAL AVIATION REGULATIONS (FAR).** The related regulation is § 25.939(a) of Title 14, Code of Federal Regulations (CFR), commonly referred to as the Federal Aviation Regulations (FAR). Compliance with § 25.939(c) is beyond the scope of this AC and should be established by the applicant to the satisfaction of the appropriate Aircraft Certification Office (ACO) prior to initiating the detailed engine operating characteristics tests.

3. **BACKGROUND.** The turbine engines of a transport category airplane must continue to operate safely during normal and emergency operation within the range of operating limitations of the airplane. Generally, compliance with § 25.939(a) can be determined to some extent while ascertaining compliance with other Part 25 requirements such as performance, controllability, maneuverability, and stalls. Turbine engines should be stable in their operation and run free of adverse characteristics in the normal flight regime. However, certain adverse characteristics are allowed in specific flight regimes if they do not present a hazardous condition.

4. **DEFINITIONS.** For the purposes of this AC, the following definitions apply:

   a. *Engine Stall*: Flow breakdown at one or more compressor airfoils.

   b. *Engine Surge*: The response of the entire engine which is characterized by a significant flow stoppage or reversal in the compression system.

   c. *Deterrent Level of Buffet:* A severe level of buffet that constitutes a clear deterrent to further decrease in airspeed or increase in angle of attack.

   d. *Engine Damage:* Damage that is in excess of the engine manufacturer's approved limits.

   e. *Normal Operating Envelope:* Altitudes between sea level (or minimum approved altitude) and the maximum approved operating altitude, airspeeds between stall warning and VMO/MMO, and sideslip angles appropriate for the type of airplane.

   f. *Abnormal Flight Conditions:* Flight conditions outside the normal operating envelope.

5. **ENGINE OPERATING CHARACTERISTICS.** Adverse engine operating characteristics range from mild to severe and are classified into three levels of severity for the purpose of defining acceptable operation. These characteristics are summarized in Appendix 1.

a. *Mild adverse operating characteristics* include:

- minor compressor stalls;
- light, audible surges; no perceived power loss;
- no engine damage (see DEFINITIONS); and
- immediate return to normal operation.

Engine operating instability is brief and of minor intensity, and crew action is not required for recovery.

b. *Moderate adverse operating characteristics* include:

- audible surges and compressor stalls,
- a momentary loss of thrust,
- an exceedance of continuous engine operating limits up to the approved transient limits,
- a temporary rotor speed decrease (i.e., from IDLE to sub-IDLE), or
- slow engine acceleration.

Power lever movements are not normally required to restore stable engine operation; however, minor power lever movements may be allowed provided the FAA and the engine manufacturer concur, the required crew actions are simple and instinctive, and the procedures are included as part of flightcrew training. Engines are not damaged and are capable of recovering to full thrust without subsequently exceeding any engine limits.

c. *Severe adverse operating characteristics* usually are characterized by loud, audible surges resulting in detrimental effects on airplane performance and controllability. One or more of the following characteristics are present:

(1) Engine stall or surge which requires large or rapid power lever movements or adjustment of other engine controls for recovery or attempted recovery.

(2) A substantial, sustained thrust loss.

(3) Engine flameout or required engine shutdown.

(4) Engine damage (see DEFINITIONS).

(5) Engine vibration requiring power reduction or engine shutdown.

(6) Engine conditions that result in a hazardous cabin pressure loss.

(7) Failure of the engine rotor(s) to accelerate.

6. **FACTORS AFFECTING ENGINE OPERATING CHARACTERISTICS.** Factors that may cause the engine to operate adversely are numerous, varied, and complex. Recognition of these factors and their impact on turbine engine operating

characteristics is essential to defining a suitable airworthiness compliance test program. Some of the more dominant factors are:

a. Engine installation effects such as the design of the inlet and exhaust systems, inlet blow-in doors, anti-ice system, fuel system, type of fuel, etc.

b. Location of the engine on the airplane and its proximity to airflow disturbance caused by the fuselage, wing, landing gear, flaps, etc.

c. Configuration of the airplane (flap position, speed brakes, gear position, etc.) that can cause airflow disturbance to the engine.

d. Atmospheric conditions such as altitude, ambient temperature, icing, windshear, etc.

e. Engine control characteristics (including the effects of trim tolerance) of variable inlet guide vanes, surge bleed valves, auto-throttle, fuel controls, temperature/speed controls, operating line, compressor pressure ratio, acceleration stall bucket (W_f/P_b vs. N), etc.).

g. Wind direction and intensity during takeoff, landing, and taxiing.

h. Flight condition (airplane attitude, configuration, flight regime, engine power setting, airplane “G” loading, flight transients, and flight handling techniques).

i. Engine accessories and equipment (bleed air and power extraction).

j. Pilot technique used in manipulating engine controls.

