

Currently, we manage dual engine shut down risk on two engine airplanes by limiting the maximum allowable diversion distance and requiring a low engine in-flight shutdown rate. This is a one-dimensional risk model in that with a constant in-flight shutdown rate, the existing ETOPS requirements and policy consider only the maximum distance that an operator may plan a route from an enroute diversion airport. It assumes that there is a constant risk during the course of a flight with no consideration of how the actual diversion times vary along the track as different alternate airports come into and out of range of the airplane. This approach also does not consider the increase in overall risk that is created by increasing an airplane's range, and thus time aloft, by adding fuel. Further, this model provides no means to assess the effect on overall risk with changes with engine failure rates. Actual ETOPS involve continuously changing distances to alternates. Current ETOPS limits on maximum diversion time don't represent real world risk because diversions can occur anywhere along the track, not just at the maximum point. The new ETOPS risk model adopted for the development of this new proposed rule is based on the introduction of a "two dimensional" model to replace the "one dimensional" maximum diversion time/distance model currently in use.

The new ETOPS Exposure Index is a simplified form of several risk equations that have been developed over the past forty years. All share similar characteristics. The ARAC ETOPS Working Group compared several different mathematical representations for allowable risk versus engine failure rate. Each showed that an engine failure rate on the order of 0.01 per 1,000 engine flight hours was adequate to allow diversion times for two engine airplanes that for all practical purposes could be considered as unrestricted.

The new risk model consists of a comparative risk index based on a combination of range, average diversion distance, and engine failure rate. Independent cause dual engine shut down risk is driven by the footprint area of the route multiplied by the engine failure rate (E) squared. The footprint area is defined as the route length (L) multiplied by the average diversion distance (D). Note that the engine shut down rate is squared to account for loss of first engine and then loss of second engine. Therefore, we define "ETOPS Exposure Index" (EEI) as a function of:

- Footprint Area (Route Length \times Average Diversion Distance) ($L \times D$) and
- E^2 (Engine Failure Rate Squared)

$$EEI = L \times D \times E^2$$

The ETOPS Exposure Index can be used as an evaluation tool to assess risk of ETOPS operations due to independent engine failure causes. Assuming the following values for each of the terms of the equation:

- Route Length = 5500 nautical miles,
- Average Distance for 180 minute ETOPS = 800 nautical miles, and
- Engine failure rate at the current required level = 0.02 shutdowns/1,000 engine-hours or 50,000 hours time between shutdowns.

The EEI would then be:

$$EEI = 5500 \times 800 \times 0.02^2 = 1760$$

With the ETOPS Exposure Index fixed at this level, longer flights and greater maximum diversion distances can be offset by decreased engine failure rate. In other words, as E becomes smaller, L and/or D can increase appropriately. An engine failure rate of one-half the current requirement ($E = 0.01/1,000$ engine-hours) would allow a four times increase in "footprint" area.

$$EEI = L \times D \times E^2$$

$$EEI = 5500 \times 800 \times 0.02^2 = 1760 \text{ equals}$$

$$EEI = 5500 \times 3200 \times 0.01^2 = 1760 \text{ equals}$$

$$EEI = 11,000 \times 1600 \times 0.01^2 = 1760$$

In other words, with an engine failure rate that is one-half the current requirement for 180 minute ETOPS we could allow four times the average diversion distance or a combination of increased route length and average diversion distance with no change in the current ETOPS risk.

For a two engine airplane, engine failure rate has the biggest impact on ETOPS risk because the factor is squared. A reduction in the engine failure rate has a large impact on the size of an allowable footprint area for the same risk. Using the ETOPS Exposure Index concept with a reduction in the engine failure rate standard allows the development of ETOPS rules for two engine airplanes that minimize restrictions on airline operations while maintaining the current excellent ETOPS safety record.

Current in-service engines are capable of achieving better than 100,000 hours time between shutdowns (.01/1,000 engine-hours), or double the current ETOPS reliability standard. This represents two in-flight shutdowns in the entire life of a typical transport airplane. It is not reasonable to expect that two in-flight shutdowns due to independent causes in the entire life of a typical transport airplane would occur on the same flight.

With an IFSD rate of 0.01/1,000 hours, the probability of complete loss of thrust due to independent failures will be sufficiently low so that the main focus

of long-range operational safety can be on reducing the possibility of other risk factors.

We emphasize that this risk model represents a good tool for evaluating the risk of critical thrust loss due to "independent" failure causes. The biggest threat to long-range operational safety continues to be the loss of thrust from multiple engines resulting from: Common Cause Multiple Failures Cascading Multiple Failures Fuel Exhaustion

These threats are common to all long-range operations, regardless of the number of engines on the airplane.

Examples of common cause multiple failure events:

Eastern Airlines L1011 nearly lost all engines after improper installation of engine magnetic chip detectors.

B-747 volcanic ash cloud encounter during volcanic eruption in Alaska—All engines severely damaged by ash.

Example of potential cascading failure:

Worn-out second engine fails after application of higher power following failure of first engine

Examples of Fuel Exhaustion events:

Air Canada 767—No power landing into Gimli, Canada

Air Transat A330—No power landing in the Azores

Sources of Common Cause and Cascading Failures:

Common Design Faults
Hardware
Software

Environmental Exposures

Weather
Volcanic Ash Clouds
Bird Strikes
High Intensity Radiated Fields (HIRF)
Lightning
Simultaneous Maintenance on More than One Engine
Contaminated Fuel

Sources of Fuel Exhaustion:

Operational Errors
Fuel System Mismanagement
Fuel Loading Errors
Misleading Fuel Quantity Indications
Misleading Fuel Loading Procedures particularly during a non-normal (MEL) dispatch

Constant awareness of potential sources of common cause failures, cascading failures, and fuel exhaustion is the key to continued long-range operational safety. This awareness, growing from operating experience, is the basis for continued ETOPS safety. ETOPS safety enhancements focus on defining methods to prevent potential threats caused by known sources.

Examples of Common Cause/Cascading Failure Prevention Strategies: