Journal of Air Law and Commerce

Volume 77 | Issue 4 Article 5

2013

Engines Turn or Passengers Swim: A Case Study of How ETOPS Improved Safety and Economics in Aviation

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ABSTRACT

UNDER THE FEDERAL Aviation Administration (FAA) regulations, no commercial airplane with fewer than three engines may fly a route that at any point exceeds 60 minutes flying time from a suitable airport. The industry calls this "the 60-minute rule." ETOPS is the exception to that rule. By satisfying stringent ETOPS requirements, an airline may fly two-engine planes on "extended operation" routes that exceed 60 minutes. ETOPS has enormously influenced the aviation industry. This article traces the history of ETOPS, including its creation and the evolution known as "early ETOPS." In doing so, the article identifies factors contributing to ETOPS's success. This article then

evaluates these factors in light of the nearly unprecedented grounding of the Boeing 787 Dreamliner following two serious battery failures. The author argues that the difficulties of the Boeing 787 warrant the application of ETOPS-like principles to the adoption of novel technology, such as lithium-ion batteries, for aviation.

INTRODUCTION

"ETOPS [is] bureaucratese for extended-range twin-engine operations . . . [but] some in the industry say the initials really stand for 'engines turn or passengers swim.'"[1]

\- John Holusha

A. To Preclude and Protect

Two commercial airline passenger flights, separated by nearly two decades, illustrate ETOPS.[2] On February 1, 1985, Trans World Airlines (TWA) Flight 810 departed Boston bound for Paris.[3] The Boeing 767 aircraft flew northeast toward Greenland, then turned southeast toward Ireland.[4] As the aircraft approached the Irish coast, in range of London radio communications, the pilots identified their flight to London ground control.[5] Over the open radio, another airborne pilot

[1] John Holusha, *Pushing the Envelope at Boeing*, N.Y. Times, Nov. 10, 1991, at 31.

[2] ETOPS has had several definitions. *See* 14 C.F.R. § 1.1 (2013). The term "ETOPS" was first used by the International Civil Aviation Organization (ICAO) to mean "extended-range twin-engine operational performance standards." *FAQ: ETOPS*, Great Circle Mapper, http://www.gcmap.com/faq/etops (last visited June 26, 2013). At that time, the FAA used the term EROPS, meaning "extended range operations" (for simplicity, this article only uses the term ETOPS). *See ETPOS Training Course*, AviationLearning.net 1, http://aviationlearning.net/files/ETOPSintroduction.pdf (last visited June 26, 2013). The FAA later defined ETOPS as "extended-range operations with two-engine airplanes"; under current FAA regulations, ETOPS is defined as "extended operations." *See* Extended Operations (ETPOS) of Multi-Engine Airplanes, 72 Fed. Reg. 1,808, 1,813 (Jan. 16, 2007) (to be codified at 14 C.F.R. pts. 1, 21, 25, 33, 121 & 135). ETOPS also has several sardonic definitions. EROPS has sometimes been called "engines run or passengers swim" or "engines run or pilots swim"; ETOPS similarly has been referred to as "Engines Turn or Passengers Swim." *See* Holusha, *supra* note 1, at 31; *Instant EROPS: Selling Point or Safety Issue?*, Flight Int'l, July 25–31, 1990, at 24–25. In titling this article with the phrase "Engines Turn or Passengers Swim," the author does not mean to suggest that ETOPS should be looked at sarcastically or skeptically.

[3] *See* James Ott, *Boeing 767 North Atlantic Flights Reshape Trans World Planning*, Aviation Wk. & Space Tech., Feb. 11, 1985, at 31.

[4] *See id.*

[5] *Id.*

with a British accent quipped, "You're very lucky to have made it."[6] Another inquired, "Are they still both running?"[7] Six hours and thirty-two minutes after takeoff, Flight 810 landed safely in Paris.[8]

Eighteen years later, on March 17, 2003, United Airlines Flight 842 departed Auckland, New Zealand, bound for Los Angeles.[9] The Boeing 777 flew north over the Pacific Ocean.[10] While most of the passengers slept, the crew received a low-oil-quantity alert from one of the two Pratt & Whitney engines, followed by a high-oil-temperature alert.[11] The crew throttled the troubled engine back to idle.[12] When the oil temperature continued to rise, the crew shut down the engine—leaving the 777 (one of the largest passenger aircraft) flying on a single engine.[13]

Flight 842 was three hours flying time from the nearest airport, Honolulu.[14] But after evaluating weather conditions in Honolulu, the crew chose to divert to Kona, Hawaii.[15] For 177 minutes, Flight 842 flew against headwinds on a single engine.[16] At the top of the descent into Kona, the crew informed passengers of the situation, and shortly thereafter Flight 842 landed safely.[17] A failed No. 3 bearing in the right engine had caused the engine loss.[18]

Flights 810 and 842 illustrate the two objectives of ETOPS: preclude and protect. ETOPS is a set of regulations designed to preclude failures or malfunctions that could cause a flight to divert from an intended destination.[19] If a diversion becomes

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6 *Id.*

7 *Id.*

8 *Id.*

9 *See* James Ott, *Record Diversion*, AVIATION WK. & SPACE TECH., Mar. 24, 2003, at 44.

10 *Accidents and Incidents*, AIR SAFETY WK., Mar. 24, 2003, at 7.

11 *Divert Details*, AIR SAFETY WK., Mar. 24, 2003, at 10; Ott, *Record Diversion*, *supra* note 9, at 44.

12 *Divert Details*, *supra* note 11, at 10.

13 *See id.*

14 *Id.* at 9.

15 *Id.* at 10.

16 *Still Tops for ETOPS*, AIR SAFETY WK., Apr. 14, 2003, at 8.

17 *Divert Details*, *supra* note 11, at 10.

18 *Id.*

19 Special Conditions: Extended Range Operations of Boeing Model 777 Series Airplanes, 59 Fed. Reg. 28,234, 28,236 (June 1, 1994) (codified at 14 C.F.R. pt. 25).

necessary, ETOPS regulations are designed to protect the airplane and occupants during the diversion.[20]

ETOPS governs "extended operation" flights by two-engine commercial airplanes.[21] ETOPS is an exception to the rule barring twin-engine passenger planes from flying routes that exceed 60 minutes flying time from a suitable airport.[22] Airplanes and airlines that satisfy stringent ETOPS requirements may fly routes that exceed 60 minutes from an airport, up to a specified limit.[23]

TWA Flight 810 from Boston to Paris was the first revenue flight operated under ETOPS rules.[24] It flew a route that at its farthest point reached 75 minutes from the nearest suitable airport.[25] This allowed for a slightly more direct route to Paris, saving a modest seventy-six nautical miles from the journey.[26]

To qualify for the ETOPS flight, the twin-engine 767-200 had been specially modified to enhance safety, reliability, and redundancy.[27] TWA and Boeing had worked closely with the FAA to develop flight operations for long-range missions with the twin-engine aircraft.[28] During the flight, eleven FAA representatives were on board watching the readings of the Engine-Indicating and Crew-Alerting System (EICAS) that monitored the two Pratt & Whitney JT9D-7R4D engines.[29] With the push of a button, the 767's computer was programmed to redirect the aircraft to an alternate airport at the first sign of trouble.[30] The 767 was also equipped with a data-link to provide real-time engine performance monitoring on the ground.[31]

As the first commercial ETOPS flight, Flight 810 was an enormous leap forward in commercial aviation, but the general public was largely unaware of this milestone. To the passengers of

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[20] *Id.*

[21] As of 2007, many ETOPS requirements apply to the extended operation flights of three- and four-engine planes. 14 C.F.R. §§ 25.1535, 121.161 (2013).

[22] *See id.* § 121.161 (after 2007, for three- and four-engine planes, the threshold is 180 minutes).

[23] *See id.* § 25.2535.

[24] Ott, *Boeing 767 North Atlantic Flights*, *supra* note 3, at 31.

[25] *Id.*

[26] *Id.*

[27] *See id.*

[28] *See id.*; John M. Swihart, *High-Tech Engines Outgrow "60-Minute Twin Rule"*, AEROSPACE AM., Jan. 1985, at 14.

[29] Ott, *Boeing 767 North Atlantic Flights*, *supra* note 3, at 31.

[30] *Id.*

[31] *Id.*

Flight 810, the event was hardly noteworthy. When the crew announced the historic nature of the flight, it was news to most passengers.[32] A student traveling with a group of classmates wrote on a commemorative postcard, "Now they tell me it's a two-engine airplane, as if I didn't have enough troubles."[33] A first-class passenger from France was awoken by the announcement and asked what was said; when told, he shrugged and fell back asleep.[34]

Eighteen years later, United Flight 842 demonstrated the other ETOPS objective: protection. The Boeing 777 had been designed from inception to fly ETOPS routes.[35] When the Pratt & Whitney engine malfunctioned, an electronic caution alert module message notified the pilots so they could idle and shut down the engine to avoid further damage.[36] When the crew was forced to shut down an engine, the remaining engine had sufficient reserve power to fly the 777 for the duration of the flight.[37]

The 777 was also designed with sufficient redundant power sources to ensure that all critical flight systems could be powered, even with only a single engine keeping the plane aloft.[38] Flight 842 demonstrated that ETOPS could protect a plane and its passengers even if an engine failed in the middle of the Pacific Ocean.

B. ETOPS AS A CASE STUDY

Why study ETOPS? ETOPS, though largely obscure to the public, has enormously impacted aviation. Millions of ETOPS flights have been flown to date.[39] The economic impact of ETOPS measures in the billions: ETOPS has directly influenced the design of planes that manufacturers build, which planes airlines decide to purchase, and the routes that planes fly.[40] ETOPS has also reduced the cost of flying by enabling the use of

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32 *Id.*

33 *Id.*

34 *Id.*

35 Boeing Commercial Airplane Corp., *ETOPS Maintenance of Non-ETOPS Airplanes*, AERO, http://www.boeing.com/commercial/aeromagazine/aero_07/etops.html (last visited Mar. 1, 2013).

36 *See Divert Details, supra* note 11.

37 *See id.*

38 *See id.*

39 *See* BOEING COMMERCIAL AIRPLANES, ETOPS EXPLAINED: AN OVERVIEW OF EXTENDED OPERATIONS Intro-1 (2008), *available at* http://boeing.com/nosearch/rptdist/pdf/ETOPS_Explained.pdf.

40 *Id.*

more-fuel-efficient and less-costly-to-operate aircraft.[41] Most notably, ETOPS has improved the safety of commercial aviation: no ETOPS flight has been lost because of a danger that ETOPS was meant to address.[42] And the enhanced maintenance requirements and reliability improvements have made their way to non-ETOPS flights, further increasing safety in commercial aviation.[43] The unqualified success of ETOPS makes it somewhat of an exception in the scheme of large regulatory regimes.

Yet the flying public is largely oblivious to ETOPS.[44] Passengers may only briefly notice the cryptic acronym stenciled on a plane's landing-gear cover. Or passengers may experience the consequences of ETOPS—for example, Alaska Airlines (an exclusive twin-engine 737 operator) offers flights to Hawaii.[45] But, ultimately, far more passengers benefit from ETOPS than know it exists.

Thus, the scope, impact, and success of ETOPS are a fertile topic of study. Indeed, little is available on the history of ETOPS. Few books and articles covering the aviation industry devote

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41 *See id.* at Intro-2.

42 *See id.* at Intro-3. Some may debate this point. In 2009, Air France Flight 447, a twin-engine ETOPS Airbus A330, crashed into the Atlantic Ocean, killing all 228 passengers and crew. *See* Pierre Sparaco, *Collateral Damages*, AVIATION WK. & SPACE TECH., Aug. 15, 2011, at 29. The crash was attributed to a pitot tube failure and pilot error. *See id.* In 2008, British Airways Flight 38, a twin-engine Boeing 777, crashed just short of the runway, with no fatalities. *See Airliner Crash-Lands at Heathrow*, BBC NEWS (Jan. 17, 2008), http://news.bbc.co.uk/2/hi/uk_news/england/london/7194086.stm. The crash was attributed to a clogged fuel/oil heat exchanger. Chad Trautvetter, *Ice in Fuel System Caused 777 Crash*, AINONLINE (Feb. 17, 2010), http://www.ainonline.com/aviation-news/aviation-international-news/2010-02-17/ice-fuel-system-caused-777-crash. In 1999, EgyptAir Flight 990, a twin-engine Boeing 767, crashed in the Atlantic Ocean. NAT'L TRANSP. SAFETY BD., AIRCRAFT ACCIDENT BRIEF: EGYPTAIR FLIGHT 990, at 1 (1999). The NTSB determined the probable cause was that the first officer intentionally crashed the plane. *Id.* at 5, 41. Finally, in 2013, Asiana Airlines Flight 214, a 777, crash-landed at San Francisco International Airport, killing three passengers and injuring many more. Matthew L. Wald, *In Asiana Crash Investigation, Early Focus Is on the Crew's Actions*, N.Y. TIMES (July 8, 2013), http://www.nytimes.com/2013/07/09/us/in-asiana-crash-investigation-early-focus-is-on-the-crews-actions.html?_r=0. Though the investigation is ongoing, pilot error is presumed. *Id.* Given that pilot error is not addressed by ETOPS and that the 777 crashes occurred during landing—a non-ETOPS portion of the flight—it is the author's opinion that no ETOPS flight has been lost because of a danger that ETOPS was meant to address.

43 *See* BOEING COMMERCIAL AIRPLANES, *supra* note 39, at Intro-4.

44 *See* Ott, *Boeing 767 North Atlantic Flights*, *supra* note 3, at 31.

45 *See Alaska Airlines 737-200*, WORLD AIR ROUTES, www.worldairroutes.com/Alaska.html (last visited July 15, 2013).

more than a page or two to ETOPS. The one notable exception is Mohan Pandey's fascinating book, *How Boeing Defied the Airbus Challenge*, which provides a detailed account of ETOPS's later evolutions, including "early ETOPS" and the 2007 ETOPS rule.[46] Indeed, this article draws heavily from Pandey's book in the section on early ETOPS. This article attempts to pull together a detailed early history of ETOPS in the hope that this will enable a better understanding of what has made ETOPS a success.