7. **FLIGHT TEST EVALUATION OF ENGINE OPERATING CHARACTERISTICS.**

a. Test conditions for demonstrating compliance with § 25.939(a) should be based upon an assessment of all factors affecting engine operating characteristics. Details of the engine design (and its control system as defined in the engine installation and operating manuals) and the effects of the engine installation on the airplane should be considered. The location of the engine and inlet on the airplane can make the engine more susceptible to operating instability under certain regimes of flight. The possibility of engine operating problems existing in some flight regimes should always be explored where experience and reasoning warrant. The specific flight and ambient conditions that produce engine operating instability are not always evident on the basis of engineering knowledge and evaluation.

b. The operating characteristics tests should be conducted utilizing any engine control system, including supervisory electronic engine controls and auto-throttles, for which certification is requested. The engine operating characteristics evaluation should also consider transient and stable operation of engine accessories and equipment, such as air conditioning packs, anti-ice systems, and electrical generator loads and their effects on engine operating characteristics.

c. Flight test evaluation of engine operating characteristics should consider all airplane configurations except those precluded by Airplane Flight Manual limitations or procedures. Certain airplane configurations may be limited as a function of altitude and/or airspeed. However, a minimum airspeed limit by itself is not considered an adequate warning means to preclude the low airspeed evaluation of in-flight engine operating characteristics. If a stick shaker is used for airplane stall warning, its actuation may be rescheduled to operate at a higher airspeed to warn of impending adverse engine operating characteristics.

d. Specific ground and flight test procedures and criteria are suggested in paragraph 8 of this AC. The complete set of test procedures pertain to the initial approval of an airplane engine installation. For follow-on engine installation changes such as engine thrust (power) rating changes, inlet modifications, engine systems modification, etc., portions of the recommended tests that are deemed necessary should be conducted. When conducting the tests described in paragraph 8, an isolated occurrence of an apparent hazardous adverse engine operating characteristic may not necessarily constitute failure in satisfying the requirements imposed by 25.939(a). Additional successful testing and/or engineering analysis may prove that the suspected adverse engine operating characteristic is, not prevalent and does not constitute an unsafe condition. For safety, most or all of the “transient power” and “engine/inlet compatibility” testing described below should be confined to checking one engine at a time or to that engine which is most critical because of its location on the airplane.

8. **GROUND AND FLIGHT TEST PROCEDURES.** To achieve the level of safety required by § 25.939(a), the following tests and criteria have generally been found by experience to be an acceptable method of demonstrating engine operating characteristics. However, certain engine installations may require tests at other flight conditions, if those conditions are deemed critical. These tests are usually qualitative and require no special instrumentation. A summary of the test criteria is shown in Appendix 2.

a. *Engine Operating Characteristics During Taxi, Takeoff, and Landing*. Except as noted below, adverse engine operating characteristics should not exist during the following taxi, takeoff, and landing segments. Compliance with this section should be established at the maximum demonstrated crosswind component and 150 percent of the limiting tailwind component for those components greater than 10 knots.

(1) *Taxiing*: No adverse engine operating characteristics (mild, moderate, or severe) should exist during taxiing except for operation in crosswinds and tailwinds where operating characteristics are acceptable.

(2) *Takeoff*: No adverse engine operating characteristics (mild, moderate, or severe) should exist after the power setting phase (normally completed by 60 to 80 knots) of the takeoff procedure through attainment of the enroute configuration and climb to 1,500 ft. above the airport. During the power setting phase of the takeoff roll, mild adverse characteristics are acceptable for operation in crosswinds and tailwinds. The tests may be conducted using the applicant’s recommended power setting procedures, provided they are acceptable for operation and are considered in establishing the Airplane Flight Manual takeoff performance.

NOTE: Satisfactory engine operating characteristics should be demonstrated during all takeoff performance tests. Tests should also be conducted to determine if any engine operating problems exist for takeoffs conducted throughout the altitude range approved for takeoff, and include engine initial thermal state (“cold” engine) conditions.

(3) *Approach and Landing*: No adverse engine operating characteristics (mild, moderate, or severe) should exist during the approach to landing from 1,500

ft. above the airport elevation, and during landing and rollout, including the use of thrust reversers at speeds down to the recommended "cutoff" speed, if applicable. At speeds less than the recommended "cutoff" speed, mild or moderate adverse operating characteristics for ground thrust reverser operation may be acceptable when using the applicant's recommended procedure (including power lever movements), provided the FAA and engine manufacturer concur that a hazardous condition does not exist. During landing rollout, mild adverse engine operating characteristics are acceptable while operating in crosswinds and tailwinds.

NOTE: Satisfactory engine operating characteristics should be demonstrated during all landing performance tests conducted within the normal engine operating range. Tests should also be conducted to determine if any engine operating problems exist for approaches and landings conducted throughout the altitude range approved for landing.

(4) *Reverse Thrust (Power) Backing*: If approval for reverse thrust backing is desired by the applicant, acceptable engine operating characteristics should be demonstrated. Using the applicant's recommended procedures (including power lever movements), mild or moderate adverse operating characteristics may be acceptable for reverse thrust backing provided the FAA and engine manufacturer concur that a hazardous condition does not exist.

b. *Transient Power Operating Characteristics*. For normal airplane and engine configurations, no adverse engine operating characteristics of any kind should exist within the normal airplane operating envelope during engine transient power conditions unless it is determined that they do not contribute to a hazardous situation, require immediate crew action, or damage the engine(s). For abnormal airplane and engine configurations addressed by Airplane Flight Manual procedures, no moderate or severe adverse engine operating characteristics should exist within the normal airplane operating envelope. After an engine shutdown, the remaining engine(s) is considered to be in a normal state, including any required bleed air and accessory power extraction changes. Mild adverse engine operating characteristics are allowed during abnormal flight conditions (e.g., airspeeds below initial low speed buffet). When using the above criteria, the following engine acceleration/deceleration and engine operating tests are the recommended procedures to be used to demonstrate satisfactory transient operating characteristics. The tests should be conducted using the most critical engine control system configuration approved for dispatch.

