Certification Authorities for Large Transport Aircraft (CATA)

CATA Worklist Item TCCA-002 – In-Flight All-Engines-Out Restart Guidance

Date Raised:	Sept. 27/2016	Updated: N/A	Status:	**Closed**
Date Revised:	July 31 2020			
Subject:	**In-Flight All-Engines-Out Restart Guidance**			
Related Issue(s): (Identify Discussion Paper number, if any)	None			

Description of Issue(s):
(Give a brief background of issue(s)

The IPs/CRIs developed for in-flight restart testing have been mostly stable over the past decade or more, with similar methods of compliance identified and recognized for numerous projects. However, recent experience, especially as a result of Human Factors Engineering, has identified possible shortcomings in the fuel interrupt test requirements currently specified in the CMT authorities' IPs/CRIs for FAR/CS/AWM(5)25.903(e).

While the requirements are the same, the interpretation differs and as such the contents of the IPs and CRIs differ between authorities. The use of differing IPs/CRIs should not continue and the authorities need to develop harmonized advisory/guidance material for use by industry.

It is noted that the CATA working group SMEs subsequently discussed and agreed that for completeness, the description of the issue of this CWI needs to include the following:

A complete loss of power of all engines occurs infrequently, but the results can be catastrophic if the engines cannot be restarted. Transport airplane airworthiness standards require the means to restart any engine in flight and require that an altitude and airspeed envelope be established for engine in-flight restarting. However, these airworthiness standards lack specific compliance demonstration requirements for all-engines-out restart capability. The inability to restart the engines in the event of an all-engines-out condition is an unsafe feature or characteristic that could preclude certification because the total thrust loss can lead to a forced landing.

Background:

FAA and EASA have specific Issue Paper/CRI which cover in-flight engine restarts.

The TCCA Issue Paper attempts to cover both EASA and FAA interpretations of the rules. There are common topics within the IPs/CRI such as all-engine power loss at various engine and flight conditions (e.g. power settings, altitudes, speeds, electrical power), and there is a specific requirement to perform fuel interrupt tests ("quick-relights") at a high power setting representing the take-off / climb phase.

One example where there are inconsistencies between the IP/CRIs is in the area of quick-relight tests. Examples of differences are listed below:

1) Fuel interrupt duration:
    a) Requirements have varied across the authorities and certification programs; typically the IP/CRIs have used between 5 – 15 sec and often with the constraint of not less than 5 sec;
    b) Evaluation of pilot response times and human factor considerations should be used in determining appropriate fuel interrupt times;
    c) A pilot/human factors assessment may yield potential for a fuel interrupt < 5 sec. Note that outside of a pilot induced shutdown, modern FADEC equipped engines incorporate auto-relight logic for flame out detection / prevention; and

   d) Aircraft speed: low altitude tests can vary from V2+10kts to Vfto.
2) Initial altitude: low altitude tests, typically at the end of initial take-off portion, > 1500ft; and
3) Altitude loss: can vary from having no requirement to a requirement of less than 1500ft to less than 2500ft.

Furthermore, a common approach to define fuel interrupt test criteria at engine and airframe level is needed to avoid potential issues during Part 25 certification (i.e. common engine/airframe requirements which then drive the FADEC SW logic & implementation).

Proposed Prioritization:

(Per CATA Technical Issues List Prioritization schema)

Question	Answer
1. Is there an active working group related to this issue?	No
2. In which documents are there deviations amongst the authorities?	Deviations are in the published Issue Papers/CRIs
3. Was this issue raised by or at the CMT?	No.
4. What is the level of impact on projects in the future (i.e. minor, major, critical)?	Major; historical issues with domestic certifications and foreign validations have taken up significant time and effort.
5. How many authorities does the issue impact?	Issue impacts all 4 authorities
6. What is the approximate technical complexity of the issue (i.e. low, medium, high)?	Medium complexity.

Recommendation:

CATA to seek CMT endorsement to create an authority/industry working group to develop an Advisory Circular/Material to address the complete scope of 25.903(e) for In-Flight Restart.

CATA Decision:

(Using CATA criteria for determination of technical issues)

CATA decision to action this issue. Authorities' SMEs consensus that topic deserved CATA attention. CATA to establish a working group to develop harmonized CRI/IP/CM/FCAR. This is viewed as a near-term achievable goal. Longer-term goal of updating the regulation has value, but is outside current scope of this CWI.

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Final CATA Position:

(Explain agreement, dissent or conclusion on this IP)

The CATA accept the SME team's recommendation and proposed guidance paper. The guidance paper is appended directly to this CWI.

This CWI represents an agreement that the guidance paper is harmonized and accepted by all CMT authorities.

The CWI form, including the appended guidance, document a CMT member authority agreement that member authorities may reference when they are acting as the certificating authority (CA). Following CA endorsement for a particular project, the other CMT member authorities, when acting as validating authority, will accept the approach.

If any member-authority under CATA becomes aware of circumstances that make it apparent that following the guidance paper would not result in compliance with the member-authority's applicable airworthiness standards, then the use of this guidance paper is non-binding and the member-authority may require additional substantiation or design changes as a basis for finding compliance.

This CWI is closed.

CATA Signatures:

CATA Representative	Name	Signature	Date
ANAC	Daniel Pessoa	Daniel	Assinado de forma digital por Daniel DN: cn=Daniel, o=ANAC, ou=GGCP, email=daniel.pessoa@anac.gov.br, c=BR Dados: 2020.08.17 15:52:15 -03'00'
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EASA	Colin Hancock	Hancock Colin	Digitally signed by Hancock Colin Date: 2020.08.18 12:19:21 +02'00'
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FAA	Tom Groves	THOMAS E GROVES	Digitally signed by THOMAS E GROVES Date: 2020.08.07 12:51:35 -07'00'
	Suzanne Masterson	Suzanne Masterson	Digitally signed by SUZANNE A MASTERSON Date: 2020.08.07 12:11:38 -07'00'
TCCA	Canh Nham	[signature]	Digitally signed by Nham, Canh Date: 2020.08.18 12:42:51 -04'00'

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Attachment to CWI TCCA-002 – Guidance Paper

1 SUBJECT.

In-Flight All-Engines-Out Restart.

