U.S. Department of Transportation
Federal Aviation Administration

Policy Statement

Subject: Guidance for Screening for Engine Rotor Lock in Transport Category Airplanes During Aircraft Certification

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Initiated By: ANM-112

Summary

This policy statement describes an acceptable compliance method for demonstrating that an engine or engines of a transport-category airplane can be successfully restarted. A complete loss of power of all engines occurs infrequently, but the results can be catastrophic if the engines cannot be restarted. The current Title 14, Code of Federal Regulations (14 CFR), part 25 airworthiness standards for engine restart encompass the engine rotor lock condition and the effects it may have on engine restart capability; however, previous FAA guidance has been applicant-specific. This policy statement defines compliance criteria for a rotor lock screening test for new engine installation certifications, or major engine installation design change programs of transport-category airplanes. The rotor lock screening test will substantiate that after an engine has experienced an in-flight shutdown, considering a critical set of conditions intended to evaluate susceptibility to an engine rotor lock or rotor drag condition, the installed engine remains capable of being restarted within the certified restart envelope.

Definition of Key Terms

In the policy statement below, the terms “must,” “should,” or “recommend” have a specific meaning that is explained in Attachment 1.

Current Regulatory and Advisory Material

The following regulations from 14 CFR may apply:

Part 21:

- Section 21.21(b)(2) states “For an aircraft, that no feature or characteristic makes it unsafe for the category in which certification is requested.”

Part 25:

- Section 25.903(e), "Restart capability," requires a means to restart any engine in flight, establishment of an in-flight restart altitude and airspeed envelope, and provisions for adequate electrical energy for engine ignition following engine shutdown during windmill conditions.

- Section 25.1351(d), "Operation without normal electrical power," requires, in part, that an airplane be able to operate safely for not less than five minutes following loss of all normal electrical supply, including engine restart capability with loss of fuel tank boost pump power, if a boost pump in each fuel tank is not powered by the emergency electrical system.

- Section 25.1585(a)(3), requires that operating procedures must be furnished for emergency procedures.

Part 33:

- Section 33.5(b), "Operating instructions," requires establishment of an in-flight restart altitude and airspeed envelope.

- Section 33.89(a)(1) requires a demonstration to restart any engine.

- Section 33.89(b) states "The operation test must include all testing found necessary… to demonstrate that the engine has safe operating characteristics throughout its specified operating envelope."

The following policy statement is also related to this policy statement:

- Policy Statement PS-ANE-33.89-1, "Policy for Turbofan, Turbojet and Turboprop Engine Rotor Lock," provides policy for screening engine rotor lock or rotor drag conditions when demonstrating compliance to 14 CFR part 33 airworthiness standards.

Background

1. **Defining Rotor Lock.** Rotor lock is a transient temporary thermal condition where (1) an engine's core rotor speed decreases to zero following an in-flight shutdown or engine flame out; and (2) the core rotor will not rotate during a subsequent windmill or assisted start attempt. Another condition, called "rotor drag," caused by engine accessory loads or rotor/stator high friction contact from loss of clearances, slows engine rotor speed during a windmilling situation. Both rotor lock and rotor drag can prevent a successful restart of a windmilling engine. The presence of rotor lock or rotor drag characteristics, or both, that precludes successful restart of an otherwise undamaged engine, would not comply with § 25.903(e), and would be considered unsafe.

2. **Susceptible Features.** When part 25 was codified in the 1960s, airplane engines had adequate all-engines restart capability and the airworthiness regulations were satisfactory in this respect. Features incorporated in the later technology engines (such as high bypass ratios, compressors with higher operating pressures, new technology burners, and optimized operating schedules affording smaller stall margins) reduced the altitude and airspeed envelope for engine in-flight starting performance when compared to the turbojet engines of the 1950s and 1960s. Since then, there have been numerous all-engines power loss events due to several different causes and reoccurring situations of flight crews having difficulty rapidly restarting engines from an all-engines-out condition. As core bypass ratios of newer engines continue to increase, higher airspeeds are generally required to enable unassisted windmill restart. The inertial effects because of the increased size, mass, and number of engine gearbox driven accessories may also contribute to increased rotor drag loads, decreased starting performance, and possibly contribute to rotor drag and rotor lock conditions. The engine's high pressure compressor rotor, or core rotor, is the only currently known rotating component of two- or three-rotor systems that slows and stops rotating during flight. Future engine designs may have different behavior.

