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ISSUE PAPER
COORDINATION GRID

APPLICANT NAME: Bombardier Aerospace

MODEL: CL-600-2C10 Regional Jet Series 700 **PROJECT NO.** AT1388NY-T

ISSUE PAPER NUMBER: P-3 **STAGE** 4 **DATE** May 31, 2000

SUBJECT: Inflight Engine Restart

PROJECT MANAGER: Gregory Marino

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ISSUE PAPER

PROJECT: Bombardier Aerospace
CL-600-2C10 Regional Jet Series 700
AT1388NY-T

ITEM: P-3

STAGE: 4

REG. REF.: § 21.16, 21.21(b)(2), 25.903(e) and 25.1585(a)(3)

DATE: May 31, 2000

NATIONAL POLICY REF.:

ISSUE STATUS: CLOSED

SUBJECT: Inflight Engine Restart

BRANCH ACTION: ANE-171, ANE-172, ANM-111, ANM-112, ANM-113

COMPLIANCE TARGET: Pre-TC

Means of Compliance

STATEMENT OF ISSUE:
Section 21.21(b)(2) precludes issuance of a type certificate if there is any feature or characteristic that would make the product unsafe. At this time, the inflight engine restart characteristics of the Model CL-600-2C10 have been identified for further review and evaluation as a potential unsafe condition. An unsafe design feature may exist since the current engine restart criteria in § 25.903(e) are inadequate with respect to unassisted inflight engine restart following an all engine flameout.

An issue paper is needed to document the potential unsafe features associated with engines incorporating high bypass turbine engine technology, such as the General Electric CF34 8C1 turbofan engines installed on the Model CL-600-2C10.

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 inflight 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 inflight engine restart capability review and evaluation. This assessment 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 which the FAA believes are critical. (Actual flight test conditions will be established following review of the results of the evaluation noted above):

a) 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).

b) 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 insure adequate terrain clearance for a majority of the flight paths that the Model CL-600-2C10 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.

c) 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). This paragraph 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 insure 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 which 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 which 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 inflight 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 CL-600-2C10 may incorporate unsafe design features since the current engine restart criteria in § 25.903(e) are inadequate with respect to unassisted inflight engine restart following an all engine flameout. Therefore, in addition to the engine restart provisions of § 25.903(e), the following criteria apply:

The means to restart engines, while inflight, following flameout or inflight 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:

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

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

c) **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 5000 feet (or an altitude loss shown by the applicant not to preclude continued safe flight and landing), either
(i) all but one engine must be restarted and produce Maximum Continuous Thrust/Power (MCT/MCP), or
(ii) 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 15000 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.

TRANSPORT CANADA POSITION:
In an e-mail message dated November 9, 1999, Transport Canada indicated they were in agreement with the Bombardier position as outlined below.

APPLICANT'S POSITION:
By letter dated August 17, 1999, Bombardier Aerospace (BA) offered the following position for complying with the conditions specified in the Issue Paper.

BA proposes that in lieu of using the criteria as proposed in the Issue Paper, and in lieu of all other guidance material, the FAA adopt the current proposed harmonized rulemaking from the ARAC process (ref. 2). This rulemaking represents a harmonized position between Industry and Airworthiness Authority members of the ARAC HWG, eliminating any differences in interpretations that require additional work on the part of the applicant.

In-line with the ref. 2 draft guidance material, BA will demonstrate that the engines of the CL-600-2C10 can be restored to a sufficient power/thrust level following an all engines out case, in order to enable the aircraft to achieve level flight without excessive loss of altitude.

BA will establish the engine restart envelope and procedures based on the results of flight tests performed for the following cases:

1) **Stabilized Windmill Airstarts and Starter-Assisted Restarts:**
Satisfactory restart capability will be demonstrated with a fully stabilized engine windmill speed at the target altitude and aircraft speed.

Engine fuel feed system, hydraulic and electrical systems will be configured to be representative of the condition of the airplane for the case considered.

2) **Rapid Relights (Spooling Down Restarts):**
Restart capability during low and slow approaches will be demonstrated following flameout.