2 STATEMENT OF ISSUE.

A complete loss of power of all engines occurs infrequently, but the results can be catastrophic if the engines cannot be restarted. Transport airplane airworthiness standards require the means to restart any engine in flight and require that an altitude and airspeed envelope be established for engine in-flight restarting. However, these airworthiness standards lack specific compliance demonstration requirements for all-engines-out restart capability. The inability to restart the engines in the event of an all-engines-out condition is an unsafe feature or characteristic that could preclude certification because the total thrust loss can lead to a forced landing. This document proposes safety objectives and describes an acceptable method for demonstrating that an unsafe feature or characteristic does not exist on the applicant airplane. This document does not address single-engine restart capability with other engines operating or validating the manufacturer's defined in-flight single-engine restart envelope.

3 APPLICABILITY.

3.1 This document proposes safety objectives and provides guidance on acceptable means of compliance to establish that the potential unsafe feature or characteristic of inability to restart the engines in the event of an all-engines-out condition does not exist on the applicant airplane.

3.2 The content of this document does not change or create any additional regulatory requirements, nor does it authorize changes in, or permit deviations from, regulatory requirements.

4 BACKGROUND.

4.1 Design Evolution History.

4.1.1 Early Turbine Engine Designs.

When the existing transport airplane airworthiness standards were developed in the 1960s, transport airplane engines had adequate all-engines restart capability and the airworthiness regulations were satisfactory in this respect. At that time, turbofan engines were still relatively new and had low bypass ratios, essentially 1:1 and had similar in-flight restart characteristics of turbojet engines. The ability of those engines to windmill, or continue to rotate from airflow through the engine created by forward speed and unassisted by mechanical means, covered nearly the entire airspeed and altitude operational envelope. As a result, the "windmill" restart envelope was relatively large, and a level of safety was established where any engine had the capability to restart in a large portion of the airplane's flight envelope without requiring a specifically defined restart envelope.

4.1.2 Later Turbine Engine Designs.

Since then, the evolution of technology to improve fuel efficiency has increased the bypass ratio of turbofan engines higher, as much as 12:1 on some engines. The high bypass ratio engines generally require higher airspeeds to provide enough airflow through the engine to create sufficient windmilling rotational energy for an unassisted engine restart. Additional features incorporated in the later technology engines, such as compressors with higher operating pressures, new technology burners, and optimized operating schedules affording smaller stall margins, have also reduced the altitude and airspeed of the "windmill" restart envelope. As a result, the "windmill" restart envelope has decreased significantly. Some manufacturers have proposed airspeeds approaching dive speeds of their airplane to conduct an unassisted engine start.

4.2 Design Features to Increase In-Flight Engine Restart Capability.

Engine manufacturers recognize the need to maintain an adequate "windmill" restart envelope and have incorporated features into their engine designs such as improved fuel scheduling, compressor bleeds, and rotational drag reduction schemes to maintain engine "windmill" restart capabilities.

4.3 Different Methods to Restart an Engine in Flight.

An assisted restart may utilize a pneumatic, hydraulic, electrical, or cartridge to power a starter that will assist in rotating the engine enough to start it. The air for a pneumatic starter typically comes from another operable engine or an in-flight operable auxiliary power unit (APU). An engine accessory generator, an APU, batteries, a ram air turbine (RAT) or a combination of these sources can provide electrical power for an electric starter. Some airplane installations use hydraulic starters, which require an onboard hydraulic source, and a few use start cartridges (although uncommon in modern designs).

4.4 Service History.

There have been numerous all-engines power loss events due to several different causes and reoccurring situations of flightcrews having difficulty rapidly restarting engines from an all- engines-out condition. A significant number of incidents of all-engines flameouts or shutdowns on transport category airplanes continue to occur. These incidents occurred for a number of reasons including fuel mismanagement, loss of electrical power, flightcrew error, fuel contamination, mistrimming of engine idle setting, selection of propeller pitch in the beta range, fuel nozzle coking, volcanic ash encounters, or inclement weather. Some of these events had catastrophic results. Many of these incidents resulted in airworthiness directives to incorporate airplane limitations and associated procedures in the AFM, as well as airplane and engine design changes to ensure in-flight restart capability. Flightcrew awareness of the in-flight engine restart envelope and the engine operating conditions is critical to conducting a successful engine restart in flight.

4.5 Guidance Evolution.

The proposed safety objectives and means of compliance in this document has evolved from guidance developed from project specific guidance over many years. This includes the guidance proposed by the Aviation Rulemaking Advisory Committee report[1]. The harmonized guidance in this document is derived from extensive CATA member-authority experience in determining compliance with the applicable airworthiness standards, and in ensuring that the potential unsafe feature or characteristic of a complete loss of power on both engines is appropriately addressed.

5 SAFETY OBJECTIVES.

The following are proposed safety objectives for demonstrating that an unsafe feature or characteristic does not exist on the applicant airplane.

5.1 Demonstrate All-Engines-Out Restart Capability.

The applicant must show by test and analysis, following the flameout or shutdown of all engines, the design has the means to restart all engines and recover thrust or power for continued safe flight and landing.

5.2 Provide Minimum Number of Starts Capability.

The applicant should provide the means and capability for the airplane design to have at least two start attempts per engine. The applicant may rely on one, or more, relevant methods to provide two start attempts per engine.