Additionally, a recent event has given further relevance to the study of ETOPS—the nearly unprecedented grounding of the Boeing 787 Dreamliner. In early January 2013, the Boeing 787, Boeing's first non-derivative "clean-sheet" design since the 777, suffered two serious battery failures: one on the ground during a routine post-flight inspection, and one during a domestic flight in Japan.[47] These failures prompted the FAA and other international regulators to ground the 787, making it the first airplane model grounded since the McDonnell Douglas DC-10 in 1979.[48] The problems and subsequent grounding of the 787 have raised a host of questions regarding the 787's design, manufacturing, certification, and operation. Tracing the history of ETOPS affords an opportunity to address the 787's problems because, like the Boeing 777, the 787 was designed from the ground up for ETOPS flights.[49]

Thus, this case study addresses two questions: why was ETOPS a success, and does the answer shed light on the 787 grounding? To that end, this article begins by tracing the history of the restrictions on two-engine airplanes. It then turns to the initial development of 120-minute and 180-minute ETOPS. The article then covers the development of the Boeing 777, the implementation of early ETOPS, and more recent ETOPS developments. It then discusses some of the factors that contributed to ETOPS's success. From there, this article covers the difficulties of the Boeing 787 and applies the factors of success to the 787 to argue for the adoption of ETOPS-like principles when implementing novel aviation technology.

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[46] *See* MOHAN PANDEY, HOW BOEING DEFIED THE AIRBUS CHALLENGE: AN INSIDER'S ACCOUNT 53–54 (2010).

[47] *Boeing 787 Suffers a Battery Fire in Boston*, N.Y. TIMES, Jan. 8, 2013, at B5.

[48] Alan Levin & Susanna Ray, *FAA Studying Bad Batteries as Possible Cause of 787 Fault*, BLOOMBERG (Jan. 17, 2013, 4:40 PM), http://www.bloomberg.com/news/2013-01-17/faa-studying-bad-batteries-as-possible-cause-of-787-fault.html.

[49] BOEING COMMERCIAL AIRPLANES, *supra* note 39, at Intro-2.

I. EARLY RESTRICTIONS ON TWO- AND THREE-ENGINE PASSENGER AIRCRAFT

A. Early Federal Regulation of Aviation

One of the earliest federal regulations of aviation concerned ensuring that a plane could safely reach an airport in an emergency. The Air Commerce Act of 1926 gave the Department of Commerce responsibility for regulating flight with the aim of winning public confidence by establishing standards of safe air travel.[50] One aim of the Act was to ensure availability of adequate airports close enough "together to insure gliding to safety."[51]

In 1935, the Bureau of Air Commerce restricted night flights over rough terrain to planes with multiple engines that were capable of flying on a single engine.[52] Starting in 1936, airlines operating twin-engine piston airplanes were required to show that intermediate fields for landing were located at least every 100 miles along the proposed route.[53] By 1945, two- and three-engine airplanes were restricted to routes that did not exceed 45 minutes flying time from an adequate airport at normal cruising speeds.[54]

The restriction on two- and three-engine aircraft was a logical consequence of the unreliability of piston engines. In 1952, aircraft piston engines failed on average once every 4,000 flight hours.[55] A double failure (loss of two engines) occurred on average once every 8,000,000 flight hours.[56] Thus, a 200-plane fleet that operates each plane for 2,500 hours a year could expect a double failure every sixteen years.[57]

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50 *See* Air Commerce Act of 1926, Pub. L. No. 69-254, ch. 344, 44 Stat. 568 (1926).

51 *See* S. Rep. No. 57-460, at 19 (1922).

52 Donald R. Whitnah, Safer Skyways: Federal Control of Aviation, 1926–1966 93 (1966).

53 FAA, U.S. Dep't of Transp., Advisory Circular 120-42A: Extended Range Operation with Two-Engine Airplanes (ETOPS) 4 (1988) [hereinafter Advisory Circular 120-42A].

54 *See* Richard W. Taylor, Boeing Commercial Airplane Co., Extended Range Operation of Twin-Engine Commercial Airplanes 3 fig. 4 (1985); 15 Fed. Reg. 6,708, 6,708 (Oct. 5, 1950).

55 Swihart, *supra* note 28, at 14.

56 *Id.*; Richard W. Taylor, Boeing Commercial Airplane Co., Worldwide Operation of Twin-Jet Aircraft (Past, Present, and Future) 17 (1983).

57 Swihart, *supra* note 28, at 14; Taylor, Worldwide Operation, *supra* note 56, at 17.

Anecdotally, the reliability of the Boeing four-engine Stratocruiser earned it the nickname "the Boeing trimotor" because of its frequent engine failures.[58] And on one round-trip North Atlantic flight, a Lockheed Constellation suffered five engine failures.[59] One former Constellation pilot recalled suffering an overspeed on the No. 2 engine, oil loss on the No. 3, and an engine fire on the No. 4—all on the same takeoff.[60]

Additionally, piston engine reliability decreased as the engines grew more powerful.[61] Engine horsepower and the frequency of in-flight failures are directly correlated.[62] Thus, a four-engine piston airplane was safer than a comparable two-engine airplane, not only because of the presence of redundant engines, but also because the individual engines could be less powerful and hence less likely to fail.[63]

In 1953, the FAA adopted the 60-minute rule, which is still largely in effect today.[64] Section 40.62 of the Civil Air Regulations (CARs) (later renamed FAR 121.161 and now codified at 14 C.F.R. § 121.161) prohibited airplanes with fewer than four engines from flying more than 60 minutes beyond a suitable airport.[65] Sixty minutes was defined as one-hour flying time at normal cruising speed with one engine inoperative.[66] The purpose was to limit flying time after power loss in one engine of a two-engine airplane.[67]

The 60-minute rule was intended to bar two-engine propeller airplanes, such as the Douglas DC-3, from flying extended routes that were more safely served by four-engine propeller aircraft.[68] The rule generally prevented two- and three-engine planes from flying long-range routes and ocean routes. But as a practical matter, two-engine airplanes lacked the range for such

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58 TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 8.

59 *Id.*

60 *TWA Expects Solid ETOPS Record Will Ease Transition to A330*, AVIATION WK. & SPACE TECH., Apr. 13, 1992, at 49.

61 BOEING COMMERCIAL AIRPLANES, *supra* note 39, at 1-4.

62 *See id.*

63 *See id.*

64 Though as of 2007, the 180-minute rule also applies to three- and four-engine planes.

65 Additionally, the rule now restricts three- and four-engine planes from flying routes that exceed 180 minutes of diversion time. FAA, Civil Air Regulations § 40.62(a) (1964); *see* 14 C.F.R. § 121.161(d) (1965).

66 FAA, Civil Air Regulations § 40.62(a).

67 Advisory Circular; Extended Range Operations with Two-Engine Airplanes, 50 Fed. Reg. 5,150, 5,150 (Feb. 6, 1985).

68 BOEING COMMERCIAL AIRPLANES, *supra* note 39, at 1-3.

trips.[69] Thus, the 60-minute rule did not generally hinder their performance.

Also in 1953, the International Civil Aviation Organization (ICAO), a United Nations agency, published recommendations for a 90-minute rule.[70] ICAO recommendations are advisory unless adopted as law by individual nations.[71] The 90-minute rule recommendation restricted airplanes from routes that strayed more than 90 minutes from a landing area.[72] Ninety minutes was more leniently defined as the plane's cruising speed with *all* engines operative.[73] This difference made the 90-minute rule roughly equivalent to double the FAA's 60-minute rule.[74] Planes meeting certain performance requirements with two engines inoperative were exempted from the rule.[75] This requirement made exemption impossible for twin-engine planes.[76] But the requirement was commonly interpreted to allow twin-engine planes to be operated under the 90-minute rule.[77] In 1984, however, an ICAO representative wrote that twin-engine aircraft were never contemplated when the 90-minute rule was being developed.[78]

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69 Ken Romain, *Air Canada Plans Overwater Use of 767s*, GLOBE & MAIL, July 16, 1984, at 6.

70 AIRBUS, GETTING TO GRIPS WITH ETOPS 10 (1998); GEORGE V. D'ANGELO, AEROSPACE AGENCIES AND ORGANIZATIONS: A GUIDE FOR BUSINESS AND GOVERNMENT 121 (1993) (The ICAO was formed in April 1947 after 26 states ratified the Chicago Convention. It was tasked with developing the principles and techniques of international air navigation and fostering the planning and development of international air transport to ensure safe and orderly growth of civil aviation throughout the world.).

71 *Boeing Wants Overwater Twins*, FLIGHT INT'L, Dec. 31, 1983, at 1709, *available at* http://www.flightglobal.com/pdfarchive/view/1983/1983%20-%202307.html?search=overwater.

72 *See* AIRBUS, *supra* note 70, at 10.

73 *See* TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 4.

74 *Id.*

75 *Extended Range Operations of Twin-Engined Commercial Air Transport Aeroplanes* 2 (Int'l Civil Aviation Org., Working Paper No. AN-WP/5693, 1985) (on file with author) [hereinafter ICAO Working Paper 5693].

76 *Id.*

77 EUR. ACAD. FOR AVIATION SAFETY, ETOPS BRIEFING SLIDE 14 (1999), *available at* http://www.coscapsa.org/Operations/Courses/ETHIST98.PPT.

78 E. Sochor, Letter to the Editor, *60 Min-Rule Corrections*, FLIGHT INT'L, June 16, 1984, at 1552 (written by the Chief Public Information Office, ICAO).

B. The Introduction of Jet Transports Spurs the FAA to Modify the 60-Minute Rule

The introduction of passenger jetliners led to the first major change to the 60-minute rule. On May 2, 1952, a year before the 60-minute rule's adoption, the first passenger jetliner, the De Havilland Comet, entered service.[79] But a series of crashes (largely due to metal fatigue) slowed adoption of the Comet.[80] Adoption of commercial jetliners did not gain significant momentum until the Boeing 707 and Douglas DC-8 entered service in 1958 and 1959, respectively.[81]

Pan-Am Airlines ordered the first commercial 707s in 1955.[82] Three years later, Pan-Am received its first 707 and began flights between New York and Paris.[83] Pan-Am and Boeing jointly marketed the 707, emphasizing its speed: "Only seven hours to brush up on your French."[84] By 1960, more passengers crossed the Atlantic by plane than by boat.[85]

Because jetliners flew higher and faster than piston aircraft, some predicted that accidents would increase. One expert took the existing accident rate and assumed that air traffic would continue to increase while the accident rate would remain the same.[86] He predicted "10,000 crash fatalities a year by the turn of the century."[87] Instead, the accident rate "declin[ed] in direct proportion to the increase in jet flights."[88] There was one fatal accident for every 150,000 flights during the first two years of jet travel.[89]

The improvement in safety derived largely from the fact that jet turbine engines are significantly more reliable than piston engines.[90] Jet engines are fundamentally simpler machines with

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79 BOEING COMMERCIAL AIRPLANES, *supra* note 39, at 3-3.

80 *See* EUGENE RODGERS, FLYING HIGH: THE STORY OF BOEING AND THE RISE OF THE JETLINER INDUSTRY 169–70 (1996); STEVEN MCGUIRE, AIRBUS INDUSTRIE: CONFLICT AND COOPERATION IN US-EC TRADE RELATIONS 27 (1997).

81 *See* PANDEY, *supra* note 46, at 5–6.

82 *Boeing Marks the 50th Anniversary of 707 First Flight*, BOEING (Dec. 20, 2007), http://www.boeing.com/news/releases/2007/q4/071220d_nr.html.

83 *See* PANDEY, *supra* note 46, at 6.

84 *See id.*

85 *Id.* at 7.

86 ROBERT J. SERLING, LEGEND AND LEGACY 155 (1991).

87 *Id.*

88 *Id.*

89 *Id.*

90 GEORGE BIBEL, BEYOND THE BLACK BOX: THE FORENSICS OF AIRPLANE CRASHES 208 (2011).

fewer moving parts.[91] While piston engines pound, turbine components "rotate smoothly and continuously."[92] Jet engines also require less maintenance.[93] "In 1958, the FAA required that turbine engines be overhauled at least once every thousand hours."[94] By 1968, it was 8,000 hours.[95] Jet engines are also simpler for pilots to operate: pilots can increase power during a rejected landing with a single motion on the throttle.[96] For the same power increase, a piston engine would require numerous engine power adjustments.[97]

Jet engines also provide the advantage of high-altitude flight. While piston-engine aircraft typically cruise around 16,000 feet—directly through bad weather—jetliners cruise far above bad weather.[98] And, unlike piston engines, jet engine reliability did not decrease as engines grew more powerful.[99] The attributes of jet turbine engines directly resulted in safe flying.[100]

Following the introduction of the 707 and DC-8, airlines wanted to expand jet service to short-to-medium routes and wanted a jet more suitable for that role.[101] Boeing launched the 727 to satisfy that demand.[102] Designing the 727 raised a difficult question: how many engines should it have? Half the market wanted a two-engine product (for lower operating costs), while half wanted a four-engine aircraft (for better performance).[103]

Federal regulations also affected the decision. The Civil Aeronautics Authority (CAA) required twin-engine planes to satisfy a climb requirement with one engine inoperative.[104] This meant

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91 *Id.*

92 *Id.*

93 *Id.* ("The Boeing 707, the first successful commercial jet[,] . . . had over 100 fewer engine-related controls, instruments, and displays in the cockpit compared to a similar piston plane.")

94 SERLING, *supra* note 86, at 154.

95 *Id.*

96 BIBEL, *supra* note 90, at 208–09.

97 *Id.* at 209.

98 *See* TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 10.

99 *See id.*

100 *See id.*

101 M.Y. Yoshina, *Global Competition in a Salient Industry: The Case of Civil Aircraft*, *in* GLOBAL COMPETITION IN GLOBAL INDUSTRIES 519 (Michael Porter ed., 1986).

102 *Id.*

103 William H. Gregory, *Valedictory for the 727*, AVIATION WK. & SPACE TECH., Feb. 28, 1983, at 11.

104 *See* HAROLD MANSFIELD, BILLION DOLLAR BATTLE 17 (1965).

that twin-engine aircraft needed very powerful engines ("particularly at high-elevation airports [such as] Denver").[105]

The CAA also prohibited twins from taking off in weather with less than a 300-foot cloud ceiling and a mile of visibility (four-engine planes were permitted to take off in weather with a 100-foot ceiling and a half-mile of visibility).[106] This rule dealt a significant competitive disadvantage to airlines operating two-engine planes. TWA's engineering vice president, Bob Rummel, summarized, "The two-engine airplane will obviously have disadvantages against the four. The CAA is down on them."[107] Boeing seriously considered these restrictions:

> [It] examined the weather in New York for a whole year, correlated it against the 11,041 departures scheduled from New York by a chosen airline at the exact times at which each flight was due to leave, and determined the precise difference in schedule reliability between a twin-engined 727 and a 727 with more than two engines. . . . Boeing ascertained that, in this respect, three-engine aircraft would be treated no worse than existing four-engine machines . . . .[108]

Boeing eventually settled on a three-engine design, concluding that three engines could provide both low operating costs and high performance.[109] But this was not an easy sell. One potential customer opined, "A three-engine airplane will never make it. . . . You've got a dead horse unless it has four engines. The 727's going to be nothing but an albatross."[110] Boeing marketed the 727 by pointing to its engine reliability. The probability of a DC-6 piston engine shutting down was 1 in 450; the 707's jet engines' probability was 1 in 1,200; and the 727's engines were expected to be 1 in 1,600.[111] The probability of two 727 engines shutting down for independent causes was 1 in 7,700,000—and the 727 could still fly with two inoperable engines.[112]

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105 *See id.*

106 *See id.*

107 *Id.* at 19.

