

FTL REPORT R87-9

A REVIEW OF EXTENDED-RANGE OPERATIONS
BY TRANSPORT AIRCRAFT

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A Review of Extended Enroute Operations by Transport Aircraft

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1. INTRODUCTION

The safety of enroute operations of aircraft engaged in public transport has been a continuous concern since the early days of air transportation. There are a variety of inflight emergency situations which can create a need to land the aircraft as soon as safely possible: fire in cargo compartments or toilet areas, incapacitated crew members or a medical problem with a passenger, insufficient fuel or oil, failure of one or more engines, or failure of other major aircraft systems such as electrical or cabin pressurization systems. All of these occur frequently enough in public air transport to cause airline operators and airworthiness authorities to consider the time to reach airports suitable for enroute diversion as a factor in planning and approving the operation of any aircraft along its intended route.

One of the inflight emergencies which does occur commonly in air transport is the failure or inflight shutdown (IFSD) of an engine. The shutdown of a single engine creates a situation where aircraft are exposed to the risk of an independent failure of a second engine, during the period of the flight to a diversion airport. For a twin-engine transport aircraft, this "double independent failure" case leaves the aircraft with no means of propulsion, and may be considered a catastrophic event since the probability of fatalities in the ensuing forced landing away from an airport is very high.

The past five years have seen the introduction of operations by modern twin-engine turbofan transport aircraft on long-haul oceanic routes. These have been dubbed ETOPS (Extended-Range Twin-Engine Operations). This caused a review of the safety of enroute operations by twin-engine aircraft with an emphasis on the situation where there might be an inflight shutdown of one engine. Various airworthiness authorities around the world have established safety regulations to approve ETOPS operations by a specific operator and aircraft-engine combination on "extended range" (ER) routes.

In 1986, ICAO amended Annex 6 of its International Standards and Recommended Practices to provide guidance on "extended range operations by aeroplanes with two power-units (ETOPS)" to its contracting states. In June 1985, the FAA issued its Advisory Circular AC 120-42 which "states an acceptable means, but not the only means for obtaining approval under FAR 121.161 for two-engine airplanes to operate over a route that contains a point farther than one hour flying time at the normal one-engine inoperative cruise speed (in still air) from an adequate airport." By the end of 1986, there had been a few years of experience with ETOPS activity by several US and foreign carriers on the North Atlantic routes and in other areas of the world.

This study is a review of the current ETOPS situation, carried out for the Transportation Systems Center and the Office of Aviation Safety, FAA, at the request of the FAA Administrator. While the activity of the past five years has focused on extended-range operations of twin-engine transport aircraft, there now seems to be general agreement that some of the regulatory actions should be extended to cover ER operations by all transport aircraft.

2. DESCRIPTION OF EXTENDED RANGE OPERATIONS

There are many routes in today's air transport system in oceanic or unpopulated remote areas of major continents, where transport aircraft are more than two hours from a safe landing due to lack of suitable airports. Faced with the occurrence of an inflight emergency, the captain must make sensible decisions in attempting to resolve it in an expeditious and safe manner. While time to landing may be critical in situations such as an uncontrollable fire, it is not the only risk factor. There are risks associated with landing under abnormal conditions, or proceeding to an isolated diversion airport with uncertain weather forecasts that may prevent landing, which may lead the captain to choose a course of action other than landing at the nearest airport. Thus, the operational risks incurred due to inflight emergencies may not be directly proportional to the time or distance to the nearest diversion airport. The quality of enroute facilities in terms of airports, air traffic control, and communications may also be important in reducing the exposure to fatal accidents due to inflight emergencies.

However, the duration of the flight to the nearest diversion airport clearly remains as one of the risk factors to be examined in approving the operation of a transport aircraft to fly a long-haul route. In creating regulations for ETOPS, the concept of a "threshold diversion time" has been used to define an extended-range segment of the complete route. Whenever a point on the route exists such that the diversion time exceeds this threshold, then the aircraft is subject to special rules. The variation of the minimum diversion time along a route is described below.

2.1 Minimum Diversion Time

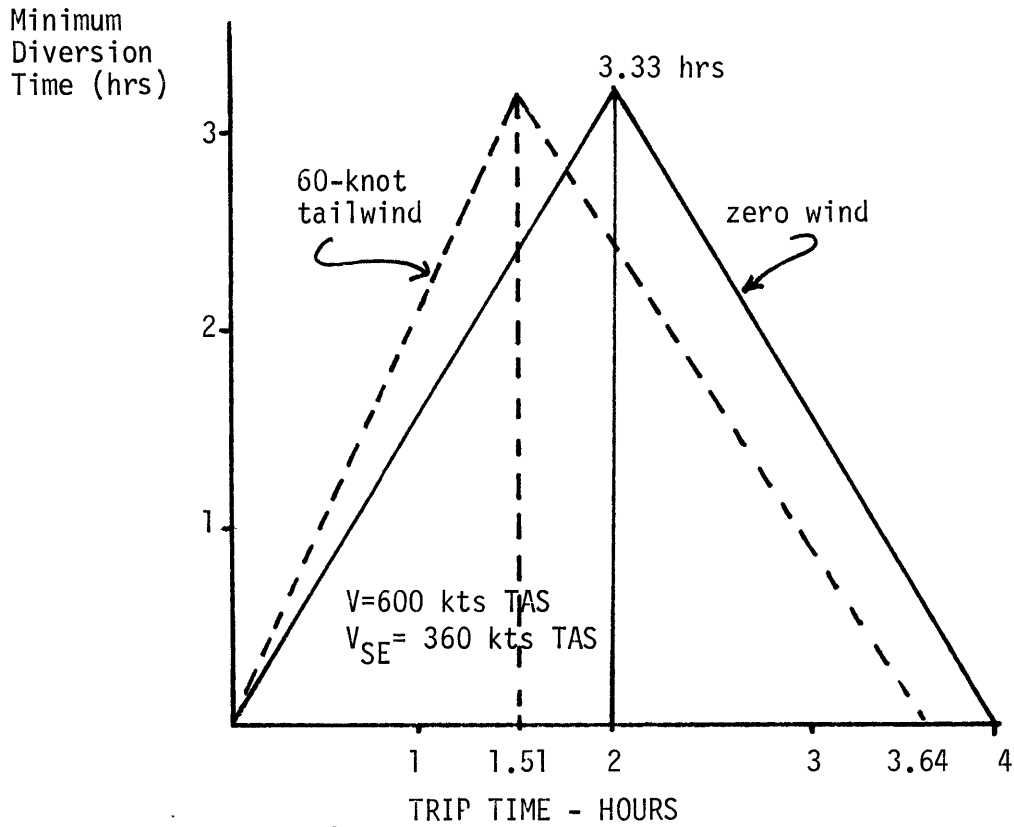
At each point along a route, there is one suitable diversion airport which can be reached in minimum time. Because of the time-critical nature of inflight emergencies, this may be the preferred diversion airport at

this point, if all other factors are equal. At certain equal time points (ETP), the preferred or minimum-time airport will change to the next airport along the route, so that there are segments of the route associated with the nearest airport. The diversion time to that airport varies along that segment, and is a function of the airspeed, altitude, and winds which would exist during the diversion. If a single engine fails, the aircraft will select a single-engine cruise airspeed and altitude, and will "drift-down" from its normal cruise conditions, following some desired speed/altitude profile. (This assumes it is free to adopt such a profile under ATC constraints.) The expected diversion time is a function of the winds at the time of diversion, and thus depends on weather forecasts along the route. This introduces some uncertainty into actual diversion times and the ETP locations. The wind effects can be strong, and can change both the geographic location of the ETP's and the actual diversion times from one day to the next along the same route.

