Design, Certify and Test for early ETOPS Operation

Brian Bixler

Agenda

- Background and Concept
  - Regulatory Requirements
  - Early ETOPS Requirements and Procedure
- Type Design Approval Process
  - ETOPS Terminology
  - Early ETOPS Approach
- ETOPS Design Requirements
  - Part 25 Appendix K
- ETOPS Testing and Problem Reporting
  - Testing and Problem Reporting
    - Manuals – AFM, CMP, MMEL
  - Operational Approval
    - Reliability Testing
    - ETOPS Crew Training
      - Flight Crew
      - Cabin Crew
      - Maintenance Crew
  - Reliability Tracking Board
- Summary

Extended Operations

Historical Perspective

- **Beginning in 1953, two engine aircraft have been limited to routes within 60-minutes of an adequate airport (FAR 121.161).**
- **On February 1st 1985, the first FAA-approved ETOPS flight was conducted by TWA, from Boston to Paris (Advisory Circular 120-42).**
- **Since 1988, two engine aircraft have operated under AC120-42A, which specified requirements for 75, 120 and 180-minute ETOPS.**
- **In 1995, the Boeing 777 was the first aircraft to comply with the 180-minute rule under the Early-ETOPS process.**
- **Effective 2007, a Final Rule for ETOPS was published in the Federal Register. Docket Number FAA-2002-6717. Powerplant sections are:**
    - 14 CFR 21, Certification Procedure for Products and Parts
    - 14 CFR 25, Airworthiness Standards: Transport Category Airplanes - Appendix K, Extended Operations (ETOPS)
    - 14 CFR 33, Airworthiness Standards: Aircraft Engines – Subpart G Section 33.201: Design and Test Requirements for Early ETOPS Eligibility

Operational Regulation

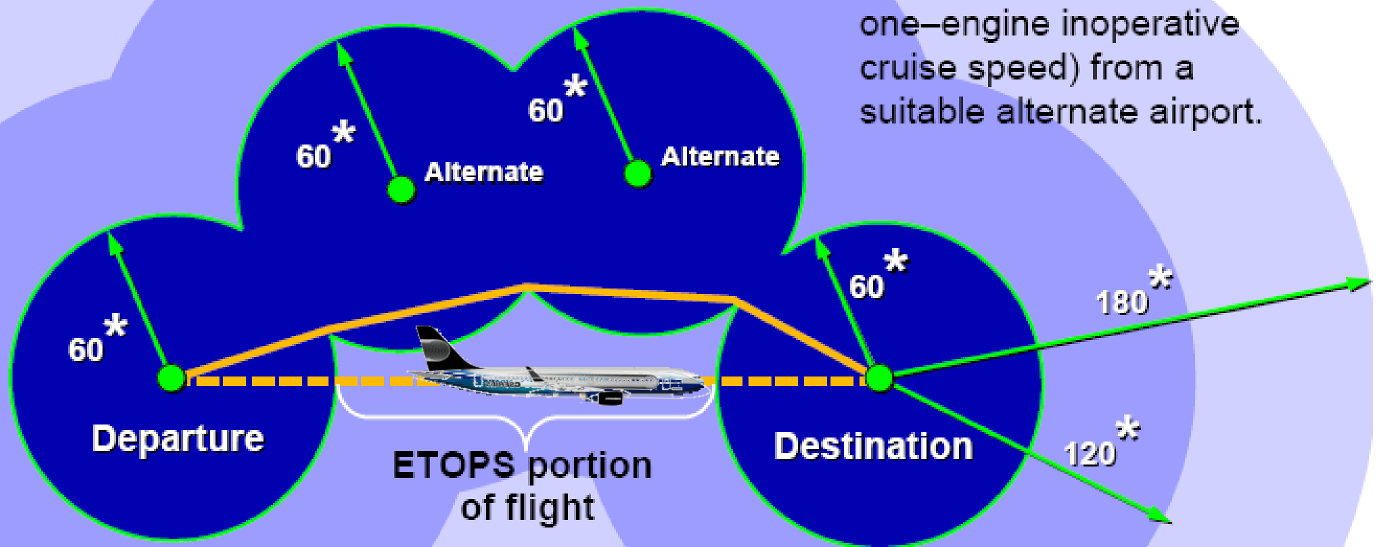
- **ETOPS stands for – Extended Operations**
  - Acronym created by ICAO to define twin engine aircraft operation over a route that contains a point further than one hour's flying time from an adequate airport at the approved one-engine inoperative cruise speed.

  - EASA AMC-6 Revision 2- "ETOPS Certification and Operation"
  - FAR Part 25, Appendix K - ETOPS

ETOPS

Extended-Range Operations with Two-Engine Airplanes

- FAR 121.161 limits two–engine jetliners to routes within 1 hour flying time (at one–engine inoperative cruise speed) from a suitable alternate airport.



Legend:

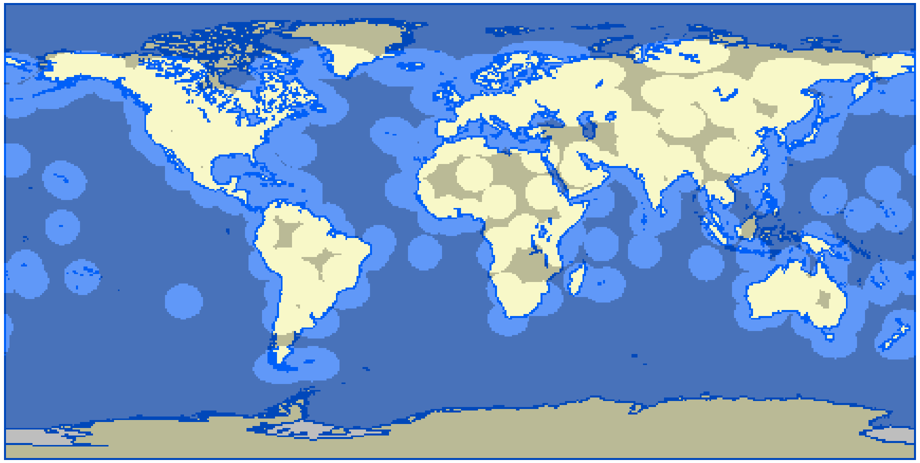
● Airports

* Distance traveled in the specified minutes at one engine inoperative cruise speed

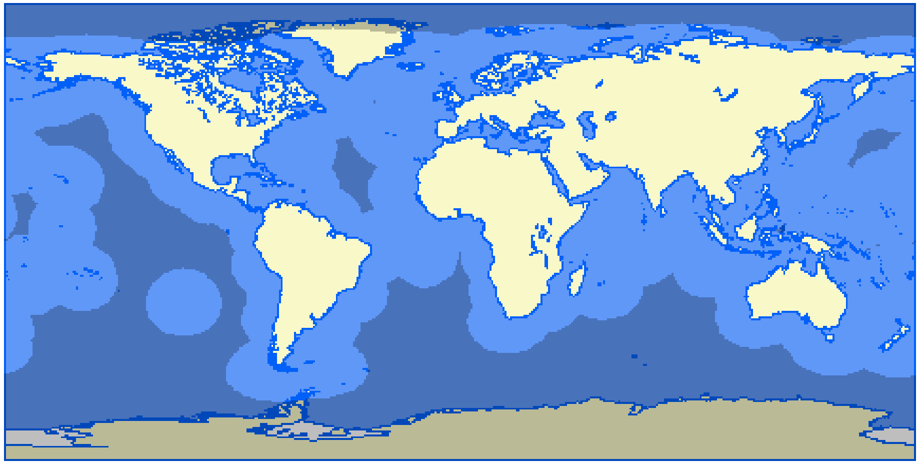
- - - ETOPS flight path

—— Non–ETOPS flight path

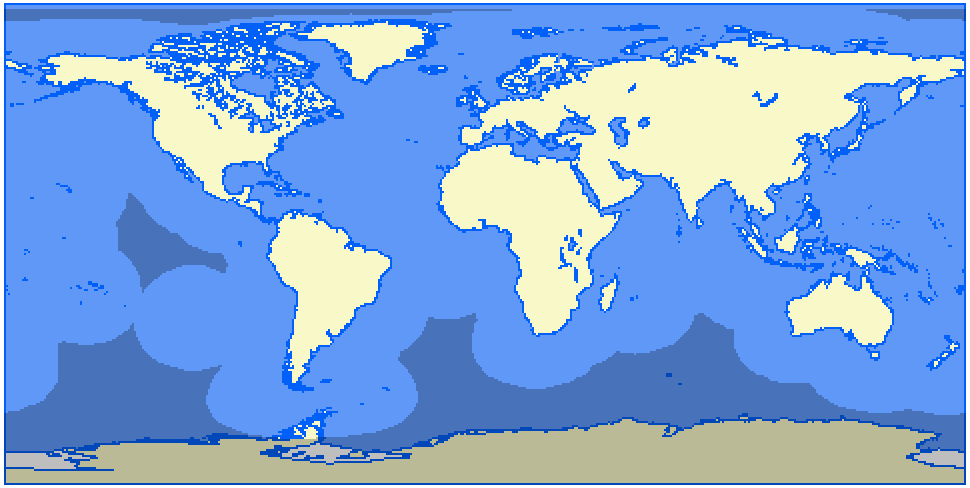
ETOPS Exclusion zones for 60, 120 and 180 minutes



60 min



120 min



180 min

ETOPS Regulatory Requirements & Advisory

FAA and EASA introduced FAR/CS 25.1535 rule and Appendix K to Part 25

FAA	Issued Advisory Circular (AC) 120-42A which provides the criteria for 75-, 120- and 180-minute operations. AC revised to issue B introducing early ETOPS operations Draft Issue of Advisory Material AC 25.1535-1X providing guidance for twin engine ETOPS certification
EASA	Advisory Material Joint (AMJ) 120-42 which provides the criteria for 75-, 90-, 120- and 180-minute operations and provisions for accelerated approval for 75-, 120- and 180-minute operations (currently published as Information Leaflet (IL) number 20) Advisory Material revised AMC 20-6
Transport Canada	issued Technical Publication (TP) 6327 which authorizes ETOPS up to 180-minute operations
CAA (United Kingdom)	issued the Civil Aviation Publication (CAP) 513 (in JAA)
DGAC (France)	issued Condition Technique Complémentaire CTC 20 Complementary Technical Condition) (in JAA)
ACAA (Australia)	issued Air Navigation Orders
ICAO Annex 6	many other countries rely on the guidance provide in the ETOPS amendment of the International Civil Aviation Organization

ETOPS Design Concept

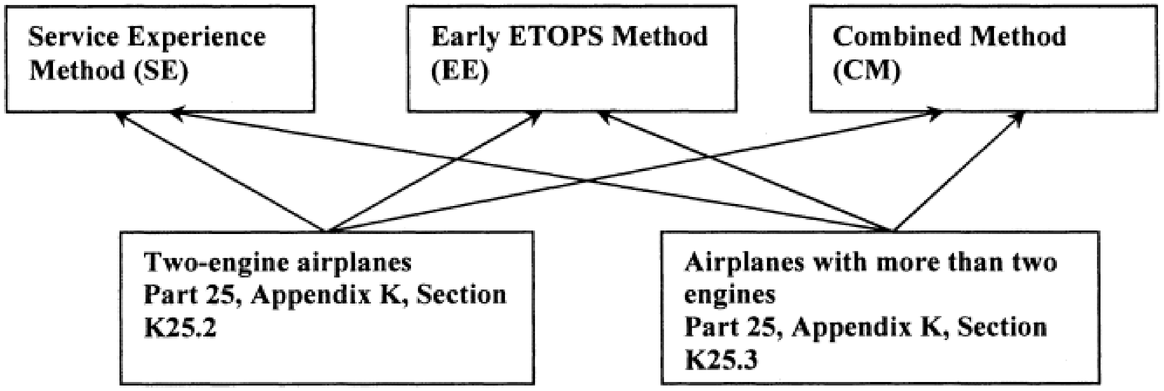
- **The ETOPS type design approval requirements focus on two main objectives:**
  - (1) Preclude any failure or malfunction that could result in an ETOPS diversion from intended flight; and
  - (2) Protect the safety of the airplane and occupants during an ETOPS diversion.
- **To meet these objectives, the airplane and engine design requirements fall into five categories:**
  - **(1)** Design to reliably provide functions necessary for safe ETOPS flights
  - **(2)** Eliminate sources of airplane diversions that occurred in current or past designs.
  - **(3)** Ground and flight testing.
  - **(4)** Reporting and correcting design problems.
  - **(5)** Demonstrated reliability.

ETOPS Design Requirements

- **The design requirements are organized into three parts:**
  - Those applicable to all airplanes;
  - Those applicable only to two-engine airplanes; and
  - Those applicable only to airplanes with more than two engines.
- **Requirements Applicable to All Airplanes.**
  - **(1)** Appendix K of Part 25 defines specific design requirements applicable to all airplanes for ETOPS type design approval. A top-level requirement in § K25.1.1 is that a candidate airplane-engine combination must comply with the requirements of Part 25 considering the maximum flight time and the longest diversion time for which the applicant seeks approval. Other design requirements include provisions for the following subject areas:
    - **(a)** Human factors evaluation of airplane failures during maximum length diversions;
    - **(b)** Operation in icing conditions;
    - **(c)** Electrical power supply;
    - **(d)** Time-limited systems;
    - **(e)** Fuel system design;
    - **(f)** Auxiliary power unit (APU) design;
    - **(g)** Engine oil tank design; and
    - **(h)** Engine condition monitoring.
  - **(2)** Other requirements define data that must be listed in the airplane flight manual and in a configuration, maintenance, and procedures (CMP) document.

Methods of ETOPS Type Design Approval

- **Global Series ETOPS Type Design will use EARLY ETOPS Method.**
- **Part 25 defines three paths for obtaining ETOPS type design approval; introduced in Appendix K**
  - Traditional service experience
    - K25.2.1, K25.3.1
  - “Early ETOPS” process
    - K25.2.2, K25.3.2
  - Combination of service and Early ETOPS process
    - K25.2.3, K25.3.3