108 *Boeing 727: A Carefully Optimized Short-Haul Jet*, FLIGHT INT'L, May 9, 1963, at 676.

109 *See* MANSFIELD, *supra* note 104, at 62–63.

110 SERLING, *supra* note 86, at 187.

111 MANSFIELD, *supra* note 104, at 103.

112 *Id.*

In 1960, vindicating the decision to include only three engines, the FAA's[113] Chief of the Air Carrier Operations Branch issued a letter stating that "a three-engine airplane with 727 characteristics would be considered to be in the same category as a four-engine plane from the standpoint of weather minimums allowed for takeoff."[114] This greatly improved the marketability of the 727.

The Boeing 727 tri-jet entered service with Eastern Air Lines on February 1, 1964.[115] By the end of production in 1984, 1,831 Boeing 727s had been sold and delivered.[116] The 727's entry into service coincided with the first significant change to the 60-minute rule. In 1963, the FAA proposed modifying the 60-minute rule for three-engine jets.[117] "It is quite possible," the FAA wrote, "that the newly emerging three-engine jet airplanes, because of their overall performance and the general dependability of turbine engines, should be considered in some instances in the same category as four-engine airplanes insofar as the regulations are concerned."[118] The FAA noted that two-engines-inoperative flight is possible with three-engine airplanes, and the loss of one engine does not result in single-engine operation.[119] It proposed allowing three-engine aircraft to operate at distances equal to 90 minutes from an adequate airport in the same manner permitted for four-engine airplanes.[120] Operation distances greater than 90 minutes from such an airport were permissible for three-engine airplanes that met the same two-engines-inoperative climb requirements as required for four-engine airplanes.[121] The FAA adopted the proposal, freeing the 727 to operate on unrestricted routes.

The 727's success inspired two aircraft manufacturers to develop wide-body, three-engine passenger jets: the McDonnell-Douglas DC-10 and the Lockheed L-1011.[122] The DC-10 entered

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[113] The FAA superseded the CAA in 1958. *A Brief History of the FAA*, FAA, http://www.faa.gov/about/history/brief_history/ (last visited Mar. 19, 2013).

[114] MANSFIELD, *supra* note 104, at 103.

[115] *Fast Facts: Boeing 727*, BOEING, http://www.boeing.com/news/feature/sevenseries/727.html (last visited Mar. 19, 2013).

[116] SERLING, *supra* note 86, at 192.

[117] Operation of Three-Engine Airplanes, 28 Fed. Reg. 7,398, 7,398 (July 11, 1963).

[118] *Id.*

[119] *Id.*

[120] *Id.*

[121] *Id.*

[122] Yoshina, *supra* note 101, at 519.

service in 1971 and the L-1011 in 1972.[123] Compared to the four-engine Boeing 747 (which entered service a year before the DC-10), these two planes offered better operating economics and, by carrying fewer passengers, they could serve routes that could not be profitably operated by a 747 "jumbo jet."

C. THE DEVELOPMENT OF LONG-RANGE TWIN-ENGINE JETS

As the first wide-body jets entered service, a new manufacturer joined the market. In July 1967, the French, German, and British governments announced a joint venture to develop Airbus Industries.[124] Airbus formed in 1970 and shortly thereafter developed the A300, the world's first wide-body, twin-engine jetliner.[125] Manufactured primarily in France, the A300 was first sold to Air France, which received its first delivery in 1974.[126]

The A300 filled a niche by offering seat capacity (267 seats standard)[127] and wide-body comfort similar to a DC-10. But with only two engines, it offered better operating economics. And when operated under jurisdictions adopting the ICAO's 90-minute rule, the A300 was a versatile plane. In 1976, A300 operators began flying across the North Atlantic, the Bay of Bengal, and the Indian Ocean under the 90-minute rule.[128]

Airbus aggressively marketed the A300. Eastern Airlines' president (and former Apollo 8 Astronaut), Frank Borman, reportedly received such a good deal from Airbus that he told his staff, "If you don't kiss the French flag every time you see it, at least salute it."[129] In mid-1977, Eastern Airlines, having agreed to purchase several A300s, sought to loosen the FAA's 60-minute rule to better utilize its A300s.[130] Borman requested that the 60-minute rule be increased to at least 75 minutes, reminding the FAA of the looser ICAO 90-minute recommendation.[131]

In 1977, the FAA granted the first deviation from section 121.161, allowing a 15-minute extension to the 60-minute rule

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[123] JOHN SUTTON, TECHNOLOGY AND MARKET STRUCTURE 453 (1998).

[124] *Timeline: A Glance at Airbus' Key Dates*, AIRBUS, http://www.airbus.com/company/history/the-timeline/ (last visited Mar. 19, 2013).

[125] *Id.*

[126] *Id.*

[127] MCGUIRE, *supra* note 80, at 49.

[128] AIRBUS, *supra* note 70, at 14.

[129] PANDEY, *supra* note 46, at 25.

[130] *See* William H. Gregory, *Eastern Weighing Reequipment Needs*, AVIATION WK. & SPACE TECH., Aug. 1, 1977, at 29.

[131] *See id.*

for flights to the Caribbean.[132] The FAA approved Eastern Airlines to operate twin-engine Airbus A300s from New York to San Juan under a 75-minute rule.[133] The FAA also approved Air Florida to operate twin-engine 737s from New York to Port Au Prince.[134] Guiding the FAA's decision was the benign nature of the Western Atlantic Caribbean Sea in 1977.[135] The area offered numerous airports and reliable communications, navigation, and air traffic control services and facilities. And the prevailing weather conditions were stable and generally did not approach extremes in temperature, wind, ceiling, or visibility.[136]

Despite making inroads into the American market, the A300 was not initially a success.[137] Airbus soon turned its attention to developing a longer range derivative of the A300, the A310.[138] Airbus's development of the A310 caused Boeing to consider—and ultimately adopt—a twin-engine configuration for its next generation of passenger planes. Launched in 1978 (and developed in tandem), the Boeing 757 and 767 were designed to offer longer range performance, with better fuel efficiency than comparable existing Boeing models.[139]

The 757 was designed to replace the 727.[140] It shared the 727's fuselage diameter, but with only two engines and by incorporating new technologies, the 757 offered significantly better operating economics.[141] One operator would later comment that the "187-seat 757 [was] 70.5% more fuel-efficient than the 148-seat 727 on the basis of available seat miles [per] gallon on a [500-mile] trip."[142]

The larger 767 was designed to fill a niche between larger double-aisle jumbo jets like the 747 and smaller single-aisle

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132 ADVISORY CIRCULAR 120-42A, *supra* note 53, at 1.

133 *Airline Observer*, AVIATION WK. & SPACE TECH., Sept. 5, 1977, at 35.

134 *See* TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 12.

135 *See* ADVISORY CIRCULAR 120-42A, *supra* note 53, at 1.

136 *See id.*

137 Yoshina, *supra* note 101.

138 *Id.*

139 *Fast Facts: Boeing 767*, BOEING, http://www.boeing.com/news/feature/sevenseries/767.html (last visited Feb. 8, 2013); *see also* SERLING, *supra* note 86, at 388.

140 JOHN G. WENSVEEN & ALEXANDER T. WELLS, AIR TRANSPORTATION 397 (6th ed. 2007).

141 *Delta Purchases 60 Boeing 757s*, AVIATION WK. & SPACE TECH., Nov. 17, 1980, at 26.

142 *Delta Foresees Savings on Crew, Fuel Efficiency*, AVIATION WK. & SPACE TECH., June 3, 1985, at 105.

jets.[143] The 767 was a double-aisle, wide-body jet offering seven-abreast seating.[144] To maximize fuel efficiency, the 767 was—after significant consideration—designed as a twin-engine airplane.[145] Production of the 767 began in 1978 when United Airlines ordered thirty.[146] The 767 entered service four years later.[147]

Boeing initially envisioned eligible airlines taking advantage of the 90-minute rule by using longer range 767s to serve transatlantic routes and routes between the Middle East and Western Europe.[148] Flying 767s between North America and Europe offered significant benefits: an airline could profitably fly the 767 on less trafficked routes. For example, flying a 747 from St. Louis to Paris, seating 370 passengers, would cost $56,000 and consume 2,508 gallons of fuel; flying a 767 with 190 passengers would cost $30,000 and consume 1,078 gallons of fuel.[149] But the 60-minute rule presented a sales obstacle for Boeing and an operating hurdle for U.S. airlines. The business rationale for altering the 60-minute rule was apparent both to the airlines and to Boeing.

II. THE PUSH FOR EXTENDED OPERATIONS

A. Manufacturers Propose Modifying the 60-Minute Rule

In 1980, Boeing approached the FAA about modifying the 60-minute rule. But despite having granted small deviations for Caribbean flights, the FAA showed little enthusiasm for extended-range twin-engine flights. When approached by Boeing Vice President Dick Taylor, FAA Administrator Lynn Helms replied, "It'll be a cold day in hell before I let twins fly long-haul over-water routes."[150] Helms later added, "The requirement for three- or four-engine aircraft for oceanic flight will continue for quite some time, and I don't mean only a year or two."[151]

143 Wensveen & Wells, *supra* note 140, at 65.

144 *707 Family*, Boeing, http://www.boeing.com/boeing/commercial/707family/index.page (last visited Mar. 19, 2013).

145 *See* Serling, *supra* note 86, at 388–89.

146 *767 Program Milestones*, Boeing, http://www.boeing.com/boeing/commercial/767family/pf/pf_milestones.page (last visited Mar. 3, 2013).

147 *Id.*

148 *See Boeing Aircraft Project Moves Forward*, Aviation Wk. & Space Tech., Nov. 9, 1981, at 121.

149 Philip Birtles, Boeing 767, at 48 (1999).

150 Serling, *supra* note 86, at 403.

151 Eugene Kozicharow, *FAA Studies Two-Engine Transoceanic Operations*, Aviation Wk. & Space Tech., Feb. 14, 1983, at 28.

Helms would later reiterate his opposition at an international aviation conference in late 1983.[152] "[T]he chief issue is not engine reliability," he explained, but whether a plane's critical subsystems could be powered by a single engine.[153] If an uncontained engine failure damaged an aircraft, forcing it to fly at peak icing altitudes between 7,000 and 21,000 feet, a single operating engine would have to power the aircraft and subsystems, including electrical, hydraulic, and avionics, and also perform deicing.[154] Helms added that the 60-minute rule was possibly too loose.[155]

But Boeing continued to build a case for twin-engine extended operations.[156] And despite Helms's opposition, in late 1982, the FAA held first-round technical discussions with aircraft manufacturers and international aviation organizations, including the ICAO, which had formed a study group in 1982[157] to consider twin-engine extended operations and determine whether new-generation twins should fly extended-range routes.[158] At a conference in Montreal in December 1982, the FAA asked aircraft manufacturers to gather data about engine reliability and fuel consumption in twin-engine aircraft operations.[159]

Jerald Davis, manager of the FAA's flight technical programs branch, explained that because limited information was available about new two-engine aircraft, the FAA and other regulatory organizations needed to build a database of engine reliability before altering regulations.[160] The FAA would also have to consider the potential loss of a critical flight operations system on a twin-engine aircraft that could impair a deviation to the nearest airport.[161] "There has been no serious consideration up to now for these aircraft. . . . The range capability didn't exist," Davis said.[162]

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152 *Helms Affirms Overwater Extension Opposition*, AVIATION WK. & SPACE TECH., Sept. 26, 1983, at 44.

153 *Id.*

154 *Id.*

155 *Id.*

156 *See* SERLING, *supra* note 86, at 403.

157 Romain, *supra* note 69, at 6.

158 Kozicharow, *supra* note 151, at 28.

159 *Id.*

160 *Id.*

161 *Id.*

162 *Id.*

In July 1983, two contemporaneous incidents on 767 flights no doubt caught the attention of regulators. On July 23, 1983, Air Canada Flight 143, a 767 carrying sixty-one passengers and six crewmembers, departed Montreal bound for Edmonton via Ottawa.[163] Before departure, a fuel quantity sensor on the 767 malfunctioned, and the ground crew had to measure the fuel quantity with a dipstick.[164] The dipstick read in centimeters, which the crew converted into liters and then into kilograms for a weight measurement.[165] A conversion error resulted in Flight 143 taking off only half fueled. At 40,000 feet, one Pratt & Whitney JT9D-7R4 engine flamed out.[166] Shortly after, the second engine stopped.[167] With both engines out and minimal equipment functioning, Captain R.O. Pearson (with ten years of experience as a glider pilot) glided the 767 for 15 minutes to a no-flaps emergency landing at a former Canadian Armed Forces air base.[168]

A month later, the crew of United Airlines Flight 310 shut down both engines of their 767 mid-flight.[169] While descending through thunderstorms, the 767, carrying 197 passengers, lost electrical power and both engines began to overheat.[170] In response, the pilots shut down both engines. The aircraft descended about 4,900 feet before the pilots restarted both engines and landed safely.[171] The problem was traced to a nozzle-coking problem.[172]

Air Canada Flight 143 was one of many subjects addressed when Boeing's Dick Taylor presented a technical paper in support of extended operations to the Royal Aeronautical Society in London in late 1983. Taylor argued that aircraft reliability had improved dramatically in the thirty years since the adoption of

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163 James Ott, *Air Canada 767 Lands Dead Stick After Flameouts*, AVIATION WK. & SPACE TECH., Aug. 1, 1983, at 24.

164 *Id.*

165 *Id.*

166 *Id.*

167 *Id.* at 25.

168 *Id.*

169 *United 767 Loses Power; Engines Shut Down*, AVIATION WK. & SPACE TECH., Aug. 29, 1983, at 30.

170 *Id.*

171 *Id.*

172 *Boeing Asks Overwater Extension*, AVIATION WK. & SPACE TECH., Dec. 19, 1983, at 30.

the 60-minute rule.[173] The odds of two separate engine failures occuring on the same flight were infinitesimally small.

While Air Canada Flight 143 demonstrated that a twin-engine plane could lose both engines in flight, running out of fuel will stop all engines on a plane, regardless of the number of engines. Thus, Taylor argued, having three or four engines protects only against the extremely rare instance of two engines failing for independent reasons.[174] Moreover, the ETOPS portion of a flight (when the plane exceeds 60 minutes flying time from an airport) by definition occurs only during the cruise portion of a flight—statistically the safest part of the journey.[175]

Taylor noted that foreign jurisdictions had allowed extended-range twin-engine flights without issue. Between 1980 and 1985, thirteen nations had some type of twin-engine extended operations, either in scheduled or charter flights.[176] Similarly, U.S. military and private business jets were exempt from the 60-minute rule and had flown such routes without issue.[177]

Taylor acknowledged the concern of FAA Administrator Helms: whether a single engine could power a plane's critical subsystems. In response, Taylor proposed design considerations to ensure adequate redundancy if an engine shut down.[178] These designs included redundant sources of hydraulic power (used to operate a plane's control surfaces), redundant sources of electrical power, and an ice-protection system capable of operating with only one functioning engine.[179] To further improve reliability, Taylor proposed expanded maintenance procedures to identify incipient part failures or performance deteriorations before in-flight failures occur.[180] He also recommended fixed-interval maintenance rather than condition-triggered maintenance—i.e., parts would be replaced before they failed.[181] Taylor also proposed mandating fire suppression capabilities in the

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173 *See* TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 7.

174 *See id.* at 14.

175 *Id.*

176 *Id.* at 12; *see also* ROBERT W. SIMPSON & RAYMOND A. AUSROTAS, A REVIEW OF EXTENDED-RANGE OPERATIONS BY TRANSPORT AIRCRAFT 22 (1987), *available at* http://dspace.mit.edu/bitstream/handle/1721.1/68084/FTL_R_1987_09.pdf.

177 TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 13.

178 *See id.* at 20.

179 *Id.*

180 *Id.* at 23.

181 *Id.*

plane's cargo area that would be sufficient to contain a fire for as long as needed to divert the plane.[182]

In late 1983, Boeing formally applied for a change in the 60-minute rule in a letter from Boeing Vice President Joseph F. Sutter[183] to Helms.[184] The FAA circulated the proposal for comment.[185] Helms, the key skeptic of loosening the 60-minute rule, left the FAA in January 1984, although "his attitude toward the Boeing proposal was more favorable before he left office."[186] Helms was reportedly won over by Boeing's inclusion of additional sources of electrical power and fire suppression systems in the cargo bays.[187]

B. The ICAO Considers Modifying the 90-Minute Rule for Twin-Engine Passenger Planes

While Boeing was pushing for an extension of the 60-minute rule, Airbus negotiated with the ICAO to extend the existing 90-minute recommendation to 120 minutes.[188] At the same time, the ICAO was considering whether to amend the 90-minute rule to create a specific limit for twin-engine planes (the 90-minute rule applied to all planes regardless of the number of engines) and whether twin-engine planes should be restricted to a more conservative limit similar to the FAA's 60-minute rule.[189]

In October 1983, the ICAO ETOPS study group wrote in a working paper that there was considerable doubt that the 90-minute restriction had any operational validity with respect to twins.[190] The then-current 90-minute rule was "only guidance material without any rationale to back it up."[191] Providing a rule with more substantive guidance was in everyone's interest.[192]

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182 *Id.* at 22.

183 Joseph Sutter is the chief engineer who designed the Boeing 747. *See, e.g.*, *2002 Hall of Fame Recipient*, INT'L AIR CARGO ASS'N, http://www.tiaca.org/tiaca/Joseph_F_Sutter.asp (last visited Feb. 26, 2013).

184 *Boeing Asks Overwater Extension*, *supra* note 172, at 30.

185 *Id.*

186 *Airline Observer*, AVIATION WK. & SPACE TECH., Mar. 5, 1984, at 31.

187 SERLING, *supra* note 86, at 403.

188 *See Helms Affirms Overwater Extension Opposition*, *supra* note 152, at 44.

189 *See id.*

190 *Extended Range Operation of Twin-Engined Commercial Air Transport Aeroplanes* 2 (Int'l Civil Aviation Org., Working Paper No. AN-WP/5514, 1983) (on file with author) [hereinafter ICAO Working Paper 5514].

191 *Id.*

192 *Id.*

The ICAO ETOPS study group recommended reducing twin-engine flights to 60 minutes.[193]

In 1983, the ICAO held two meetings and correspondences with representatives from the regulatory agencies of France, Germany, the United Kingdom, and the United States; manufacturers and operators; the International Air Transport Association; and the International Federation of Air Line Pilots Association (IFALPA).[194]

At an October 1983 ICAO meeting, participants failed to agree on a new 90-minute rule.[195] The ICAO airworthiness authority asked for a reduction of the 90-minute rule for twins,[196] while airlines and manufacturers strongly opposed the reduction.[197] Outsiders predicted a 75-minute compromise for single-engine operation.[198]

Airbus opposed the reduction to 60 minutes for twins, noting that its twins had already operated successfully under the 90-minute rule.[199] It also noted that the FAA had already granted a 75-minute deviation for the Airbus A300.[200] Pointing to the A300's safety and reliability records, Airbus recommended that the present 90-minute, all-engine time limit be kept in place for twin-engine planes.[201]

The IFALPA sought to tighten the 90-minute rule for twin-engine planes, possibly to parallel the United States' 60-minute rule.[202] A representative from the British Air Line Pilots Association argued, "[W]e do not think that the statistics can hold up against the philosophic argument . . . . This sort of rule would be tantamount to permitting single-engine passenger flights over water, which is something that's not permitted over land."[203] At the same time, pilots' associations were not entirely opposed to twin-engine extended operations under some circumstances. But they demanded assurances that such flights would be safe, particularly proof that the twin-engine aircraft

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193 *Oceanic-Twin Rules Tightened,* FLIGHT INT'L, Mar. 31, 1984, at 793.

194 ICAO Working Paper 5693, *supra* note 75, at 2.

195 *See Oceanic-Twins Rule Soon?,* FLIGHT INT'L, Nov. 19, 1983, at 1335.

196 *Id.*

197 *Id.*

198 *Id.*

199 *Oceanic-Twin Rules Tightened, supra* note 193, at 793.

200 *Id.*

201 *Id.*

202 *See Overwater Rule Extension Sought,* AVIATION WK. & SPACE TECH., Apr. 11, 1983, at 30.

203 *Id.*

could maintain engine and subsystems reliability for sustained transoceanic flight.[204]

IFALPA delegates adopted a new policy regarding overwater flights.[205] The IFALPA's proposal largely mirrored Boeing's, but it included three- and four-engine as well as twin-engine aircraft.[206] It proposed factors including demonstrated engine and systems reliability; the ability to continue to operate all essential systems with a single engine failure; and adequate support mechanisms, such as air traffic control availability, communications channels, meteorological information, and search-and-rescue facilities, in the event of an engine failure.[207] The IFALPA's resolution stated that the current level of safety on long-range operations with three- and four-engine aircraft was the minimum acceptable level.[208]

The ICAO study group reached a similar conclusion. Twin-engine extended operations could be permitted if four general requirements were satisfied: (1) the plane was specifically certified for ETOPS, taking into account its "system reliability and the possibility of flying for long periods with only one engine operating"; (2) the plane's engine reliability made "the risk of double engine failure from independent causes . . . acceptably low"; (3) "specific flight dispatch requirements were met"; and (4) "specific operational authorization was granted by the State of the Operator."[209] The study group believed that 60 minutes on a single operating engine was the appropriate threshold for requiring enhanced flight rules, particularly because twin-engine planes rarely operated beyond that amount of time.[210]

C. ETOPS Takes Form

As extensions to the 60- and 90-minute rules were considered, airlines began testing the 767's potential for transatlantic flights. Israeli airline El Al was the first customer to receive an extended-range 767 derivative, the 767-200ER.[211] On March 27, 1984, El Al began the first commercial non-stop transatlantic

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204 *See id.*

205 *See* David A. Brown, *IFALPA to Seek Stronger 90-Min. Rule,* Aviation Wk. & Space Tech., Apr. 25, 1983, at 32.

206 *See id.*

207 *Id.*

208 *Id.*

209 ICAO Working Paper 5693, *supra* note 75, at 2.

210 *Id.* at 3.

211 *See News Digest,* Aviation Wk. & Space Tech., Apr. 9, 1984, at 27.

flight by a Boeing 767-200ER.[212] The flight—the longest 767 flight to date—was an eleven-hour, 5,800-mile journey from Montreal to Tel Aviv.[213] The flight operated within the 60-minute rule.[214]

By mid-1984, Boeing began flight-testing a 767 with the additional redundancies proposed by Taylor.[215] The 767 included a fourth electrical generator that was independently powered by a hydraulic motor.[216] This was in addition to the two-engine-driven systems and the Auxiliary Power Unit (a separate gas-powered turbine engine in the tail).[217] With four independent power sources, the 767 had the electrical power equivalent of other three-engine overwater aircraft.[218]

At the same time, the FAA began drafting an advisory circular on extending the 60-minute rule to 120 minutes under certain conditions.[219] The 120-minute extension was comparable to the 90-minute ICAO rule because the FAA measured 120 minutes on a single-engine speed, while the ICAO measured 90 minutes on two-engine speed.[220]

In June 1984, Boeing briefed the new FAA head, Donald D. Engen, on the 767's overwater capabilities.[221] Boeing underscored the 767's capabilities by scheduling a 6,503-nautical-mile delivery flight of an Ethiopian Airlines 767-200ER from Washington Dulles International to Addis Ababa (the flight stayed within the ICAO's 90-minute guideline).[222] Further, Boeing emphasized that no cruise, non-restartable engine shutdown had occurred on a 767 flight in 1984 (though six occurred in 1983).[223]

In July, the FAA issued a draft advisory circular for twin-engine extended operations. The circular stated that it provided

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212 *El Al Retires Veteran 767 Aircraft*, EL AL (Oct. 11, 2011), www.elal.co.il/elal/italian/aboutelal/elal_news_en_items/en_news_767_111011.html.

213 *News Digest*, *supra* note 211, at 27.

214 *Id.*

215 *See Boeing Presses 767 Overwater Certification*, AVIATION WK. & SPACE TECH., May 7, 1984, at 27.

216 *Id.*

217 *Id.*

218 *Id.*

219 *Id.*

220 *Id.*

221 *Boeing Urges 2-Engine Ruling*, AVIATION WK. & SPACE TECH., June 4, 1984, at 32.

222 *Id.*; *see Ethiopian 767 Sets Distance Record*, FLIGHT INT'L, June 16, 1984, at 1532.

223 *Boeing Urges 2-Engine Ruling*, *supra* note 221, at 32.

an acceptable—but not the only—means for obtaining approval for extended operations.[224] The advisory circular required a level of safety and redundancy comparable to long-range operations of three- and four-engine turbine-powered airplanes.[225] It proposed criteria under headings of airworthiness, in-service experience, and operations.[226] The draft included six design criteria:

(1) "[a]n acceptably low risk of double engine failure";
(2) demonstrated "propulsion system reliability based on in-service experience with a particular airplane-engine combination";
(3) "essential or critical airframe systems" are operational if an engine fails;
(4) "[a]ssessment of an air carrier and manufacturer's maintenance programs in achieving a level of systems reliability for a particular airplane-engine combination";
(5) "[r]eview of an air carrier's training programs, operations, and maintenance programs to assess ability to maintain systems reliability with a particular airplane-engine combination"; and
(6) "[a]pplication of fail-safe criteria for design of engines and essential or critical systems of a particular airplane."[227]

With regard to demonstrated propulsion system reliability, the FAA proposed to assess engine reliability only after an engine type obtained a combined 250,000 hours of operation on a particular airplane–engine combination (though the advisory circular opened the door for exceptions based on "adequate compensating factors").[228] At the time, Boeing offered the 767 with two engine options: Pratt & Whitney JT9D-7R4 and General Electric CF6-80A. The 767 and Pratt & Whitney JT9D-7R4 engines combination had accumulated 276,920 hours, while the General Electric CF6-80A combination had accumulated 191,400 hours.[229] The FAA stated that it would publish a report on its engine reliability data.[230] Demonstrated reliability was de-

[224] *See* ADVISORY CIRCULAR 120-42A, *supra* note 53, at 1.

[225] James Ott, *FAA Prepares Overwater Guides*, AVIATION WK. & SPACE TECH., July 16, 1984, at 28.

[226] *Id.*

[227] *Id.*

[228] *Id.*

[229] *Id.*

[230] *Id.*

fined as a maximum number of engine shutdowns per set number of flight hours.[231] The engines would be required to maintain a maximum shutdown rate of 0.05 shutdowns per 1,000 flight hours (i.e., 5 shutdowns per 100,000 hours).[232] Calculations showed that 0.05 was a safe threshold based on the risk of a dual, unrelated shutdown during 120-minute ETOPS.[233] Boeing figures also showed that the 0.05 figure was achievable by current engines.[234]

Airlines would separately qualify for extended-range operations.[235] Eligible carriers would be required to operate a particular airplane–engine combination for at least twelve consecutive months.[236] From this, the FAA would develop a report from the maintenance review board on scheduled maintenance, replacement, and inspection programs for the particular aircraft.[237]

If all conditions were satisfied, a qualified airplane and airline would be permitted to fly extended-operation flights up to 120 minutes from a suitable airport.[238] The 120-minute limit could be increased by up to 15% if the carrier met "special requirements for propulsion reliability, operating practices, crew training, and equipment."[239]

Responding to the draft advisory circular, McDonnell Douglas—a manufacturer of twin-engine aircraft that did not offer long-range capability at the time—took a more reserved position.[240] It noted that ETOPS "represents a 'totally new risk' that the industry has a limited capability to offset."[241] McDonnell Douglas argued that "'the possible adverse consequences of premature extension of the operating limits can never be balanced by economic gain.'"[242] Finally, "[t]he existing rule has contrib-

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231 ADVISORY CIRCULAR 120-42A, *supra* note 53, at 19–20.

232 *Id.*

233 Email from Daryl Heinzerling, Boeing, to J. Angelo DeSantis, UC Davis School of Law (Mar. 1, 2013, 06:27 PST) (on file author).

234 *Id.*

235 ADVISORY CIRCULAR 120-42A, *supra* note 53, at 11.

236 *Id.*

237 Ott, *FAA Prepares Overwater Guides*, *supra* note 225, at 28.

238 *Id.*

239 *Id.*

240 *See Risk to 60-Min. Rule Cited*, AVIATION WK. & SPACE TECH., Dec. 17, 1984, at 25.

241 *See id.*

242 *Id.*

uted to the industry's outstanding safety level and 'should not be lightly or prematurely superseded.'"[243]

III. THE BEGINNING OF ETOPS PASSENGER FLIGHTS

A. FLYING 120 MINUTES FROM AN AIRPORT

In January 1985, John M. Swihart of Boeing wrote in *Aerospace America*, "One day this winter—possibly even this month—aviation history will be made, very quietly."[244] On February 1, 1985, TWA flew the first revenue flight under the draft Advisory Circular 120-42.[245] The TWA 767-200 flew from Boston to Paris under a 75-minute deviation from the 60-minute rule.[246] The 767-200 had been retrofitted to satisfy the circular's requirements.[247] Under the 75-minute deviation, the flight took 20 to 30 minutes longer than a direct "Great Circle" flight would have, but the flight was seventy-six miles shorter than the same route under the 60-minute rule.[248] Flight 810 consumed approximately 10,000 pounds of fuel per hour—7,000 pounds per hour less than the three-engine L-1011 that typically operated the route.[249]

Passenger opposition to flying a twin-engine plane on an overwater, long-haul flight was non-existent.[250] Passengers surveyed for their opinions of the 767 in comparison to other wide-body transports were either positive or indicated that they did not fully understand what they were flying on.[251] And when the crew announced the historic nature of the flight, it was uninteresting news to most passengers.[252]

In February 1985, the FAA published in the Federal Register a notice of availability of the draft Advisory Circular 120-42 and wrote that current two-engine airplanes "provide levels of redundancy (except with respect to the number of engines) and reliability as good [as] or better than the levels exhibited by the

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243 *Id.*

244 *See* Swihart, *supra* note 28, at 14.

245 *See* Ott, *Boeing 767 North Atlantic Flights*, *supra* note 3, at 31.

246 *See id.*; Brad Bachtel, *ETOPS Extended Operations, and En Route Alternate Airports*, BOEING 6 (Oct. 3, 2003), www.boeing.com/commercial/airports/faqs/etopseropsenroutealt.pdf.

247 *See* Ott, *Boeing 767 North Atlantic Flights*, *supra* note 3, at 31.

248 *See id.*

249 *Id.*

250 *See id.*

251 *See id.*

252 *See id.*

previous generation of three- and four-engine airplanes."[253] Current turbine engines are "much less likely to fail than many older models."[254] Thus, twin-engine "extended range operations should be permitted" if airplanes and airlines "meet stringent airworthiness and operating standards . . . designed to ensure that the level of safety provided to the traveling public would in no way be reduced."[255]

The notice continued, explaining the draft criteria would provide "safety equal to or better than that required of three- or four-engine airplanes currently flying these routes."[256] The draft Advisory Circular would "implement the work of the [ICAO's] Extended Range Operations (ETOPS) Study Group, which the [United States] actively participated in and supported."[257]

In March 1985, the United Kingdom's aviation regulatory body, the Civil Aviation Authority (CAA), also signaled a willingness to permit extended-range twin-engine flights.[258] The CAA called twin-engine jets "'inherently more vulnerable'" than three- or four-engine aircraft, but it believed that improved safety standards could allow twins to match the safety of bigger planes.[259]

In June 1985, the FAA formally issued Advisory Circular 120-42, defining a process for obtaining 120-minute extended operations approval.[260]

B. ETOPS Flights Grow in the Atlantic

Flying 767 ETOPS flights between North America and Europe offered airlines logistical benefits. The 767 transported half the payload of a 747, but reached almost the same flight distance.[261]

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253 *See* Advisory Circular; Extended Range Operations with Two-Engine Airplanes, 50 Fed. Reg. 5,150, 5,150–51 (Feb. 6, 1985).

254 *Id.* at 5,151.

255 *Id.*

256 *See id.*

257 *Id.*

258 *See* Michael Smith, *Jet Twins Sign For Acceptance/Civil Aviation Authority Expected to Approve Long Distance Flights for Twin-Engined Jets*, Guardian (London), Mar. 29, 1985.

259 *See id.*

260 *See* Extended Operations (ETOPS) of Multi-Engine Airplanes, 72 Fed. Reg. 1,808, 1,810 (Jan. 16, 2007) (to be codified at 14 C.F.R. pts. 1, 21, 25, 33, 121, & 135).

261 Taylor, Extended Range Operation, *supra* note 54, at 1–2; *767 Family*, Boeing, www.boeing.com/commercial/767family/background.html (last visited Mar. 5, 2013); *Boeing Freighters*, IAL Cargo 4, 6, 9 (2003), www.ialcargo.com/specs/b747.pdf.

This increased the number of point-to-point routes an airline could profitably operate.[262] Carrying a smaller payload the same distance was highly desirable to airlines.[263] Indeed many airlines bought the original 747 jumbo jet for its range rather than its payload.[264] This could be a costly proposition because a 747-100 only 70% full would still use approximately 95% of its normal fuel load.[265]

In May 1985, while airlines were beginning ETOPS operations, Boeing began collecting, "on a worldwide basis, a complete [database of] incidents of the major systems of its 767s, including electrical power; hydraulic power; air conditioning and pressurization; and automatic flight and navigation."[266] From May 1985 through December 1986, 13,000 ETOPS flights led to twenty-five reported events: twenty-one flights turned back or diverted, while four continued to their destinations.[267] Six events occurred during the ETOPS portion of the flight (i.e., where the plane was more than 60 minutes from an airport).[268]

The FAA also closely monitored ETOPS flights. An FAA official admitted being "'a little surprised at the frequency of engine problems in the first six months.'"[269] In three instances, maintenance issues caused oil shortages that forced crews to shut down engines.[270] In one event, "mechanics failed to tighten an accessory on a gearbox, which permitted oil to leak."[271]

In December 1985, the FAA type certified a second aircraft for 120-minute ETOPS: the Boeing 737-200.[272] The 757 was type

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262 *See* BIRTLES, BOEING 767, *supra* note 149, at 48.

263 *Id.*

264 *See* Carole A. Shifrin, *British Airways Starts Transatlantic Service with new Boeing 747-400s*, AVIATION WK. & SPACE TECH., Aug. 14, 1989, at 62.; Bruce A. Smith, *Boeing Shuns Very Large Jets While Aiming for Longer Range*, AVIATION WK. & SPACE TECH., Jan. 1, 2001, at 28.

265 *Greenhouse Gas Emissions from International Aviation and Allocation Options*, DANISH ENVTL. PROTECTION AGENCY, http://www2.mst.dk/udgiv/Publications/2003/87-7972-489-2/html/kap09_eng.htm (last visited July 18, 2013).

266 SIMPSON & AUSROTAS, *supra* note 176, at 17.

267 TAYLOR, EXTENDED RANGE OPERATION, *supra* note 54, at 17.

268 *Id.* at 18.

269 James Ott, *Engine Reliability Prompts Bid for Unlimited Overwater Flights*, AVIATION WK. & SPACE TECH., May 11, 1987, at 36.

270 *See id.*

271 *Id.*

272 *FAA Extends Boeing Next-Generation 737 ETOPS from 120 to 180 Minutes*, BOEING (Sept. 14, 1999), www.boeing.com/news/releases/1999/news_release_990914a.html.

certified in 1986.[273] The first Airbus aircraft, the A310 and A300-600, were also type certified for ETOPS in 1986.[274]

By the winter of 1986, five airlines were operating forty-nine ETOPS-certified 767s over the North Atlantic and had flown more than 3,000 flights.[275] By 1987, the number of ETOPS operators had grown to fourteen.[276] By 1990, 175 ETOPS-certified 767s were operating more than 4,000 ETOPS flights per month. Two years later, among U.S. carriers, more twin-engine planes were crossing the North Atlantic than three- and four-engine aircraft.[277]

IV. FLYING BEYOND TWO HOURS FROM A SUITABLE AIRPORT

A. Flying 180 Minutes from an Airport

By 1987, manufacturers and operators began pushing to extend 120-minute ETOPS flights.[278] Some key routes remained off-limits to 120-minute ETOPS flights: a flight to Hawaii from the mainland was outside the 120-minute limit.[279] Allowing 180-minute ETOPS flights would open routes from Europe, Australia, and Africa to South America.[280] It would also permit routes that take advantage of better winds and weather.[281] For example, a 120-minute ETOPS flight requires three alternate airports to cross the North Atlantic.[282] "On northern routes[,] Keflavik Airport in Iceland and Sondre Stromfjord Airbase in Greenland

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273 *757-200 Background,* BOEING, www.boeing.com/boeing/commercial/757family/pf/pf_200back.page (last visited May 27, 2013).

274 *Overview of New ETOPS/LROPS/EDTO Rules,* ICAO 5 (Oct. 2011), www.mexico.icao.int/Meetings/RASGPA/RASGPA4/Presentation1Airbus.pdf.

275 RICHARD W. TAYLOR, BOEING COMMERCIAL AIRPLANE COMPANY, TWIN-ENGINE TRANSPORTS: A LOOK AT THE FUTURE 11 (1990).

276 *See* Ott, *Engine Reliability, supra* note 269, at 36.

277 *See More Twins Flying Atlantic than Other Multi-Engine Jets,* AVIATION DAILY, Feb. 5, 1992, at 215.

278 Ott, *Engine Reliability, supra* note 269, at 36.

279 *Id.*; *Air Canada Expects ETOPS Success to Bring Faster Approvals in Future,* AVIATION WK. & SPACE TECH., Apr. 13, 1992, at 51. A flight to Hawaii exceeds 150 minutes of ETOPS flight. Email from Daryl W. Heinzerling, Boeing Co. (June 2013).

280 *Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS,* AVIATION WK. & SPACE TECH., Apr. 18, 1988, at 85.

281 *Id.*

282 *TWA Expects Solid ETOPS Record Will Ease Transition to A330,* AVIATION WK. & SPACE TECH., Apr. 13, 1992, at 49.

are within range," but if weather prevents landing at those airports, a 120-minute ETOPS aircraft must fly farther south.[283]

In the event of a diversion, 180-minute ETOPS would also offer pilots a "wider choice of alternate airports."[284] Some argued that having a "wider choice of alternate airports" would enhance safety: in an emergency, pilots could divert to a farther airport offering safer landing conditions.[285]

Improvements in engine reliability also supported increasing the ETOPS limit. From September 1985 to May 1987, no Pratt & Whitney JT9D-7R4 engine had shut down during the ETOPS portion of a 767 flight.[286] And General Electric's CF6-80A and CF6-80C2 engines never caused an in-flight shutdown in the ETOPS portion of a flight (though twenty-seven in-flight shutdowns of the CF6-80A occurred during non-ETOPS operations).[287] Pratt & Whitney and Boeing submitted data to the FAA that supported extending diversion time to 180 minutes.[288]

The FAA, however, took a cautious approach. Jerald M. Davis of the FAA's Office of Flight Standards noted that no engine–airframe combination had reached one million engine flight hours.[289] "The carriers are doing a good job, but the record needs to be expanded with a few more operators," Davis said.[290]

In April 1987, the Massachusetts Institute of Technology Flight Transportation Laboratory Department of Aeronautics & Astronautics completed a report on ETOPS commissioned by the FAA.[291] The study criticized the FAA's procedures and methods for evaluating ETOPS flights.[292] It pointed out "shortcomings in the methodology and reliability calculations that manufacturers, [the] FAA and other airworthiness authorities use[d] to define EROPS risks."[293]

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283 *Id.*

284 *Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS*, *supra* note 280, at 85.

285 *Id.*

286 Ott, *Engine Reliability*, *supra* note 269, at 36.

287 *Id.*

288 *Id.*

289 *Id.*

290 *Id.* (internal quotation marks omitted).

291 *See* SIMPSON & AUSROTAS, *supra* note 176, at 1, 4.

292 *Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS*, *supra* note 280, at 85.

293 *Id.*

The report criticized ETOPS rules that measure maximum diversion time in minutes rather than distance.[294] Though ETOPS flights were restricted to flying within 120 minutes from an airport, strong headwinds "could increase the actual interval by 20% or more."[295] This increase could pose a hazard considering that many ETOPS safety measures, such as cargo fire suppression, were designed to provide protection for only the 120-minute interval (and perhaps a few extra minutes for ground evacuation).[296] The report added, "This inconsistency would not stand serious scrutiny by lawyers looking for careless or incomplete efforts on the part of airworthiness authorities after an accident."[297]

More fundamentally, the report criticized the lack of a "clear statement of how risk is being assessed in ETOPS."[298] It noted that while the ICAO study group created two risk models, the models lacked "rigor or detail."[299] The report also criticized the FAA for not requiring airlines to perform test flights with only a single operating engine.[300] Airlines that voluntarily performed such flights had uncovered issues that needed to be addressed.[301] The report stated, "It seems odd that the traveling public may be onboard when approved diversionary procedures are actually flown for the first time."[302] The FAA initially resisted a Freedom of Information Act (FOIA) request for the report from the Air Line Pilots Association (ALPA), but the agency released the report a year later in April 1988.[303]

While the FAA was considering the extension, troubles on 767s again caught regulators' attention.[304] In January 1988—in the span of four days—three 767s diverted (two in ETOPS flights).[305] On January 14, a TWA 767 with Pratt & Whitney JT9D-7R4 engines, flying from London to St. Louis, diverted to

294 *Id.*

295 *Id.*

296 *Id.*

297 SIMPSON & AUSROTAS, *supra* note 176, at 42.

298 *Id.* at 43.

299 *Id.*

300 *Id.* at 43–44.

301 *Id.* at 43.

302 *Id.* at 44.

303 *Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS*, *supra* note 280, at 85.

304 *See Engine Problems Divert 767 Flights*, AVIATION WK. & SPACE TECH., Jan. 25, 1988, at 143.

305 *Id.*

Goose Bay "when the crew shut down the No. 2 engine after receiving an oil bypass indicator warning."[306] The crew later found metal chips in the oil filter.[307] On January 18, another TWA 767 out of Paris shut down an engine following a high-oil-temperature reading.[308] The flight was diverted to Montreal.[309] The same day, a non-ETOPS 767 flight from Los Angeles to Washington, D.C., diverted to Kansas City when the No. 1 engine "experienced repeated surges."[310]

Despite these issues, in February 1988, newly-appointed FAA Administrator Allan McArtor announced that the FAA would accelerate its consideration of a 180-minute rule and directed his staff to finish the process by the fall.[311] *Aviation Week & Space Technology*, an industry publication, opined the following:

> The FAA has been under strong pressure to increase the diversion time maximums from aircraft and engine manufacturers anxious to expand markets since the 1970s. Permission to use twin-engine aircraft such as the Boeing 737-300, 757-200[,] and particularly the 767-300ER on EROPS[312] routes would significantly increase Boeing's potential markets.[313]

On December 30, 1988 (nine days after the bombing of a Pan Am 747 over Lockerbie, Scotland), the FAA released AC 120-42A, allowing for 180-minute ETOPS.[314] AC 120-42A conditioned 180-minute certification on increased reliability—beyond that required for 120-minute ETOPS.[315] It created tiers of certification for ETOPS: 75-, 120-, and 180-minute tiers.[316] Type certification for 180-minute approval would require at least 250,000

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306 *Id.*

307 *Id.*

308 *Id.*

309 *Id.*

310 *Id.*

311 *FAA Will Speed Approval Process on Overwater Flights Extension*, AVIATION WK. & SPACE TECH., Feb. 1, 1988, at 77.

312 U.S. regulators sometimes refer to ETOPS as EROPS: Extended Range OPerationS. Some call it "Engines Running or Passengers Swimming." *See* Holusha, *supra* note 1, at 31; *Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS*, *supra* note 280, at 85.

313 *See Review Criticizes FAA's Criteria for Approving Twin-Engine EROPS*, *supra* note 280, at 85.

314 *See* ADVISORY CIRCULAR 120-42A, *supra* note 53, at 1; David A. Brown, *Bomb Destroys Pan Am 747 in Blast over Scotland*, AVIATION WK. & SPACE TECH., Jan 2, 1989, at 28.

315 *See* ADVISORY CIRCULAR 120-42A, *supra* note 53, at 15.

316 *See id.*

engine hours.[317] Operational certification would require an airline to operate under approved 120-minute ETOPS for one year before gaining approval for 180-minute ETOPS.[318] Certified planes and engines must maintain a maximum in-flight shutdown rate of 0.02/1000 hours (two failures per every 100,000 engine hours).[319] The FAA would periodically review the propulsion system reliability of aircraft operating under 180-minute ETOPS, as was required for 120-minute operations, but with shorter scheduled intervals.[320]

AC 120-42A also required sufficient fire suppression capability to suppress a fire during maximum diversion under 180-minute ETOPS.[321] Modifying a 767 to provide three hours of fire suppression would cost about $20,000 per plane.[322]

Airplanes and airlines could still qualify for 120-minute ETOPS under the old standards of 0.05 shutdowns per 1,000 flight hours (or five shutdowns per 100,000 hours).[323]

In January 1989, American Airlines flew a 767-300ER aircraft on a validation flight from Dallas to Hawaii under the 180-minute rule.[324] By April 1989, both the 767-300ER and GE CF6-80C2 engines received type certification for 180-minute ETOPS, and American Airlines received the first 180-minute operational certification.[325] Underlying the approval was the fact that American Airlines had achieved an impressive reliability record. By mid-December, the airline was expected to fly its 20,000th transatlantic crossing and was operating more than 780 ETOPS flights per month.[326] During that time, American Airlines had an in-flight shutdown rate of 0.019 per 1,000 engine flight hours on its 767-200 and no shutdowns on its 767-300s.[327]

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317 *Id.* app. at 1.

318 *Id.* at 15.

319 *Id.* at 5.

320 *Id.* at 10, app. at 7.

321 *Id.* at 10.

322 *TWA Expects Solid ETOPS Record Will Ease Transition to A330*, AVIATION WK. & SPACE TECH., Apr. 13, 1992, at 49.

323 ADVISORY CIRCULAR 120-42A, *supra* note 53, at 15.

324 *The FAA*, AVIATION WK. & SPACE TECH., Jan. 23, 1989, at 32.

325 *American Airlines*, AVIATION WK. & SPACE TECH., Apr. 10, 1989, at 32.

326 *Reliable EROPS*, AVIATION WK. & SPACE TECH., Dec. 4, 1989, at 15.

327 *Id.*

B. ETOPS BY THE EARLY 1990S

June 1990 marked the five-year anniversary of ETOPS.[328] In 1990, Boeing 767s were crossing the Atlantic approximately 1,764 times each month.[329] Boeing 757s flew approximately 397 extended-range flights each month.[330] And airlines were also operating the twin-engine A310 across the Atlantic, with Airbus counting thirty-three city pairs linking Europe and North America with A310s.[331] By April 1992, ETOPS flights accounted for one of every three North Atlantic crossings.[332] Among U.S. carriers, ETOPS crossings over the Atlantic exceeded three- and four-engine crossings by late 1991.[333] Engine reliability "generally exceeded expectations in figures monitored by both Canada and the [United States]."[334] Of the major Canadian carriers, both had shutdown rates below 0.01; in fact, one carrier that operated 767-300ERs with General Electric CF6 powerplants had a rate as low as 0.006.[335]

Additionally, the more stringent ETOPS maintenance requirements were reaping unexpected benefits for carriers.[336] Dispatch reliability improved.[337] And reducing in-flight shutdowns not only improved safety, but also provided significant cost savings to airlines.[338] In 1991, the cost of an in-flight shutdown was substantial.[339] At a seminar, airline attendees were asked to estimate the cost of an in-flight shutdown.[340] The average estimate was $850,000.[341] One-third of the respondents estimated associated losses for each shutdown at more than $1 million, not including the indirect costs of customer dissatisfaction.[342] By comparison, an airline's average annual profit per air-

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328 James Ott, *North Atlantic Traffic to Hit Record with New Services*, AVIATION WK. & SPACE TECH., June 18, 1990, at 90.

329 *Id.*

330 *Id.*

331 *Id.*

332 David Hughes, *ETOPS Proves a Success on North Atlantic Routes*, AVIATION WK. & SPACE TECH., Apr. 13, 1992, at 44.

333 *Id.*

334 *Id.*

335 *Id.*

336 Robert E. Weiss, *Cost Operators*, FAST AIRBUS TECHNICAL DIG., Jan. 1991, at 23.

337 *Id.*

338 *Id.*

339 *See id.*

340 *Id.*

341 *Id.*

342 *Id.*

craft was estimated in an industry study to be approximately $639,000 (depending on many factors).[343] Thus, in 1991, the cost of a single in-flight shutdown could exceed the annual profit from flying an airplane.[344]

Engine manufacturers with a vested interest in reducing in-flight shutdowns on ETOPS flights developed improved procedures to reduce shutdowns.[345] Pratt & Whitney, for example, encouraged operators to undertake external inspections for frayed wires, missing clamps, and loose nuts that had caused in-flight shutdowns on ETOPS aircraft in the past.[346] Recognizing the economics of improved reliability, airlines began to incorporate these enhanced maintenance techniques on non-ETOPS flights.[347] At a June 1991 symposium, Tom Edwards Jr. presented a paper on behalf of United Airlines explaining how United had implemented ETOPS practices on its ETOPS-exempt 747s, which greatly reduced the number of in-flight shutdowns.[348]

In 1992, the former director of operations for Pan Am explained the ETOPS pre-flight check.[349] Maintenance crews would conduct an "over-ocean" check of the aircraft's fluid levels and standby systems.[350] They would then plug a laptop computer into the engines to perform diagnostic checks.[351] The readouts would be stored and compared to detect trends that might predict an in-flight shutdown.[352]

V. EARLY ETOPS AND THE BOEING 777

A. Trouble Selling the World's Largest Twin

The 1990s saw a major shake-up of aerospace companies.[353] By the decade's end, Airbus would emerge as a major industry

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343 *Id.*

344 *Id.*

345 *Id.* at 24.

346 *Id.*

347 *Id.*

348 Pandey, *supra* note 46, at 74; Thomas M. Edwards, Jr., United Airlines, Lessons Learned in Maintaining Aircraft in ETOPS Operations 2–3 (1999).

349 *Delta Reaps Economic Benefits From Pan Am's A310 ETOPS Program*, Aviation Wk. & Space Tech., Apr. 13, 1992, at 53.

350 *Id.*

351 *Id.*

352 *Id.*

353 *Expansion (1991–1992)*, Airbus, http://www.airbus.com/company/history/the-narrative/expansion-1991-1992/ (last visited Mar. 3, 2013).

manufacturer.[354] And McDonnell Douglas—largely forced out of the commercial airplane business by Airbus—would merge with Boeing, leaving Boeing and Airbus as the two remaining major commercial aviation manufacturers.[355]

In the early 1990s, airlines sought to eventually replace or supplement their older 747s, L-1011s, and DC-10s.[356] The 767 and A310 had demonstrated the value of smaller, more efficient planes capable of long-haul flights. Airlines wanted the range of a 747, the seat capacity of a DC-10 or L-1011, and the efficiency of a 767.[357]

Boeing, Airbus, and McDonnell Douglas each prepared an offering.[358] McDonnell Douglas was first to the market with the 300-seat, three-engine MD-11.[359] Launched in 1986 and beginning revenue service at the end of 1990, the MD-11 was a DC-10 derivative.[360] It offered better range and capacity than the DC-10.[361] But the MD-11 was a commercial disappointment with only 200 sold.[362]

Several factors contributed to its failure. McDonnell Douglas failed to deliver the MD-11 at the promised weight, range, and fuel efficiency.[363] Singapore Airlines very publically cancelled their MD-11 order for that reason.[364] The MD-11 also struggled against Boeing's 747-400, which offered the longest range at the time.[365]

But perhaps the single largest reason for the MD-11's demise was Airbus's offering: the 300-seat A330 and A340. Launched simultaneously at the Paris Air show in 1987, the A330 and A340

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354 *Record-Breakers*, AIRBUS, www.airbus.com/company/history/the-narrative/record-breakers-1993-2000/ (last visited Mar. 3, 2013).

355 Steve Rolinitis, *The Boeing & McDonnell Douglas Merger*, ILL. STATE UNIV., Apr. 17, 1997, at 4–5.

356 *See* Shifrin, *supra* note 264, at 62.

357 *Id.* (stating, "British Airways officials, in Seattle to take delivery of the first two of [nineteen] 747-400s on firm order, said the 767-X transport is a candidate, along with the Airbus Industrie A330, to replace its fleet of [twenty-five] Lockheed L-1011 and McDonnell Douglas DC-10 three-engine aircraft").

358 *McDonnell Douglas MD-11: A Brief History*, MD-11.ORG, www.md-11.org/history.html (last visited Mar. 3, 2013).

359 *Id.*

360 *Id.*

361 *Id.*

362 *Id.*

363 Geoffrey Thomas, *A340 Trade-in a Coup for Boeing in Singapore*, AVIATION WK. & SPACE TECH., June 28, 1999, at 28.

364 *Id.*

365 *Id.*

were essentially two- and four-engine versions of the same plane.[366] The A330, a wide-body twin-engine aircraft designed for medium-haul flights, competed with the 767, offering larger capacity and better economics.[367] The A340, with four engines, added long-range capability to the A330's capacity.[368] And with four engines, the A340 was exempt from the 60-minute rule. Aggressively marketed, the A340 outsold the MD-11, forcing McDonnell Douglas out of commercial aviation.[369]

Boeing's answer to the MD-11 and A340 differed in several aspects. Launched in October 1990, Boeing's 777 was last to enter the market; at twenty feet, four inches in diameter, the 777 was larger than the other offerings.[370] But its most distinguishing characteristic was its engines: it only had two.[371]

Designing the 777 required the most powerful commercial jet engines ever produced. The 80,000 pounds of thrust generated by the first 777's engines was greater than the rocket that lifted the first American into space.[372] But even with such powerful—and fuel thirsty—engines, a twin-engine configuration inherently offered better economics.[373] Two engines meant reduced fuel consumption and drag, as compared to three or four engines. It also reduced the number of engines needing maintenance.

But with only two engines, the 777 fell within the ambit of the 60-minute rule.[374] Under the existing ETOPS regime, this was a serious obstacle: the 777 could fly 7,500 nautical miles, but it would be largely limited to domestic routes under the 60-minute rule until the 777's engines and airframe accumulated 250,000 flight hours.[375] And for operational certification, airlines would need to operate the 777 for one year before qualifying for 120-minute certification and two years before qualifying for 180-min-

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[366] PANDEY, *supra* note 46, at 44.

[367] *Id.* at 45.

[368] *Id.*

[369] *Id.*

[370] *Id.* at 48.

[371] *Id.* at 49.

[372] KARL SABBACH, TWENTY-FIRST-CENTURY JET: THE MAKING AND MARKETING OF THE BOEING 777, at 122 (1996).

[373] *Id.* at 45.

[374] *Id.*

[375] *Id.* at 140.

ute certification.[376] By contrast, MD-11s and A340s could cross the Pacific on delivery.[377]

The need to immediately take advantage of a plane's long range was of paramount concern to customers. An industry observer explained that "[n]o airline wants to buy an airplane and have to wait two or three years to fully utilize it."[378] Indeed, engine maker Pratt & Whitney lost a sale of its PW4000 engine to competitor General Electric's CF6-80C2 because the PW4000 had not acquired enough in-service hours to qualify for ETOPS.[379] The customer, Qantas, needed to begin ETOPS as soon as possible, and the PW4000 was not expected to accumulate sufficient hours for ETOPS certification for another year.[380]

B. Boeing Proposes Another Modification to ETOPS

To get around the requirement of two years in-flight experience, Boeing proposed another modification to ETOPS: it sought to have the 777 receive 180-minute ETOPS certification immediately upon entry into service.[381] Boeing called this "early ETOPS" or "ETOPS out-of-the-box."[382] Boeing had anticipated that the in-service requirement would become a problem, and in 1988, Boeing launched an internal study of alternatives to in-service experience requirements for ETOPS.[383] On July 6, 1989, Boeing CEO Phil Condit issued a policy that any new or derivative twin-engine Boeing airplane would support 180-minute ETOPS at entry.[384]

Boeing proposed a set of design objectives to achieve early ETOPS; chief among those objectives was an assurance that the 777 and its engines would enter the market "mature."[385] The engine would be designed to have a low shutdown rate at the outset.[386] In the early 1980s, reducing engine shutdown rates during development was not a priority. Engines were built, and through improvements and corrections, they "matured" into

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376 *Id.* at 142.

377 *Id.*

378 Holusha, *supra* note 1, at 31.

379 Stanley W. Kandebo, *Engine Markets Will Be Strong As Global Traffic Grows*, Aviation Wk. & Space Tech., Mar. 14, 1988, at 194.

380 *Id.*

381 Pandey, *supra* note 46, at 54.

382 *Id.*

383 *Id.* at 55.

384 *Id.*

385 *Id.*

386 *Id.*

lower in-flight shutdown rates.[387] With the 777, Boeing set an expected shutdown rate "budget" and required that individual components have a reliability rate that did not exceed the budgeted contribution to an engine shutdown.[388]

In late 1989, Boeing organized its first symposium on early ETOPS at the Museum of Flight in Seattle.[389] At the symposium, FAA Associate Administrator Tony Broderick stated that the FAA would keep an open mind toward early ETOPS.[390] But, he continued, "Operator in-service experience has also been instrumental in giving the FAA confidence that the operator's maintenance, dispatch, and flight crew training programs and operating procedures are satisfactory for ETOPS. . . . Eliminating this phase cannot be done without thought, preparation, and analysis."[391] Boeing held a second early ETOPS symposium in May of the following year.[392] Both symposiums preceded the 777's official launch.