6 AN ACCEPTABLE MEANS OF COMPLIANCE.

The applicant should use the following as an acceptable means of compliance to demonstrate the safety objectives of section 5. The applicant may use one, or more, relevant methods to show the design's in-flight engine restart capability.

6.1 Potential Restart Methods for In-flight Engine Restart and Capability Requirements for Each Method Used.

If the applicant finds that a restart method or procedure is required to meet any of the test scenarios in Section 6.4.6, then the capability to provide that method or procedure is required.

[1] Powerplant Installation Harmonization Working Group report addressing 25.903(e), In-flight Starting, dated March 8, 2000.
https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAEpihT7-09231998.pdf

6.1.1 Windmilling.

The requirements for windmilling restart capability are described in each applicable test scenario. If windmilling is not described in the scenario, it is not an applicable method for meeting all requirements and demonstrating all-engines-out in-flight engine restart capability for that scenario.

6.1.2 Rapid Restart.

A rapid restart, sometimes referred to as a rapid relight, quick relight or quick windmill restart, is any non-assisted in-flight start that is manually commanded following an in-flight shutdown before the engine has reached stabilized windmilling conditions. This does not include auto-restart or auto-relight features of engine control systems that function without flightcrew action. The requirements for rapid restart capability are described in each applicable test scenario. If rapid restart is not described in the scenario, it is not an applicable method for meeting all requirements and demonstrating all-engines-out in-flight engine restart capability for that scenario.

6.1.3 Battery Considerations.

If battery power is used to supply power for an electrical starter, the following conditions should be met:

6.1.3.1 Establish and validate minimum capacity reliability by flight test within critical portions of the flight envelope,

6.1.3.2 The AFM must include the means to assure that the required battery capacity is available at dispatch,

6.1.3.3 The applicant should define a battery maintenance program to ensure the battery capacity value does not fall below the certified value when the airplane operates in service. Any features of the maintenance program that are critical to ensuring minimum battery capacity should be identified as certification maintenance requirements that maintain the long-term battery capacity reliability. The airplane maintenance manual should clearly identify and include any associated limits.

6.1.3.4 The authority will evaluate the master minimum equipment list (MMEL) dispatch considerations with reduced battery capacity and without the contribution of the APU generating capability. Should reduced battery capacity contribute to an unsafe condition, then the associated battery limits must be established to preclude the possibility of an MMEL from contributing to an unsafe condition, and

6.1.3.5 Unless otherwise specified, the applicant should demonstrate a minimum capability of two in-flight restart attempts of each engine after complete loss of engine power and electrical generating power.

6.1.4 Ram Air Turbine (RAT) Considerations.

If the applicant finds that use of a RAT is required to provide power to meet any of the test scenarios in Section 6.4.6, the following conditions should be met:

6.1.4.1 The applicant should propose and demonstrate a minimum RAT reliability that supports emergency electrical sources availability prior to each flight,

6.1.4.2 The applicant should establish a minimum RAT deployment, from the stowed position until capable of providing minimum functions, and substantiate by flight test with a minimum of two RATs to develop the deployment reliability database,

6.1.4.3 The applicant should define a RAT maintenance program to ensure that the RAT deployment reliability does not fall below the certified value when the airplane operates in service. Any features of the maintenance program that are critical to ensuring minimum RAT deployment reliability should be identified as certification maintenance requirements that maintain the long-term RAT deployment reliability, and

6.1.4.4 The authority will evaluate the MMEL dispatch considerations with the RAT inoperative. The applicant should implement type design limitations, as necessary, to prevent the MMEL from contributing to an unsafe condition.

6.1.5 APU Considerations.

If the applicant finds that use of the APU is required to provide power to meet any of the test scenarios in Section 6.4.6, the following conditions should be met:

6.1.5.1 The applicant should classify the APU as essential.

Note: Extended Operations (ETOPS) requirements for APU installations are independent from classifying an APU as essential for the purposes of using the APU to support all-engines-out in-flight engine restart capability.

6.1.5.2 The applicant should either:

- Require APU operation during the entire flight, or
- Demonstrate a minimum APU start reliability (validated by flight test) and evaluate operation of the APU within critical portions of the flight envelope.

6.1.5.3 An APU reliability demonstration should include the following:

- A minimum APU start reliability of 95 percent is acceptable,
- Substantiated with actual in-flight start testing,

- A minimum of two APUs are used to develop the start reliability database,
- Start testing following cold-soak cruise conditions,
- A maximum of two APU start attempts

Note: The first start attempt allows cold oil and hardware of a cold-soaked APU to warm. The first start attempt may mitigate the effects of cold oil and hardware and allow a successful start on the second attempt. Relatively new APU hardware should not need more than two attempts to demonstrate a successful start for type certification testing. Once in service, an operator may attempt as many starts as the APU operation instructions allow.

6.1.5.4 The applicant should account for any automatic starting features of an APU installation that will reduce flightcrew workload and contribute to APU start reliability.

6.1.5.5 The applicant should define an APU maintenance program to ensure the APU start reliability does not fall below the certified value when the airplane operates in service. Any features of the maintenance program that are critical to ensuring minimum should be identified as certification maintenance requirements that maintain the long-term APU start reliability, and

6.1.5.6 The authority will evaluate the MMEL dispatch considerations with the APU inoperative. The applicant should implement type design limitations, as necessary, to prevent the MMEL from contributing to an unsafe condition.

6.1.6 Start Cartridges.

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

6.2 Flight Deck Indications.

The applicant should account for any indications on the flight deck that provide additional awareness to the flightcrew. This may include the following:

6.2.1 Engine Non-Normal Conditions.

Providing flightcrew awareness of an engine flameout or sub-idle engine.