Engine fuel feed system, hydraulic and electrical systems will be configured to be representative of an all engine flameout condition.

It will be demonstrated that the engine will relight and accelerate to idle without requiring any crew action other than monitoring indicated airspeed.

3) **Restart after Engine Cold Soak:**
Satisfactory restart capability of the engines will be demonstrated following flameout during take-off at high power settings.

It will be demonstrated that the engine will relight and accelerate to idle without requiring any crew action other than monitoring indicated airspeed.

Note that BA does not intend on addressing the Suction Feed Flameout case, as the configuration of the aircraft does not fall within criteria outlined in the ref. 2 document, and in the case of the CL-600-2C10, this would represent a double failure.

In order to evaluate and substantiate the declared inflight restart envelope of the CL-600-2C10 BA has developed Test Definition Sheet (TDS) No. 670-72-GE-100. A copy of this test plan will be forwarded for TC acceptance once formal approval is obtained.

All substantiation for the inflight restart capability of the engines will be documented in Bombardier Aerospace reports:

- RAP-GE670-102 Propulsion System Engine Relight Performance
- RAP-GE670-170 Propulsion System Design Compliance Report
- RBR-GE670-174 Engine Starting System Design Compliance Report

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<u>Bombardier Aerospace Reference 2</u>

Revision dated 8/12/99

AC / ACJ 25.903(e)

ENGINE RESTART CAPABILITY DEMONSTRATION FOR TRANSPORT CATEGORY AIRPLANES

1 - PURPOSE

This Advisory Circular (AC) provides information and guidance concerning a means, but not the only means, of compliance with section 25.903(e) of Part 25 of the Federal Aviation Regulations (FAR) which pertains to engine restart capabilities of Transport Category Airplanes. Accordingly, this material is neither mandatory nor regulatory in nature and does not constitute a regulation. In lieu of following this method, the applicant may elect to establish an alternate method of compliance that is acceptable to the Federal Aviation Administration (FAA) for complying with the requirements of the FAR sections listed below.

2 - SCOPE

This Advisory Circular provides guidance for a means of showing compliance with regulations applicable to engine restart capability in Transport Category Airplanes. This guidance applies to new airplanes designs as well as modifications to airplane or engine designs that would adversely affect engine restart capabilities.

3 - RELATED FARs and JARS

FAR Part 25, sections, 25.903(e), 25.1351(d), 25.1585(a)(3), JAR 25.903(e), JAR-E910, FAR 33.5(b)(3) and 33.89(a)(1).

4 - BACKGROUND

4.1 - Regulatory history

The inflight engine restart requirements for turbine powered airplanes are identified in §§§ 25.903 and 25.1351 and 25.1585 of the Federal Aviation Regulations (FAR). Sections 25.903 and 25.1585 requirements were developed from the engine inflight restart requirements of the earlier Civil Air Regulations (CAR) Part 4b. Paragraph 4b.401(c) required the ability for individually stopping and restarting the rotation of any engine during flight.

This intention was further incorporated into Part 25, specifically § 25.903(e), which requires 1) the ability to restart any engine during flight must be provided; 2) an altitude and airspeed envelope must be established for inflight engine restarting, and each engine must have a restart capability within that envelope; and 3) if the minimum windmilling speed of the engines following the inflight 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 inflight engine ignition for restarting. In addition, Section 25.1351(d) requires demonstration that the airplane can be operated for 5 minutes following the loss of all normal electrical power (excluding the battery) with the critical type fuel (from the standpoint of flame out and restart capability) and with the airplane initially at the maximum certificated altitude. For airplanes equipped with Alternating Current (AC) powered fuel pumps that are powered from the engine electrical generators, this requirement has resulted in demonstration of the capability to windmill relight the engine while on suction feed with battery power for ignition. Relight of the engines has typically occurred at altitudes between 16,000 and 25,000 feet. In addition, as stated earlier in CAR 4b.742(d), the recommended procedures to be followed in restarting turbine engines in flight are to be described, including the effects of altitude.
This intention was also incorporated into Part 25, specifically § 25.1585(a), which states that information and instruction must be furnished, together with recommended procedures for restarting turbine engines during flight (including the effects of altitude).

There are no explicit inflight restarting requirements imposed on the engine in FAR 33 or JAR-E. Nevertheless there are requirements to define starting procedures (33.5(b), 33.89, E910) and to recommend an envelope (E910).

Compliance with § 25.903(e) has been shown by establishing that adequate engine restart capabilities exist for the various engine types installed on transport category airplanes. For example, many turbopropeller airplanes utilize electric starters that allow restart of the engine throughout the airplane airspeed and altitude flight envelope. Compliance is therefore easily shown by flight test demonstration of restart capability and analysis to show availability of electrical power for the starter. Turbo jet/turbo fan engines typically have windmill restart capability that is effective throughout a portion of the flight envelope, and utilize pneumatic starters to achieve restart throughout the remainder of the envelope. Compliance demonstration for these airplanes have included establishing both a windmill and a starter assist restart envelope. In several instances the windmill restart envelope has been limited to a small portion of the flight envelope. Applicants have utilized supplemental restart means, such as an essential APU installation to supply pneumatic power for restart to substantiate compliance.

Lack of an explicitly defined inflight restarting minimum standard has resulted in wide variations in the restart capabilities of transport category airplanes. Some newer technology engines require several minutes at airspeeds above 250kts to windmill restart.

In addition, some turbopropeller engines with free turbines have limited or no windmill restart capabilities within the normal airplane operating envelope. On certain airplane types that are not equipped with means to assist restart, reduced engine restart capabilities could result in an unsafe condition following an all-engine flame out event at mid to low altitudes. The altitude loss required to obtain sufficient airspeed for a windmill restart, in conjunction with the associated long restart times, may not allow restart prior to reaching ground level.

4.2 - Service History

Since the beginning of aviation, all-engine power loss incidents have occurred. Incidents have been reported on almost every airplane type for various reasons such as fuel mismanagement, loss of electrical power, crew error, mis-trimming of engine idle setting, fuel nozzle coking, volcanic ash encounters, and inclement weather. The FAA has determined that the all-engine power loss event must be considered in airplane design.

Section 25.671 requires that the flight controls be designed such that control of the airplane can be maintained following the loss of all engine power. The service experience supports the position that suitable engine restart capability must be available following the loss of all engine power to avoid an unsafe condition.

4.3 - Industry Restart Data

Industry historical records contain many (at least 30 events in the period 1982 up to 1993) multiple engine power loss events.
These records show all-engine power loss events that jeopardized continued safe flight have occurred (over the altitude range) for the following reasons :

Weather	(Low Altitude to FL410)
Volcanic Ash	(FL370, FL330, FL250, low altitude possible)
Crew error	(FL030 to FL410)
Compressor Surge	(Takeoff to cruise altitude)
Maintenance Error	(Takeoff to cruise altitude)
Other/Unknown	(Takeoff to cruise altitude)

It does not appear that it is possible to define in advance all of the potential causes for critical power loss and/or preclude their occurrence. Thus it is necessary to define what engine restart capabilities are required to maintain the current level of safety.

5 - DEFINITIONS

a) Relight : The combustor lights off and sustains combustion.

b) Restart : The engine has accelerated to stabilized flight idle.

c) Windmill Relight Envelope : The portion of the airplane airspeed/altitude envelope where the engine is capable of being restarted without starter assistance.

d) Power Assisted Relight Envelope : The portion of the airplane airspeed/altitude envelope where the engine requires starter assistance to achieve restart.

e) Auto Ignition System : A system that automatically activates the engine igniters if pre-determined conditions apply (e.g., ice detectors indicate icing conditions, flaps are configured for approach/landing, etc.).

f) Auto Start System : A system that monitors engine parameters during starting and automatically sequences fuel flow accordingly. It may include logic protecting against turbine temperature limit exceedance and sub-idle stall, among other features.
It reduces pilot work load by eliminating the need to manually turn fuel on at a given core speed and to monitor the speed/turbine temperature relationship during the start.