(1) Engine accel-decel (jam accelerations) tests should be conducted by rapidly moving (one second or less) the power lever from stabilized IDLE to the specified thrust setting, allowing the engine to stabilize, and then rapidly moving the power lever back to IDLE.

(2) Interrupted engine deceleration tests (Bodes) should be conducted by a rapid deceleration (power lever to IDLE stop) followed by a rapid acceleration back to the initial power lever position when the engine rotor speed passes through a specified turnaround speed. Several different turnaround speeds, including IDLE, are required unless the critical speed (minimum surge margin) has been identified by the engine manufacturer.

NOTE: The tests described in paragraphs (1) and (2) above should be conducted using the maximum thrust (power) approved for the test altitude at the following speed/altitude points and any others deemed critical:

- As near as practical to V_{MO}/M_{MO} (maximum operating) and V_{IB} (initial buffet) + 10 knots and initiated at the maximum approved operating altitude, and

- V_{FE} (flaps extended), and V_{IB} + 10 knots at an altitude 1,500 ft. above the maximum approved takeoff altitude.

These tests specify rapid power lever movements to evaluate the engine control system response to a rapidly changing demand for thrust (power). In most cases, rapid power lever movements have provided the least stall margin during engine acceleration and deceleration tests. However, some engines have been found to be more sensitive to slow power lever movements because of control system features that depend on the rate of engine acceleration or deceleration. An example is a normally modulating bleed valve that goes to the full open position during rapid thrust (power) changes. In this case, the engine control system should be analyzed and the appropriate accel-decel tests performed using the most critical power lever manipulation rates.

(3) Engine acceleration tests should be conducted by rapidly advancing the power levers from IDLE to maximum thrust (power) as the airplane stalls and a normal recovery is initiated [see § 25.201(d) for stall definition]. These tests should be conducted using the critical flap configuration and at altitudes sufficient to verify acceptable engine operating characteristics for the altitude range approved for landing. (Mild adverse engine operating characteristics are acceptable for these tests.)

(4) Low rate descents at IDLE thrust (power) should be conducted from within 3,000 ft. of the maximum approved operating altitude to 10,000 ft. altitude. At the bottom of descent, the engines should accelerate normally to maximum continuous thrust (power).

c. *Engine/Inlet Compatibility Tests*. The purpose of this flight test is to investigate the effects of distorted engine-inlet airflow that may result from unusual airplane attitudes in the normal and emergency operating range of the airplane. Inlet airflow distortion may cause adverse engine operating characteristics. Qualitative flight tests, such as sideslips, windup turns or symmetrical pull-ups, and approaches to power-on stalls, may be used to demonstrate satisfactory engine operating characteristics at high thrust (power) settings and angles of attack.

(1) The following thrust (power) settings are recommended:

(i) Use thrust (power) settings up to the maximum approved thrust (power) limit at altitudes up to 1,500 ft above the maximum approved takeoff altitude.

(ii) From the maximum altitude considered in paragraph (i) up to the maximum altitude approved for operation, the engines should be operated at thrust (power) settings up to the maximum continuous thrust (power) limit for the tests.

(2) The degree of adversity allowed for engine operating characteristics depends on the airplane speed range being considered:

(i) No adverse engine operating characteristics should exist within the normal airplane operating envelope from V_{MO}/M_{MO} down to natural or artificial (stick shaker) stall warning cues used to show compliance with

§ 25.207. However, at altitudes greater than 3,000 ft. above the highest altitude approved for takeoff and landing, mild adverse operating characteristics may be permitted if it is determined that they do not contribute to a hazardous situation.

(ii) At altitudes up to 3,000 ft. above the maximum approved takeoff altitude, between the angle of attack for stall warning and an angle that exceeds the stall warning angle by an amount that might occur during recovery from a dynamic penetration past stall warning, the engines should be free of moderate or severe adverse engine operating characteristics. However, at altitudes greater than 3,000 ft. above the highest altitude approved for takeoff and landing, mild and moderate adverse operating characteristics may be permitted if it is determined that they do not contribute to a hazardous situation.

NOTE: Flight maneuvers to an angle of attack that exceeds the stall warning angle by approximately 10 percent will fulfill the intent of this requirement although other proposals offered by the applicant will be considered if they are based on sound reasoning that relates to the applicant's specific design. During the windup turn and approach to stall, the airplane angle of attack should be increased to that point before recovery is initiated, unless one of the following conditions is reached first:

- An FAA approved structural limit, or
- A controllability limit, or
- A deterrent level of buffet or an artificial barrier (stall prevention device).

(3) If stall characteristics and/or static directional and lateral stability testing is required for airframe approval, the engines should not exhibit any severe adverse operating characteristics during these tests while outside of the normal operating envelope. Thrust (power) settings appropriate for the type of test being conducted should be used.