3. **NTSB Recommendations.** In October 2004, an airplane accident occurred on a non-revenue flight. The National Transportation Safety Board (NTSB) accident investigation concluded that, among others, one of the probable causes of the accident was the pilots' improper management of the double-engine-failure checklist, which allowed the engine core rotor to stop rotating and resulted in an engine core rotor lock condition. The NTSB also cited engine rotor lock as a contributing factor (reference NTSB Accident Report NTSB/AAR-07/01 dated January 9, 2007). The NTSB issued safety recommendations (reference NTSB safety recommendations A-06-70 through A-06-76 published on November 20, 2006) as a result of this accident to specifically address engine rotor lock. Those safety recommendations requested that the FAA require airplane manufacturers to evaluate if engines are susceptible to rotor lock. If so, the airplane manufacturer should provide procedures in the airplane flight manual (AFM) to both alert the flight crew of the potential for rotor lock and to prevent rotor lock from occurring. In addition, the NTSB recommended that the FAA require certification tests to evaluate for rotor lock susceptibility and to require airplane manufacturers provide design or operational means to ensure restart capability if an engine is shown to be susceptible to rotor lock during the type certification process.

4. **FAA Actions.** In response to these recommendations, this policy statement describes a method for screening engine installations for potential rotor lock so that engines can successfully restart when engine power is lost and the engine rotor(s) stop, or are slowed, due to friction or accessory drag. Sections 25.903(e) and 25.1351(d) require restart capability; rotor lock and rotor drag conditions have only recently arisen as issues that can prevent a successful restart of a windmilling engine. The intent of § 25.903(e) includes the hazards associated with engine rotor lock and rotor drag and the effects they may have on engine restart capability from an all-engines-windmilling condition by requiring the ability to restart any engine in flight. Currently, there are no published advisory circulars or other guidance material addressing engine rotor lock or rotor drag

and their effect on engine restart capability. In light of this new knowledge, standardized, documented, and acceptable means of compliance are needed to evaluate susceptibility of an engine rotor lock or rotor drag condition when demonstrating compliance to § 25.903(e). Note that there are additional airworthiness requirements for other all-engines-out situations, such as § 25.671(d) for flight control systems, that are independent of this policy statement.

Relevant Past Practice

In 1995, the Transport Airplane Directorate developed an issue paper addressing loss of all-engines thrust/power and all-engines restart. That issue paper was used as the basis for an Aviation Rulemaking Advisory Committee recommendation. Because § 25.903(e) lacks specific compliance demonstration requirements for all-engines-out restart capability, the criteria presented in the issue paper provided a means of compliance to evaluate potential unsafe conditions per § 21.21(b)(2). Since then, the issue paper has been applied to all new engine installation certification and major engine installation design changes for transport-category airplane programs. The issue paper identifies three specific conditions that should be included to show acceptable engine restart performance:

1. Low altitude, low airspeed, high power, fuel supply interrupt, all-engines-out condition,

2. High altitude, windmilling all-engines-out drift down condition, providing for a cold-soaked engine, and

3. A windmilling all-engines-out condition at low airspeed and 20,000 feet.

At that time, engine rotor lock or rotor drag and their potential impact on all-engines-out windmilling restart capability were not a known safety concern.