The FAA had previously considered an early ETOPS proposal from various engine makers. One U.S. manufacturer proposed early ETOPS certification for a 35,000–40,000 pound–thrust engine.[393] The proposal failed when the engine "simply did not live up to expectations."[394] A second proposal from another manufacturer did not meet expectations either, despite the engine's "'very low initial shutdown rate.'"[395]

Nevertheless, Broderick had a high opinion of ETOPS. In May 1990, he called it "one of two programs in recent times which have significantly improved aviation safety."[396]

On June 18, 1990, Boeing officially applied for a type certificate for the 777.[397] Broderick opined, "'[I]n 1990, I wouldn't sign any contracts to buy or sell an airplane with 180-minute ETOPS approval out of the box as a condition.'"[398]

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387 *Id.*

388 *Id.* at 56.

389 *Id.* at 57.

390 *Id.* at 58.

391 *Id.* at 59.

392 *Id.* at 60.

393 *FAA Is Studying Proposals to Ease Requirements for Airline ETOPS*, AVIATION WK. & SPACE TECH., Jan. 22, 1990, at 29.

394 *Id.*

395 *Id.*

396 PANDEY, *supra* note 46, at 60 (the other being the aging aircraft programs).

397 Special Conditions: Extended Range Operation of Boeing 777 Series Airplanes, 59 Fed. Reg. 28,234, 28,235 (June 1, 1994) (codified at 14 C.F.R. pt. 25).

398 PANDEY, *supra* note 46, at 61.

As a means for satisfying the 250,000-engine-hours requirement for existing ETOPS certification, Boeing built a 3,000-cycle engine test to simulate an engine acquiring a quarter million hours.[399] Boeing also tested an additional 2,000 on–off cycles on constructed aircraft, noting that 97% of propulsion system problems occur in the first 3,000 cycles.[400] Additionally, each 777 airframe–engine combination would conduct eight 180-minute diversions on a single engine.[401]

Pilots were skeptical of early ETOPS. "'They are pushing the edge of the envelope, and it's a pure marketing ploy on their part,' said Bob Reich, a United Airlines first officer and member of the ALPA committee tracking the issue."[402] Furthermore,

> Richard Livingston, [the] chairman of the Airline Passengers Association of North America and a former FAA official, cautioned: "No amount of testing can take the place of real life, day-in and day-out use. Before we go putting a couple of hundred people out over some ocean, we think it's important that everything possible is done to assure the aircraft will, in fact, be reliable on those routes."[403]

Gary Wagner, an Air Canada pilot who was skeptical of the original ETOPS regulation, asked,

> Do you want to take a new airplane out of the barn and, when the paint is still wet, fly it to the edge of the envelope? Or, would you rather fly it comfortably within the envelope for [a while], until you're sure you've got all the bugs worked out?[404]

Nevertheless, Robert W. Reich of the ALPA offered:

> What Boeing is attempting to do is very difficult and it remains to be seen if it will be successful in achieving full, early ETOPS certification. We at ALPA and others in the industry will continue to provide input to the process. With early ETOPS as a goal, the 777

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399 *Id.* at 64.

400 Richard G. O'Lone, *Service Readiness is Key Objective in Boeing 767-X Development*, AVIATION WK. & SPACE TECH., Aug. 20, 1990, at 95.

401 PANDEY, *supra* note 46, at 66.

402 Byron Acohido, *Boeing's Lobbying over 777 Blasted*, SEATTLE TIMES (Apr. 21, 1991), http://community.seattletimes.nwsource.com/archive/?date=19910421&slug=1278641.

403 *Id.*

404 Byron Acohido, *Boeing Co. Pushing the 'Envelope'—Could Early Etops Erode 777's Margin of Safety?*, SEATTLE TIMES (Apr. 21, 1991), http://community.seattletimes.nwsource.com/archive/?date=19910421&slug=1278761.

certification process will be more thorough and the 777 will consequently be a far better product for the effort.[405]

Airbus opposed Boeing's initiative. An industry journal noted that "Airbus fears that one or two dramas could prejudice press and public against ETOPS, and that dramas are probable with [180-minute] diversion times over the North Atlantic and Pacific."[406]

Despite the oppostion, by 1991, the FAA continued to signal tacit approval of early ETOPS as a concept. Broderick explained,

> [The] FAA must continue to acknowledge and encourage developments which have been proven to enhance reliability at an early stage. . . . We at the FAA are willing to listen. We are willing to observe and learn from experience. At the same time we also intend to fulfill our role as regulator.[407]

By April 1991, the FAA accepted early ETOPS as a "viable concept" and issued draft criteria for Boeing, Pratt & Whitney, and United Airlines to review.[408] In late 1991, Boeing submitted to the FAA a three-volume proposal for achieving early approval of extended twin operations.[409]

To achieve early ETOPS, Boeing built the Integrated Aircraft Systems Lab (IASL) and began testing in late 1992.[410] The $370 million aircraft lab was dedicated to delivering a highly reliable aircraft to the first customers.[411] The newly-appointed FAA Administrator, David Hinson, announced that the FAA would grant the 777 ETOPS authority upon service entry if the 777 and its engines could clear the FAA's stringent design and test hurdles.[412]

In May 1993, the FAA formally proposed a set of "special conditions"[413] that would permit the 777 to operate under 180-min-

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405 Robert W. Reich, *Negative Slant—Setting the Record Straight on Boeing's New 777 Airliner*, SEATTLE TIMES (May 7, 1991), http://community.seattletimes.nwsource.com/archive/?date=19910507&slug=1281813.

406 J.M. Ramsden, *Airbus: Time for Change?*, FLIGHT INT'L, Apr. 23, 1988, at 25.

407 PANDEY, *supra* note 46, at 76.

408 *Id.* at 77.

409 Richard G. O'Lone, *Japan Airlines' 777 Decision Boosts Twinjet Program, Offers Lift to Lagging Orders*, AVIATION WK. & SPACE TECH., Nov. 4, 1991, at 32.

410 Paul Proctor, *New Boeing Test Lab Targets Higher Reliability*, AVIATION WK. & SPACE TECH., Apr. 11, 1994, at 56.

411 *Id.*

412 *Id.*

413 A special condition is a regulation that applies to a particular aircraft design.

ute early ETOPS if Boeing could show compliance with those conditions (instead of with the existing service experience prerequisites).[414] If Boeing was successful, ETOPS type and operational certification would be granted together.[415]

The FAA acknowledged that historically, actual revenue service experience was necessary to identify problems not uncovered during the normal certification process.[416] But several recent airplane–engine combinations had demonstrated a high level of reliability.[417] This reliability was evidenced during basic certification when few problems occurred.[418] Based on this, the FAA considered it feasible that Boeing could deliver a relatively "mature" product upon entry into revenue service.[419]

Early ETOPS certification would focus on the airplane's compliance with a process designed to result in reliability.[420] The FAA wanted a level of reliability equal to that found acceptable through service experience.[421] To measure success, the special conditions would focus on defining a measurement process as well as providing a feedback loop to quickly resolve problems.[422]

In June 1994, the FAA officially adopted the proposed special conditions for early ETOPS.[423] The special conditions consisted of five main elements.[424] The first, "design for reliability," required that the propulsion system be designed to ensure that any failures or malfunctions would not lead to an in-flight engine shutdown.[425] This requirement diverged from existing regulations, which required only that an in-flight shutdown not jeopardize flight safety.[426] Thus, preventing in-flight engine shutdowns was not always a major airplane design objective, but

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414 Special Conditions: Extended Range Operation of Boeing Model 777 Series Airplanes, 58 Fed. Reg. 26,710, 26,710 (May 5, 1993) (codified at 14 C.F.R. pts. 21, 25).

415 *Id.*

416 *Id.* at 26,711.

417 *Id.*

418 *Id.*

419 *Id.*

420 *Id.*

421 *Id.*

422 *Id.*

423 Special Conditions: Extended Range Operation of Boeing Model 777 Series Airplanes, 59 Fed. Reg. 28,234, 28,234 (June 1, 1994) (codified at 14 C.F.R. pt. 25).

424 *Id.* at 28,237.

425 *Id.*

426 *Id.*

under "design for reliability," it was.[427] The second element, "lessons learned," required the 777's design to preempt problems that had caused in-flight shutdowns or diversions on other airplanes in the past.[428] The third element, "test requirements," required tests to prove that the 777's design features would prevent previous problems.[429] This validation process included the 3,000-cycle engine test and 1,000-cycle airplane test.[430] The fourth element, "demonstrated reliability," required that the engine and airplane systems maintain a failure rate during the flight test program and the 1,000-flight cycle that was consistent with the average failure rate of "presently certified 180-minute ETOPS airplanes."[431] The fifth element, "problem tracking system," required any problems occurring during development and certification that could affect the safety of ETOPS operations to have proven remedies incorporated into the design before ETOPS type certification would be awarded.[432] Additionally, the fifth element required prompt reporting of any problems occurring after ETOPS operations commenced.[433] If corrective action required a major system redesign, either ETOPS type design approval would be delayed, or operations shorter than than 180-minute ETOPS would be granted.[434]

Influencing the FAA's willingness to proceed with the special conditions was Airbus's experience with the A320, which was the first completely new twin-engine airplane to be certified since ETOPS began.[435] The FAA noted that the A320's CFM56-5 engines had an in-flight shutdown rate of 0.14 per 1,000 engine hours after four months of service—well in excess of the 0.02 shutdowns required for 180-minute ETOPS.[436] It seemed as though the A320 had not demonstrated acceptable reliability until it had accumulated a substantial amount (sixteen months) of service experience.[437] But a closer inspection uncovered that only two in-flight shutdowns occurred in the first two years of

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427 *Id.*
428 *Id.*
429 *Id.*
430 *Id.*
431 *Id.*
432 *Id.*
433 *Id.*
434 *Id.*
435 *Id.* at 28,238.
436 *Id.*
437 *Id.*

revenue service.[438] By the time the first in-flight shutdown dropped out of the 12-month rolling average in-flight shutdown rate, the shutdown rate fell below the 0.02 standard for 180-minute ETOPS operation and has been stable ever since.[439] Thus, the A320 with CFM56-5 engines had in fact achieved high reliability at the time of type certification.[440] This demonstrated that maturity at service entry was possible and motivated the FAA to seriously consider Boeing's proposal, particularly given that the A320 had achieved high reliability without the five-element certification program included in the 777 special conditions.[441] Thus, it is ironic that although Airbus tried to persuade the FAA to reject early ETOPS to protect the A340's sales, it unintentionally motivated the FAA to allow early ETOPS.

The Joint Aviation Authorities (JAA) (Europe's aviation authority), however, took a more measured approach. It approved a set of strict requirements that, if met, would permit certification for 120-minute ETOPS at launch.[442] But 180-minute ETOPS certification would only come after 20,000 hours for the Pratt and Rolls Royce engines and after 50,000 hours for the GE90s, which were not a derivative of an existing engine.[443]

C. Building a "Mature" Aircraft from Inception

By 1995, Boeing's 777 test program had flown more than 1,600 flights and 3,000 flight hours—roughly double those of the 757 and 767.[444] During testing, the 777 performed eight single-engine, 180-minute diversions for a total of twenty-four hours, the equivalent of the total diversion hours accumulated by the Boeing 767 in its first five years of ETOPS operations.[445] Early ETOPS added nine months onto the certification time; in total, "the 777 absorbed 120,000 labor hours among FAA officials, about three times more than any other plane."[446] The 777

438 *Id.*

439 *Id.*

440 *Id.*

441 *Id.*

442 *See* Phillip Birtles, Boeing 777, at 22, 25 (1998).

443 *Id.*

444 Paul Proctor, *Certification Tests Continue on GE and Rolls-Powered 777s*, Aviation Wk. & Space Tech., May 1, 1995, at 50.

445 *PW4084-Powered 777 Wins ETOPS Certification*, Aviation Wk. & Space Tech., June 5, 1995, at 31.

446 Jeff Cole, *Boeing 777 to Be Cleared for Long Over-Water Flights*, Wall St. J., May 30, 1995, at 3.

received FAA type certification and European certification in nineteen countries.[447]

On May 24, 1995, the FAA formally approved the operational side of the early ETOPS program.[448] In a letter dated May 24, 1995, the FAA wrote that Boeing "has successfully complied with all the requirements of the ETOPS Operational Approval Plan."[449] In May, the Pratt & Whitney PW4084 engine was type certified for 180-minute ETOPS.[450] In June, United Airlines, the launch customer, began revenue operations for ETOPS flights.[451] But, to appease ALPA pilots, United voluntarily restricted its ETOPS operations to 120 minutes for the first few months.[452] At the 777's ETOPS approval ceremony, Broderick called the 777 "the finest, most reliable and safest airplane ever delivered."[453]

Nearly eight years after the 777 entered service, a 777 set the record for the longest passenger diversion when United Airlines Flight 842 flew for 177 minutes to Kona, Hawaii, on a single engine following an engine shutdown.[454] One veteran ETOPS pilot commenting on the flight explained that the diversion demonstrated the inherent safety of ETOPS with twin jets:

> Would you rather be in a twin-engine B777, with one engine shut down, 1,100 NM from the nearest suitable ETOPS alternate airport, or would you rather be in a four-engine DC-8, with all four engines running, 1,100 NM from the nearest suitable ETOPS alternate airport, with a cargo compartment fire and no cargo compartment fire detectors or extinguishers? That's what we used to do on the Hawaii flights for many, many years. How times have changed![455]

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447 *Boeing 777 Type Certified*, TRANSPORT CERTIFICATION UPDATE, Summer 1995, at 4, *available at* www.faa.gov/aircraft/air_cert/design_approvals/transport/Cert_Update/Edition11-20/media/Edition19.pdf.

448 PANDEY, *supra* note 46, at 85.

449 *Id.*

450 *PW4084-Powered 777 Wins ETOPS Certification*, *supra* note 445, at 31.

451 PANDEY, *supra* note 46, at 87.

452 *Id.*; *United Launches 777 Commercial Service*, AVIATION WK. & SPACE TECH., June 12, 1995, at 50.

453 PANDEY, *supra* note 46, at 87.

454 *Voice of History*, AIR SAFETY WK., Mar. 31, 2003.