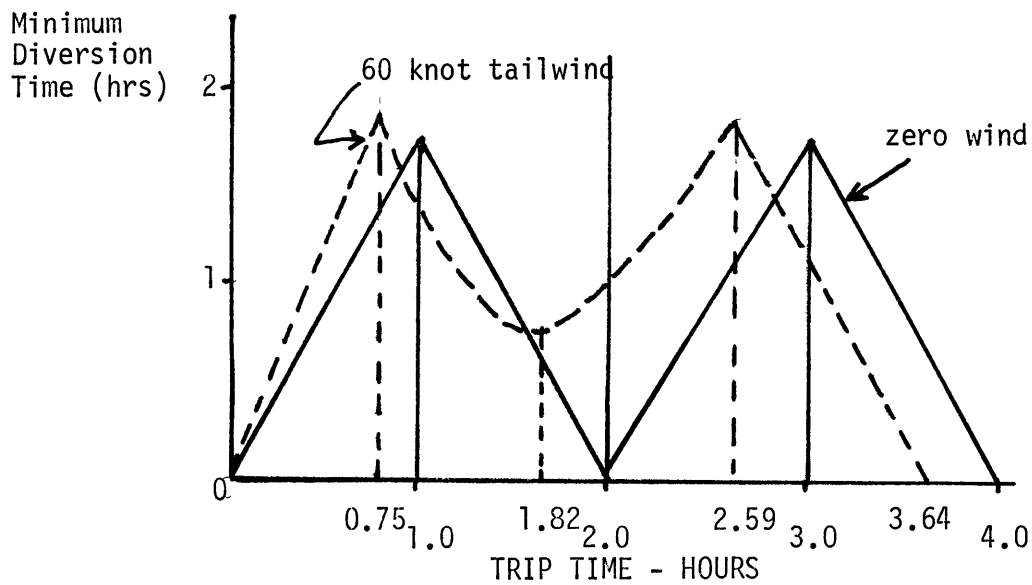
For example, Figure 1a) shows the effect of a 60-knot tailwind component on a 4-hour trip by an aircraft with 600-knot cruise speed, 360-knot single-engine cruise speed. In still air, the first two hours of the trip, the aircraft would divert back to the origin, with a diversion time equal to trip time at any point. The maximum diversion time would be 3.33 hours at the mid-point, and the average diversion time over the route would be 1.66 hour. A 60-knot tailwind component moves the equal-time point (or "point of no return") from the mid-point to only 1.51 hours into the trip. Maximum and Average diversion times remain at 3.33 and 1.66 hour, respectively.

Figure 1b) shows the reduction in maximum diversion time to 1.77 hours for zero wind if there were a suitable diversion airport 300 n. miles from the mid-point of the trip. For the 60-knot tailwind, the ETP's are still equally spaced relative to the mid-point. It now becomes a complex calculation to derive the average diversion time for the trip, especially if the forecast winds are varying during the duration of the trip, or along the path into the diversion airport (see Appendix 1).

Figure 1. Minimum Diversion Time Along a Route



(a) No Enroute Alternate Airport



(b) Mid-Point Alternate Airport

Obviously, there can be a number of enroute alternate diversion airports which create more ETP's and cause the calculated diversion time to vary up and down throughout the trip in a more complex manner. Furthermore, while these alternate airports may generally be adequate to land the particular type of aircraft, weather or facility outages may render them unsuitable when dispatching a particular flight, or during the operation of the flight. It requires constant monitoring of NOTAM's and weather reports and forecasts to maintain an accurate, up-to-date representation of minimum diversion times.

2.2 Evaluating Risk in Extended-Range (ER) Operations

Currently, airworthiness authorities are struggling with the problems of introducing modern, statistically-based methods of risk analysis into their decision-making. The overall worldwide risk of a fatal accident in air transportation at the present time can be expressed as one event in just over two per million flying hours, and one current risk methodology divides this risk into a budget for various causes such as airworthiness, weather, operations, maintenance, manufacturing, etc. Within each of these areas, the budgeted risk can be further subdivided, e.g., airworthiness might declare budget risk levels for aircraft system failures, structural failures, etc.; or operations might have budget risk levels for crew error, onboard fires, crew incapacitation, etc.

Risk levels have been classified by ICAO into "improbable" and "extremely improbable". "Improbable" is further described as "Remote" and "Extremely Remote":

Improbable

Remote: unlikely to occur to an individual airplane during its lifetime, but may occur several times in the total service life of a fleet. This is given an hourly risk in the range of 10^{-5} to 10^{-7} events per hour of flight.

Extremely unlikely to occur during the total service life of the
Remote: fleet. This is given an hourly risk of 10^{-7} to 10^{-9}
events per hour of flight.

Extremely a frequency of occurrence so small that it does not have to be
Improbable: regarded as "possible". This is given a value of 10^{-9} or
fewer events per hour of flight.

It is not clear why "hour of flight" has been selected as a measure of exposure to risk. Any review of risk events in aviation generally shows that there is a higher risk in takeoff, landing, climb, and descent operations than there is in cruise operations. The implication is that unsafe events are occurring randomly over time. It is equally plausible to create and use measures of risk based on cycles, or flights, or departures, and to associate certain types of unsafe events with phases of flight such as takeoff and climb, or descent and landing.

In the course of work by the ICAO Study Group on ETOPS, a probability model emerged to compute the risk associated with the "dual-independent engine failure" case on a "per-flight" basis rather than a "per-hour" basis. It can be described briefly as:

$$P_f = 2P_1P_2TY = (2P_1T) \cdot P_2Y = P_h(0.6 + 0.4T)$$

where

- P_f = probability per flight of a "dual-independent failure"
- P_h = desired probability per hour = 10^{-8} per hour
- P_1 = probability per hour of single propulsion system failure in normal cruise
- P_2 = probability per hour of another single propulsion failure in cruise with one engine inoperative
- T = an appropriate duration of flight (such as the duration of the extended range segment)

Y = a diversion time following first failure (properly the mean diversion time during the extended-range segment)

The probability of dual-independent engine failure per flight, P_f , can be expressed as the product of the probability of the first failure ($2P_1T$) and the probability of a second failure during diversion (P_2Y). If one wishes to relate this back to a target level of safety (or allocated risk budget) expressed on an hourly basis, there apparently is an empirical relationship to justify

$$P_f = P_h(0.6 + 0.4T)$$

(ICAO did not refer to any justification for this empirical relationship, nor explain the database from which it was derived.)

Note that this model assumes that the risk of engine failure is proportional to exposure time. In working with this model, the statistics on inflight shutdown (IFSD) per hour have often been used instead of inflight failure (IFF) per hour, and it seems to be usual to assume that the cruise rates are one-half the overall IFSD rate for normal operation, and that they are twice the IFSD rate for single-engine inoperative cruise. There is some evidence that the first assumption may be reasonable (see first four years of B-767 operation with either engine), but there simply is no experience with single-engine inoperative cruise to support the second assumption.

There are alternative risk models which can be used. In the ICAO ETOPS Study Group, a simpler model was proposed which simply stated that on routes where diversion time did not exceed 120 minutes, then the achieved level of propulsion system reliability should be better than 0.05 per 1000 hours. Alternatively, the first ICAO risk model described above can be modified to avoid the empirical conversion to probability per flight by removing T, the flight duration. Then, one states that there is an IFSD rate expressed in terms of shutdowns per flight hour and a probability of a

serious secondary failure (engine or airframe system) during the diversion, which is proportional to the exposure time during the diversion. This appears to be the model used by Airworthiness authorities for evaluating dual independent engine failure, since it leads directly to a risk expressed in overall flight hours. Expressed mathematically in terms similar to the first ICAO model above,

$$P_h = 2(IFSDR) \cdot (P_3 Y) \quad \text{per flight hour}$$

IFSDR = inflight shutdown rate per engine flight hour

P_3 = probability per hour of failure of any airframe/engine system which has serious (or fatal) consequences

This model uses Y, the diversion time, as a factor in determining risk. If the IFSD events are uniformly distributed in time over the duration of the complete flight, then Y should be the average diversion time over the complete trip. Alternatively, one could concentrate on the extended-range trip segment and estimate IFSDR for cruise, to find the risk per flight hour on extended range segments.

In contrast to the passive, retrospective, statistical methods of risk analysis, there is the traditional use by airworthiness authorities of "engineering judgement" or "engineering assessment", which relies on past experience in reviewing or monitoring the design and operation of aircraft. Whereas statistical methods imply a "hands-off" review of ongoing operations and no attempt to understand or explain unsafe events, traditional airworthiness activities attempt to control risk by relying on careful investigation of activities, incidents, and accidents, to impose modifications which change the processes which produce them. Thus, while statistical measures based on past experiences over 6 months or a year assume a stable, coherent process which is generating those statistics, airworthiness engineers may have changed the process to eliminate or reduce the risk. Subsequently, they "filter" the statistics to remove unsafe

events of various types, and thus they interpret past event history from different points of view. This activity depends very heavily on the intuition and judgement of the airworthiness engineers, and the zeal and thoroughness with which they monitor ongoing operations and implement changes. They require the cooperation of aircraft manufacturers and airline operators in execution of their duties, as well as sufficient other internal resources and support.

In extended-range operations, the risks involved in proceeding to a safe landing after various forms of inflight emergencies have to be assessed. Generally, the risks of a fatal accident involve a double independent failure, since there must be a second unsafe event during the diversion following the first inflight emergency event. Aircraft flying routes with larger maximum and average diversion times presumably have greater exposure to the occurrence of this second independent unsafe event. Examples of compound failures are: a cargo compartment fire followed by exhaustion of the fire suppression capability; or a failure of cabin pressurization followed by icing and a failure of the anti-icing system. Since they are independently caused and each unsafe event is rare, it is usually easy to show that such dangerous compound events are extremely remote or improbable.