ETOPS Certification

Early ETOPS Process

Type Certificate Holder

Operator

Systems Design

Systems Assessment & reliability testing

Airplane testing

Required for 120, 180 & above

Operation

Procedures, Training & Maintenance

Reporting, Tracking and Resolving Problems

FAR/CS 25.1535

TP6327E*, AC25.1535-1X & *AMC 20-6

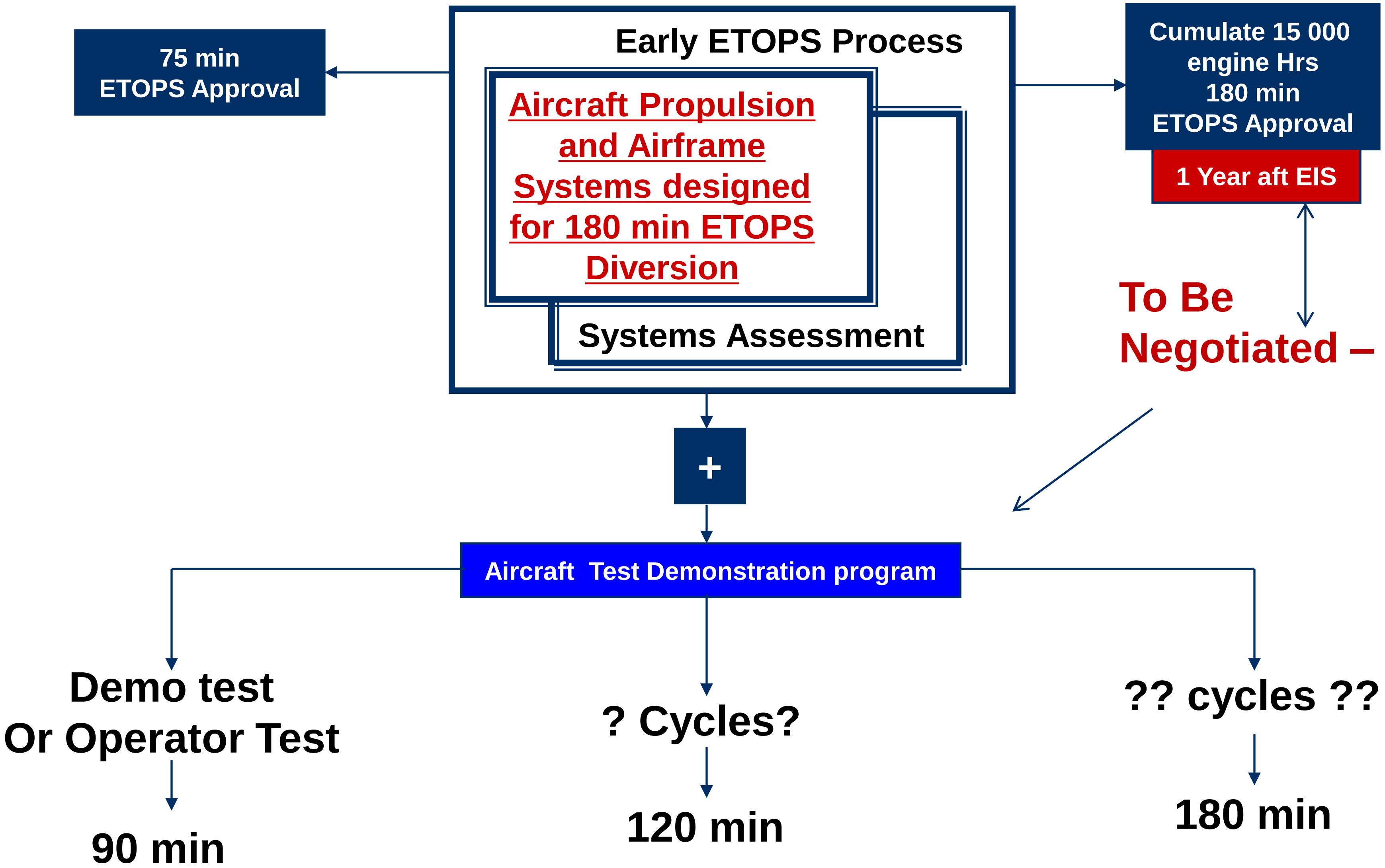
Eligibility Type Approval

FAR121.161

AC120-42B

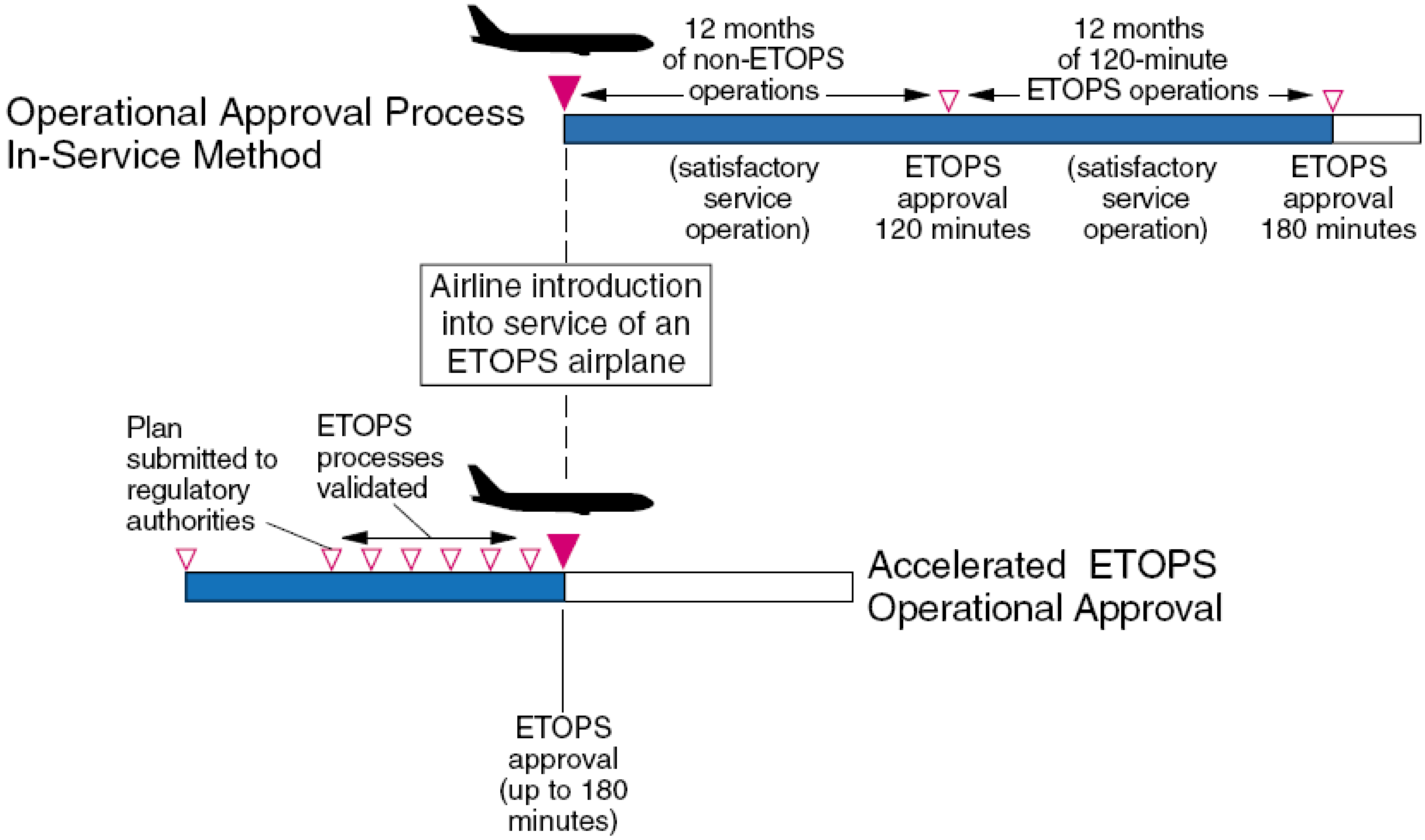
Capability Type Approval

ETOPS Eligibility Type Approval



Propulsion IFSD Rate (plus Test Time) Largely Determines 120 vs. 180 min.

ETOPS Operational Approval Option



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ETOPS Terminology

- **ETOPS Significant System**

  An airplane system, including the propulsion system, the failure or malfunctioning of which could adversely affect the safety of an ETOPS flight, or the continued safe flight and landing of an airplane during an ETOPS diversion.

  (1) **An ETOPS group 1 significant system** -

  - **(a)** Has fail-safe characteristics directly linked to the degree of redundancy provided by the number of engines on the airplane.
  - **(b)** Is a system, the failure or malfunction of which could result in an in-flight shutdown, loss of thrust control, or other power loss.
  - **(c)** Contributes significantly to the safety of an ETOPS diversion by providing additional redundancy for any system power source lost as a result of an inoperative engine.
  - **(d)** Is essential for prolonged operation of an airplane at engine inoperative altitudes.

  (2) An ETOPS group 2 significant system is an ETOPS significant system that is not an ETOPS group 1 significant system.

ETOPS Significant Group 1 & 2

Group 1

ATA	ETOPS Significant Systems
24-20	AC Power Generation
24-30	DC Power Generation
24-50	AC Load Distribution
24-60	DC Load Distribution
26-10	Engine & APU Fire Detection
26-20	Engine & APU Fire Extinguishing System
28-10	Fuel Storage System
28-20	Fuel Distribution System
28-40	Fuel Quantity Indicating System
29-00	Main Hydraulic Power
30-10	Wing Anti-Ice System
30-20	Cowl Anti-Ice System
36-10	Bleed Air Distribution
36-20	Bleed Air Indication
49-00	Auxilliary Power Unit
71-00	Power Plant

Group 2

ATA	ETOPS Significant Systems
21-20	Air Conditioning Distribution
21-30	Pressurization Control
21-50	Air Conditioning System
21-60	Temperature Control System
23-10	Communications (HF, SATCOM)
26-25	Cargo Fire Extinguishing System
27-00	Flight Control System
34-40	Independent Position Determining (Nav, TCAS)

ETOPS Significant Group 1 & 2

ATA Chapter	ETOPS Significant Systems	ATA Section	A	B	C
21 Air Conditioning	Air supply control system	-20			X
	Cabin pressure control	-30			X
	AC packs and associated equipment	-50			X
	Electrical and/or Electronic cooling	-27			X
23 Communication	VHF system	-12			X
	HF system	-11			X
	Satcom system	-15			X
	Datalink system	-11			X
24 Electrical Power	Main AC/DC power system	-20, 30	X		
	Integrated Drive Generator and/or GCU	-20	X		
	APU driven generator and/or GCU	-20			X
	Backup AC power system (VSCF)	-25	X		
	Electrical load management system	-09		X	
26 Fire Protection	Engine fire detection and extinguishing	-11, 21		X	
	APU fire detection and extinguishing	-15, 22		X	
	Pneumatic duct leak detection	-18			X
	Cargo compartment smoke detection and fire extinguishing.	-16, 23			X
27 Flight Controls	Primary flight controls	-11,21,30			X
28 Fuel	Engine fuel feed system	-22		X	
	APU fuel feed system	-25			X
	Fuel quantity indication system	-41			X
	Fuel temperature indication system	-43			X
29 Hydraulic	Engine driven hydraulic pumps	-11	X		
	Electric driven hydraulic pumps	-11			X
	Air Driven hydraulic pumps	-11			X
	Ram Air Turbine	-20			X
	Hydraulic reservoirs	-11			X
30 Ice and Rain	Wing thermal anti-icing	-11			X
	Engine inlet thermal anti-icing	-21	X		X
	Pitot static probe anti-icing	-31			X
	Total air temperature probe heat	-33			X
	Engine probe heat	-34	X		X
	Flight compartment window anti-icing	-41			X

ATA Chapter	ETOPS Significant Systems	ATA Section	A	B	C
31 Instrumentation	Standby flight instruments	-11			X
34 Navigation	Flight Management Computers *	-61			X
	Multi Control Display Unit	-61			X
	Weather radar	-43			X
	Global Positioning System	-58			X
36 Pneumatic	Air Supply Distribution	-10	X		
49 Airborne Auxiliary Power	Auxiliary power unit (APU)	-00			X
	APU mounts	-13			X
	APU harness	-14			X
	APU air intake	-15			X
	APU drains and vents	-16			X
	APU and generator lubrication	-27			X
	APU fuel system	-31			X
	APU ignition and/or starting system	-40			X
	APU cooling air system	-50			X
	APU surge bleed system	-53			X
	APU control system	-61			X
	APU exhaust gas temperature indicating system	-70			X
	APU exhaust system	-81			X
All Engine chapter-section items are ETOPS Significant EXCEPT those listed below.					
70 - 80 Engines **	Airborne vibration monitoring	77-31			
	Thrust Reverser System	78-31			
	Thrust Reverser Control System	78-34			

** **Engine ignition systems on the same engine; (A and B) are not considered as a dual system for ETOPS requirements, as work on either system will only affect a single engine. It is acceptable for one technician to remove/replace both ignitors or work on both A&B systems only on the same engine. All ETOPS requirements are met when approved procedures are followed.**

Airframe Systems - APU

- **Considerations:**
  - Required APU start altitude FL410
    - APU start should be with generator assist whenever possible, not batteries only. This will ensure a good start at altitude all the time.
  - If APU is required to run during ETOPS leg there will be increased fuel burn due to APU fuel burn and open inlet door (usually 2% increase in drag)