6.2.2 Engine Restart is Clearly Progressing.

Providing the flightcrew awareness that the start is clearly progressing normally, showing the flightcrew that the engine has reached idle or selected power setting.

6.2.3 Awareness of In-flight Engine Restart Envelope.

The applicant should perform a human factors evaluation to determine whether situational awareness is adequate or if visual means is necessary to assure the flightcrew will initiate the correct procedures within the in-flight engine restart envelope.

6.2.4 Automatic Limit Adjustments on Indications.

Other considerations may include if there are specific engine limits for in-flight starting that are automatically adjusted on the flight deck displays during the starting sequence.

6.2.5 Human Factors Substantiation of Flightcrew Awareness.

The applicant should use a human factors evaluation to substantiate that a reasonable flightcrew will reliably interpret the flight deck indications during an all-engines-out scenario and subsequent in-flight engine restart.

6.3 Airplane Flight Manual (AFM).

The applicant should include all limitations and procedures necessary to enable continued safe flight and landing following an all-engines-out condition in the AFM.

6.3.1 Differences from single-engine-out in-flight engine restart envelope.

The applicant should identify in the AFM any differences in all-engines-out restart capability from single-engine-out restart capability, if any. This may include differences from the following, if applicable:

6.3.1.1 A “windmill restart envelope” based on nominal engine restart time,

6.3.1.2 If an “extended windmill restart envelope” is implemented, provide appropriate awareness to the flightcrew, such as noting areas of the envelope where longer restart times may apply and what indications show that the engine start is clearly progressing,

Note: A potential example of this is when a hydraulic engine driven pump (EDP) depressurization valve is not available,

6.3.1.3 An “assisted restart envelope” if starter assist is utilized,

6.3.1.4 A “rapid restart envelope,” “quick windmill restart envelope,” or “quick relight envelope” if applicable,

6.3.1.5 Appropriately labeled differences for “assisted” and “unassisted” regions and including additional areas if the applicant chooses to include “rapid restart” or “quick windmill restart” envelopes.

6.3.2 Limitations to All-Engines-Out Restart Capability.

The applicant should identify any specific limitations to all-engines-out restart capability in the AFM. This may include, but is not limited to, the following, if applicable:

6.3.2.1 Limitations on applicable in-flight engine restart methods, such as “windmilling” when at very low altitudes,

6.3.2.2 Limitations on available in-flight engine restart attempts, such as limited battery power following the loss of normal electrical power,

6.3.2.3 Limitations on maximum flightcrew delay or other limiting conditions prior to initiating a “rapid restart,” if applicable,

6.3.2.4 Any mandatory minimum airspeed operational limitations and procedures intended to preclude rotor lock conditions. There should be means, such as flightcrew indications, that will provide awareness to the flightcrew of their proximity to the limitations and necessary actions, if any, and

6.3.2.5 Limitations if the airplane does not have the capability to start more than one engine at the same time.

6.3.3 Procedures for All-Engines-Out Non-Normal Conditions.

The applicant should identify any specific procedures for restarting engines during all-engines-out conditions in the AFM. This may include, but is not limited to, the following, if applicable:

6.3.3.1 All applicable methods used by the applicant to demonstrate all-engines-out in-flight engine restart capability,

6.3.3.2 An immediate restart procedure,

6.3.3.3 If necessary, the specific airspeed the flightcrew must accelerate the airplane to within the envelope to achieve restart that minimizes altitude loss while maximizing the likelihood of successful restart,

6.3.3.4 Procedures to preclude the flightcrew from unknowingly exhausting the battery capacity required for successful restarts and the remaining flight should the restart attempts be unsuccessful, and

6.3.3.5 Failures occurring at low altitude where the flightcrew has limited time to address the failure before it becomes necessary to prepare for a forced landing.

6.4 Flight Test Demonstration and Analysis.

The applicant should conduct flight tests to substantiate the means to restart an engine in flight following flameout or in-flight shutdown of all engines.

6.4.1 Airplane Configuration for Test.

The applicant should demonstrate all-engines-out in-flight engine restart capability by simulating the all-engines-out condition when testing one engine. Only the aircraft systems available in an actual all-engines-out situation should be used to support the restart of the engine under test. The applicant should adhere to flight test safety standards.

6.4.2 Test Engine and Engine Installation.

The following describe the condition the engine should be in when used for testing.

6.4.2.1 *Representative Engine*.

The test engine and installation should be representative of the final type design. The applicant should justify and support by test and analysis that any deviations from the final configuration do not influence in-flight engine restart characteristics.

6.4.2.2 *Undamaged Engine.*

The in-flight engine restart evaluation is not intended to demonstrate that an engine can be restarted after experiencing damage from a failure (e.g., engine high pressure fuel pump failure) that is independent from the causes of engine shutdowns described earlier (e.g., volcanic ash, inclement weather, fuel mismanagement or fuel contamination), which would in and of itself preclude a successful restart.

6.4.2.3 *Only One Engine Tested at a Time per Condition.*

The applicant should test only one engine at a time and simulate the all-engines-out condition on the remaining engines and affected airplane systems.

6.4.2.4 *Repeat Test Condition on Different Engines.*

The applicant should use at least two different engines for testing restart capabilities, with the exception of scenarios where it states only one engine test is necessary. This is to account for engine-to-engine variation and difficulty in accurately predicting in-flight engine restart characteristics. Testing at least two different engines helps account for some of the uncertainty and adds significant confidence that the test results are representative of the type design.