However, one of the inflight emergencies which is not so rare is the inflight shutdown of an engine. The rates of inflight shutdown (IFSD) for aircraft engines have typical values of 0.1 to 1 per 1000 engine flight hours for piston engines, 0.05 to 0.1 for turboprop engines, and 0.04 to 0.2 for jet and turbofan engines. Thus, if a modern transport aircraft with 4 engines and an engine IFSD rate of 0.05 per 1000 engine flight hours is flying a route of 10 hours duration, it is expected that there will be an engine shutdown every 5000 hours, or every 500 trips. If the route is flown five times per day, it is expected that there will be an engine shutdown on the route every 100 days. Note that if the aircraft has only two engines, the expected IFSD rate will be half that of the four engine aircraft, and the expected interval between shutdown events on the route

will double to 200 days. The point is that IFSD is a relatively frequent occurrence in terms of inflight emergencies.

The shutdown of a single engine as the first inflight emergency exposes the aircraft to all forms of second failures during the diversion flight. If the second independent failure is one which is considered to be dangerous when combined with the engine failure, in that the probability of subsequently avoiding a fatal accident is not very large, then it may become necessary to show that this compound failure is extremely remote or improbable. For twin-engine transport aircraft, the risk that the second failure will be another engine failure qualifies as a dangerous combination. However, it is also necessary to show that it will be possible for the aircraft to fly safely to the diversion airport without undue risk of failure of any of the primary airframe systems if that combination of might also be judged to be dangerous.

It is important to note that an inflight shutdown of an engine is not necessarily an engine failure. The crew may use its discretion in shutting down an abnormal engine, given the possibility of continued safe flight with the remaining engines, and may consider restarting such an engine if subsequent difficulties begin to arise with one of the remaining engines. There will not be a discretionary shutdown of the last remaining engine.

There is a need to review the history of IFSD events if a correct assessment of the risk of "second independent failure" is to be made. While the first shutdown can be assumed to occur at the expected IFSD rate for the cruise phase of flight, the second shutdown can be expected to occur at a lesser rate corresponding to "hard" or non-discretionary shutdowns. There may be a significant difference in the IFSD rates by phase of flight. Only those IFSD events occurring in the cruise, descent, and approach and landing phases need to be applied in making an assessment of the risk of the "second independent engine failure" situation for ER operations.

The possibility of an all-engine common failure case is not zero in air transport where heavy volcanic ash, fuel contamination or starvation, and loss of oil from all engines have caused several incidents and accidents. The relative risk of the "all-engine common failure" case and the "dual-independent failure" case would seem to be in favor of the dual-independent failure case, since there have been no such recorded cases for twin jet transports to this point in time.

The shutdown of a single engine as the first inflight emergency exposes all transport aircraft, regardless of the number of engines, to the possible failures of the primary airframe systems such as Flight Controls and Hydraulics, Electrical Power, Cargo Fire Suppression, Communication, Navigation, Flight Instrumentation, and Cabin Pressurization systems. These systems have been designed and approved by airworthiness authorities to provide flight safety for long-haul routes. Unless there is some relationship to the first engine failure which reduces their reliability, they should continue to provide acceptable risk during the diversion flight (which should be equal to or less than the original time to destination). Such relationships exist whenever an "uncontained failure" of the first engine might cause damage to one or more of these airframe systems, or whenever these systems depend on the failed engine as their source of power. Failure of any engine should leave the primary airframe systems in a configuration where the risk of system failures is still acceptable over the duration of the maximum allowable diversion. It could be that the maximum allowable diversion time, or mean allowable diversion time, is limited by the reduced reliability of one of the degraded airframe primary systems, and not by the possibility of a second independent engine failure. If so, there would be a need to apply such restrictions to all multi-engine transports in extended-range operations.

3. HISTORICAL REVIEW AND DESCRIPTION OF CURRENT ENROUTE OPERATIONS

The early years of regulation of the airline industry in the United States began with the Air Commerce Act of 1926. The Aeronautics Branch was created to enforce the U.S. Air Commerce Regulations of 1926. Section 53 of those Regulations addressed "supplies and equipment for flights over water" and required an adequate supply of potable water", ..."a Very's pistol...and lights and life preservers...". The implication of these regulations, then, was that any unexpected landing would be survivable and that adequate resources should be on hand while signalling and awaiting rescue. The regulations remained in effect as the commercial air transport industry grew from Fokker F-10's and Ford Trimotors (1928) to the Boeing 247 (1933), the first of the modern airliners.

As the Aeronautics Branch expanded, it became the Bureau of Air Commerce in 1934. Regulations were added and revised. In 1935, the same year as the advent of the DC-3, the following rules were added:

For night flying, multiple-engine planes, capable of flying on one engine in an emergency over terrain where landings were rough, must be used.

Airlines had to get Bureau approval of their entire operational divisions, using the suggestions in the bureau's operations manual.

Planes used in instrument flying must be multi-engined and have two-way radios in good operating order.

Guarding against fatigue, pilots must fly not more than 1,000 hours per year, 100 hours per month, and not over 400 hours for any 4 consecutive months. They could not fly over 8 hours in any 24-hour period, nor over 30 hours within 7 days.

Dispatching procedures and the personnel of the airlines involved had to be approved by the bureau.¹

¹"Safer Skyways", D.R. Whitnah, Iowa State University Press, Ames, Iowa, 1966, p. 93.

As many regulations had been issued and modified, it was becoming unclear as to which rules had to be obeyed, since only rules officially issued by the Secretary of Commerce could be enforced. In 1937 all regulations were brought together in the Civil Air Regulations (CAR), which henceforth became the official source of all rules.

The early rules governing operations of aircraft were based on the reliability of piston engines in use at that time. CAR 41, adopted in the U.S. in 1953, limited all twin-engine and three-engine airplanes to routes where they were never more than 60 minutes at one-engine-inoperative cruising speed from an adequate airport. (The ICAO adopted a standard of 90 minutes in 1953.) In 1964, following the introduction and experience of the U.S. trijets, the U.S. modified FAR 121.161 to exempt three-engine turbine-powered aircraft from the "60-minute rule". (The FAA retained flexibility to make changes under FAR 121.161 and did so in 1977 and 1980, allowing some twin-jet operations with a "75-minute rule".) Finally, in June 1985, FAA Advisory Circular 120.42 allowed 120-minute operations under carefully defined conditions.

An ICAO review in 1986 (AN-WP/6007) of ETOPS by member states during the years 1980-1985 revealed that thirteen nations have had some type of ETOPS since 1980, in either scheduled or charter flights. These have ranged from the slight deviations, such as Beech Super King Air flights over the Tasman Sea from Sydney and Brisbane to Lord Howe Island (487 and 459 miles, respectively) and beyond to Norfolk Island (558 miles), as well as flights from New Zealand around the southwestern Pacific Ocean with F27's, F28's, and B737's. More substantial were non-stops over the Bay of Bengal -- routes such as Kuala Lumpur and Singapore to Madras with A300's. Hours flown in ETOPS have steadily increased from 7,000 in 1980 and 11,000 in 1981 (most of which were Australian and New Zealand flights) to 14,000 (1982), 27,000 (1983) and 29,000 (1984) as the Air India, Singapore and Malaysian Airline flights were added.

The largest impetus came in 1985 as AC 120.42 was approved and B767 operations began over the North Atlantic. In 1985 total hours reached almost 50,000. (El Al had initiated some North Atlantic B767 service in 1984.) Currently, five airlines fly twins over the North Atlantic, as shown in Table 1. The largest number of operations are currently by the B767, although the B757-200 and the B737-200 and -300 have ER Airworthiness Approvals. Table 2 (courtesy of the Boeing Company) shows the extent of B767 operations through December 1986. Ten out of the total of 21 B767 operators have ETOPS-equipped aircraft, although only six are conducting ETOPS.

Incident Review

Since May 1985, the Boeing Company has been maintaining, on a world-wide basis, a complete data base on incidents of the major systems of its 767s: (a) electrical power; (b) hydraulic power; (c) air conditioning/pressurization; (d) automatic flight and navigation. The events are further categorized by phase of flight: (1) take-off/climb; (2) cruise; (3) descent/approach; and whether or not the events occurred during ER operation.

Of a total of 48 events which occurred involving electric power systems, 28 occurred during the cruise portion; however, only 5 occurred during ETOPS. Of the 28 events, 20 resulted in diversions of which 3 were during ETOPS.

Hydraulic power events totaled 20, of which 14 occurred during cruise and 3 during ETOPS. There were 3 diversions, none of which were during ETOPS. The air conditioning/pressurization systems had 14 events, of which 3 were during cruise (one ETOPS), resulting in one diversion (not ETOPS). Automatic flight and navigation systems have had a total of 7 events, 3 during cruise. Of the two diversions, one was during ETOPS.

TABLE 1
WINTER 1986 ETOPS ON THE NORTH ATLANTIC

<u>Airline</u>	<u>Market</u>	<u>Aircraft</u>	<u>Weekly Frequency</u>
<u>AMERICAN</u>	ORD - ORY	B767	(7X)
	ORD - MAN	B767	(7X)
	ORD - FRA	B767	(7X)
	ORD - DUS	B767	(7X)
<u>PAN AM</u>	IAD - CDG	A310	(3X)
	DTW - LHR	A310	(5X)
	JFK - CDG	A310	(4X)
	(effective May)		
<u>TWA</u>	JFK - MIL	B767	(7X)
	IAD - CDG	B767	(5X)
	BOS - CDG	B767	(5X)
	STL - LHR	B767	(7X)
<u>AIR CANADA</u>	YMX - LHR	B767	(5X)
	YYZ - FRA	B767	(6X)
	YMX - ZRH	B767	(1X)
	YYZ - CDG	B767	(2x)
	YYT - LHR	B767	(3x)
<u>EL AL</u>	ORD - AMS	B767	(1X)
	BOS - TLV	B767	(1X)

TABLE 2

767 Fleet Data, Total and ER Equipped

As of December 31, 1986

767 Fleet Customers	Number of Airplanes Total	EROPS Equipped	Flight Hours Total	EROPS Operations as of 12/31/86	Current Rate of EROPS Usage
✓ AAL	22	9	157877	1400 N. Atl Cross	280 N. Atl/Mo
✓ ACN	14	2 (120 min) 2 (90 min)	125138	600 N. Atl Cross 1400 Caribbean	32 N. Atl/Mo
ANA	23	0	113767		
ANS	5	0	32093		
✓ ANZ	3	3	8029	2800 Tasman and Pacific Regional	
✓ BEJ	2	2	4971		
BRI	4	0	34743		
BRT	0	0	9800		
CHI	2	0	18429		
DAL	20	0	171632		
EGP	3	0	22833		
✓ ELAL	4	2	31848	More than 390 N. Atl	18 N. Atl/Mo
ETH	2	0	14750		
✓ JAL	6	4	8748		
✓ KUW	3	3	3878		
✓ LAN	2	2	4115		
PWA	0	0	9200		
✓ QAN	6	6	22474	2875 Tasman Sea Cross	
TAC	1	0	4941		
TBL	3	0	38392		
✓ TWA	10	10	126173	3650 N. Atl Cross	150 N. Atl/Mo
UAL	19	0	250353		
VAR	2	0	2340		
Totals:					
Current Operators	767 Airplanes	EROPS 767's	Total Hours	Number of EROPS Operations	Current Total of EROPS Flts/Mo
21	156	45	1,216,524	13,015	480

Note: Data is Actual Count or Conservative Estimate

An even more comprehensive data base exists on inflight shutdowns, encompassing the complete service life of the 767, equipped with both the JT9D-7R4 and CF6-80A engines. Both combinations began service in the second quarter of 1982. Since then the 767/JT9Ds have accumulated 1,314,000 engine hours, while the 767/CF6s have 1,120,000.

Of the total of 104 IFSDs experienced by the 767/JF9Ds, 33 have occurred during the cruise portion of flight, resulting in 26 diversions. Of these, four came during TWA's ETOPS introduction over the North Atlantic, in the spring and summer of 1985. The May 13, 1985, IFSD (engine stall) on the St. Louis-Paris flight resulted in a one hour and fifty-eight minute diversion to Bangor. The June 4, 1985, IFSD (high oil consumption) on the Frankfurt-St. Louis flight resulted in a one hour and three minute diversion to Keflavik. The August 31, 1985, IFSD (high oil consumption) resulted in a one hour diversion to Goose Bay. The September 18, 1985, IFSD (high oil consumption) on the Munich-New York flight resulted in a one hour and thirteen minute diversion to Prestwick.

The first three IFSDs were deemed to have been caused by poor maintenance practices and led to tightened-up maintenance procedures at TWA. The last recorded TWA ETOPS IFSD was attributed to a leaking float caused by poor quality control during manufacturing.

The 767/CF6s have experienced 43 IFSDs, of which 20 were recorded during cruise. Of these 20, 10 resulted in diversion, none of which occurred during ETOPS.

Thus, with the advent of the B757, B767, A300 and A310, Grover Loening's observations (made about the aircraft of the 1930's), have come of age:

Actually, safety with multiengine installation was not the fundamental reason why the engineers adopted this feature, although added safety had some merit. The real reason was that all indications

on the economy of commercial plane operation showed clearly that larger aircraft meant more earnings, more customers, less maintenance per passenger mile, etc....The safest way to attain safety to start with was to design a reliable motor and to install it with care. But when we had a good motor and needed to double the size of the plane, the solution was to double the number of motors. The practice holds to this day, as even individual jet engines are not powerful enough to satisfy the ravenous appetite of commercial requirements. So let us be clear on this point, where many historians are misinformed: a multimotor is not a sine qua non of safety. It is only the solution to economic size. ²

²"Takeoff into Greatness", Grover Loening, G.P. Putnam's Sons, New York, N.Y. 1968, p. 203-204.

4. ANALYSIS OF CURRENT ETOPS REGULATIONS

This section provides a comparative analysis of guidelines for ETOPS published by various nations. The basic document is the FAA Advisory Circular AC 120.42, which seems to have been the cornerstone from which the other nation's documents have been derived. The following publications have been analyzed:

FAA Advisory Circular AC120.42	June 1985
CAA (United Kingdom) CAP 513	January 1986
Transport Canada TP 6327	February 1985
CAA (New Zealand) CA Pamphlet 35	October 1985
ICAO Amendment 18 to Annex 6, Part 1	November 1986
ICAO Amendment to Airworthiness Technical Manual	November 1986

The outcome of the activities of the ICAO Study Group in the period 1983-1985 was a set of guidance materials for its member states to use in adopting airworthiness approval processes for ETOPS. The various documents listed above are strongly based on the FAA document rather than the ICAO guidance material. The following analysis will use the FAA AC120.42 as the basis for comparison, noting any differences in the other documents where pertinent.

4.1 Definition of Extended Range Operations -- Threshold Criteria

The definition of extended-range operations currently being used by the FAA (and UK, Canada, and New Zealand) is based on a threshold distance from any point on the route to a diversion airport with adequate landing facilities for the aircraft. This threshold distance is defined to be that distance which corresponds to 60 minutes at "normal" single-engine cruise speed in still air. In contrast, the ICAO Annex 6, Part 1 (which became an international standard in November 1986) requires that a threshold time be used with no caveat specifying still air. ICAO also suggests a value of 60

minutes. The "normal" single-engine cruise speed has to be defined by the operator, since there are various "drift down" profiles to final single-engine cruise altitudes and thrust settings which could be used.

The use of threshold distance instead of threshold time allows aircraft to use fixed airway segments for non-ETOPS independent of the daily variation in winds or weather affecting the availability of the adequate airports. Threshold radii can be drawn around these adequate airports to define a "non-ETOPS" geographic area for route planning for a given aircraft, even though the actual diversion times experienced in flying the route may exceed the nominal diversion time of 60 minutes on some (or perhaps, due to prevailing winds, even most) trips. This methodology seems to have been inherited from FAA Part 121.161, which had restricted two- and three-engine transport aircraft to this threshold distance (instead of a threshold time) for many years.

4.2 Area of Operation for ETOPS -- Rule Criteria

All the current guidelines create a geographic area for ETOPS based on a "Rule Distance" from adequate airports along the route. This Rule Distance is defined currently to be that distance which corresponds to 120 minutes (or less) at the normal single-engine cruise speed in still air. This is exactly analogous to the Threshold Distance, and creates a geographic area for allowable ETOPS for each aircraft. The FAA AC 120.42 (unlike the UK, Canadian, and New Zealand documents) modifies this simple area definition by also insisting that at least 50% of any extended-range route segment be less than a distance equivalent to 90 minutes from an adequate airport at still-air normal single-engine cruise speed. This can be applied to any fixed-geometry airway or route, but it is difficult to see how it can be used to define the geographic area of operation for oceanic routes where the tracks can be freely selected, or an oceanic track system may vary from day to day. This appears to be a restriction on some

of the tracks which might be defined within the Area of ETOPS as defined by the Rule Distance. Subject to these geographic definitions, an operator may be authorized to conduct ETOPS on various routings within the ETOPS Area.

4.3 Flight Dispatch Limitations on ETOPS

Flight Plan routes within the ETOPS area are further restricted by Flight Dispatch rules, which require that the maximum diversion distance from any point on the planned route to a suitable airport cannot be greater than a distance equivalent to 120 minutes cruise at normal single-engine speed in still air. A suitable airport is an adequate airport "whose latest available forecast weather conditions for a period commencing one hour before the established earliest time of landing and ending one hour after the established latest time of landing at that airport equals or exceeds the authorized IFR weather minima". There is no application of the "90 minute, half segment rule" to a flight plan route by the FAA. Under special maintenance and operating restrictions, this 120-minute maximum diversion distance to suitable airports applied to flight planning may be increased to a maximum diversion distance equivalent to 138 minutes, but only if it remains within the ETOPS Area of Operations defined by adequate airports.

It is, perhaps, surprising to note that forecast winds are not used in flight dispatch to compute the expected diversion time from points along the route. (They are, however, used to compute fuel burn in flying a critical fuel reserve requirement scenario for the flight.) The forecast and actual diversion times for a particular flight dispatched at the maximum diversion distance could exceed the nominal diversion times of 120 minutes by substantial margins. For example, if the normal single-engine cruise speed were 360 knots, and the wind factor enroute to the suitable airport was 60 knots, then the time to fly the maximum diversion distance of 720 n. miles is 144 minutes. There could be additional time required to

clear safely an oceanic track system, and to conduct the approach and landing, and perhaps a missed approach. It is true that the probability of the occurrence of the inflight emergency exactly at the point of maximum diversion distance is very small. In estimating the risk of dual engine failure, it is common to assume that the first engine failure occurs randomly at any point along the extended-range segment, so that the average exposure to the second engine failure is proportional to the mean diversion time, not the maximum diversion time.

It is also pertinent to note that weather forecasts are not as reliable as the aircraft/engine systems. Even though the flight plan uses the "latest available forecast", it is possible that the suitable airport critical to dispatch planning has become "unsuitable" (or is forecast as becoming unsuitable) in the time between dispatch and before the aircraft enters the extended-range segment. Instances have been quoted by pilots flying the North Atlantic ETOPS of inflight estimates of 190 minutes to the nearest suitable airport, caused by the enroute airports becoming unsuitable. There apparently is no guidance from airline managements or airworthiness authorities to aircrews (who are monitoring actual and forecast weather during the flight) as to whether proceeding as originally planned is judged to be a safe operation on the average under these circumstances. It has been left open to the "final authority and responsibility of the pilot-in-command for the safe operation of the airplane" to judge whether or not to enter the ETOPS segment under such circumstances.

The significance of this discrepancy between the "nominal" or "approved" maximum diversion time and the actual potential diversion times experienced during operations depends upon the variation of risk with exposure time during diversion. Certainly, any endurance-limited systems, or reliability assessments which use diversion time, need to be subjected to close scrutiny. There are interesting semantic differences amongst the guidance material of different airworthiness authorities relating to time-critical items. For example, the phrase "in still air at normal single-

engine cruise speed" is not used in any material to qualify the time in stating requirements that the maximum diversion time must exceed cargo fire protection system endurance plus 15 minutes, or "must exceed a figure which is 15 minutes less than the nominal endurance of any time-related system" (UK CAP513). FAA AC 120.42 states in analysis of failure effects and reliability for Type Design Approval, that for fire protection "considering the time required to terminate an extended range operation, the ability of the system to suppress or extinguish fires is adequate to assure safe flight and landing at a suitable airport" (7.c.(6)(ii)). Earlier, (7c.(1)) states that "analysis of airframe and propulsion system failure effects and reliability should be based on the largest diversion time for extended range routes likely to be flown with the airplane" (note no caveat on single-engine, still air), and continues to say that the "approved maximum diversion time" must exceed any lesser time due to time-limited systems. The "approved maximum diversion time" is apparently established as 120 or 138 minutes in 9(e)(2)(i) and (ii) under Flight Dispatch Limitations on ETOPS, but as described here, those sections effectively establish an approved maximum diversion distance and do not limit actual or forecast diversion time.

4.4 Airworthiness Approval Processes for ETOPS

Approval must be sought by each operator for each route/airframe/engine combination. The approval process consists of three major parts: 1) Type Design Approval (sought by operator and aircraft manufacturer together); 2) Inservice Experience Approval; and 3) Operations Approval.

Briefly, the Type Design Approval must find that the reliability for the aircraft and its primary systems due to design factors is satisfactory for extended single-engine flight. The Inservice Experience Approval is a special finding that the reliability of the propulsion system for the

airframe/engine combination is satisfactory based on worldwide experience and at least 12 months of the operator's own experience. In particular, all the authorities have chosen a target level of safety for the probability of dual engine failure for all independent causes, which must be shown to be less than 10^{-8} per hour. (The UK, NZ and Canadian documents all qualify this target to be "in cruise".) The Operations Approval finds that the operator's continuing activities and programs in flight crew training, maintenance, flight dispatch, and operations are adequate to safely conduct and support ETOPS. Also, there is a requirement for continuing surveillance of the IFSD rate for the worldwide and individual operator's fleet (and the publication of a propulsion system reliability report by the FAA for every airplane/engine combination), which might be considered a continuation of the Inservice Experience Approval process during the ongoing ETOPS.

4.4.1 Type Design Approval

If a twin-engine transport aircraft is to be used in ETOPS, its reliability and fail-safe performance due to design factors is evaluated in a special engineering inspection and test program. Airworthiness approval is extended by means of an FAA-approved Airplane Flight Manual (AFM) or supplement, and a Type Certificate Data Sheet or Supplemental Type Certificate. These contain information on limitations, performance changes, special ETOPS equipment or procedures, and a description of the approved airplane configuration. This extended evaluation reviews the design of the propulsion system and essential airframe systems to ensure that they meet desired levels of reliability relative to an "approved maximum diversion time". Since the aircraft should have met airworthiness requirements for normal operations, the evaluation is focused primarily on extended single-engine operations, and the possible effects of damage which might result from the failure of the first engine. However, it appears that all failure combination cases are to be reviewed from an ETOPS viewpoint.

There are some differences amongst the various authorities as to what is required for type design approval. The documents are poorly written, with a section on "Criteria" that talks about matters other than criteria, and a section on "Analysis of Failure Effects and Reliability" which talks about criteria. The original ICAO study group document was well-written and provided clear guidance. It had two sections clearly defined to deal with "Reliability Assessment" and "Analysis of Failure Effects". The current national documents have attempted to merge these topics, and do not provide clear, unambiguous guidance on either reliability criteria or evaluation methodology. As an example of careless writing, all national documents (except Canada) refer to suitable airports in this type design section where it clearly should be an adequate airport.

The target level of safety for the "dual-independent propulsion system failure" case due to design-related causes is set at 10^{-9} or less per hour by FAA AC 120.42, and is described as based on all IFSD events on a worldwide basis, taking into "due account the approved maximum diversion time, rectification of identified engine problems, as well as events where inflight starting capability may be degraded." It does not clarify this last phrase, but the USA reported to ICAO (ICAO AN-WP/6005) in February 1987, that this "statistical analysis is done for the anticipated mean diversion time with the inflight shutdown rate for the one operating engine assumed to be twice that for both engines." (Note that there is a discrepancy between maximum and mean values.) The CAA (UK) CAP 513 differs in setting its target level of safety in this regard, setting its acceptable level to vary from 10^{-8} per hour for a one-hour flight to approximately 0.5×10^{-8} per hour on a ten-hour flight." CAP 513 does not provide any description of how this value would be computed, or why the target level of safety varies with flight duration (rather than the duration of the extended-range segment).

Note that there are two target levels of safety set for the "dual-independent engine failure" case. The value of 10^{-9} or less for type

design set by the FAA is an order of magnitude more severe than the value of 10^{-8} or less, set as due to all operational causes. Airworthiness personnel associated with type design approval are charged in these documents with continuously monitoring ETOPS (FAA 7(f)) and identifying significant problems through the normal airworthiness directive procedures. This presumably allows a satisfactory operational reliability to be achieved at the level of 10^{-8} per hour, while unsatisfactory performance at the type design level of 10^{-9} per hour would remove the approval for ETOPS until effective airworthiness directives could be issued.

While the above "dual independent engine failure" case can be evaluated by using worldwide IFSD data as a conservative measure of engine failure rate, it will be necessary to use data or engineering judgement on contained and uncontained engine failure rates to assess the probability of failure combination cases which involve extended single-engine flight and the probability of a second failure of essential airframe systems, where there may be damage due to the first engine failure. There should be sufficient redundancy in the essential airframe systems after the first engine failure to sustain safe flight to the diversion airport, both in terms of endurance for any time-related systems (such as cargo fire or batteries), and in terms of the risk of failure of an essential airframe system operating in a reduced state due to damage or loss of power sources on the failed engine. The documents talk about "any single failure or combination of failures not shown to be extremely improbable" (i.e., 10^{-9} or less per flight hour). If any such cases exist, then it is stated (except for the Canadian document) that the maximum approved diversion time can be based on any time limitations arising from endurance or reliability time limitations discovered in this analysis. It is not clear how the "safety assessment methods" or "fail-safe methodology" or "engineering judgement" would be used to determine a different "approved maximum diversion time." The CAA (UK) document insists that this time will be 15 minutes less than any such time limitation discovered.

It is also not clear that any target levels of safety have been

established for the independent failure of most of the airframe systems after a single engine failure. The original ICAO study group document called for such risk levels to be improbable (i.e., 10^{-5} per flight hour or better). The current national documents call for a "proper level of fail-safe design" without specifying what that means. It is impossible to determine a reduction in approved diversion times due to time limitations in airframe systems reliability without such a target level being specified.

Instead, the national documents examine only the performance capability of the various degraded systems for any single failure or combination of failures not shown to be extremely improbable. There are two main requirements used: the "continued safe flight and landing" requirement; and the "adverse conditions requirement." The second is not clearly defined, but apparently deals with the ability of the flight crew to cope with engine or system failures without using exceptional skills, crew coordination, and exceptional workload.

The performance capabilities of the essential airframe systems required by the national documents for the failure modes not shown to be extremely improbable may be briefly summarized as follows:

Hydraulic Power and Flight Controls: If the aircraft has all primary flight controls hydraulically powered, the evaluation of system redundancy should meet the "continued safe flight and landing" requirement after the loss of any two hydraulic systems and either engine. These two systems are paired together. There seem to be no requirements on either system for aircraft where primary flight controls are not all hydraulically powered.

Electrical Power: For extended single-engine flight, the national documents all require that electrical power should continue to be available at levels necessary to meet the "continued safe flight and landing" requirement. The necessary levels are described repetitiously in various parts of the documents as "essential flight instruments, warning systems,

avionics, communications, navigation, required route or destination guidance equipment, support systems, and any other equipment deemed necessary to extended range operation." Multiple independent sources of electrical power are required with each being capable of supplying the necessary level of power specified above. If one or more of these independent sources is an APU, hydraulic system, or ram air turbine, then there are statements to the effect that they should be "reliable" (with some variance between the national documents as to what this entails). For the APU, reference is made to meeting standard FAR Part 25 or JAR requirements, and any additional requirements specified by airworthiness authorities. The CAA (UK) document also states that unless there is a "high" probability that, after the failure of one or two generated sources of power, the APU can be started without delay at any altitude up to and including the airplane's "certificated" altitude, the APU must be kept running through the ETOPS segment. For the hydraulic source of electrical power, there should be two or more independent energy sources. The CAA (UK) document further specifies that one source should continue to be available in the event of failure of either engine, and it also notes that it will not "normally" accept batteries as a source of electrical power. The FAA and New Zealand documents specify three or more AC electrical power sources. The Canadian document specifies three or more electrical power sources, and the CAA (UK) document specifies a sufficient number of electrical power sources, noting with current systems that this is likely to be three or more. The FAA, NZ, and Canadian documents specifically state that "a review should be conducted of fail safe and redundancy features supported by a statistical analysis considering 'exposure' times established in 7c(1)" (i.e., the "largest diversion time" or "maximum approved diversion time" which, it is claimed, might be established by the reliability of some time-limited airframe system).

Cargo Compartment: The documents all deal with fire protection of the cargo compartment in two different (and redundant) sections. One section states that analysis and tests should be made to show that the ability to

suppress or extinguish fires is adequate to meet the "safe flight and landing" criterion considering "the time required to terminate an extended range operation." The second section reiterates this requirement, stating that "time-related cargo fire limitations" must be less than the "most critical diversion time (including an allowance for 15 minutes holding and an approach and landing)." The CAA (UK) document uses the phrase "Rule Time" and defines that in its Glossary as the maximum diversion time from any point on the route from a suitable airport (note there is no specification of still air which converts Rule Time to Rule Distance). It is not clear that cargo airlines should receive special attention for ETOPS, since these precepts apply to transport aircraft with any number of engines.

Communication, Navigation, and Basic Flight Instruments: The various national documents simply require that "under all combinations of propulsion and/or airframe systems which are not extremely improbable, "reliable" communication, "sufficiently accurate" navigation, "basic" flight instruments and any required route and destination guidance will be "available."

Cabin Pressurization: In this sole case amongst all the airframe systems, the national documents all establish a target level of safety by requiring that a "review of fail safe and redundancy features should show that the loss of cabin pressure is improbable under single engine operating conditions (i.e., 10^{-5} to 10^{-9} per flight hour by ICAO definitions). It is also required that unless cabin pressure can be maintained at single-engine cruise altitudes, that sufficient oxygen be available to sustain the passengers and crew for the "approved maximum diversion time."

This brief summary of the Type Design Approval process shows that the various national authorities have the intention to review the reliability of the propulsion and airframe systems of aircraft proposed for ETOPS for failure modes which cannot be shown to be extremely improbable. However, they have not revealed the methodology by which they will assess risks to

establish maximum approved diversion times. Instead, the substantive requirements are stated in terms of residual capabilities or performance of these systems after probable failure modes. While proposing the use of statistical reliability analysis, it is not clear that they can exercise anything other than engineering judgement in finding that aircraft can meet the "safe continued flight and landing" requirement. This is not a criticism and represents no deficiency in that it represents the usual situation in airworthiness activities. ETOPS activities over the past few years may have focused the aviation community on the difficulties in making statistical reliability assessment with regard to airworthiness, and shown a need for further research into the development of practical methodologies to be used by airworthiness practitioners. In the ETOPS approval process, there is a need to determine a maximum or mean diversion time as a function of the reliability of the aircraft and its systems, due to type design causes, as well as causes from the manufacture, maintenance, and operation of the aircraft and its systems.

4.4.2 Inservice Experience Approval

Subsequent to Type Design Approval, and as a prerequisite to obtaining Continuing Airworthiness/Operational Approval, there is a requirement in all national documents to show that a certain level of propulsion system reliability has been achieved in worldwide service for the particular airframe/engine combination, and that the operator requesting approval has appropriate operational experience with this airframe/engine combination.

The level of operator experience on the airplane/engine combination required is described variously as normally "12 consecutive months," although variances can be granted or imposed based on a review by the particular airworthiness authority.

The level of propulsion system reliability proposed by all national

documents is that the probability of dual-independent engine failure be 10^{-8} per hour or less, based on the worldwide data base for all IFSD events, and all phases of flight. This probability determination is said to take account of the approved maximum diversion time, rectification of identified propulsion system problems, and "events where inflight starting capability may be degraded." The methodology is described as "engineering judgement" applied in accordance with an Appendix attached to all national documents entitled, "Propulsion System Reliability Assessment and Report." The FAA document uses the phrase "engineering and operational judgement" to describe its assessment methodology used in making this determination.

In the Appendix, the national authorities vary as to who will be making this determination. The FAA has formed a Propulsion System Reliability Assessment Board (PSRAB) consisting of specialists from several parts of the airworthiness organization, and an FAA Order has been drafted to formalize the operation and existence of this Board. The CAA (UK) states that it will make its own determination. The Canadian document states that a "group of FAA/DOT specialists" will conduct the assessment (which seems to imply that the airplane/engine selected by a Canadian operator will always be of interest to the FAA). The New Zealand document states that for airplanes which have been type-certificated by the FAA, its Appendix I (which is a copy of the FAA Appendix) will apply, and that similar procedures will apply to other cases. (It is not clear whether a group of New Zealand airworthiness personnel would conduct this assessment, or request the FAA to make a determination in cases where it has not already been made, or that New Zealand expects that the FAA will normally have made a determination.)

When this group of specialists has made its assessment, Appendix I for AC 120.42 states that the FAA will "publish a Report" declaring whether or not the current propulsion system reliability of this airplane/engine combination satisfies the "relevant considerations of this AC." These findings will be forwarded to the Transport Airplane Certification Directorate (FAA Northwest Mountain Region) for its approval, and thence to

the Directors of Flight Operations and Airworthiness for review and concurrence. This report may specify the design configuration of the propulsion system, operating conditions, maintenance requirements, and limitations, etc., which are necessary to qualify the propulsion system for ETOPS.

To make this assessment, the PSRAB must obtain a worldwide data base on IFSD events for the propulsion system and the airplane/engine combination. This is currently being done with the close cooperation of airframe and engine manufacturers who monitor the IFSD events of all operators using their products, and who are forwarding a detailed description of each event. While the ICAO study group report recommended that accumulation of 500,000 hours of engine operation (of which 250,000 hours should be on the particular airframe) would be necessary to achieve a "stable value of reliability," the FAA Appendix normally requires only 250,000 engine hours (on any airframe) to provide "a reasonable indication of reliability trends and significant problem areas," and states that this requirement may be reduced if there are compensating factors which establish a reasonably equivalent data base such as the "use of the same engine model on a different airplane installation." (This would qualify in the 250,000 hours anyway as the Appendix I is currently written.) The CAA (UK) simply states that the data "should be extensive enough and of sufficient maturity to enable the Authority to assess with a high level of confidence...."

The issue of "maturity" is a difficult one for airworthiness authorities to resolve. Many mechanical systems display an initial period of unreliability in their first months of service, as flaws in design and manufacturing appear. However, there may be a continuing exposure to wider sets of operating conditions long after initial operations have matured. Continuing modifications of systems may be carried out by the manufacturer, and it may be difficult to decide when a "revised" system should be regarded as a "new" one. While the same engine may be installed on a new airframe, it may have a different nacelle and perhaps should be regarded as

a different propulsion system. At present there seem to be quite different IFSD rates for such cases, although perhaps the differences are due to operations and maintenance. It requires engineering analysis and judgement to decide when a stable statistical environment has been achieved, and when modifications to systems invalidate the prior data. This requires detailed data gathering and monitoring.

The various national documents also call for Continuing Surveillance of the world fleet IFSD rate for airframe/engine combinations used for ETOPS. If an "acceptable" level of reliability is not maintained, or if "significant deficiencies are detected in the conduct of operations," then airworthiness authorities will require the operators to "take all necessary action to resolve the problems in a timely manner," or will "withdraw the authorization for extended range operations." There are no clear criteria for actions in this area, since it is difficult to determine the significance and applicability of known deficiencies. The occurrence of 4 major failures of the JT9D-R7 engine during 1986 on the A-310 airframe led to an airworthiness directive to remove a fourth-stage air seal from that engine to eliminate ultrasonic fatigue failures. Although no failures occurred for that engine on the B767 airframe, cracks were found in that same seal on B767 engines. ETOPS operations by B767 aircraft with that engine were not interrupted.

As part of continuing surveillance, all the airworthiness authorities have promised to publish an Engine Reliability Report for each airframe/engine combination in world fleet operations. While the frequency of such publications is not declared, there appear to be no such reports published to date.

4.4.3 Operational Approval

Following Type Design and Inservice Experience approval for the reliability of airframe/engine combinations, the operator can apply for

Operational Approval by submitting data to his airworthiness authority describing his engineering and maintenance program, flight dispatch procedures, flight crew training program, and his own experience in achieving airframe/engine reliability. Following review and concurrence with this material, the various authorities call for a demonstration of operational capability before issuing Operational Approval. The original ICAO Study Group called for an "observed proving flight," incorporating a demonstration of emergency procedures following total thrust loss of one engine, or total loss of electrical power from one power unit (or any other risk condition considered pertinent by the airworthiness authority), with the emergency conditions and timing unknown to the operator's crew, and the flight conditions "representative of those for which approval is sought."

This strict requirement for an actual proving flight has been relaxed by the national authorities of Great Britain, Canada, and New Zealand, to a flight in an aircraft or acceptable simulator. The FAA AC-120-42 still calls for an actual flight to be witnessed by FAA personnel, but allows the demonstration of emergency conditions and procedures (total thrust loss, or total electrical loss from one engine, or other as per ICAO) to be performed prior to that flight in an acceptable simulator. If this is done, it is not clear what is observed by FAA personnel during the actual flight where no unusual events occur. In the absence of any requirement for a proving flight which validates the capability of the airframe/engine systems to perform extended single-engine cruise at altitude, some of the operators have conducted their own demonstrations during delivery flights of new aircraft from the factory to the airline, when there are no passengers or FAA personnel on board. Upon successful demonstration, the operator receives a modified Operations Specification (or Air Operator's Certificate for U.K., etc.), which allows him to conduct ETOPS.

The data submitted for review before Operational Approval as described in the various national ETOPS documents is briefly outlined below:

Assessment of Operator's Propulsion System Reliability: Data is

submitted by the operator to show that he is below or at a certain IFSD rate determined in the Inservice Experience Approval process (as being necessary to achieve a risk of dual-independent engine failure of 10^{-8} per hour or less). As well, his past experience in achieving reliability with related propulsion systems is reviewed, and the current "trend" of his data compared to other operators and the world average. For some unknown reason, all the national documents state the requirements for specific operator's experience with the airframe/engine under "Inservice Experience" and not here, where approval is sought.

Engineering and Maintenance Program: The operator's program is reviewed to ensure compatibility with ETOPS and to incorporate any changes due to ETOPS modifications or equipment. Any subsequent changes in maintenance or training procedures should be submitted for approval 60 days before adoption. A continuous Reliability Report on propulsion and airframe systems used in ETOPS is required to be submitted by ETOPS operators to airworthiness authorities (at least monthly by UK, Canada, and New Zealand). The engine maintenance program must be a "condition monitoring" program with hard times for inspection of components not otherwise observable, and there must be an engine oil consumption monitoring program.

Flight Dispatch Considerations: Again, the operator's existing procedures for flight dispatch are reviewed to ensure that they are adequate for ETOPS. The Minimum Equipment List (MEL) is reviewed and adjusted to ensure appropriate system redundancy is available for an ETOPS dispatch. Communications and Navigation equipment must be available to provide reliable, two-way voice communications with the appropriate ATC services, including those to any suitable enroute diversion airport, and to provide navigation and guidance during diversion and approach and landing to these same airports. The fuel and oil requirements for dispatch are based on a "critical fuel scenario," where the most critical point for fuel is identified based on time for diversion to a suitable alternate airport using forecast winds at the appropriate flight level. The critical fuel

scenario considers the simultaneous failure of one engine and the pressurization system at the critical point with immediate descent to 10,000 feet (unless oxygen supplies are adequate, as defined elsewhere) for single-engine cruise to the suitable diversion airport, a descent to 1500 feet for 15 minutes of holding, followed by an approach, a missed approach, and then a "normal" approach and landing. If it is forecast that icing might occur and operation of ice protection systems might be used, or planned that the APU or RAT (Ram Air Turbine) will be operated, then the fuel computations should include their effect. If there are known ATC constraints, these are to be accounted for (such constraints might be getting clearance to leave an Oceanic Track Structure to start the diversion). On top of all of this computation, contingency corrections of 5% additional fuel to cover errors in wind forecasts and another 5% to cover deviations in fuel mileage (unless the operator has established a value) are added to the critical diversion fuel computation.

Despite all the detailed calculations to check diversion fuel requirements, it is unlikely that additional fuel will be required at dispatch, since the time to divert will normally be less than that required to complete the trip. It would appear that the operator is required to perform these detailed calculations for each dispatch, due to the weather effects on availability of suitable airports and the forecast times to divert. If so, the forecast critical diversion times are known for each trip and can be compared with the nominal limit declared elsewhere in the national documents. Flight dispatch procedures are required to provide all suitable airports in the flight plan documents for the trip, checking facilities available and the runway expected to be used, given forecast wind and runway surface conditions. The Operations Manual for the aircraft dispatched on ETOPS must contain detailed data on single-engine performance, including effects of RAT deployment, ice accretion, etc. There is no requirement for this data to be included in any FMS (Flight Management System) for the aircraft, and thus be available in a more convenient form for faster decision-making by the flight crew.

Flight Crew Training and Evaluation Program: The operator's ETOPS training program for flight crew members should provide initial training and recurrent evaluation in two areas: Performance, which covers flight planning and flight progress monitoring; and Procedures, which covers normal and abnormal diversion procedures covering all foreseeable combinations of failures of equipment and crew.

Operations Specifications: The operations specifications (or equivalent for other than FAA) should be modified to cover the following items:

- i) Designation of the particular airframe/engine combinations by make/model and serial and registration numbers which are approved for ETOPS, including their ETOPS modifications.
- ii) Authorized Area of ETOPS, including minimum altitudes to be flown on planned and diversionary routes.
- iii) "Maximum Diversion time, at normal one-engine inoperative cruise speed, that any point on the route may be from a suitable airport for landing." (Note the absence of any caveat on still air -- the UK document clearly states this is a Rule Distance, admitting there is no time limit.)
- iv) Authorized airports adequate to be enroute diversionary alternates, including instrument approaches and their ETOPS minima.
- v) Approved Maintenance Program for ETOPS, including those special ETOPS items specified in the Type Design Approval.

5. SUMMARY AND ISSUES

To this point in time, it appears that ETOPS has been safely introduced worldwide by major carriers from several nations. In the first five years, there have been several IFSD incidents where extended single-engine cruise diversions have been safely achieved without undue complication. As ETOPS grows in annual flight hours with more carriers, newer aircraft and engines, and more routes, there will be an increasing number of these ETOPS incidents, and thus more annual exposure to a second failure during the diversion. It will be necessary to maintain a level of awareness which matches that expended by everyone in the aviation industry during this introductory five-year period.