9. **IN-FLIGHT OPERATED AUXILIARY POWER UNITS.** The operating characteristics of in-flight operated auxiliary power units (APU) may be evaluated concurrently with the engine/inlet compatibility tests. The APU should not exhibit any hazardous adverse operating characteristics. The APU operating characteristics should be checked within the APU operating envelope while operating in the most critical mode with respect to power extraction and pneumatic air supply as appropriate for the flight condition. A nonessential APU may be shut down, using adequate annunciation and normal procedures, as a means to prevent a hazardous situation. However, if an APU is to perform essential tasks, then it must continue to perform those functions.

AC 25.939-1 FIGURE 1. SUMMARY OF DEFINITIONS

Level of severity is determined by the occurrence of one or more of the most serve characteristics.

Adverse Engine Operating Characteristics	Mild	Moderate	Severe
Audible Surges	Yes	Yes	Yes
Operating Instability	Minor/Brief	Yes	Yes
Engine Rotor Acceleration	Normal	Slow	None
Engine Limits Exceedance	None	Brief	Substantial
Power Loss/Rotor Speed Decrease	None	Temporary	Substantial
Engine Vibration	None	Minor	Requires Shutdown
Crew action required for recovery	No	Maybe	Yes
Engine Flameout	No	No	Yes
Engine Damage	No	No	Yes
Hazardous Cabin Pressure Loss	No	No	Yes

AC 25.939-1 FIGURE 2. RECOMMENDED TEST CRITERIA

Engine Operating Characteristics Tests	Adverse Engine Operating Characteristics Allowed			
	None	Mild	Moderate	Severe
Takeoff & Landing Operations				
• Taxiing (Calm Air)	X			
In Crosswinds or Tailwinds	X	X		
• Takeoff (Calm Air)	X			
In Crosswinds or Tailwinds	X	X		
• Approach & Landing (Calm Air)	X			
In Crosswinds or Tailwinds	X	X		
At Speeds Below Reverser "Cutoff" Speed	X	X		
• Reverse Thrust (Power) Backing	X	X		
Transient Power Conditions				
• Jam Accels & Decels	X			
• Bodes (Interrupted Deceleration)	X			
• Airplane Stall Recovery ("Idle" to "Max. Power")	X	X		
For the Above Transient Tests:				
At Abnormal Airplane & Engine Configuration	X	X		
• Cold Soak Descent & Recovery	X			
Engine Airflow Distortion Tests				
• Sideslips, Windup turns, or Symmetrical pull-ups, Approaches to Power-On Stalls:				
1.VMO to stall warning @Altitude	X			
Well above Take Off & Landing	X	X		
2.Speeds below stall warning	X	X		
@ Altitude well above Takeoff and Landing	X	X		
• Airframe Stalls & Sideslips @ conditions outside normal operating envelope (if required)	X	X		

Note: X = Allowed
= May Be Allowed (FAA and Engine Manufacturer must concur)

■■

END OF ADVISORY CIRCULAR 25.939-1.

(2) For further guidance, see Advisory Circular 25-7, “Flight Test Guide for Certification of Transport Category Airplanes,” Revision A, Section 99 (titled *Turbine Engine Operating Characteristics - § 25.939).*

e. **References.**

(1) Amendment 4b-8 (23 FR 2590, April 19, 1958)

(2) Amendment 25-AD (29 FR 18289, December 24, 1964).

(3) Notice of Proposed Rulemaking 65-43 (31 FR 93, January 5, 1966).

(4) Amendment 25-11 (32 FR 6912, May 5, 1967).

(5) Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1976).

(6) Amendment 25-40 (42 FR 15043, March 17, 1977).

(7) Advisory Circular 25-939-1, “Evaluating Turbine Engine Operating Characteristics,” March 19, 1986 [incorporated in this Mega AC].

(8) Advisory Circular 25-7, “Flight Test Guide for Certification of Transport Category Airplanes,” Revision A, March 31, 1998.

Section 25.941 Inlet, engine, and exhaust compatibility.

a. **Rule Text.**

For airplanes using variable inlet or exhaust system geometry, or both-

(a) The system comprised of the inlet, engine (including thrust augmentation systems, if incorporated), and exhaust must be shown to function properly under all operating conditions for which approval is sought, including all engine rotating speeds and power settings, and engine inlet and exhaust configurations;

(b) The dynamic effects of the operation of these(including consideration of probable malfunctions) upon the aerodynamic control of the airplane may not result in any condition that would require exceptional skill, alertness, or strength on the part of the pilot to avoid exceeding an operational or structural limitation of the airplane; and

(c) In showing compliance with paragraph(b) of this section, the pilot strength required may not exceed the limits set forth in § 25.143(c), subject to the conditions set forth in paragraphs (d) and (e) of § 25.143.