g) Auto Depulse Logic/Stall Recovery Logic : Logic incorporated into the engine control that momentarily shuts off fuel flow to clear an engine stall.

h) Auto-Relight : A feature which monitors the operation of the engine to attempt to recover an engine flameout. In its most basic form, it is equivalent to automatically selecting continuous ignition. When the engine control senses that an engine has flamed out (by rotor speed decay, a drop in combustor pressure, or other means), it turns on the igniters.
Auto-relight typically reacts much more quickly to a flame out than a pilot could.

k) Rapid Relight/Quick Windmill Relight : A procedure in which the pilot executes a windmill start shortly after the engine has been shut down, so that the core speed is significantly above stabilized windmill speed.

6 - DESIGN CONSIDERATIONS

6.1 - Auto-adaptive systems

Several manufacturers have implemented features which are intended to enhance safety by reducing the likelihood of engine damage during start or eliminating all engine flame-out events for specific causes. These systems may improve safety but should not be considered as eliminating the need for a safety evaluation of all engine power loss occurrences. The following are methods Airworthiness Authorities are currently aware of :

Autostart Systems :

This feature is intended to protect the engine from damage due to a hung start. These systems are typically software controlled (FADEC) and monitor the engine start to assure limits are not exceeded during the start sequence. Typically fuel flow is interrupted ("depulsed") if the Exhaust Gas Temperature (EGT) reaches the defined limit. No specific indication may be provided to the crew that the depulse feature has been activated, however the crew may detect its activation by monitoring fuel flow, EGT and rotor speeds. This system will attempt multiple restarts inflight unless the crew intervenes and switches to the manual mode or the system will alert the crew if it discontinues attempts to restart the engine.

Auto Relight Systems :

These systems typically activate the engine igniters if the engine rapidly decelerates and a reduction in engine combustor pressure (or EGT/fuel flow below specified levels) is sensed. These systems are generally used to recover from engine flameout in turbulent conditions and inclement weather.

6.2 - Cockpit Indications

Service history has shown that in some instances flight crews have not been aware that the engine was below idle power until the engine failed to respond when the throttle was advanced.

Conversely, during engine airstarts, flight crews have aborted start attempts that would have been successful, or shut down engines that had successfully reached idle. As a consequence :

1) Consideration should be given to providing the crew with indication(s) that the engine has flamed out and/or is at a sub-idle condition.

2) Consideration should be given to providing the crew with indication(s) that inflight restart is progressing normally in addition to indications of start faults.

3) Consideration should be given to providing the crew with indication(s) that the engine has reached idle following an inflight restart.

7 - Compliance Guidance

This section is intended to define overall restart performance that includes the use of power assisted and windmill restart capabilities and to describe acceptable compliance guidelines. The effects of the loss of engine power from one, multiple and all engines must be considered. However, the loss of all engines generally determines the most stringent requirements in terms of restart capability, and the intent of the regulation will be satisfied by addressing this critical case.

In order to confirm that engine restarting can be achieved, in circumstances where all engines run down or are shut down, the applicant will be expected to show by test or analysis supported by tests that sufficient power/thrust can be restored to enable the airplane to achieve level flight without excessive loss of altitude.

Four conditions are to be addressed :

1) Shut down from take off/climb power with pilot recognition time delay based on analysis of indications (inherent or dedicated indicators) to the flight crews (Pilot recognition time has typically ranged from 5 to 15 seconds based on service data).
Acceptable means of compliance include rapid relight procedures or starter assistance from an external power source. The altitude loss between initiating the restart and achieving level flight should not exceed 2500ft.

2) An engine should be able to be restarted at a minimum altitude of 15,000ft from a shut

down at typical descent speed at 20,000ft or above.

3) The engine should be able to be restarted with an altitude loss not exceeding 5000ft from a power loss occurring between 10,000 and 20,000 feet.

The aircraft speed at the time of power loss should be representative of the normal flight profile (climb or descent) in this altitude range for the flight phase considered.