Following the NTSB investigation of the accident noted above, and the resultant safety recommendations to address engine rotor lock, the FAA contacted the Aerospace Industries Association (AIA) for assistance in gathering service history from engine and airplane manufacturers. The FAA was interested in information regarding ground and flight engine rotor lock events and related experience. In response to the FAA's request, the AIA formed the Rotor Lock Study Group. The FAA reviewed the information and recommendations provided by the group. At the same time, the FAA also generated an issue paper for airplane certification projects that included a compliance screening test for engine rotor lock susceptibility. The information in that issue paper was based on the details of the accident investigation and initial information provided by the AIA Rotor Lock Study Group. The guidance in the issue paper was used in two airplane certification programs, but lacked the appropriate test condition definition to adequately address the hazard associated with rotor lock preventing or delaying engine restart capability from an all-engines-windmilling condition. The all-engines-out restart capability issue paper was also revised so that rotor lock and rotor drag conditions were considered when conducting windmilling engine restart investigations, but no specific compliance criteria were provided.

During the AIA discussions, some airplane manufacturers stated they had experienced engine rotor lock conditions during their production acceptance flight tests for certain certified airplane models. In two instances, the airplane manufacturer implemented a rotor lock screening test on each airplane. If rotor lock occurred during the screening test, the airplane manufacturers performed an in-flight grind-in procedure. The procedure had been shown to eliminate the potential for rotor lock and was satisfactorily demonstrated by continued production acceptance flight tests. The rotor lock screening test and, if necessary, an in-flight grind-in procedure, was conducted on each engine until the engine manufacturer implemented a design change. Further, one of the airplane manufacturers had established a practice of screening for rotor lock susceptibility on each new engine type certificated for its airplanes, including major engine design change programs.

Policy

Engine rotor lock is a separate issue from the comprehensive all-engines-out restart demonstration; however, the two issues are related because if engine rotor lock occurs during specific conditions following an all-engines power loss, the affected engine or engines cannot be restarted. These two issues have been addressed by separate issue papers. The guidance in this policy statement supersedes the information in the existing “Engine Rotor Lock Evaluation” issue paper. The issue paper for all-engines-out restart capability will continue to be in effect to ensure that an aircraft will not be certified with an unsafe design feature or characteristic, in accordance with § 21.21(b)(2), until the FAA decides to initiate and issue a rulemaking action.

1. **Compliance Methods.** The applicant must show compliance with § 25.903(e) by establishing an in-flight restart envelope using all relevant methods for in-flight restart (e.g., windmill, engine cross-bleed, auxiliary power unit assisted, and/or electric starter assisted) and by establishing that each engine has the capability to restart within that envelope. The rotor lock screening test is one acceptable means to substantiate that the installed engine is capable of being restarted within the certified restart envelope, after experiencing a set of critical conditions intended to evaluate an installed engine’s susceptibility to engine rotor lock and rotor drag. The rotor lock screening test is not intended to demonstrate that an engine can be restarted after experiencing damage from a failure that is independent from the inherent design causes of rotor lock or rotor drag described earlier (e.g., engine high pressure fuel pump failure), which would in and of itself have precluded a successful restart.

   Only one engine representative of the entry-into-service condition and conforming to the installed type design needs to be subjected to the rotor lock compliance screening test. The flight test conditions used to screen for rotor lock should be conducted prior to any abusive engine testing that may rub-in or increase clearances between the rotating and static structure of the test engine beyond that experienced during routine engine operation anticipated in-service. The condition of the components of the engine installation that may affect rotor lock or rotor drag should be representative of the critical case. A given engine should only be subjected to the rotor lock compliance screening test once due to the inherent break-in or rubbing of seals that may occur during the test. If additional tests are conducted, they should be conducted with either a different engine meeting the applicant-defined engine condition or the original test engine should be restored to the pre-test engine condition.

The applicant is encouraged to use results from the part 33 engine rotor lock evaluation, as documented in the engine's installation and operating manuals, to avoid a rotor lock or rotor drag condition. However, a part 25 compliance demonstration is still required due to installation effects, such as nacelle cooling of engine external components, horsepower extraction, bleed air extraction, and ram air effects.