(Amdt. 25-38, 41 FR 55467, Dec. 20, 1976)

b. **Intent of Rule.** The intent of this rule is to ensure continuous operation of the propulsion system which incorporates either variable geometry inlet or variable geometry exhaust nozzle, or both. Compliance must be demonstrated for both individual components and their special design features. In addition, compliance must be demonstrated for the integrated propulsion system to ensure adequate investigation of their interrelationships under all propulsion and aircraft operating conditions for which certification is desired. The scope of compliance must be broad enough to ensure that performance objectives are met in normal operation and that the consequences of malfunctions on individual components and the integrated system are fully investigated.

c. **Background.**

(1) This rule originated from FAA/NASA/Industry work on the US Supersonic (SST) Program to develop a preliminary certification basis. It was reported in a Department of Transportation/Federal Aviation Administration report entitled, “Tentative Airworthiness Standards for Supersonic Transports,” dated November 1,1965.

(2) This specific rule initiated with Notice of Proposed Rulemaking Notice 75-10 (40 FR 10802, March 7, 1975). The following excerpt is from Notice 75-10 and provides insight into the intent of the regulation.

> The inlet, engine and nozzle compatibility is affected by the system complexity which requires both a substantiation of individual components as well as an evaluation of their interrelated effects. The evaluation must include the consequences of system malfunctions on:

(a) propulsion system operation and,

(b) on the airplane aerodynamic and control characteristics.

Amendment 25-38 (41 FR 55467, December 20, 1976) followed Notice 75-10 and adopted the proposal.

d. **Policy/Compliance Methods.** Because of the nature of this regulation, there has not been a requirement to produce written policy and/or compliance guidance. Should future transport category aircraft be developed that use some or all of the features described in the regulation, the FAA must then develop the needed guidance material. The following, however, represents the current FAA Transport Airplane Directorate's guidance methodology.

Methods of compliance may consist of analysis, wind tunnel testing and flight testing. Regardless of the method, compliance of individual components and the integrated system must be demonstrated at all flight conditions and engine power conditions which represent critical operation of the propulsion system. Critical operation will depend upon the complexity and type of inlet and its associated sub-systems, type of engine, and type of exhaust nozzle and its associated sub-systems.

Supersonic external or mixed compression inlets with variable position centerbody (for axisymmetric inlets) or ramps (for 2-D inlets), variable bleed, variable bypass, auxiliary door and, or other design features must demonstrate compliance at on-design and off-design operation. Critical operation would consist of low speed takeoff, approach and climb, subsonic cruise, transonic climb, operation at the "start Mach number (for a mixed compression inlet)," supersonic climb and cruise operation "at the Design Mach number (for a mixed compression or external compression inlet)" to assess inlet steady-state performance and engine/inlet dynamic stability.

Subsonic variable geometry inlets with variable capture area, bleed, auxiliary door and, or other design features must demonstrate compliance at on-design and off-design operation. Critical operation would consist of takeoff, approach, climb, and subsonic cruise operation to assess steady-state performance and engine/inlet dynamic stability.

Convergent or convergent-divergent nozzles employing variable geometry throat area, exit area, mixer-ejector, and, or other design features must demonstrate compliance at on-design and off-design operation. Critical operation would consist of low speed takeoff, approach and climb, subsonic cruise, transonic climb, supersonic climb and cruise operation to assess nozzle steady-state performance and engine/nozzle dynamic stability.

e. **References.**

(1) DOT/FAA Report, "Tentative Airworthiness Standards for Supersonic Transports," November 1, 1965.

(2) Notice of Proposed Rulemaking 75-10 (40 FR 10802, March 7, 1975).

(3) Amendment. 25-38 (41 FR 55467, December 20, 1976).

Section 25.943 Negative acceleration.

a. **Rule Text.**

No hazardous malfunction of an engine, an auxiliary power unit approved for use in flight, or any component or system associated with the powerplant or auxiliary power unit may occur when the airplane is operated at the negative accelerations within the flight envelopes prescribed in § 25.333. This must be shown for the greatest duration expected for the acceleration.

(Amdt. 25-40, 42 FR 15043, Mar. 17, 1977)

b. **Intent of Rule.** The intent of this rule is self-evident.

c. **Background.**

(1) Notice of Proposed Rulemaking 65-43 (31 FR 93, January 5, 1966) originally introduced negative acceleration requirements for turbine powerplant installations in § 25.939. The explanation for the proposal is included in the following excerpt from the preamble to the Notice:

> Section 25.939 would be amended to require that negative acceleration loads will not cause hazardous turbine powerplant malfunctions. Three major turbine characteristics make this proposal necessary:
>
> - First, the turbine has no continuous ignition source. It is therefore important that fuel flow be sustained in order to prevent flameouts and the need for restarts.
> - Second, high speed increases the probable negative acceleration loads caused by gust and maneuvering.
> - Third, complex turbine fuel system components are sensitive to negative acceleration loads.
>
> Section 25.939 also would be amended to require that the vibration characteristics of critical turbine engine components will not be adversely affected in normal operation. Turbine engines are vibration tested throughout their normal operating ranges as part of their type certification under Part 33. However, as mentioned in paragraph 2 of this preamble, the combination of specific engines and airframes can introduce unforeseen vibration problems.
>
> This proposal, and the requirement now in § 25.939, are in response to problems affecting turbine engines generally, not only transport category airplanes. It is therefore further proposed to add new §§ 27.939 and 29.939 containing the requirements in this proposal and in present § 25.939.

Amendment 25-11 (32 FR 6906, May 5, 1967) followed Notice 65-43 and added §§ 25.939(b) and (c) to Part 25. Subparagraph (b) contained the negative acceleration requirements; subparagraph (c) contained the vibration requirements. The following excerpt from the preamble to the Amendment discusses the disposition of comments and provides additional insight into the intent of the rule:

> The notice proposed to amend § 25.939 to require that operation of the airplane within the portion of the flight envelope that produces the “highest negative acceleration loads” may not cause hazardous malfunction of any part of the turbine powerplant, and to require that “the vibration characteristics” of turbine engine components whose failure could be catastrophic may not be “adversely affected” during normal operation. The notice also proposed to add new §§ 27.939 and 29.939 containing the requirements of § 25.959 in effect prior to this amendment plus the same negative acceleration and vibration requirements added of § 25.939.
>
> One commenter objects to the negative acceleration requirement for the following reasons:
>
> - The commenter states that the requirement involves engine design and may therefore be beyond the aircraft manufacturer’s control. The Administrator does not agree that responsibility for proper operation of the turbine engine powerplant within the established flight envelope can be divided between the airplane and engine manufacturers during type certification of the airplane. Further, aircraft applicants have shown themselves capable of showing compliance with Special Conditions requiring that powerplant operation be safely maintained at vertical accelerations of less than zero g for specified lengths of time.
>
> - The commenter states that the requirement could be administered to require that the airplane be flown continuously to the negative limits of the maneuvering and gust envelopes for the airplane, whereas lesser negative acceleration loads may in fact be more critical from a fuel flow standpoint. The Administrator agrees with this comment. This result is not intended. The proposal is therefore amended to refer to “the negative acceleration . . . that is most critical from a fuel flow standpoint.”
>
> - The commenter states that substantiation of the fuel flow provisions under negative loads is not necessary because turbine engine powered airplanes either have continuous ignition systems that, when operated according to instructions in the Airplane Flight Manual, will provide ignition continuously during critical phases of takeoff, landing, icing conditions and in turbulence. The Administrator disagrees. While continuous ignition operation may broaden the range of fuel flow disturbances that can be tolerated without flameout, and is therefore significant from a safety standpoint, such ignition cannot prevent a flameout that results from fuel flow stoppage such as occurs when negative acceleration allows fuel ports to become uncovered. In such a case a restart cycle may be necessary. Instructions in the Airplane Flight Manual are no substitute for substantiation of the fuel system under negative loads.
>
> - The commenter states that long service experience shows that turbine engine fuel system components are not sensitive to negative acceleration loads, contrary to a statement in the preamble to the notice. The Administrator agrees in part. The sensitivity of the turbine fuel system to negative loads lies not in specific components, but rather in the sensitivity of the turbine engine to fuel flow stoppage, the high flow rates in the system,

and the consequent speed with which air introduced into the system can reach the engine and result in flameout.

- The commenter states that, while it is true that extended periods of negative acceleration may result in deterioration in performance due to interrupted flow, turbine engine fuel systems have been shown to be acceptable for the shorter exposure times actually encountered. The Administrator agrees. Investigation of the safety of turbine fuel systems under representative negative acceleration loads has long been required by Special Condition. This amendment therefore changes the proposal by adding the words *." . . this must be shown for the greatest duration expected for that acceleration."*

(2) Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975) proposed further changes to the rule to introduce requirements for APU's. The following excerpt from the preamble to the Notice provides explanation for the proposed change:

> Powerplant and APU components and systems other than the engine fuel system can be adversely affected during negative acceleration. The proposal would make the current provision clearly applicable to such components and systems and would place it in a separate section. In addition, the proposal would revise the section to make it applicable to reciprocation engines as well as turbine engines.

Amendment 25-40 (42 FR 15034, March 17, 1977) followed Notice 75-19 and adopted the proposal without substantive changes. The following excerpt from the preamble to the Amendment discusses the comments received and provides additional insight as to the intent of this rule:

> Several commenters object to the proposed new § 25.943 concerning the effect of negative accelerations on engine and APU operation. One commenter recommends that the word "sustained" be used in place of the word "hazardous" in relation to which malfunction need be considered under the proposed rules. The FAA disagrees, since the significance of a malfunction is whether it is hazardous, irrespective of its duration.
>
> A commenter does not concur with the proposal, stating that a differentiation is necessary between ground-use APU's and other APU's. The commenter apparently misinterpreted the proposal since the proposal explicitly only applies to an APU if it is approved for use in flight.
>
> Two commenters indicate that the proposal should be limited to APU's that are essential to the safety of flight. The FAA does not agree since the malfunction of a nonessential APU approved for use in flight might be hazardous. All flight-use APU's should therefore be evaluated under the proposal.
>
> A commenter states that, since negative acceleration could affect all engines simultaneously, the requirement should refer to "engines." The proposal applies to any engine at any point during the negative acceleration and would necessarily include a determination of the effect of negative acceleration on each engine during the entire acceleration.

One commenter requests information on the duration of acceleration to be considered. The duration of acceleration to be considered under the provision is that expected in service and depends on the maneuver-time history of a particular aircraft type being evaluated within its flight envelope.