4) Flame out or shut down from descent power below 10,000ft with a delay in crew action based on indications (inherent or dedicated indicators) to the flight crew of all engine power loss.
A 30 second crew recognition time should be used if no dedicated indication is provided. Crew Recognition Time may be shortened based upon dedicated indications that engines have flamed out or rolled back to sub-idle, as well as aircraft design features which minimize the potential for inadvertent shutoff. Other factors which may be considered in the crew recognition time evaluation include automatic relight and automatic sub-idle stall recovery systems.
The initial airplane speed that should be used for the all-engine out restart evaluation is 1.45V stall (clean configuration) of the maximum landing weight of the aircraft.
Acceptable means of compliance include rapid relight, starter assistance from an external source and stabilized windmill start. The airplane should not lose more than 5000 feet altitude between initiating restart procedures and achieving level flight. In addition, the maximum aircraft speed to achieve the restart should not exceed 250kts.

These compliance guidelines are summarized in a tabular form here below :

	I TAKE OFF	II HIGH ALTITUDE	III CLIMB/DESCENT	IV LOW/SLOW
INITIAL ALTITUDE	Approved Takeoff Altitude Range	20 kft +	10 to 20 kft	10kft to landing
ALTITUDE LOSS *	2500 ft	Relight by 15kft	5000 ft	5000 ft
MAX ALLOWABLE AIRSPEED	N/A	N/A	N/A	250 KTS (based on max airspeed below 10 kft)
INITIAL AIRSPEED	Minimum Clean Configuration speed or 250 kts **	Typical descent speed	Normal flight profile (climb or descent speed)	1.45 V stall (clean airplane config.)
RECOGNITION TIME	typically 5 to 15 seconds	N/A	N/A	30 seconds or less depending on indications
ACCEPTABLE MEANS OF COMPLIANCE	Rapid relight or assisted relight from an external source	Stabilized windmill start or starter assist from an external source	Stabilized windmill start or starter assist from an external source	Rapid relight, starter assist from an external power source or stabilized windmill start

* Note Altitude loss measured from initiation of restart procedure
** Note – the lesser of the two speeds

8 - COMPLIANCE DEMONSTRATION

8.1 - General

The restart envelope and procedures declared by the applicant are intended to fulfill the guidelines specified in section 7.

The declared restart envelope will generally consist of several zones.

- One zone where the engine is rotated by windmilling at a sufficiently high RPM to achieve a successful restart. This zone may be subdivided into a stabilized windmill restart envelope and a spooling – down restart envelope (rapid relight).

- Another zone where the engine is rotated with the assistance of a starter to a sufficiently high RPM to achieve a restart.

Each zone must be identified in the Airplane Flight Manual. Sufficient tests must be carried out in each zone to validate it reliably.

8.2 - Demonstration procedure for stabilized windmill airstarts

- Tests should be conducted so that the windmill speed of the test engine is fully stabilized when the target altitude and aircraft speed are reached.

- The engine fuel feed system, hydraulic system and electrical system should be configured to be representative of an all engine flame-out condition.

- The time to relight should not exceed 30 seconds and the spool-up time from relight to idle should not exceed 90 seconds. A longer spool-up time may be acceptable if a positive indication is available to the crew that the start is progressing normally. However the altitude loss associated with the total restart time (from fuel on to idle) in an all engine flame-out condition should not exceed 5000ft, when the restart is initiated at or below 20000ft (as stipulated in section 7).

8.3 - Demonstration procedure for spooling-down windmill airstarts (rapid relight)

- The declared rapid restart envelope should be based on a fuel interruption of not less than 30 seconds. A shorter time may be acceptable if a dedicated engine failure annunciation is provided to the crew.

- Tests should be conducted with the engine initially stabilized at idle. The engine should relight and accelerate to idle without requiring any crew actions other than selecting ignition and fuel.

- The same conditions as in § 8.2 above should be observed for the engine fuel feed system, hydraulic system and electrical system.

- The same criteria as in § 8.2 should be used for times to relight and spool-up.

8.4 - Demonstration procedure for starter-assisted airstarts

- Tests should be conducted so that the windmill speed of the test engine is fully stabilized when the target altitude and aircraft speed are reached.