Airframe Systems - Electric

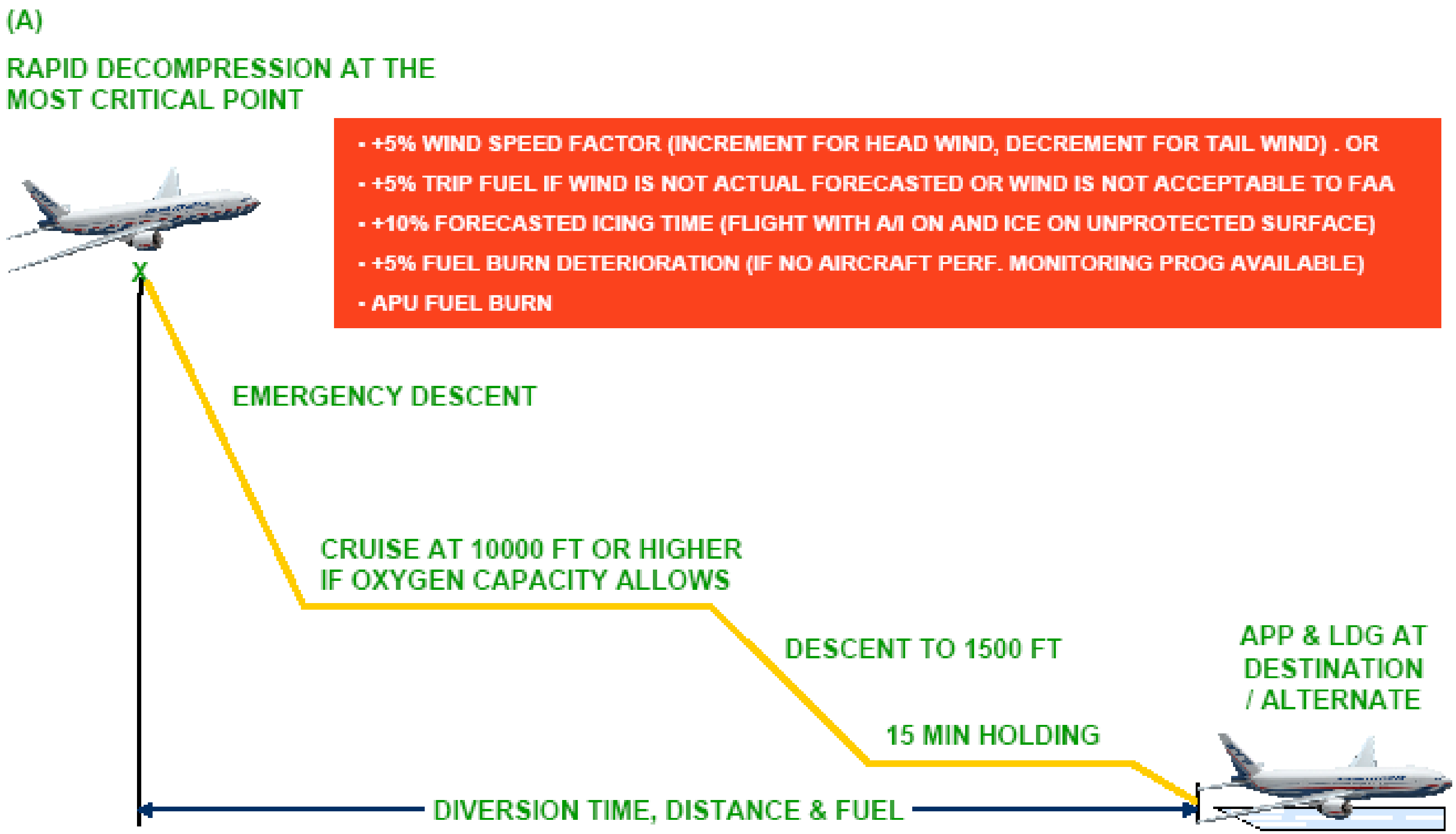
- **Considerations:**
  - Third independent sources of electrical power:
    - Combined electric APU generator and ADG
    - Each source to provide electric power to the minimum set of airplane system functions

    "the FAA has not accepted any APU in-flight start reliability as sufficient to allow ETOPS flight with the APU not running on an airplane with the three-generator minimum. The FAA assumes the APU will not start and has required the APU to be running during the ETOPS portion of a flight."

ETOPS Rule – Type Design Approval
Early ETOPS method

- **Compliance with Part K 25.2**
  - **K 25.2.2 Early ETOPS Method**
    - **Assessment of relevant experience with airplane previously certified**
    - **Propulsion system design**
    - **Maintenance and operational**
    - **Propulsion system validation test**
    - **New technology testing**
    - **APU validation test**
    - **Airplane demonstration**
    - **Problem tracking**
    - **Acceptance Criteria**

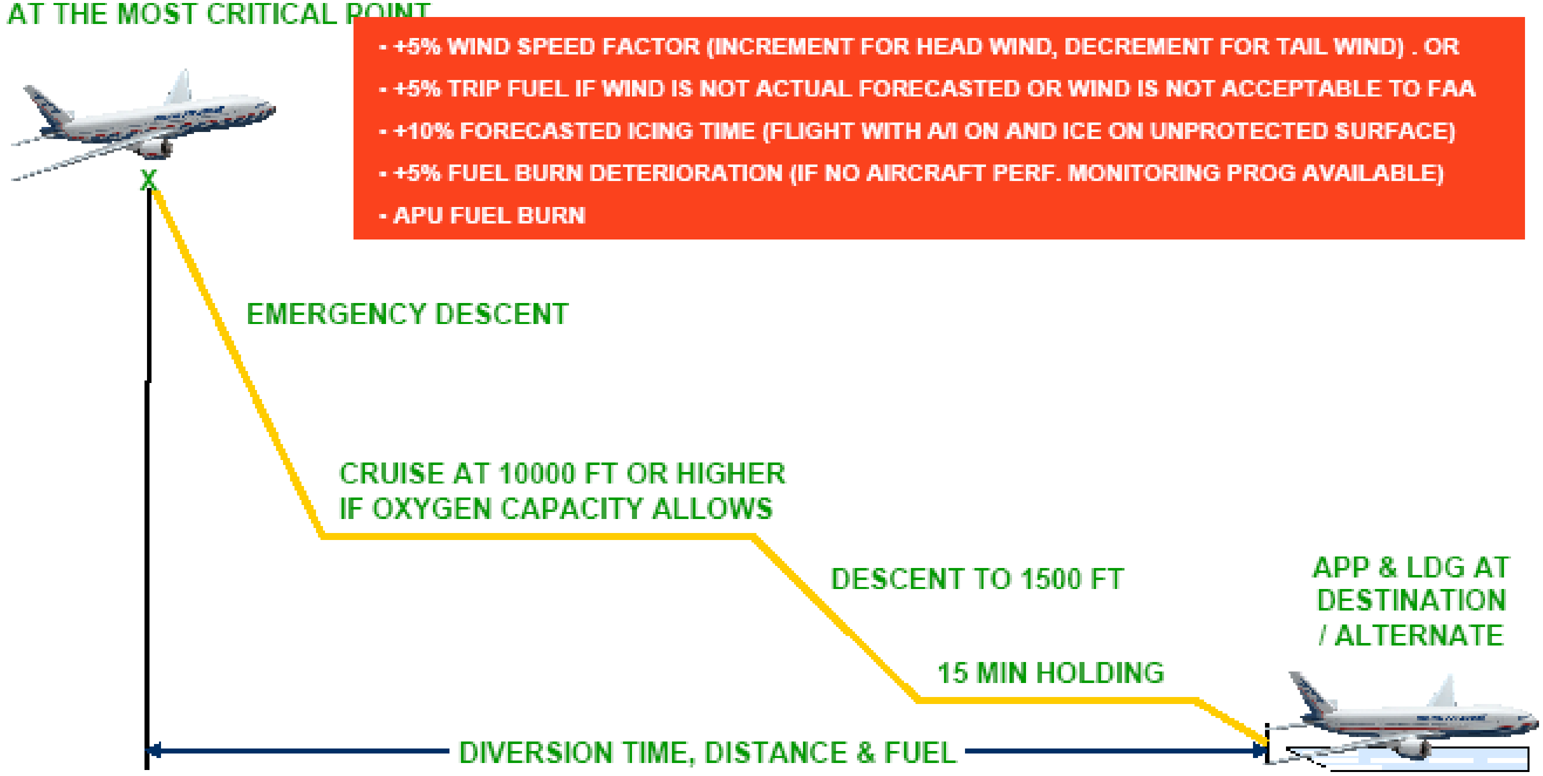
ETOPS FLIGHT PROFILES & FUEL SUPPLY



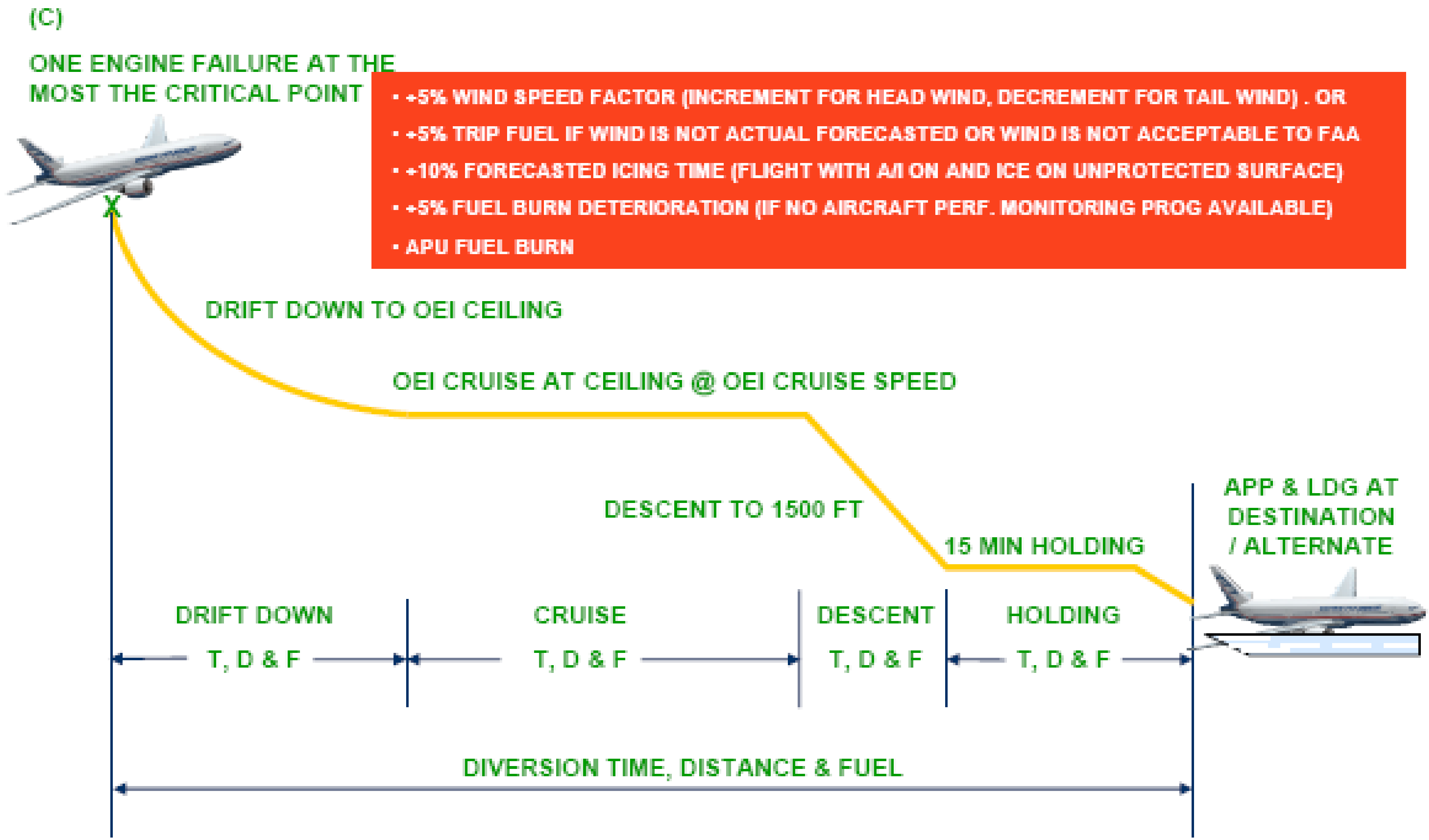
ETOPS FLIGHT PROFILES & FUEL SUPPLY

(B)

RAPID DECOMPRESSION & SIMULTANOUS ENGINE FAILURE
AT THE MOST CRITICAL POINT



ETOPS FLIGHT PROFILES & FUEL SUPPLY



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ETOPS– Design Requirements

ETOPS design requirements are grouped in 11 subject/discipline as follow:

- **a. Part 25 Compliance in Consideration of ETOPS**

Airplane Safety Assessment

- **b. Human Factors**
- **c. Operation in Icing Conditions**
- **d. Electrical Power Supply**
- **e. Time-limited Systems**
- **f. Airplane Fuel System Design**
- **g. Low Fuel Alerting**
- **h. APU Design**
- **i. Engine Condition Monitoring**

Airplane Design Requirements

- **j. Configuration, Maintenance, and Procedures Document**
- **k. Airplane Flight Manual**

Airplane Manuals

ETOPS– Design Requirements

- **a. Part 25 Compliance in Consideration of ETOPS**
  - **(1)** comply with the requirements of part 25 considering the maximum flight time and the longest diversion time (# hours flight time /180 min diversion).
  - **(2)** ETOPS Scenario: Define typical ETOPS flight profiles and apply scenario with possible failures.
    - Flight Phases included in the ETOPS Scenario:
      - **(a)** All-engine climb through possible icing conditions to cruise altitude;
      - **(b)** A maximum ETOPS flight with a maximum ETOPS diversion initiated at a critical point in the flight determined from an analysis of system failure conditions;
      - **(c)** Enroute step climbs if the normal initial cruising altitude of a maximum gross weight airplane would be below the final desired cruising altitude;
      - **(d)** Diversions at both the most critical one-engine inoperative cruise altitude and the cabin decompression diversion altitude, normally 10,000 feet;
      - **(e)** Possible icing conditions that may be encountered during an engine-inoperative diversion;
      - **(f)** Diversion descent with a fifteen minute hold, missed approach and go-around followed by landing with icing conditions specified in Appendix C to part 25;
      - **(g)** In-flight shutdown of one engine;
      - **(h)** Cabin decompression;
      - **(i)** Combination of IFSD and cabin decompression;
      - **(j)** Loss of system redundancy to the minimum allowable configuration for safe airplane diversion as determined from system safety assessments.

ETOPS– Design Requirements

- **b. Human Factors**
  - **Evaluation of crew workload, operational implications, and the crew's and passengers' physiological needs during continued operation, with failure effects for the longest diversion time of 180 min.**
  - **BA/TCCA agreement on the minimum set of airplane system functions required during a maximum length ETOPS diversion. Considering**
    - **the long-term effect of the loss of functions on the safety of a diversion, and**
    - **the impact of the loss of multiple functions from expected common-cause failure conditions.**

ETOPS– Design Requirements

- **b. Human Factors - Continued**
  - **BA to propose and justify the minimum set of airplane system functions required for:**
    - **(a) Continued safe flight and landing in the approved operating environment considering a maximum duration diversion;**
    - **(b) Flight control capability;**
    - **(c) Autopilot/autothrottle capability;**
    - **(d) Navigational capability;**
    - **(e) Communications capability;**
    - **(f) Operating in the air traffic environment (lighting, transponder, radios, SATCOM, TCAS, ground proximity warning system, etc.);**
    - **(g) Flight deck environmental control;**
    - **(h) Cabin environmental control; and**
    - **(i) Emergency lighting control.**
  - **The airplane flight testing (required for ETOPS Approval) must validate**
    - **the adequacy of the airplane's flying qualities and performance, and**
    - **the flightcrew's ability to safely conduct an ETOPS diversion.**
    - **the failure effects used to substantiate compliance with the human factors requirement**

ETOPS– Design Requirements

- **c. Operation in Icing Conditions**
  - Compliance with § 25.1419 a prerequisite for ETOPS type design approval
  - Operation in icing conditions during an ETOPS diversion with the most critical ice accretion resulting from:
    - **(a)** Icing conditions encountered at an altitude that the airplane would have to fly following an engine failure or cabin decompression.
    - **(b)** A 15-minute hold in the continuous maximum icing conditions specified in Appendix C to part 25, with a liquid water content factor of 1.0.
    - **(c)** Ice accumulated during approach and landing in the icing conditions specified in Appendix C to part 25
  - no acceptance by industry of icing conditions as defined in (Appendix C) that may be encountered during an altitude-limited diversion due to an engine failure or cabin decompression.
    - BA to propose an acceptable method for showing compliance with this requirement.
  - Once agreement between the TCCA and BA is reached on icing conditions expected to be encountered at an altitude that CSeries airplane would have to fly following an engine failure or cabin decompression, these condition to be applied to ETOPS Scenarios.

ETOPS– Design Requirements

- **d. Electrical Power Supply**
  - Airplane to be equipped with at least three independent sources of electrical power for ETOPS approval
  - Each electrical power source, whether or not it is time-limited, must power all of the electrically powered systems and equipment necessary to provide the minimum set of airplane system functions
    - **(a)** Continued safe flight and landing in the approved operating environment considering a maximum duration diversion;
    - **(b)** Flight control capability;
    - **(c)** Autopilot/autothrottle capability;
    - **(d)** Navigational capability;
    - **(e)** Communications capability;
    - **(f)** Operating in the air traffic environment (lighting, transponder, radios, SATCOM, TCAS, ground proximity warning system, etc.);
    - **(g)** Flight deck environmental control;
    - **(h)** Cabin environmental control; and
    - **(i)** Emergency lighting control.

ETOPS– Design Requirements

- **d. Electrical Power Supply - Continue**
  - FAA policy has not allowed dispatch of an ETOPS flight with less than three operable generators on routes with maximum diversion times greater than 120 minutes
  - Integrated drive generator (IDG) mounted on each engine plus an APU generator is acceptable for ETOPS approval, however,
    - all three generators must be operational for ETOPS dispatch.
    - FAA has not accepted any APU in-flight start reliability as sufficient to allow ETOPS flight with the APU not running on an airplane with the three-generator minimum.
    - The FAA assumes the APU will not start and has required the APU to be running during the ETOPS portion of a flight.

ETOPS– Design Requirements

- **e. Time-limited Systems**
  - **(1)** BA to define the system time capability of each ETOPS significant system.
    - AFM to contain the system time capability for the most limiting ETOPS significant system other than / as well as fire suppression systems for Class C and D cargo or baggage compartments- TBD
  - **(2)** AFM will determine the maximum diversion time on an ETOPS route from the time of both classes of ETOPS significant systems.
  - **(3)** For any potential ETOPS alternate airports within distance, the most limiting ETOPS significant system other than cargo fire suppression systems must have sufficient time capability for the longer time it would take to fly this distance at the one-engine inoperative cruise speed.
  - **(**4) For 180 minutes ETOPS under part 121, the operating rules have different time-limited system requirements, the maximum diversion time is based on the approved one-engine inoperative cruise speed under standard conditions in still air.
    - This requirement applies to both cargo and baggage compartment fire suppression systems, and other time-limited ETOPS significant systems. This provision also includes an additional 15 minutes for holding, approach and landing at the diversion airport. So, for 180-minute ETOPS, all ETOPS significant systems must have at least 195-minute time capability

ETOPS– Design Requirements

- **e. Time-limited Systems - Continued**
  - (8) BA assessment of what system functions are truly time-limited for compliance with this requirement.
    - Some systems are obviously time-limited because of the capacity of quantity-limited consumables.
      - Fluid tanks or storage containers for oil and slow time-release fire extinguishing agents fit into this category. Fuel system tanks are also time-limited, but are not specifically covered by § K25.1.3 because separate operating rules determine fuel loading sufficient to support ETOPS flights.
  - (9) Other factors may determine a system time capability that may not be so obvious. Air and fluid filter capacity may limit the length of time that a system may safely function with maximum contamination present..
  - (10) System safety assessments may indicate that the acceptance of certain system failure conditions for continued safe flight and landing may be time-limited. For example,
    - certain degraded flight control configurations may be acceptable for short periods of time, but not for a maximum length ETOPS diversion.
    - loss of certain navigation and communication system functions, or
    - environmental control system failures.

    Safety hazard assessments should determine any time limits associated with degraded system functions. Airplane systems should be designed to ensure that any airplane system failure conditions that would be unacceptable for a maximum length ETOPS diversion are extremely improbable. This assessment should also consider potential common cause or common mode failures that contribute to loss of multiple redundant system components.

ETOPS– Design Requirements

- **f. Airplane Fuel System Design**
  - **(1)** the amount of fuel necessary to complete an ETOPS flight (including a diversion for the longest time must be available to the operating engines at the pressure and fuel-flow required by § 25.955 under any airplane failure condition not shown to be extremely improbable.
    - The fuel feed system needs to be able to supply fuel pressure within the limits specified under the part 33 type certificate, under all failure conditions not shown to be extremely improbable.
      - This requirement essentially defines operation with an engine fuel pump inlet pressure below the certified engine limit as a catastrophic failure condition.
      - Existing policy for compliance with the safety objectives of § 25.1309 specifies that a catastrophic failure condition should occur at a rate of 1 x 10-9 per hour or less.
      - Traditional compliance methods for § 25.955 only evaluate the performance of a fully operating fuel system.
      - For ETOPS, § K25.1.4(a) now requires an applicant to also evaluate fuel system performance with expected failure conditions in meeting the pressure and fuel flow requirements of this section.
  - **(2)** The intent of § K25.1.4(a) is to ensure that the airplane fuel system will always deliver fuel within the normal engine pump inlet pressure limit, or that the engines are certified to operate at the lowest engine pump inlet pressure expected to occur during operation with the normal airplane fuel boost pumps inoperative (suction feed).
    - If an applicant chooses to use suction feed as a means to comply with this rule, it must demonstrate safe operation of the airplane in that configuration for the longest diversion time for which the applicant is requesting approval.

ETOPS– Design Requirements

- **f. Airplane Fuel System Design - Continued**
  - **(3) Standard fuel system configurations utilize two fuel boost pumps per tank. A typical fuel boost pump reliability of approximately 10,000 hours mean time between failure (MTBF) would not meet the reliability objective for compliance with § K25.1.4(a) for the failure of both boost pumps. There are several ways to increase the reliability of an airplane fuel system to meet this safety objective.**
    - **(a) Add a third boost pump. This adds significant complexity to a fuel system design and may increase the risk of exposure to fuel tank explosion hazards.**
    - **(b) Improve pump reliability. For a two-pump installation, an MTBF of greater than 30,000 hours would be required. Pump failure conditions factored into the MTBF include those that reduce the performance of a boost pump below that required to meet the pressure and flow requirements of § 25.955, even if the pump still functions.**
    - **If boost pump reliability is to be a part of a means to comply with § K25.1.4(a), the Instructions for Continued Airworthiness should contain procedures to determine that the pump meets its minimum performance standard. The time interval for performing these pump performance procedures must ensure that fuel system will continue to meet § K25.1.4(a) throughout the life of the airplane.**
    - **(c) Ensure adequate electrical system reliability for electrically powered boost pumps and control valves or other necessary fuel system components.**
    - **(d) Enlarge the fuel capacity of the main fuel tanks to lessen the impact of the loss of fuel boost pressure to a single fuel tank. This would ensure that there is sufficient fuel to complete a maximum length diversion with the fuel in one tank having normal boost pressure. This may add structural weight, be a significant design change for existing airplanes, and may not be practical for some airplane designs.**
    - **(e)** Demonstrate adequate suction feed operation for the diversion time being approved, in other words, establish a time-limited suction feed inlet pressure limit for the engine.

ETOPS– Design Requirements

- **f. Airplane Fuel System Design - Continued**
  - **(4) In addition to Part 25 regulations ETOPS airplanes are require to demonstrate engine operation at suction feed inlet pressures for extended periods of time.**
    - **The types of engine failure conditions that could result from extended suction feed operation fall into two categories,**
      - **engine operating problems and**
      - **mechanical failures.**

    Engine operating problems could mean engine instability, permanent loss of thrust, or flameout. Mechanical failures of the engine pump would result in flameout and permanent loss of the engine for the remainder of the flight.
  - **(5) The FAA is aware of at least one engine pump failure that occurred during a test of suction feed operation. A loss of fuel boost pressure to more than one engine during an ETOPS diversion on an airplane with engines that have this kind of vulnerability could potentially result in the failure of multiple engines from the same cause.**
    - **To meet the requirements of § K25.1.4(a) for extended suction feed operation, fuel feed system to deliver fuel above a suction feed pump inlet pressure limit established for the engine.**
    - **The engine manufacturer must demonstrate acceptable engine operation and integrity in accordance with part 33 requirements in order to establish this suction feed limit.**
    - **The airplane manufacturer may need to establish a lower airplane maximum operating altitude limit for suction feed operation in order to meet the certified engine suction feed limit.**

ETOPS– Design Requirements

- f. Airplane Fuel System Design - Continued
  - (6) Section K25.1.4(a)(1) defines additional requirements for demonstrating suction feed performance of a fuel system for an engine that has been certified for limited operation on suction feed. These are:
    - (a) Airplane demonstration testing must cover worst-case cruise and diversion conditions involving:
      - 1 Fuel grade and temperature;
      - 2 Thrust or power variations;
      - 3 Turbulence and negative G; and
      - 4 Fuel system components degraded within their approved maintenance limits.
    - (b) Unusable-fuel quantity in the suction feed configuration must be determined in accordance with § 25.959. Because the location of a suction feed pick-up may be in a different location from that for the normal fuel boost pumps, the most critical airplane attitude for this configuration may be different from normal boosted operation. The flight test to determine suction feed unusable fuel quantity should be adjusted accordingly. However, a single suction feed pick-up may be more sensitive to high or low pitch attitudes depending on where it is located in the fuel tank. These factors are to considered when designing and testing a suction feed configuration.
  - (7) When using suction feed to comply with § K25.1.4(a), the ICA developed in accordance with § 25.1529 must include procedures for maintaining the integrity of the fuel system plumbing. The purpose of these procedures is to prevent the introduction of air into the fuel feed lines during suction feed operation. Any air in the fuel feed lines can lead to power loss or flameout of a turbine engine.

ETOPS– Design Requirements

- **g. Low Fuel Alerting**
  - **(1)** The rule states that the alert must be given when there is enough fuel remaining to safely complete a diversion and must account for abnormal fuel management or transfer between tanks, and possible loss of fuel.
  - **(2)** Conditions that could trigger the low fuel alert include:
    - **(a)** Fuel leaks;
    - **(b)** Higher than expected fuel consumption;
    - **(c)** Fuel system component failures;
    - **(d)** Improper fuel loading; and
    - **(e)** Improper fuel usage.
  - **(3)** The low fuel alerting system must provide enough warning to safely complete a diversion. This means that the alert should be given with sufficient time for the flightcrew to stop any fuel loss and reconfigure the fuel system with enough remaining fuel to fly to the diversion airport. (flightcrew training and fuel monitoring procedures for low fuel alerting system).

ETOPS– Design Requirements

- **g. Low Fuel Alerting - Continue**
  - **(4)** flight deck indications to determine when there will be insufficient fuel to fly to the intended destination. A low fuel alerting system may incorporate these indications, as well as other dedicated design features and logic, to determine when to display the low fuel alert. Flight deck indications may vary but generally include:
    - **(a)** *Fuel configuration.*
    - **(b)** *Fuel imbalance*.
    - **(c)** *Fuel disagree*.
    - **(d)** *Insufficient fuel*.
    - **(e)** *Fuel leak.*

ETOPS– Design Requirements

- **h. APU Design**
  - **(1)** APU installation is required to have adequate reliability. If it is necessary that a required APU be able to start in flight, it has to be able to start at any altitude up to the maximum operating altitude of the airplane, or 45,000 feet, whichever is lower, and to run for the remainder of any flight.
  - **(2)** For ETOPS, APU electrical generator on a two-engine airplane normally provides the third electrical power source required by the rules. All two-engine airplanes approved for ETOPS at the time the ETOPS rule was issued have used an APU only for the required back-up electrical power. However, the same principles discussed here would apply to any required ETOPS significant system component driven by an APU.

ETOPS– Design Requirements

- **h. APU Design - Continued**
  - **(3) Adequate Reliability.**
    - **The numerical probability analyses supporting compliance with § 25.1309 may be used to define the contribution of the APU to overall system reliability. In-flight start reliability should be included in the numerical probability analyses fault tree if the applicant intends that the APU will not run continuously during the ETOPS portion of a flight.**
    - **The start and run reliability objectives for the APU must support compliance with § 25.1309 for the functions it provides.**
    - **A target reliability for certification above the minimum value in the safety analysis should be specified to provide margin in case of unforeseen problems in service. Typically, an in-flight start reliability of 95% or higher has been the industry standard for ETOPS type design approval.**
    - **The Instructions for Continued Airworthiness (ICA) should contain procedures to maintain adequate APU reliability in service. These procedures should allow an operator to determine when an APU can no longer provide its maximum load at the maximum airplane operating altitude.**
  - **(4) For a new airplane, the 3,000 cycle APU validation test required for Early ETOPS approval method provides an acceptable test program for demonstrating the target APU reliability.**
    - **For an existing design with service experience, that service experience may be used to demonstrate acceptable APU reliability under the airplane systems assessment of § K25.2.1(d) for two-engine airplanes.**

ETOPS– Design Requirements

- **h. APU Design - Continued**
  - **(5) Maximum in-flight start capability.**
    - demonstrate several APU starts from a stabilized temperature at maximum cruise altitude.
    - incorporate the APU starts into the airplane flight testing required for ETOPS approval. The number of starts required depends on how quickly and reliably an APU starts from this condition.
    - An analysis of engine gas temperature and rotor speeds should demonstrate a steady acceleration rate with no propensity for the start to hang, with sufficient margin below auto-shutdown limits for rotor speed, temperature, and start time to ensure successful starts. Slow starting is expected from this extreme operating condition, but excessively long starts, even if eventually successful, would be cause for more starts to gain confidence in the reliability of APU starting.
  - **(6) Cold soak.** An APU mounted in an unpressurized part of an airplane typically approaches outside air temperature in cruise when it is not operating.
    - Oil temperature is typically the most critical parameter for starting a cold-soaked APU. Determine the component temperatures or operating conditions most detrimental to APU starting at high altitudes for its specific airplane installation.
    - The cold-soak time for an airplane APU start test program that will stabilize these critical component temperatures should be long enough to give a reasonable representation of the expected environment in service.
    - The FAA would expect a minimum of at least one start after four hours at cruise altitude to adequately demonstrate cold-soak starting of an APU.
    - Additional starts at shorter cold-soak times may be acceptable if it can be demonstrate that the APU critical component temperatures reach a steady-state cold-soaked condition in less time.

ETOPS– Design Requirements

- **i. Engine Condition Monitoring**
  - (1) Part 33 requirement states that engine conditioning monitoring procedures must be able to determine, prior to flight, whether an engine is capable of providing, within approved engine operating limits, maximum continuous power or thrust, bleed air, and power extraction required for a relevant engine inoperative diversion. For an engine to be installed on a two-engine airplane approved for ETOPS, the engine manufacturer must validate the engine condition monitoring procedures in accordance with section A33.3(c) before ETOPS eligibility is granted for that engine.
  - (2) Engine and Airframe manufacturer should develop **jointly** an engine condition monitoring program. The engine condition monitoring procedures should encompass the maximum continuous thrust ratings and engine loading demands, if known, of the actual airplane installation (for example wing and engine inlet anti-ice and electrical system loads).
  - (3) Validate the engine condition monitoring procedures in addition to any specific analyses and tests required by the FAA’s engine certification office for part 33 compliance during ETOPS testing program.

ETOPS– Design Requirements

- **j. Configuration, Maintenance, and Procedures Document**
  - **(1)** Configuration, Maintenance, and Procedures (CMP) document should include:
    - Configuration, operating and maintenance requirements, hardware life limits, Master Minimum Equipment List (MMEL) constraints.
      - For example, the CMP document would not contain all hardware life limits, only those additional life limits necessary to comply with the ETOPS requirements for ETOPS type design approval.
    - The CMP document should also identify any optional equipment such as different capacity cargo or baggage compartment fire protection system configurations, which may define the most limiting system time capability for the airplane.
  - **(2)** FAA airworthiness inspectors use compliance with the CMP document to determine if an airplane may be added to an air carrier's operations specifications for ETOPS.
    - CMP requirements must be in an FAA-approved document and should contain all the information necessary to establish a particular airplane's eligibility to conduct ETOPS.
    - The AFM contains airplane ETOPS flight limitations and operating procedures that may also aid in establishing an airplane's eligibility for ETOPS since it is approved for issuance of the type certificate. However, the AFM would not normally contain other configuration or maintenance related information included in a CMP document.

ETOPS– Design Requirements

- **j. Configuration, Maintenance, and Procedures Document - Continued**
  - **(3) Identification of CMP Requirements. CMP includes:**
    - (a) Corrective actions for problems identified in propulsion and airplane system assessments, or reported under a problem tracking and resolution system, and that are not a part of the basic type design of the airplane or engines. These CMP requirements are a condition for ETOPS type design approval.
    - (b) Optional hardware configurations for equipment required for ETOPS type design approval, or to support compliance with operating requirements such as for different capacity cargo fire suppression system configurations, alternative approved ETOPS significant system configurations, approved SATCOM radios, etc.
    - (c) Other equipment configurations that are not a part of the basic type design of the airplane, but are required to meet ETOPS reliability objectives or system functional requirements as identified through the system safety assessments or other analyses.

ETOPS– Design Requirements

- **j. Configuration, Maintenance, and Procedures Document - Continued**
  - (4) CMP Document Contents. CMP document may include direct statements of the requirements, or reference the required information in the following forms:
    - (a) Service bulletins;
    - (b) Service letters;
    - (c) Equipment part numbers;
    - (d) Drawing numbers;
    - (e) Specific maintenance or operations manual references; and
    - (f) Other pertinent documents that define the alterations, maintenance or operating requirements and hardware life-limits or other limitations applicable to the ETOPS approval.
  - (5) The CMP document should include the applicable revision and date of each item listed. Service bulletins and other forms of service information referenced in a CMP document may identify specific times or dates when compliance should be completed. For ETOPS type design approval, compliance with each item listed in the CMP document is required before an airplane may be used in ETOPS, takes precedence over the MMEL for airplanes used in ETOPS.
  - (6) FAA Approved Changes to CMP Requirements. The CMP document is a part of the airplane type design definition described in § 21.31 and is a prerequisite for the airplane being eligible for ETOPS. The CMP document establishes the airplane minimum design standard for ETOPS. The initial design standard defined in a CMP document is analogous to other type design approvals for specific operations such as approval of autopilot systems with Category III autoland capability.

ETOPS– Design Requirements

- **k. Airplane Flight Manual**
  - requires specific information applicable to an ETOPS type design approval be provided in the AFM. These include:
    - special limitations,
    - required markings and placards,
    - the airborne equipment required for extended operations and
    - flightcrew operating procedures for this equipment, and
    - the system time capability for the most limiting ETOPS significant systems on the airplane.
    - Section K25.1.7 also provides specific wording for an ETOPS type design approval statement in the AFM.

Agenda

- Background and Concept
  - Regulatory Requirements
  - Early ETOPS Requirements and Procedure
- Type Design Approval Process
  - ETOPS Terminology
  - Early ETOPS Approach
- ETOPS Design Requirements
  - Part 25 Appendix K
- **ETOPS Testing and Problem Reporting**
  - Testing and Problem Reporting
    - Manuals – AFM, CMP, MMEL
  - Operational Approval
    - Reliability Testing
    - ETOPS Crew Training
      - Flight Crew
      - Cabin Crew
      - Maintenance Crew
  - Reliability Tracking Board
- Summary

Early ETOPS Occurrences Reporting, Tracking and Resolving Problems

- **Prior to Type Certification**
  - Ground Test
    - Supplier test: Rig and Component
      - Suppliers Reporting Problem Reporting
    - Rigs
      - Adoption of Flight Test Process, Procedure and Database
  - Flight Test
    - Reporting and Resolving Problems process, Procedure and Database
- **In-Service**
  - FRACAS type process
    - Reporting and Resolving Problems process, Procedure and Database

Reliability Tracking Board

Early ETOPS Occurrences Reporting, Tracking and Resolving Problems

- ***Problem tracking and resolution system***
- ***ETOPS reportable occurrences***
- ***Problem tracking and resolution system plan.***
- ***Applicable airplane and engine testing***
- ***ETOPS occurrence reporting***
- ***Problem identification and resolution***
- ***CMP requirements***
- ***Applicability to changes to previously approved airplanes***

System Reliability Testing

- Compliance with Part K 25.2
  - K 25.2.2 Early ETOPS Method
    - Assessment of relevant experience with airplane previously certified
    - Propulsion system design
    - Maintenance and operational
    - Propulsion system validation test
    - New technology testing
    - APU validation test
    - Airplane demonstration
    - Problem tracking
    - Acceptance Criteria

Powerplant Reliability Testing

- Tests of simulated ETOPS service operation and vibration endurance consist of 3,000 representative service start-stop cycles (take-off, climb, cruise, descent, approach, landing and thrust reverse), plus
- three simulated diversions at maximum continuous thrust for the Maximum Approved Diversion Time
  - **These diversions are to be approximately evenly distributed over the cyclic duration of the test, with the last diversion to be conducted within 100 cycles of the completion of the test.**

Fuel System Reliability Testing
Flight Controls System Reliability Testing

- **“New” technology, to the “applicant,” not necessarily new to the industry requires testing to validate the new technology, not analysis.**
  - This requirement would not normally have a major impact on a new airplane program because most applications of new technology are addressed in special conditions or issue papers, which usually require testing to substantiate compliance. For ETOPS type design approval, § K25.2.2(e) requires
    - Tracking and documenting the testing used to validate all new technology used on the airplane

APU Reliability Testing

- The APU should demonstrate the required in-flight start reliability throughout the flight envelope (compatible with overall safety objective but not less than 95%**,** or an acceptable procedure demonstrated for starting and running the APU, (e.g. descent to allow start), taking account of all approved fuel types and temperatures. If this reliability cannot be demonstrated, it may be necessary to require continuous operation of the APU.
- For a new airplane, the 3,000 cycle APU validation test required by §§ K25.2.2(f) and K25.3.2(c) of the Early ETOPS approval method provides an acceptable test program for demonstrating the target APU reliability. For an existing design with service experience, that service experience may be used to demonstrate acceptable APU reliability under the airplane systems assessment of § K25.2.1(d) for two-engine airplanes