(3) The background and history of the negative acceleration requirements can be found in the turbine powerplant installations section in § 25.939§ of this Mega AC.

d. **Policy/Compliance Methods.** Historically, this requirement can be satisfied by flight test demonstrations which take into consideration the critical airplane, engine, and APU configurations. The duration of the negative acceleration excursions is intended to represent anticipated non-normal operational events such as atmospheric upsets, collision avoidance maneuvers, etc.

Negative acceleration flight test maneuvers on transport category airplanes are typically conducted at approximately 15,000 ft. and 250 to 300 KIAS. The airplane is put into a shallow dive followed by a pull up and then a push over to induce the negative acceleration.

The designation “test engine” is given to the engine which has unique instrumentation installed in its fuel system, oil lubrication system, generator oil system, and electrical system for the negative acceleration test. These systems should be monitored for proper operation throughout the test condition.

During the test, fuel tanks should not be more than half full. The tank quantity is critical since low quantity ensures that under negative acceleration, there is room for the fuel to lift and uncover the boost pump pickups and suction bypass inlets (if applicable). The most critical fuel (usually JP-4) should be used relative to potential for pump cavitation. The airplane fuel system configuration for this test is typically “tank to engine.” Fuel samples should be taken to ensure the fuel type’s Reid vapor pressure and density. Examples of adverse fuel system characteristics include engine/APU flameout, surge, stall, or fuel starvation.

On four-engine airplanes, it has been the conservative policy to conduct the initial negative acceleration condition with the test engine (usually an inboard engine) and the other inboard engine at maximum continuous thrust (MCT) with the non-test engines reduced to flight idle just prior to entering the negative “g” condition. If this policy is followed, the test must be repeated with the outboard engines at MCT to evaluate fuel starvation characteristics. This additional test condition is required due to differences in fuel tank size, location of the boost pump inlets, and plumbing line lengths.

All new airplanes, engines or engine installations, or significant airplane components (e.g., integrated drive generators - IDG) should be required to conduct a negative acceleration demonstration per the procedure outlined below. This testing is usually concurrent with electrical, hydraulic, and pneumatic system negative acceleration demonstrations.

The compliance procedure for this requirement involves the following:

(1) In conducting negative acceleration tests, consideration should be given to engine accessory configurations, and critical levels of fuel and oil.

(2) Accelerations should be measured as close as practicable to the airplane's center of gravity position.

(3) With the test engines operating at maximum continuous thrust, and the APU operating with normal loads (if flight operable), the airplane should be flown at a critical negative acceleration within the flight envelope. The duration of each test condition should be a minimum of 7 seconds between 0.0 and -1.0g, with a total accumulation of 20 seconds of negative acceleration operation.

(4) Test data should be analyzed with regard to maintaining adequate fuel flow to the engines and APU, and maintaining lubrication of critical components.

e. **References.**

(1) Notice of Proposed Rulemaking 65-43 (31 FR 93, January 5, 1966).

(2) Amendment 25-11 (32 FR 6906, May 5, 1967).

(3) Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975).

(4) Amendment 25-40 (42 FR 15034, March 17, 1977).

(5) Advisory Circular 25-7, "Flight Test Guide for Transport Category Airplanes," Revision A, March 31, 1998

Section 25.945 Thrust or power augmentation system.

a. **Rule Text.**

(a) General. Each fluid injection system must provide a flow of fluid at the rate and pressure established for proper engine functioning under each intended operating condition. If the fluid can freeze, fluid freezing may not damage the airplane or adversely affect airplane performance.

(b) Fluid tanks. Each augmentation system fluid tank must meet the following requirements:

(1) Each tank must be able to withstand without failure the vibration, inertia, fluid, and structural loads that is may be subject to in operation.

(2) The tanks as mounted in the airplane must be able to withstand without failure or leakage an internal pressure 1.5 times the maximum operating pressure.

(3) If a vent is provided, the venting must be effective under all normal flight conditions.

(4) [Reserved]

(c) Augmentation system drains must be designed and located in accordance with § 25.1455 if --

(1) The augmentation system fluid is subject to freezing; and

(2) The fluid may be drained in flight or during ground operation.

(d) The augmentation liquid tank capacity available for the use of each engine must be large enough to allow operation of the airplane under the approved procedures for the use of liquid-augmented power. The computation of liquid consumption must be based on the maximum approved rate appropriate for the desired engine output and must include the effect of temperature on engine performance as well as any other factors that might vary the amount of liquid required.

(e) This section does not apply to fuel injection systems.

(Amdt. 25-40, 42 FR 15043, March 17, 1977; Amdt. 25-72, 55 FR 29785, July 20, 1990)

b. **Intent of Rule.** The intended purpose of this rule is to provide system operating limitations for thrust or powered augmented systems excluding any fuel injection systems. This rule provides guidance regarding fluid flow rate, fluid pressure, tank loads, and tank venting; and references § 25.1455 for systems subject to freezing.

c. **Background.**

(1) This rule originated in Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19. 1975). The explanation for the proposed rule is provided in the following excerpt from the preamble to the Notice:

> A requirement is needed to ensure that augmentation system operation is compatible with engine functioning characteristics and that the systems strength and operating characteristics are adequate for its intended function.

