

with these takeoff- and climb-related shutdowns tend to be cyclic in nature for a couple of reasons.¹ For failure modes where the risk of failure increases with engine thrust, the takeoff portion of the flight is most critical. Failure modes that occur due to improper maintenance or engine servicing, for instance loss of engine oil due to improper assembly of an oil tube connection, also tend to occur early in the flight. A larger number of airplane flights increases the exposure to these types of failures. The FAA considered a cyclic test to be the most appropriate airplane validation test for the original Model 777 ETOPS special conditions. However, as stated above, we now consider that the 3000-cycle engine and propulsion system test required by paragraph (e)(6) provides an adequate opportunity to discover cyclic-related failure modes associated with the design when the test hardware goes through an appropriate level of post-test teardown and inspection.

For inflight shutdowns where improper maintenance is a main causal factor, the 1000-cycle airplane demonstration test provides multiple opportunities for these types of failures to occur. However, the maintenance procedure validation program required by paragraph (d)(2) is intended to minimize the probability of these occurrences. The airplane used for the airplane demonstration test provides opportunities to demonstrate those maintenance tasks associated with the normal operation of the airplane. The FAA considers that these demonstrations can be accomplished in fewer than 1000 cycles.

Although the fewest inflight shutdowns occur during cruise, this is the phase of flight that is most important to an ETOPS operation. Traditionally, the FAA and industry have avoided trying to differentiate between those inflight shutdowns that may occur during cruise from those that would only occur in a non-ETOPS environment. The main reason for this approach in existing ETOPS policy is that by correcting all causes of inflight shutdowns, the overall integrity of the propulsion system is assured. Since adequate cyclic exposure would be evaluated by an enhanced 3000-cycle engine demonstration test, as proposed for paragraph (e)(6) of these special conditions, the FAA has concluded that

the airplane validation program should emphasize exposure to the cruise phase of flight. During the three 1000-cycle tests conducted for the original Model 777 engine installation certification programs, only 91 of the total 1000 cycles were of durations of two hours or more. Since the intent of paragraph (e)(7) is to simulate an actual airline operation, this would better be accomplished through longer duration flight cycles. Long duration flight exposure provides additional confidence in the design against those cruise-related failure modes that cannot be evaluated in a cyclic test environment. Such failure modes could include freezing of entrapped water condensation or binding of propulsion system components, neither of which would likely occur in a sea level test facility.

Based on these considerations, the FAA has determined that the airplane demonstration test requirement should be refocused on those conditions that are most prevalent in an ETOPS operating environment. Those conditions include long flights to a variety of airports with broad variations of airport elevation, temperature, and humidity. It is also important that these flights expose the airplane to several enroute climbs, such as may occur with a fully loaded Model 777-300ER on a long-range flight, and a number of single engine diversions. As such, the airplane demonstration test requirement of paragraph (e)(7) is revised to more clearly state the objectives of the test program. Those objectives include demonstrations that the aircraft, its components, and equipment are capable of long-range operations and airplane diversions, including engine-inoperative diversions, and function properly during those operations and diversions. This change in focus constitutes a significant departure from the original purpose of the 1000-cycle airplane demonstration test requirement, as discussed in the preamble to Special Conditions No. 25-ANM-84.

Reliability of 777

In order to further justify this change in philosophy for the airplane demonstration test requirement from being a demonstration of "reliability" to a demonstration of "capability," the FAA reviewed the original intent of Special Conditions No. 25-ANM-84, as documented in the preamble to those special conditions. The purpose of this review was to assess whether the assumptions we made in justifying the special conditions are still valid, or whether they should be revised based

on ETOPS certification experience since their issuance in June 1994.

In the preamble to Special Conditions No. 25-ANM-84, the FAA stated that:

existing practices to achieve airplane certification safety objectives have involved definition of performance requirements, incorporation of safety margins, and prediction of failure probabilities through analysis and test. However, historical evidence, in general, indicates that a period of actual revenue service experience is necessary to identify and resolve problems not observed during the normal certification process. Successful achievement of this experience has been a prerequisite for granting ETOPS type design approval for a specific airplane engine combination. However, several recent airplane engine combinations incorporating new or substantially modified propulsion systems have demonstrated a high level of reliability consistent with ETOPS operation upon entry into revenue service. In addition, this high level of reliability was demonstrated by the small number of problems encountered during basic certification activity. Based on these successful airplane and engine development and certification programs, the special conditions were designed to "result in a level of airplane reliability that is equivalent to the level of reliability previously found to be acceptable based upon service experience."

The basic premise behind the engine and airplane demonstration tests required by paragraphs (e)(6) and (e)(7) of the original special conditions was that those tests would provide a final validation of an "inherent" level of reliability that was the product of an enhanced design and test process. This is similar to the purpose of the function and reliability testing required by § 21.35(b)(2). The FAA's expectation for these tests was that no significant failures would occur. The probability of significant design failures occurring on a one-airplane flight test is so low that if any *do* occur, that would be indicative of a design that is not suitable for ETOPS approval. This expectation is contained in the "type and frequency" requirement of special conditions paragraph (h)(1). Statistical reliability studies have shown that a much larger database would be required to validate a design's true reliability with a significant degree of confidence.

No major engine failures occurred during the 1000-cycle airplane demonstration tests for any of the three engine types certified on the Model 777 series airplane, although several engine design problems were discovered during other certification testing that affected the start and conduct of those tests. The Reliability Assessment Board (RAB) evaluated each of these design problems in compliance with paragraph (g) of the special conditions, and found the Model

¹ Data provided to the Aviation Rulemaking Advisory Committee (ARAC) ETOPS Working Group confirm that the inflight shutdown rate during the takeoff flight phase is on the order of 6 to 16 times the fleet average inflight shutdown rate and during the climb phase is 2.5 to 4.5 times the fleet average.