6.4.2.5 *Engine Accessory Loads and Other Design Features.*

The applicant should account for engine accessory loadings and design features that automatically disengage accessories following an engine shutdown. These types of features may reduce in-flight engine restart times. Conversely, the engine and installation should not have design features that prevent restart or intentionally delay the restart sequence, such as engine controlled cool-down times, or engine controlled rotor speed decrease to a specific value.

6.4.3 Critical Point Analysis.

The applicant should conduct a critical point analysis to identify if the specific test conditions for each scenario are critical for their airplane design and adjust the test points as necessary to evaluate the most critical condition. This method derives critical test points from the collection and analysis of data on parameters that influence in-flight engine restart capability. The applicant should submit the results of the critical point analysis for authority review and concurrence prior to the applicant conducting the test scenarios.

6.4.3.1 Based on experience, the potential factors influencing in-flight engine restart capability, include, but are not limited to the following:

- Initial altitude of all-engines-out condition,
- Airspeed,
- Engine temperature,
- Engine power setting or rotor speed (accounting for different power ratings, if applicable),
- Engine oil temperature,
- Fuel tank temperature,
- Fuel type (this may be critical if fuel pressure is lost in an all-engines-out event),
- Dispatch allowance, such as engine ignitor or EDP depressurization valve configuration,
- Normal engine wear and deterioration, (e.g., compressor blade tip clearance changes, engine ignitor deterioration),
- Engine accessory loads during all-engines-out conditions,
- Airplane systems configuration during all-engines-out conditions, and
- Cold-soak effects.

Note: Cold-soak effects may be more critical for single-engine-out restarts since the duration before an in-flight engine restart is attempted could be very long or for engine rotor lock conditions due to potentially longer engine shutdown times than the test scenarios in Section 6.4.6. Refer to guidance in FAA AC 25-7D for further guidance on cold-soak restarting. Refer to FAA policy statement PS-ANM-25-02 and CATA Worklist Item TCCA-003 for further guidance on engine rotor lock.

6.4.4 Engine Restart Time.

The engine must achieve the appropriate engine power setting following restart to enable continued safe flight and landing. The following general engine restart requirements should be accounted for in each scenario described in Section 6.4.6, as applicable.

6.4.4.1 *Ignition Time.*

Ignition (also known as light-off) should occur within 30 seconds of the start initiation (the first flightcrew action).

6.4.4.2 *Time to Achieve Required Power Setting.*

The required engine power setting should be achieved in the shortest duration necessary to achieve continued safe flight and landing for each scenario. Achieving the required engine power setting should also occur within a maximum of 90 seconds. A longer time may be acceptable provided the engine achieves the required power setting to enable continued safe flight and landing and that the flightcrew is aware that the engine start is clearly progressing (refer to paragraph 6.2.2). A flightcrew may inadvertently terminate a successful engine start if they do not have adequate evidence the engine start is clearly progressing. This is important for engines that have characteristics where the engine temperature is climbing with no increase in engine speed and the start appears to the flightcrew to be "hung." The applicant may need appropriate notes in the AFM to describe an acceptable engine start progression to the flightcrew.

Note: A dedicated flight deck indication may provide this awareness or the applicant may use a human factors assessment to show that the flightcrew has adequate awareness the engine start is clearly progressing throughout the entire start using normally available flight deck instruments.

6.4.5 Altitude Loss.

Each scenario specifies the allowable altitude loss before thrust is recovered and airplane descent is arrested.

6.4.6 Test Scenarios.

The following scenarios represent the minimum capability necessary to demonstrate an adequate level of safety for in-flight engine restart:

6.4.6.1 Scenario A: High Power and Low Altitude. The applicant should demonstrate that it is possible to restore engine power immediately following an all-engines-out scenario, during take-off and the initial climb-out. The applicant should use any method available (refer to Section 6.1). The intent of this test is to demonstrate an acceptable level of safety by minimizing the time exposure of unrecoverable total thrust loss in the event of a "common cause" total thrust loss (i.e., flightcrew error, unrecoverable compressor stall, etc.) at a combination of high engine power, low airplane speed and low altitude. While flightcrew errors in service have led to this scenario, it is not the only concern. There is still potential for a total thrust loss from an engine stall or environmental encounter where auto-restart features are insufficient and the engines are recoverable through flightcrew action. The airplane should have this capability following an all-engines power loss that occurs at a low airspeed that is operationally representative of the end of the take-off and lower end of the climb portion of flight. This speed is typically the initial climb-out airspeed and for most large transport airplanes is typically V2 +

10 knots. For the purposes of this test scenario, the V2 is defined as the normally scheduled balanced field length V2 for an airplane taking off using the greatest appropriate flap setting. If an applicant proposes a higher airspeed, then the applicant should justify a higher airspeed is representative of the end of the take-off and lower end of the climb portion of flight for the specific airplane under evaluation. The applicant should also justify why it is acceptable not to demonstrate capability for their airplane between the proposed higher airspeed and at V2 + 10 knots. This higher airspeed should not be more than VFTO. The airplane and engine systems supporting engine start should not preclude restart capability during these conditions (e.g., the engine control should not wait for the engine to spool down to idle before allowing restart or otherwise intentionally delay the restart sequence). The applicant should plan the flight test for Scenario A using the following:

6.4.6.1.1 Low airplane speed that is operationally representative of the nominal airspeed at the end of the take-off and lower end of the climb portion of the flight at a conservatively representative operational airplane weight and flap setting (also see 6.4.6.1),

Note: A conservatively representative airplane weight should account for either the longest or shortest anticipated mission plus additional margin, whichever condition is more critical for the airplane design with respect to restart characteristics.

6.4.6.1.2 High engine thrust or power (most critical thrust or power setting during takeoff climb),

6.4.6.1.3 Using the results of the critical point analysis for this scenario (e.g., critical fuel type and temperature from Section 6.4.3),

6.4.6.1.4 Fuel cut-off (sometimes referred to as "fuel chop") to the test engine,

Note: A fuel cut-off or "fuel chop" is a shutdown of the engine by closing a fuel valve at the engine without moving the engine throttle or power lever. A rapid deceleration of the throttle or power lever to either the shutdown position or to idle followed by an immediate shutdown is acceptable if the airplane design does not allow for a rapid engine shutdown by closing a fuel valve, provided the applicant demonstrates that the shutdown procedure is representative of the scenario. There should be no "cool down" period for the engine prior to shutdown.

6.4.6.1.5 The duration of the fuel shutdown should be based on:

- A duration range up to the longest reasonable flightcrew recognition of all-engine power loss and response times,
- Human factors considerations, such as inherent or dedicated flight deck indications of the engine failure or power loss, and
- A range of flightcrew recognition and response times sufficient for demonstrating in-flight engine restart capability should be used in this scenario. Some flightcrews may react in less than 5 seconds; however, experience has shown it is not possible to adequately substantiate that shorter recognition and response times are representative of a reasonably expected pilot's response for this scenario. Therefore, the range of times should be based on human factors considerations and include at least a 5 second test point.
- Note: As described before, the design should not prevent restart from initiating. Therefore, the design should be capable of initiating restart without any delay if a flightcrew reacts in less than 5 seconds.
- The applicant may need to demonstrate multiple delay times if there are features that would make a shorter delay more critical than the longest reasonable flightcrew recognition and response times. For example, inherent restart characteristics of a particular engine may make 3 seconds more critical if it would take longer to recover engine thrust. Therefore, the applicant should demonstrate both conditions.
- If there is a limiting reaction time, above which, the design does not allow restart, the applicant should identify this limitation.

6.4.6.1.6 Restoration of the fuel supply to the engine,

6.4.6.1.7 The test engine should accelerate to the previous power setting,

Note: If the airplane design requires to use the power lever to shut down the engine then it should be moved back to the previous power setting.

6.4.6.1.8 The airplane test altitude should adhere to normal flight test safety standards and still be representative of the scenario. There is no requirement to perform the test at low altitudes above ground level. The applicant should justify that the flight test altitude is appropriate in their certification documents.

6.4.6.1.9 Allowable altitude loss during the airplane test recovery maneuver is based on the airplane design and nominal operational conditions this scenario is based on. Therefore, the altitude loss should not be more than the altitude of an airplane at the nominal airspeed at the end of the take-off and lower end of the climb portion of the flight. For most transport airplanes this is approximately 1500 feet. It may be higher or lower, depending on the airplane design. The altitude loss during the recovery maneuver is measured starting at the altitude where the engine is shutdown. The applicant should propose an allowable altitude loss and provide justification.

6.4.6.1.10 The engine restart time should not exceed the guidance in Section 6.4.4; however, the altitude loss criterion may require a shorter engine restart time than would be accepted using the criteria in Section 6.4.4 alone. The applicant should meet the more limiting criteria between allowable altitude loss and maximum engine restart time.

6.4.6.1.11 The test should be repeated on at least one different engine, preferably a different installation location if possible (refer to Section 6.4.2.4).

6.4.6.2 Scenario B: Cruise Speed and High Altitude. The applicant should demonstrate that it is possible to restart engines necessary to ensure adequate terrain clearance for a majority of the flight paths that the airplane will encounter following an all-engines-out scenario that occurs at cruise speed and maximum altitude. The applicant should use any method available (refer to Section 6.1) that is capable of restarting a stabilized windmilling engine. The applicant should plan the flight test using the following:

6.4.6.2.1 Cruise speed,

6.4.6.2.2 The applicant should use a conservatively representative operational airplane weight to establish the cruise speed,

6.4.6.2.3 Maximum certified altitude,

6.4.6.2.4 Using the results of the critical point analysis for this scenario (e.g., critical fuel type and temperature from Section 6.4.3 of this attachment),

6.4.6.2.5 Fuel cut-off (or "fuel chop") to the test engine or rapid engine shutdown,

Note: Refer to the note following paragraph 6.4.6.1.7.

6.4.6.2.6 The engine will remain shutdown until the airplane is within the appropriate in-flight engine restart envelope,

6.4.6.2.7 The test engine should be at a stabilized rotor speed (windmilling) and temperature representative of an all-engines-out descent from the maximum certified altitude to a point within the flight envelope where restart is probable,

6.4.6.2.8 Using the AFM procedures for a method capable of restarting a stabilized windmilling engine that the applicant selects as the primary method, prior to descending below an altitude of 15,000 feet, the engine should be restarted and accelerated to MCT/MCP.

6.4.6.2.9 The engine restart time should meet the criteria in Section 6.4.4.

6.4.6.2.10 The test should be repeated on at least one different engine, preferably a different installation location if possible (refer to Section 6.4.2.4).

6.4.6.3 Scenario C: Holding Speed and Low Altitude. The applicant should demonstrate that it is possible to restart engines necessary to maintain safe flight following an all-engines-out scenario that occurs at speeds equal to or greater than the minimum flaps-up “holding speed” and at altitudes below 20,000 feet. The applicant should use any method available (refer to Section 6.1) that is capable of restarting a stabilized windmilling engine. The intent of this test is to demonstrate an acceptable level of safety exists in the event of a “common cause” thrust loss at a combination of low engine power, moderate to low altitudes, and moderate airspeeds (such as a typical holding pattern). This scenario is not intended to require the applicant to demonstrate in-flight engine restart capability at any airplane speed within the flight envelope below an altitude of 20,000 feet. The scenario 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-engines restart can be accomplished. This demonstration should account for all altitudes above where it is practical to rely on the available methods (refer to Section 6.1) to restart a stabilized windmilling engine. The applicant should plan the flight test using the following:

6.4.6.3.1 Holding speed (minimum flaps up speed),

- The applicant should conduct an evaluation (i.e., a combination of analysis and testing) to determine the airspeed that is critical for the airplane,

6.4.6.3.2 Altitude 20,000 feet and below,

6.4.6.3.3 Using the results of the critical point analysis (e.g., critical fuel type and temperature from Section 6.3.4 of this attachment),

6.4.6.3.4 The test engine should be at a stabilized windmill speed,

6.4.6.3.5 Using the AFM procedures for a method capable of restarting a stabilized windmilling engine that the applicant selects as the primary method, prior to descending 5000 feet from the initiation of the restart procedure, the engine should be restarted and accelerated to MCT/MCP.

6.4.6.3.6 However, the engine restart should be accomplished without exceeding an airspeed of 300 knots or VMO, whichever is lower.

Note: The intent of the maximum altitude loss criteria of 5000 feet is to limit the time required for a restart from a stabilized windmilling engine and reduce the minimum airspeed for a windmill restart.

6.4.6.3.7 The engine restart time should meet the criteria in Section 6.4.4.

6.4.6.3.8 The test should be repeated on at least one different engine, preferably a different installation location if possible (refer to Section 6.4.2.4).

6.4.6.4 Scenario D: Low Speed and Low Altitude. The applicant should demonstrate that it is possible to restart engines necessary to continue safe flight and landing at the lowest airspeed, lowest engine power setting and lowest altitude practical. The applicant should use any method available (refer to Section 6.1) that is capable of restarting an engine in this scenario. The applicant should use test and analysis to substantiate in-flight engine restart capability for this scenario. Since each design is unique, there is not specific criteria for this scenario. The applicant should propose appropriate test and analysis conditions for their design. The applicant should account for the following in their proposal:

6.4.6.4.1 In an all-engines-out scenario occurring at certain low airspeed and low altitude flight conditions, it may not be possible to demonstrate engine restart capability because there is insufficient time to perform the in-flight engine restart procedure. In these cases, the applicant may take credit for engine failure recognition and "Auto Restart" design features. Additionally, the applicant may propose a specific procedure that relies on a prompt flightcrew response to initiate a restart procedure, such as rapid restart or quick windmill restart; however, it is only acceptable for low altitude conditions where there may be insufficient time to perform the in-flight engine restart procedure with the initial condition of a stabilized windmilling engine.

6.4.6.4.2 Scenario D is a separate scenario because it is not acceptable to only rely on rapid relight, quick relight or quick windmill restart to fully demonstrate the capability of Scenario C (Section 6.4.6.3) for in-flight all-engines-out restart because those methods do not adequately address the critical conditions of the scenario. A quick windmill restart procedure is not capable of addressing all cases identified in service history, and therefore, does not warrant credit for use in demonstrating compliance with Scenario C. The quick windmill restart procedure is dependent on pilot reaction, since there is an operational limitation on its use (i.e., initiating a restart must be accomplished within a short time duration after the power loss occurs in order to achieve a successful restart) and cannot be completely relied on for all cases of all-engines-out. The purpose of

Scenario C, and Scenario B, has always been the demonstration of the critical safety concern of having windmilling engines and the need for the airplane to get into the in-flight engine restart envelope for successful restarts. A reasonable pilot response may lead to delaying restart until the engine has stabilized and the airplane should be capable of restarting from those conditions to the maximum extent practical. Therefore, the applicant should only rely on automatic features and prompt flightcrew response (similar to Scenario A) at very low altitude where it is impractical to have sufficient time for an engine to restart in flight from stabilized windmilling conditions.

6.4.6.5 Scenario E: Loss of Normal Electrical Power. This scenario only applies to airplanes with an electrical driven fuel pump in the airplane fuel system that lose electrical power (e.g., cannot use battery power) during an all-engines-out condition. The applicant should demonstrate that it is possible to restart engines necessary to maintain safe flight following an all-engines-out scenario that occurs following the loss of normal electrical power (electrical power sources excluding the battery). The applicant should use any method available (refer to Section 6.1) that is capable of restarting a stabilized windmilling engine. This scenario shows the potential that a more critical condition may exist than what airworthiness standards for operation without normal electrical power require; therefore, this document highlights the need to demonstrate the more critical condition, if it exists. Applicants are reminded that compliance with all applicable airworthiness standards, such as operation without normal electrical power requirements, are independent of this document and still required. The applicant should consider this scenario supplemental to what is already required by transport airplane airworthiness standards. The authority does not intend for this document to influence the requirement to show compliance with all applicable airworthiness standards. Operation without normal electrical power at the maximum operating altitude with the critical fuel (type and temperature), from the standpoint of flameout and restart characteristics, can result in vapor formation in the fuel system that may inhibit restart. For example, an all-engines-out condition due to the loss of normal electrical power occurring just above the maximum altitude where fuel suction feed capability exists may lead to a lower recovery altitude than if the same all-engines-out condition occurred at a higher altitude. In one design, the heat soak from the engine following flameout caused vapor lock in the engine fuel feed system, resulting in the inability to restart either engine. The applicant should plan the flight test using the following:

6.4.6.5.1 Critical fuel type at critical fuel temperatures,

6.4.6.5.2 Cruise speed or most critical, 6.4.6.5.3 The applicant should use a conservatively representative airplane weight to establish the cruise speed,

6.4.6.5.4 Maximum altitude or a more critical altitude if one exists considering the lowest recovery altitude,

6.4.6.5.5 Loss of normal electrical power (engine on suction feed),

6.4.6.5.6 Fuel cut-off (or "fuel chop") to the test engine or rapid engine shutdown,

Note: Refer to the note following paragraph 6.4.6.1.7.