Amendment 25-40 (42 FR 15043, March 17, 1977) followed Notice 75-19 and adopted the proposal. Further guidance on the intent of the regulation is provided in the following excerpt from the preamble to that Amendment:

> One commenter suggests that the heading of proposed new § 25.941 be revised to read "*Thrust or power augmentation system*" for clarification. The FAA agrees and the heading is revised as suggested. The same commenter also points out that the section designation § 25.941 has been used in connection with another proposal in Notice 75-10. The FAA agrees and the section as adopted is designated as § 25.945
>
> A commenter, referring to proposed § 25.941(b)(3), states that it is not necessary to specify how the venting should be done, and suggests that the proposal be revised to require that the venting arrangements for each tank must perform their intended function under any foreseeable conditions. While the FAA does not agree with the revision suggested by the commenter, the FAA does agree that the vent need not be from the "top" of the expansion space. If the venting is effective under "any normal flight condition" the vent could be located in other places in the expansion space. Proposed § 25.941(b)(3) is revised accordingly to allow the applicant any needed flexibility.
>
> Another commenter on proposed paragraph (b)(3) states that the proposal would preclude pressurization as a means of pumping. The FAA agrees. The proposal was not intended to preclude pressurization and is revised to apply only to vented tanks.
>
> Another commenter thinks that placards should be treated separately from system design and that the proposal should be deleted because similar requirements for fuel and oil systems are being considered for deletion. The FAA believes that marking the tank fluid opening to identify the fluid to be used may avoid the inadvertent use of incorrect fluids.
>
> One commenter states that it is highly probable that the filler cap will not be large enough to indicate the required markings and that markings adjacent to the fluid filler cap should be allowed, as is the case for § 25.1557(b). The FAA agrees and paragraph (b)(4) is revised to require marking at or near the filler cover.
>
> Another commenter believes that the proposal should be combined with § 25.963(e) to cover all fluid tanks. The FAA agrees that current § 25.963(e) should be combined with other augmentation system requirements, but does not believe that augmentation system requirements and fuel tank requirements should be combined. Proposed § 25.941 and current § 25.963(e) are combined in a new § 25.945.

> Finally, a commenter on the fuel-injection exclusion in proposed paragraph (d) questions whether water-methanol, as used on [*a specific engine*], would be regarded as a fuel. In that application, the water-methanol system is not regarded as a fuel injection system. Therefore, the water-methanol system used on that engine would not be excluded from the augmentation system requirements of § 25.945.

(2) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984) proposed a revision to this rule. The explanation for the proposed revision is provided in the following excerpt from the preamble to the Notice:

> [This Notice proposes to amend] § 25.945 by removing paragraph (b)(4) and marking it "reserved." Explanation: The requirement for marking the augmentation system and filler openings would be transferred from § 25.945 to § 25.1557 for editorial convenience and clarity.

Amendment 25-72 (55 FR 29756, July 20, 1990) followed Notice 84-21 and adopted the proposal. Additional guidance is provided in the following excerpt from the preamble to that Amendment:

> One commenter supports the proposed transfer of the requirement for marking the augmentation system tank filler openings from § 25.945 to § 25.1557 and removal of the redundant reference to § 25.1557(C) from § 25.973.
>
> Another commenter opposes deletion of marking requirements based on the rationale that the requirements are redundant. The commenter notes that, in other sections of Part 25, the FAA proposes to add references to requirements to ensure that important requirements are not overlooked, and states that this policy is preferable from an airworthiness standpoint. The FAA concurs that references are appropriate, in some instances, to ensure that important requirements are not overlooked. In other instances, however, references are unnecessary and merely serve to obscure other requirements. The FAA does not concur that the transfer of the marking requirements of § 25.945(b)(4) to § 25.1557 and the elimination of the cross reference in § 25.979 will adversely affect airworthiness since the requirement continues to exist in another section appropriately identified as a marking section. Sections 25.945(b)(4) and 25.973(a) are, therefore, removed as proposed."

(3) This rule specifically does not provide coverage for fuel injection systems, such systems are covered in §§ 33.65, 33.69, 33.73, 33.79, and 33.87.

d. **Policy/Compliance Methods.** Compliance with § 25.945 may be demonstrated by component tests, ground tests, or flight testing. Testing could include the following:

(1) ***Ground / component testing:***

(a) Demonstrate tank integrity to vibrational, inertial, fluid and structural loads at flight conditions and engine operating conditions that demonstrate worst case scenarios.

(b) Demonstrate tank integrity to internal pressure 1.5 times maximum operating pressure.

(c) Demonstrate tank integrity and system integrity in worst freezing case or show by analysis and flight testing that freezing will not occur.

(2) ***Flight testing:***

(a) Demonstrate compliance to system operational requirements at airplane flight conditions and engine operating conditions representative of worst case to be expected in operation.

(b) Demonstrate system operation with tank venting at airplane flight conditions and engine operating conditions representative of worst case to be expected in operation.

e. **References.**

(1) Notice of Proposed Rulemaking 75-19 (40 FR 21866, May 19, 1975).

(2) Amendment 25-40 (42 FR 15043, March 17, 1977).

(3) Notice of Proposed Rulemaking 84-21 (49 FR 47358, December 3, 1984).

(4) Amendment 25-72 (55 FR 29756, July 20, 1990).