2. **Key Elements to Consider.** A rotor lock compliance screening test is intended to maximize the thermal mismatch between the rotating hardware and static hardware during spool down and thermal cool down and is strongly influenced by the following key elements:

   a. A hot engine shut down (fuel cut-off) following sustained operation at high engine thrust where the engine has reached thermal equilibrium. This provides a high engine internal temperature at the start of spool down.

   b. The altitude when the engine is shut down and during the engine spool down. High altitude results in low-density air entering the engine which should allow for a large thermal gradient between the engine case and engine core rotor as well as reduce the airflow through the engine core. This provides an opportunity for the engine case to cool more quickly than the engine core rotor, which occurs during rotor lock events.

   c. A low airspeed that is a conservative representation of operational conditions, with a safety margin. This airspeed after shutdown should be representative of a reasonably expected pilot's response, not the optimal response, where best glide speed is likely set while the flight crew troubleshoots the emergency for several minutes prior to descending in altitude to restart the engines. This provides a low airflow through the engine core allowing the engine core rotor to quickly reduce speed and increase the opportunity for the engine case to cool more quickly than the engine core rotor.

   d. A time duration at the low airspeed determined by key element c, low airspeed, that allows the engine to cool significantly and the rotor to achieve the minimum windmill rotational speed and potentially come to a full stop. Prior to initiating a restart, allow additional time for the rotor and stator interference to potentially occur.

3. **Detailed Test.** A rotor lock compliance screening test for new engine certifications, or major engine design change programs which directly affect the engine or installation characteristics that may influence rotor lock or rotor drag, should be conducted on the airplane receiving type certification. An applicant should perform a critical point analysis to ensure the factors applied to their engine installation are appropriate (e.g.,

an engine may need more than 10 minutes of operation to thermally stabilize). Applicants may propose an alternative to the screening test described below that includes the factors described above.

The rotor lock compliance screening test should include the following procedures:

Step 1. After a minimum of 10 minutes of operation with the test engine at the maximum declared climb rating, typically maximum continuous thrust (MCT), and at the maximum certified altitude (service ceiling) and the maximum achievable airspeed at or below the maximum operating speed (or V_{MO}/M_{MO}, as defined by § 25.1505), using non-test engine thrust as required to maintain target airspeed throughout this screening test, perform a fuel chop (fuel cut-off) on the test engine by rapidly moving the throttle lever to the off position.

Step 2. Minimize altitude loss (drift-down) using the non-test engine thrust, as required, and reduce airspeed to the best glide airspeed (commonly known as maximum lift-to-drag ratio or max L/D) minus 10 knots (or lower airspeed, if a lower airspeed is operationally recommended). The best glide airspeed is determined using the airplane gross weight corresponding to 25% of maximum payload (as defined by § 125.9), plus fuel onboard equal to 45 minutes at normal cruising fuel consumption. The flight test airplane will use the appropriate amount of fuel as payload to ensure flight test safety requirements are met. If additional fuel is needed then the calculated speed is maintained and the time to reach the engine windmill restart envelope should be adjusted to account for the additional weight.

Step 3. Maintain the target airspeed defined in step 2 and descend to the engine windmill or starter assist restart envelope defined in the AFM. (Note: If normal airplane instrumentation, or any other airplane data source that reliably indicates engine rotation (e.g., electrical generator output or flight test instrumentation), shows that the engine is still rotating (i.e., positive rotation) after descending at the target airspeed to the top of the engine windmill or starter assist restart envelope, one can assume that rotor lock will not occur.) At the top of the restart envelope, begin acceleration to the minimum windmill or starter assist restart envelope airspeed using the non-test engine thrust as required to maintain altitude.

Step 4. After reaching the minimum windmill or starter assist restart airspeed, restart the test engine following the AFM procedure.

4. **Avoid Damage.** To avoid undue damage, use the following precautions:

   a. Accelerate the airplane slowly from the low airspeed condition (i.e., best glide speed minus 10 knots). This is particularly important if the core rotor is not rotating.

   b. Do not perform repeated starter-assisted start attempts if rotor lock is present.