ETOPS Failure Cases

- **ETOPS three failure Scenarios**
  - Loss of one engine
  - Depressurization
  - Loss of one engine and Depressurization
- **Systems failures not shown to be extremely improbable**
  - Flight Controls
  - Fuel and Fuel Alerting
  - Fidex
  - Electrical
  - Avionics
  - APU
  - Hydraulic
  - Landing Gear
  - Avionics
  - ECS

Proposed Aircraft Early ETOPS Demonstration program

- **Rough Estimate- Based On Boeing 777/767-400ER/ 787 Actual Experience**
- **(1) or (2) dedicated ETOPS airplanes**
- **Over and above Part 25 basic certification program**
- **'Typical' representative customer interior- configuration TBD**
- **Fly approximately 50 'supercycles', or approximately 250-300 flight hours- various conditions**
- **Approximately 3-8 conditions/flight**
- **Variety Of ETOPS Dispatch Conditions, with customer mechanics dispatching the airplane, using customer ETOPS manuals, with customer flight crews participating as well alongside OEM/ regulatory authorities**
- **ETOPS MANUALS**

Proposed Aircraft Early ETOPS Demonstration program

- **Proposed test airports- for specific conditions**
- **Flight test conditions- variety of takeoff thrust ratings (full, D1, D2), density altitudes, at various airport temperatures and altitudes- bell-shaped (Poisson) distribution- to be negotiated with TC/EASA**
- **(3) full-up MCT ETOPS diversions, with (1) engine shutdown, and other associated systems failures per agreement**
- **Human Factors flight tests mix of regular and simulator**
- **OEM and regulators working together in pre- agreed on test conduct/conditions - NO SURPRISES**
- **ETOPS test scope and conduct agreed upon well before beginning of ETOPS flight test**
- **Pre ETOPS- Pre-TIA flight test – SAME**

ETOPS Flight Test

- **K25.2.2(g) Airplane demonstration**

- Flight test to demonstrate airplane and equipment function properly during ETOPS flights, including maximum length diversions.
- May be performed in conjunction with, but may not substitute for function and reliability (F&R) testing required by § 21.35(b)(2).

ETOPS Flight Test

- **K25.2.2(g) Airplane demonstration (continued)**

- Airplane demonstration must include:
- Flights simulating actual ETOPS, including flight at normal cruise altitude, step climbs, and APU operation.
- Maximum duration flights with maximum duration diversions.
- Maximum duration engine-inoperative diversions.
- Flights demonstrating ETOPS diversion with worst-case ETOPS significant system failures. (loss of normal electrical power)
- Diversions into representative diversion airports.
- Repeated exposure to humid and inclement weather on ground followed by long-duration flight at normal cruise altitude.

ETOPS Flight Test

- **K25.2.2(g) Airplane demonstration (continued)**
- Airplane demonstration must validate adequacy of airplane flying qualities and performance during required test conditions. (Same as service experience method flight test requirement)
- Test airplane must be operated and maintained using recommended operating and maintenance procedures.
- **At completion of airplane demonstration test:**
- **Each ETOPS significant system must undergo on-wing inspection or test to establish condition for continued safe operation.**
  - Engines must undergo a gas path inspection.
  - Any abnormal conditions that could result in IFSD or diversion must be resolved.

Reliability of two-engine airplanes

- **Section 21.4(b) Reliability of two-engine airplanes**

- Requires type certificate holder to report monthly to respective FAA office on the reliability of the world fleet of: A two-engine airplane approved for ETOPS, and
- An engine installed on a two-engine airplane approved for ETOPS.
- Reporting must include: Engine IFSDs, except planned IFSDs performed for flight training
- World fleet 12-month rolling average IFSD rate
- ETOPS fleet utilization

- FAA may approve quarterly reporting if IFSD rate is at or below required level.

Reliability of two-engine airplanes

- Type certificate holder must investigate any cause of an IFSD and report results to responsible FAA office.
- Investigations may be combined with those for 21.3 reports, if applicable.
- Any identified unsafe conditions would be corrected by airworthiness directive.

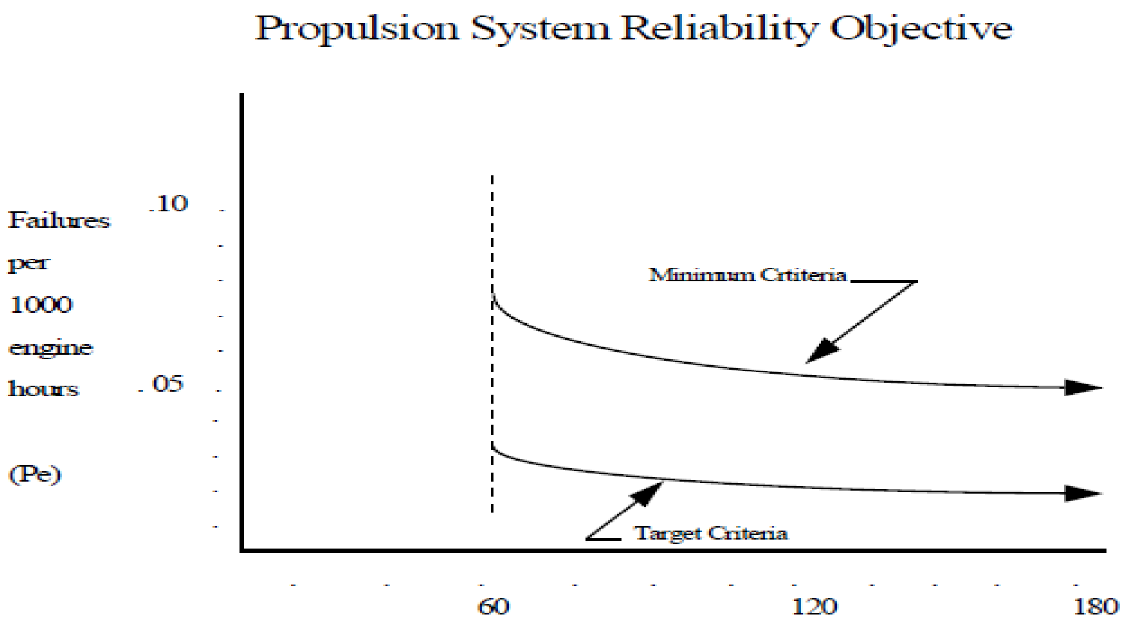
Reliability of two-engine airplanes

- TC holder must issue service information to the operators of its airplanes or engines to maintain the IFSD rate at or below the required level.
  - **–Required IFSD rates:120-minute ETOPS: 0.05 per 1000 world fleet engine-hours until operators have complied with CMP, then 0.02.**
  - **180-minute ETOPS: 0.02 per 1000 world fleet engine-hours**
  - **ETOPS beyond 180 minutes: 0.01 per 1000 world fleet engine-hours**

TCCA believes some tolerance is required to account for verified corrective actions and precautionary shutdowns and also to provide for the expected variance over time in propulsion system reliability statistics. Reported occurrences beyond the tolerance are grounds for withdrawal of ETOPS approval, or reduction in allowed diversion time. The maximum criteria is defined by the following formula:

$(.25)(109)(Pe^2)(t) \leq 1$

FIGURE 1



DIVERSION TIME (MINUTES) (T)

RELIABILITY TABLE (ENGINE FAILURES PER 1000 HOURS)

Diversion Time (t)	Target Criteria	Minimum Criteria
60 minutes	.032	.063
75 minutes	.028	.056
90 minutes	.026	.052
120 minutes	.022	.044
138 minutes	.021	.042
180 minutes	.018	.036

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Summary

Systems Design Are the proposed systems architecture meets/address early ETOPS requirements for 180 min diversion time?	Yes Considering additional requirements or operational limitations	Propulsion System Fuel / Alerting System APU Hydraulic Flight Controls Landing Gear Electrical Avionics ECS & Firex
Processes and Procedures Are the existing processes (testing, reporting, cert,…) addresses early ETOPS requirements for 180 min diversion time?	Yes Considering planned integrated processes {Problem Reporting, testing,…..}	CMP Problem Reporting
Systems Ground & Flight Testing Is ground and flight test program address early ETOPS requirements for 180 min diversion time?	Yes including reliability testing required from suppliers	Sys reliability testing Time-limited Sys tests Problem Reporting
Airplane ETOPS Flight Test Program Is there an early airplane ETOPS test program for: - 180 min diversion time? - 120 min diversion time? - 90 min diversion time? - 75 min diversion time? Is there a combined method ETOPS program for 180 min diversion time?	Airplane ETOPS Flight Test Program Is there an early airplane ETOPS test program for: - Yes – requires clarification - Yes – requires clarification - Not required from TCH - Not required Yes after cumulating 15 000 engine flight hours {one year aft EIS}	Proposed ETOPS Demo Program

Summary

Early ETOPS success is measured against:

1. ***Actual*** IFSD rate accumulated from 3K ground test, Part 25 certification testing, and ETOPS demonstration flight test program
2. 3K teardown results, and resolution of design and operational issues discovered during 3K ground test
3. Demonstrated reliable APU/ electrical power sources
4. Part 25 Cert Program overall engine/airframe performance
5. Overall Part 25 & ETOPS flight test program results
6. Successful problem reporting and resolution process
7. Successful integration of ETOPS operational and maintenance procedures from OEM to customer(s) – must start ***early*** in the process
8. Compliance to the regulations, and detailed tracking of same
9. Demonstrated good, reliable design

Summary

- **Early ETOPS is a thorough process that must be followed rigorously**

- ***Success is assured by adopting ETOPS Principles and Practices***