At the same time, there appear to be several logical inconsistencies in the airworthiness procedures developed for ETOPS which bear reconsideration, and a weakness in the methods currently being used to evaluate the level of risk in ETOPS. There will be continuing airworthiness issues as the desire to extend the areas of operations occurs, and the extension of similar risk analysis under ETOPS to EROPS in all transport aircraft. These issues are briefly discussed here as a means of focusing further discussion.

5.1 Issue 1 -- Maintenance of the Quality of ETOPS Airworthiness Activities

There is currently a draft FAA Order which formalizes the Propulsion Systems Reliability Assessment Board (PSRAB), and restricts its function to making a determination of adequate reliability (as required by AC 120.42) of any airplane/engine combination proposed for ETOPS. The FAA personnel who serve on the PSRAB at present have had the experience of introducing ETOPS in the past 5 years; however, they may move on to other responsibilities in future years. There will be a growth in ETOPS in terms of routes, operators, and aircraft/engine types in future years. There

should not be a loss of continuity of airworthiness personnel monitoring and introducing new ETOPS, nor a lack of resources in terms of manpower or travel funds needed to monitor operators and manufacturers worldwide. At present the PSRAB has representation from various airworthiness offices, to ensure coordination of all aspects of ETOPS; it is not just making a determination of propulsion system reliability. Consideration should be given to broadening the PSRAB function to ensure coordination of all airworthiness activities relative to ETOPS, and renaming this board with a name such as "ETOPS Assessment Board." Airworthiness activities would still take place in their responsible airworthiness offices under the coordinating actions of their representatives on the ETOPS Board. ETOPS seems to be a uniquely complex combination of airworthiness factors whose successful implementation and maintenance currently depends on coordinating engineering and operational judgement from different areas in a timely manner. The public reaction to any ETOPS accident would focus intense scrutiny on airworthiness activities and easily warrant special handling within the airworthiness organizations.

5.2 Issue 2 -- Rule Time versus Rule Distance

The current ETOPS rules do not limit flight plan routes to 120 minutes flying time from a suitable airport, although many of the guidelines from airworthiness authorities assume this to be true. Instead, a Rule Distance equivalent to 120 minutes has been used as an extension of the Threshold Distance, which has been traditionally used to define extended-range operations. This inconsistency would not stand serious scrutiny by lawyers looking for careless or incomplete efforts on the part of airworthiness authorities after an accident. The current airworthiness guidance material claims that a risk level of 10^{-8} per hour is being achieved, based on the actual average or maximum diversion flying time, but then allows aircraft to be dispatched on flight plans which exceed the declared values.

5.3 Issue 3 -- Extension of Rule Time

The issue of extending the rule time from 120 minutes to 180 minutes focuses attention on the above issue and on the following issue on Risk Assessment. A set of airworthiness procedures has been established which set as a goal a target level of safety of 10^{-8} per hour for the occurrence of a dual-independent engine failure case. The impact of adding an extra hour of single-engine cruise to the diversion requires a clearly-stated model for risk assessment, which can account for the effect of diversion time.

5.4 Issue 4 -- Development of Models for Risk Assessment in ETOPS

At present there is no clear statement of how risk is being assessed in ETOPS. While there is a role for "engineering judgement," it should be exercised on a simple model of the factors which play a basic role in determining risk, and what assumptions are currently being made in using the model. The ICAO study group created two such models, but did not develop them with much rigor or detail. There are several issues to be addressed: how does risk vary with diversion time when we are evaluating the possibility of a second system failure? Does system failure occur randomly over cruise time? Are cruise failure rates significantly different from rates in other modes of flight? Are system failure rates different during single-engine cruise? Are we trying to minimize risk per hour of flight or per trip?

5.5 Issue 5 -- Extended Single-Engine Flight Test to Prove Airworthiness

While airworthiness authorities seem to have backed off from requiring an actual test flight on extended-range single-engine cruise, the operators seem to feel it is necessary, and have found significant items from such flights. Simulator activities can test emergency procedures and

performance of flight crews, but they do not demonstrate performance of real flight hardware systems under abnormal operation in their actual operating environment. It seems odd that the traveling public may be onboard when approved diversionary procedures are actually flown for the first time.

APPENDIX 1

CALCULATION OF DIVERSION TIMES

A) No Enroute Diversion Airport

Consider a route of distance $R(o) = 2400$ n. miles. Let the aircraft cruise speed with two engines be V_2 , and with one engine be V_1 . The wind factor (tailwind) is w .

Then the distance along the route, $D(t)$, is a function of trip time, t , as is the trip distance remaining, $R(t)$.

$$D(t) = (V_2 + w) \cdot t$$

$$R(t) = R_o - D(t)$$

and the time to return to origin with one engine out, $TTR(t)$, and time to destination, $TID(t)$, are given by

$$TTR(t) = \frac{D(t)}{V_1 - w} = \frac{V_2 + w}{V_1 - w} \cdot t$$

$$TID(t) = \frac{R_o - D(t)}{V_1 + w}$$

The equal time point, ETP, occurs when $TTR(t_e) = TID(t_e)$, where t_e = trip time at ETP. Then

$$\frac{D(t_e)}{V_1 - w} = \frac{R_o - D(t_e)}{V_1 + w}$$

or

$$D(t_e) \left[\frac{1}{V_1-w} R + \frac{1}{V_1+w} \right] = \frac{R_0}{V_1+w}$$

$$D(t_e) \left[\frac{2V_1}{(V_1-w)(V_1+w)} \right] = \frac{R_0}{V_1+w}$$

$$D(t_e) = \frac{V_1-w}{2V_1} \cdot R_0$$

$$(V_2+w) \cdot t_e = \frac{V_1-w}{2V_1} \cdot R_0$$

$$t_e = \frac{V_1-w}{V_2+w} \cdot \frac{R_0}{2V_1}$$

$$TTR(t_e) = \frac{V_2+w}{V_1-w} \cdot \frac{V_1-w}{V_2+w} \cdot \frac{R_0}{2V_1} = \frac{R_0}{2V_1} \quad (\text{independent of } w)$$

Example Calculations

$$V_2 = 600 \text{ knots}$$

$$w = 0.60 \text{ knots}$$

$$V_1 = 360 \text{ knots}$$

$$R_0 = 2400 \text{ n. miles}$$

$$\text{For zero wind, } t_e = \frac{360}{600} \cdot \frac{2400}{2(360)} = 2 \text{ hours}$$

$$TTR = TTG = \frac{1200}{360} = 3.33 \text{ hours}$$

For a 60-knot tailwind, $w = 60$

$$t_e = \frac{300}{660} + \frac{2400}{2(360)} = 1.51 \text{ hours}$$

$$\text{TTR} = 3.33 \text{ hours}$$

$$D(t_e) = 660 (1.51) = 1000 \text{ n. miles}$$

$$\text{total trip time} = \frac{2400}{660} = 3.64$$

B) Enroute Diversion Airport at Mid-Point (with Offset Distance)

Consider a diversion airport, M , with an offset distance, d , from the midpoint of the route, $R_0/2$.

$$\text{Distance to } M = D_M(t) = \sqrt{d^2 + \left(\frac{R_0}{2} - D(t)\right)^2}$$

$$\text{Time to } M_1 \text{ TTM}(t) = \frac{D_M(t)}{(V_1 + w_M)}$$

$$\text{At ETP, } \text{TTR}(t_e) = \text{TTM}(t_e)$$

or

$$\frac{D_1(t_e)}{V_1 - w} = \frac{D_M(t_e)}{V_1 + w_M}$$

Example Calculations

Assume an airport at 300 n. miles offset from midpoint.
Suppose $w = 0$ (still air) for our previous example. Then

at ETP, $D(t_e) = D_M(t_e)$

$$D(t_e) = \sqrt{d^2 + \left(\frac{R_o}{2} - D(t)\right)^2}$$

$$D^2 = d^2 + \left(\frac{R_o}{2}\right)^2 - R_o D(t) + D^2$$

$$D(t_e) = \frac{d^2 + (R_o/2)^2}{R_o} = \frac{300 + 1200^2}{2400}$$

$$= \frac{1,530,000}{2400} = 637.5 \text{ n. miles}$$

$$t_e = \frac{637.5}{600} = 1.06 \text{ hours}$$

$$TTR = \frac{637.5}{360} = 1.77 \text{ hours} = TTM$$

Reach midpoint at 1.82 hours

At the midpoint of the track, after two hours of flight:

$$TTM = \frac{300}{360} = 0.833 \text{ hours}$$

Thereafter, TTM increases, until at 2.94 hours into the flight (1.06 hours to go), it again reaches 1.77 hours.

If airport at midpoint with no offset, then for $w = 60$:

ETP₁ = 0.75 hours, with 1.66 hours diversion

ETP₂ = 0.75 hours past midpoint at 1.82 hours = 2.59 hours, with 1.05 hours to go in trip time of $3.64 - 2.59 = 1.05$.