5. **Reporting Results.** If rotor lock, rotor drag, hung start, or any condition adversely affecting restart capability is encountered during the applicant's engineering or certification testing, the applicant must provide actions to mitigate the issue in accordance with § 25.903. The FAA certification office should report this and the applicant's proposal to address the issue to the Transport Airplane Directorate Standards Staff. The factors leading to the adverse condition and the effects on restart capability will indicate what actions may be appropriate. Some issues to consider that may indicate the need for additional action include:

    - The severity/duration of the rotor lock-up, rotor drag, hung start, etc.,
    - Airspeed at which zero core rotation speed is achieved,
    - Delay and reliability of achieving restarts, and
    - Any unexpected engine damage identified through borescope inspections.

    Potential actions to mitigate adverse conditions that result in rotor lock include, but are not limited to:

    - Incorporate engine and/or installation design changes,
    - Developing an in-flight or uninstalled engine seal grind-in procedure,
    - Procedures to reduce drag from accessories,
    - Use of starter-assist, if available in an all-engines-out condition (e.g., electrical starter with sufficient battery capacity), and
    - Mandatory minimum airspeed operational limitations and procedures, possibly in combination with other mitigating actions, such as flight crew indications that will ensure limitations are not exceeded.

    Newly built and overhauled engines that are delivered to airlines as spare engines should be considered when developing mitigating actions. An in-flight engine seal grind-in procedure may not be able to address these engines.

    A subsequent rotor lock screening test may be required to demonstrate that mitigating actions have been successful.

As stated above, this policy only applies to new engine installation certifications, or major engine installation design change programs for transport-category airplanes.

Effect of Policy

The general policy stated in this document does not constitute a new regulation. Agency employees and their designees and delegations must not depart from this policy statement without appropriate justification and concurrence from the FAA management that issued this policy statement. The authority to deviate from this policy statement is delegated to the Transport Standards Staff Manager.

Whenever a proposed method of compliance is outside this established policy, the project aircraft certification office must coordinate it with the policy-issuing office using an issue paper. Similarly, if the project aircraft certification office becomes aware of reasons that an applicant's proposal that meets this policy should not be approved, the office must coordinate its response with the policy-issuing office. Applicants should expect that the certificating officials will consider this information when making findings of compliance relevant to new certificate actions. In addition, as with all guidance material, this statement of policy identifies one means, but not the only means, of compliance.

Implementation

This policy discusses compliance methods that should be applied to type certificate, amended type certificate, supplemental type certificate, and amended supplemental type certification programs. The compliance methods apply to those programs with an application date that is on or after the effective date of the final policy. If the date of application precedes the effective date of the final policy, and the methods of compliance have already been coordinated with and approved by the FAA or its designee, the applicant may choose to either follow the previously acceptable methods of compliance or follow the guidance contained in this policy.

Conclusion

Based on the number of all-engines power loss events and flight crew difficulty with restarting engines combined with the new knowledge of engine rotor lock and rotor drag, the FAA has concluded that it is necessary to provide specific guidance concerning the effects of engine rotor lock and rotor drag on the capability to restart an engine from an all-engines-windmilling condition after a rapid engine shutdown. If other data is presented that demonstrates otherwise, the intent and content of this policy will be reconsidered.

/s/ Jeffrey E. Duven

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Attachment

Terms
Table A-1 defines the use of key terms in this policy statement. The table describes the intended functional impact.

Table A-1 Definition of Key Terms

	Regulatory Requirements	**Acceptable Methods of Compliance (MOC)**	**Recommendations**
Language	Must	Should	Recommend
Meaning	Refers to a regulatory requirement that is mandatory for design approval	Refers to instructions for a particular MOC	Refers to a recommended practice that is optional
Functional Impact	No Design Approval if not met	Alternative MOC has to be approved by issue paper.	None, because it is optional