6.4.6.5.7 The engine will remain shutdown until the airplane is within the appropriate in-flight engine restart envelope,

6.4.6.5.8 The test engine should be at a stabilized rotor speed (windmilling) and temperature representative of an all-engines-out descent from the maximum certified altitude (or most critical altitude) to a point within the flight envelope where restart is probable, and

6.4.6.5.9 Using the AFM procedures for a method that is capable of restarting a stabilized windmilling engine that the applicant selects as the primary method, prior to descending below an altitude of 15,000 feet (or 10,000 feet if the fuel volatility is greater than that of Jet A/Jet A1), the engine should be restarted and accelerated to MCT/MCP.

6.4.6.5.10 The engine restart time should meet the criteria in Section 6.4.4.

6.4.6.5.11 A single engine database is acceptable for tests performed to demonstrate this scenario; therefore, it is not necessary to repeat this test condition on a different engine.

6.4.6.6 The test scenarios described in Section 6.4.6 are summarized in Table 1.

Table 1. Summary of the Section 6.4.6 all-engines-out in-flight engine restart scenarios.

Conditions	**Scenario A** High Power and Low Altitude (6.4.6.1)	**Scenario B** Cruise Speed and High Altitude (6.4.6.2)	**Scenario C** Holding Speed and Low Altitude (6.4.6.3)	**Scenario D** Low Speed and Low Altitude (6.4.6.4)	**Scenario E** Loss of Normal Electrical Power (6.4.6.5)
Initial Airspeed	Representative of end of takeoff (V2 +10 knots). Not more than VFTO, if justified) (6.4.6.1 & 6.4.6.1.1)	Cruise speed (6.4.6.2.1)	Minimum flaps-up holding speed (6.4.6.3.1)	Applicant proposed critical condition	Cruise speed or most critical (6.4.6.5.2)
Initial Power Setting	Most critical thrust/power during climb (6.4.6.1.2)	That required for initial altitude and airspeed	That required for initial altitude and airspeed	Applicant proposed critical condition	That required for initial altitude and airspeed
Initial Altitude	Most critical and minimum for flight test safety (6.4.6.1.8)	Maximum certified cruise altitude (6.4.6.2.3)	20,000 feet or most critical lower altitude (6.4.6.3.2)	Applicant proposed critical condition	Maximum cruise altitude or most critical (6.4.6.5.4)
Critical Point Analysis	Yes (6.4.6.1.3)	Yes (6.4.6.2.4)	Yes (6.4.6.3.3)	Applicant proposed	Yes (6.4.6.5.1)
Flightcrew Recognition & Response Time	A range of times including 5 seconds and most critical (6.4.6.1.5)	N/A – shutdown duration based on windmilling engine (6.4.6.2.7)	N/A – shutdown duration based on windmilling engine (6.4.6.3.4)	Applicant proposed critical condition	N/A – shutdown duration based on windmilling engine (6.4.6.5.7)
Maximum Allowable Airspeed	N/A – based on AFM procedures	N/A – based on AFM procedures or VMO	300 knots or VMO, whichever is lower (6.4.6.3.6)	Applicant proposed critical condition	N/A – based on AFM procedures or VMO
Allowable Altitude Loss	Applicant proposed critical condition based on shutdown, typically 1500 feet (6.4.6.1.9)	Prior to descending below 15,000 feet (6.4.6.2.8)	Within 5,000 feet of initiating restart (6.4.6.3.5)	Applicant proposed critical condition	Prior to descending below 15,000 feet (6.4.6.5.9)
Recovered Power Condition	Same setting prior to shutdown (6.4.6.1.7)	MCT/MCP (6.4.6.2.8)	MCT/MCP (6.4.6.3.5)	Applicant proposed critical condition	MCT/MCP (6.4.6.5.9)
Allowable Restart Time	More limiting time of altitude loss or criteria in section 6.4.4 (6.4.6.1.10)	Meet criteria in section 6.4.4 (6.4.6.2.9)	Meet criteria in section 6.4.4 (6.4.6.3.7)	Applicant proposed critical condition	Meet criteria in section 6.4.4 (6.4.6.5.10)
Test Engine Database	Repeat on at least one other engine (6.4.6.1.11)	Repeat on at least one other engine (6.4.6.2.10)	Repeat on at least one other engine (6.4.6.3.8)	Applicant proposed	Single engine database acceptable (6.4.6.5.11)

Conditions	**Scenario A** High Power and Low Altitude (6.4.6.1)	**Scenario B** Cruise Speed and High Altitude (6.4.6.2)	**Scenario C** Holding Speed and Low Altitude (6.4.6.3)	**Scenario D** Low Speed and Low Altitude (6.4.6.4)	**Scenario E** Loss of Normal Electrical Power (6.4.6.5)
Available Restart Methods	• Assisted restart[2] • Rapid restart[3]	• Stabilized windmill restart[1] • Assisted restart[2]	• Stabilized windmill restart[1] • Assisted restart[2]	• Stabilized windmill restart[1] • Assisted restart[2] • Rapid restart[3] • Auto-restart[4]	• Stabilized windmill restart[1] • Assisted restart[2]

1. Stabilized windmill restart (requires minimum airplane speed)
2. Assisted restart from an airplane system such as APU, electrical, hydraulic, or other system that is available in an all-engines-out scenario
3. Rapid restart or quick windmill restart (requires minimum airplane speed and initiation within a maximum timeframe following flameout or shutdown)
4. Auto-restart or auto-relight (automatic engine control features that do not require flightcrew action)

7 DEVIATIONS.

The applicant must justify any deviations to the acceptable means of compliance in section 6.0 using a documented method acceptable to the certification authority.

END