- The engine fuel feed system, hydraulic system and electrical system should be configured to be representative of the condition of the airplane for the case considered.

- The same criteria as in § 8.2 should be used for times to relight and spool-up.

8.5 - Demonstration procedure for APU assisted engine airstarts

If an APU assisted engine airstart is used for compliance with any of the section 7 restart conditions, the following guidelines should be followed:

- the APU installation should be certified as "essential"
- a minimum of a 95% APU start reliability must be demonstrated by test considering:
  - i) maximum APU cold soak appropriate for restart condition being addressed (note that the APU coldsoak associated with the maximum airplane range should be considered for the high altitude cruise condition II and the descent condition IV)
  - ii) a maximum of two APU start attempts shall be allowed for each start condition
  - iii) continuous APU operation throughout the affected flight regime may be used in lieu of demonstrating APU inflight start reliability
- APU start time should be considered in the airplane altitude loss calculation
- In order to maintain the APU's demonstrated start reliability after the airplane is introduced into service, the airplane and APU manufacturer should develop a maintenance program for the APU installation. This maintenance program should include general APU maintenance tasks, periodic checks of the APU's inflight starting capability and a post-maintenance inflight start verification. The critical maintenance tasks, start functional checks, as well as their associated time intervals should be mandated. Consideration of including these items as Certification Maintenance Requirements should be given.
- if an APU assisted engine start is used for complying with the low altitude conditions I or IV (takeoff and descent/landing), then the airplane should incorporate logic which automatically recognizes the all engine powerloss condition and automatically

restarts the APU. Further, consideration should be given to also automatically reconfigure the airplane pneumatic and/or electrical system to minimize the crew workload associated with achieving main engine restart during these critical low altitude conditions.

8.6 - Additional compliance demonstrations

As a complement to the compliance demonstrations carried out to establish and validate the declared airstart envelope, the capability to restart the engine should be demonstrated in the following particular cases:

a) Restart after engine cold-soak

Some restarts should be carried out within the declared restart envelope after shut down periods of 5 minutes and 15 minutes.

b) Immediate restart after shut down from high power

- The capability to immediately restart the engine after a shut down from max climb power following a take-off should be demonstrated.

- If the means of compliance is a quick relight procedure, the fuel interruption should last typically 5 to 15 seconds depending on indications available to the crew (as stipulated in section 7), and the engine should relight and reaccelerate to its original power without any crew actions other than selecting ignition and fuel.

c) Restart after suction feed flameout

For airplanes equipped with AC powered booster pumps, the effect of the loss of all normal AC power should be tested.

The test should be conducted using the worst case fuel from an engine flame-out standpoint. If the fuel volatility is greater than that of Jet A/Jet A1, the fuel should be preheated in mass such that the fuel temperature in the aircraft tank is at least 110° F after refueling.

The capability to restart engines should be demonstrated when the suction feed flame-out occurs at the maximum cruise altitude, and also at the maximum suction feed climb altitude if no alert is provided to deter the crew from climbing above it when operating in gravity feed conditions.

For the maximum cruise altitude case, the test should consist of a straight climb to the aircraft ceiling altitude, where the loss of AC power will be simulated for one engine. If flame-out occurs, the restart of the engine should be attempted with the aircraft configured to be representative of an all engine flame-out condition.

For the suction feed climb case, the loss of AC power should be simulated for one engine immediately after take-off and a continuous climb performed until the engine flames out. The restart should be attempted with the aircraft configured to be representative of an all engine flame-out condition.

For both cases, a successful restart should be achieved prior to reaching 10000 ft if the fuel volatility is greater than that of Jet A/Jet A1, or 15,000ft with all others.

CONCLUSION:
The FAA agrees that the position of Bombardier Aerospace is an acceptable means of compliance to the criteria outlined in this Issue Paper. The FAA also agrees to allow Transport Canada to determine compliance to these criteria on behalf of the FAA. Transport Canada should confirm completion of their action to FAA New York Aircraft Certification Office via normal FAR 21.29 procedures. This Issue Paper is closed.

Tansport Airplane Directorate
Aircraft Certification Service

Date

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