455 *Id.*

D. A Brief Summary of Recent ETOPS Evolutions

In 1996, Boeing and Airbus jointly approached regulators to extend the 180-minute rule.[456] Operation under 180-minute ETOPS freed operators to fly nearly any route on the globe.[457] But weather conditions could render a diversion airport unavailable, delaying or preventing flights operating under 180-minute ETOPS.[458] Manufacturers and carriers sought a 15% extension (similar to the 15% extension granted to the original 120-minute ETOPS) that would increase the time to 207 minutes.[459] This would offer increased flexibility and result in fewer cancellations when weather affected some on-route diversion airports.[460]

To qualify for 207-minute ETOPS, the FAA imposed new requirements beyond the 180-minute level.[461] Planes were required to have an electrical system to power at least one fuel boost pump in each main fuel tank, effectively excluding 767s from operating under the 207-minute rule.[462] The 207-minute ETOPS policy took effect on March 21, 2000,[463] and the 777 received type approval for 207-minute ETOPS in April.[464] United Airlines was the first to receive operational approval in May 2000.[465]

Early 2007 saw a significant change to ETOPS rules.[466] The ETOPS rule of 2007 derived from recommendations from the Aviation Rulemaking Advisory Committee (ARAC), a group of representatives of airlines, transport associations, manufacturers, pilots' associations, and regulators tasked by the FAA to review ETOPS requirements and recommend updates.[467] The 2007 rule codifed ETOPS regulations in the Code of Federal

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456 Pandey, *supra* note 46, at 117.

457 *Id.* at 120.

458 *Id.*

459 *Id.*

460 *Id.*

461 *Id.* at 130.

462 *Id.* at 131.

463 *Id.* at 142.

464 *Id.*

465 *Id.*

466 Indeed, to keep this article a manageable size, the author provides only a thumbnail sketch. Mohan Pandey's book, *How Boeing Defied the Airbus Challenge*, provides a much more detailed history of the events that led up to the 2007 change.

467 Extended Operations (ETOPS) of Multi-Engine Airplanes, 72 Fed. Reg. 1,808, 1,809 (Jan. 16, 2007) (to be codified at 14 C.F.R. pts. 1, 21, 25, 33, 121 & 135).

Regulations for the first time.[468] ETOPS rules had previously been administered only through "FAA advisory circulars, policy letters, and special conditions."[469] The 2007 rule also changed the definition of ETOPS from "extended-range operations with two-engine airplanes" to simply "extended operations."[470]

In recognition of the success of ETOPS regulations, the 2007 rule applied ETOPS regulations to passenger planes with more than two engines for the first time.[471] Three- and four-engine planes would be limited to routes not exceeding 180 minutes (at one-engine-inoperative cruise speed) from an airport.[472] These planes could exceed that limit through ETOPS type and operation certification.[473] However, the rule created grandfather provisions for existing and in-production three- and four-engine planes until February 17, 2015; the rule permanently grandfathered such planes no longer in production by 2015.[474]

And starting in February 2013, three- and four-engine aircraft diversion time would be limited by their maximum fire suppression time.[475] As of 2003, although all three- and four-engine planes flying long-range routes had cargo-fire surpression systems, many would require additional Halon bottles to increase suppression time and comply with the new rule—many 747s flew with only 90-minute fire suppression capacity.[476]

The 2007 rule also established a framework for plane–engine type certification for operations beyond 180 minutes, up to the airplane's maximum capability.[477] A primary limiting factor would be fire suppression capability.[478] Certification beyond 180 minutes would also require greater propulsion reliability and additional safety enhancements.[479] The maximum diversion time would consider the effects of weather and temperature fore-

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468 *Id.*

469 Chester L. Exstrand et al., *The New FAA ETOPS Rule*, AERO. Q., Feb. 2007, at 8.

470 Extended Operations (ETOPS) of Multi-Engine Airplanes, 72 Fed. Reg. at 1,809–10.

471 *Id.*

472 *Id.* at 1,816.

473 *Id.*

474 *Id.* at 1,816–17.

475 *See id.* at 1,817.

476 David Hughes, *New ETOPS Rules*, AVIATION WK. & SPACE TECH., Dec. 22, 2003, at 51.

477 *See* Extended Operations (ETOPS) of Multi-Engine Airplanes, 72 Fed. Reg. at 1,809.

478 *See id.* at 1,815.

479 *See id.* at 1,814.

casts.[480] Maximum diversion time, however, would be limited by the needs of the geographic region.[481] North Atlantic flights could maintain a maximum diversion time of 180 minutes because routes in that region do not require longer ETOPS.[482] But flights between the West Coast of the United States and Australia and New Zealand could exceed 240 minutes.[483]

In 2008, Advisory Circular 120-42B provided guidance for extending maximum ETOPS to 240 minutes.[484] Operating under a parallel Civil Aviation Authority of New Zealand regulation, Air New Zealand was the first operator to fly 240-minute ETOPS, flying a 777-300ER from Los Angeles to Auckland.[485] Although Air New Zealand could have operated the route under 180-minute ETOPS, 240-minute ETOPS allowed for a slightly more direct path.[486] Captain David Morgan, chief pilot for Air New Zealand, explained: "Less fuel is burned and less carbon dioxide is emitted into the atmosphere. It's also good for customers because flights are potentially shorter and passengers could arrive sooner at their destinations."[487]

In 2011, Airbus stopped production on the A340, having sold 377.[488] The same year, Boeing delivered its 1,000th 777 to Dubai-based Emirates Airline.[489] At the time of writing this article, Boeing had sold over 1,300 777s and was in the early stages of designing a derivative 777.[490] Airbus continues to manufac-

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480 *See id.* at 1,839, 1,844.

481 *See id.* at 1,814.

482 *See id.* at 1,847.

483 *See id.* at 1,838, 1,849. New Zealand's EDTO rule was enacted in November 2010.

484 FAA, U.S. DEP'T OF TRANSP., ADVISORY CIRCULAR 120-42B: EXTENDED OPERATIONS (ETOPS AND POLAR OPERATIONS) 38–39 (2008) [hereinafter ADVISORY CIRCULAR 120-42B].

485 *Air New Zealand Operates World's First 240 ETOPS Flight*, AVIATION INST. (Dec. 14, 2011), http://www.aviationinstitute.co.nz/ai/about-us/news/air-new-zealand-operates-world-s-first-240-etops-flight/.

486 *Id.*

487 *Boeing to Offer up to 330-Minute ETOPS on 777*, BOEING (Dec. 12, 2011), http://boeing.mediaroom.com/index.php?s=43&item=2070.

488 *Airbus Stops Production of A340 Aircraft*, SCIENTIAWEB, www.scientiaweb.com/2011/11/10/airbus-stops-production-of-a340-aircraft/ (last visited Mar. 12, 2013).

489 *Boeing Begins Work on 1,000th 777*, BOEING (Nov. 9, 2011), http://boeing.mediaroom.com/index.php?s=43&item=2012.

490 *Boeing 777 Long-Range Wide Body Airliner, United States of America*, AEROSPACE-TECHNOLOGY.COM, www.aerospace-technology.com/projects/boeing777/ (last visited Mar. 13, 2013).

ture the twin-engine Airbus A330, which has sold over 1,000 copies.[491]

VI. WHAT HAS CONTRIBUTED TO THE SUCCESS OF ETOPS?

In some respects, ETOPS had little to do with the number of engines on a plane. When ETOPS was proposed in the early 1980s, engine reliability had improved to the extent that the odds of two engines failing for independent reasons were extremely small. From that perspective, there was little to be gained in terms of safety by having three or four engines.

Given this background, the FAA could have simply exempted twin-engine jet aircraft from the 60-minute rule—similar to what it did in the mid-1960s when it exempted three-engine jet airplanes from the 60-minute rule following the development of the Boeing 727. Moreover, in the 1980s, nations adopting the ICAO 90-minute rule allowed twin-engine planes, such as the A300, to operate routes equivalent to what would become 120-minute ETOPS.[492] And U.S. military and private twin-engine planes operated exempt from the 60-minute rule without issue.[493] The FAA could have simply relied on this precedent to change the 60-minute rule to something comparable to the ICAO 90-minute rule, or to exempt twin-engine planes altogether.

To the FAA's credit, it did not. Rather, the FAA used the advent of long-range twins to implement a regulatory regime that would further enhance safety. As FAA Administrator Lynn Helms correctly identified, there was a legitimate question of whether a single engine could power a plane's critical subsystems at the same time it maintained flight.[494] This concern was particularly applicable to a plane's deicing system. An airplane operating on a single engine will fly at a lower altitude than one operating on both engines.[495] At the lower altitude, icing (the buildup of ice on the plane's control surfaces) seriously threatens flight safety.[496] To prevent ice buildup, a plane's ice-protection system typically bleeds hot engine air onto the control

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491 *Airbus A330*, BUS. AVIATION GRP., http://www.businessaviation.com/aircraft-guide/airliners_guide/airliners/airbus-a330 (last visited Mar. 12, 2013).

492 *See* TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 4.

493 *Id.* at 13.

494 *See Helms Affirms Overwater Extension Opposition*, *supra* note 152, at 44.

495 TAYLOR, WORLDWIDE OPERATION, *supra* note 56, at 26.

496 *See id.*

surfaces.[497] This further taxes the engine, making it more difficult for the single engine to keep the plane aloft while powering other critical systems. The FAA demanded solutions before it would consider twin-engine extended operations.

With the benefit of hindsight, it may seem obvious for the FAA to demand multiple redundant power sources prior to allowing extended operations. But this was not required for planes operating under the 90-minute rule.[498] To Boeing's credit, when it proposed ETOPS, it pushed for improvements that would increase safety beyond that offered by three- and four-engine airplanes.[499] Boeing not only proposed solutions to the problem of powering critical sub-systems, but also proposed additional safety features for long-haul flights. One additional safety feature was fire suppression capable of suppressing a fire for the length of the longest possible diversion—a significant safety enhancement over many three- and four-engine airplanes.[500] In addition, pilots and other airline organizations provided a loud and necessary voice, demanding adequate safety measures before allowing any change in the status quo.

In the end, ETOPS was a rare compromise that left everyone happy. The FAA satisfied its dual mandate of regulating and promoting civil aviation. Airlines won the ability to more fully utilize their jets. Manufacturers won the ability to better market their twin-engine products. Aviation professionals have enjoyed improved safety—most pilots finish a career having never experienced an in-flight shutdown.[501] Passengers have benefited because ETOPS flights allow more direct flights from smaller markets; the industry calls this practice "dehubbing."[502] Finally, the environment has benefited from airlines' ability to operate smaller, more fuel-efficient planes.[503]

Thus, ETOPS's success is largely attributable to an involved and technically proficient industry regulator. Another large factor is the involvement of powerful industry players, such as Boeing, that have a vested interest in improving safety. Boeing does

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497 *See id.*

498 *See id.* at 6, 14.

499 *See id.* at 30.

500 *See id.* at 22.

501 *See* BIBEL, *supra* note 90, at 208.

502 *See* KERRY M. TAN, THE EFFECT OF DE-HUBBING ON AIRFARES 2 (2012), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2102893.

503 *See* Elisabeth Rosenthal, *Your Biggest Carbon Sin May Be Air Travel*, N.Y. TIMES (Jan. 26, 2013), http://www.nytimes.com/2013/01/27/sunday-review/the-biggest-carbon-sin-air-travel.html.

not operate its planes commercially (though long ago, Boeing, United Airlines, and Pratt & Whitney were the same company),[504] but its business model depends on airlines' safe operation of planes. If airlines operate unsafely, passenger traffic will drop, putting Boeing's customers out of business. Indeed, the McDonnell Douglas DC-10's reputation was severely damaged following a crash in 1979.[505] That incident involved Flight 191, a DC-10 with 271 passengers and crew that departed from Chicago O'Hare.[506] A series of incidents occurred, starting with the No. 1 engine and pylon separating from the wing during takeoff.[507] The loss of the engine led to an uncommanded slats retraction on the left wing, rolling the aircraft into an unrecoverable dive and killing all occupants and two on the ground.[508] The Chicago Tribune published a photo of the inverted DC-10 missing an engine on the front page.[509]

Thus, Boeing depends on the safe operation of its products more so than Ford, Toyota, or General Motors. Accordingly, even though Boeing had an interest in removing the 60-minute rule to better market its next-generation twin-engine airplanes, it had an even greater interest in ensuring that extended operations would not jeopardize safety. This self-interest has contributed to ETOPS's stellar safety record.

Early ETOPS has been similarly successful. It avoids the problem of developing a multi-billion dollar long-range twin only to wait for several years before airlines can fully utilize it. Early ETOPS provoked predictable opposition. A headline on the topic stated, "Boeing Co. Pushing the 'Envelope'—Could Early Etops Erode 777's Margin of Safety?"[510] But early ETOPS succeeded largely because it was a logical extension of ETOPS concepts; rather than using in-service experience to validate the

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504 *See The Boeing Logbook: 1927–1932*, BOEING, www.boeing.com/boeing/history/chronology/chron03.page (last visited June 25, 2013).

505 John Curley, *McDonnell-Douglas Must Decide Soon Whether to Stop Producing DC-10 Jets*, WALL ST. J., May 8, 1985, at 12; BIBEL, *supra* note 90, at 24–25 ("The Chicago crash and the subsequent grounding of DC-10s directly relate to the cancellation of new orders for the DC-10, the end of its production in 1989, and the eventual takeover of McDonnell Douglas by Boeing in 1997.").

506 NAT'L TRANSP. SAFETY BD., NO. NTSB-AAR-79-17, AIRCRAFT ACCIDENT REPORT 2 (1979).

507 *Id.*

508 *Id.*

509 *See* NEWSROOM HISTORY, www.newsroomhistory.com/wp-content/gallery/test-gallery_1/00189_s_r12agqgpjw50189.jpg (last visited June 26, 2013).

510 Acohido, *supra* note 402.

maturity of engines and other critical components, Boeing and engine manufacturers could simulate that experience using lessons learned from previous products. Because new engines had entered service many times before, Boeing and the engine manufacturers could be confident that pre-service validation tests would accurately reproduce in-service experience. In the end, the 777's safety record bears this out. Again, early ETOPS's success is attributable to an open-minded, but demanding, industry regulator and to manufacturers with a vested interest in ensuring the safety of their products. Indeed, had the 777 been perceived as unsafe in the slightest, airlines had two alternative aircraft to choose from.

VII. THE GROUNDING OF THE BOEING 787 DREAMLINER

A. The Boeing 787 Dreamliner

In early 2003, Boeing began developing a more efficient twin-engine aircraft, the 7E7.[511] Boeing later renamed it the 787—the number eight is considered lucky in Chinese culture.[512] The 787 entered service in September 2011—nearly three years behind schedule—with launch customer All Nippon Airways.[513]

A year after Boeing announced the 787, Airbus announced its own next-generation twin: the A350.[514] At the time of writing, the A350, dubbed the A350-XWB ("extra-wide-body," to differentiate it from the A330), has had its first flight, but it is still in development.[515]

Both the 787 and A350 were designed to fly ETOPS routes. In 2011, the FAA granted 330-minute ETOPS type-design certifica-

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[511] J. Lynn Lunsford, *Navigating Change: Boeing, Losing Ground to Airbus, Faces Key Choice—Amid Downturn, Firm Ponders Spending on Innovation or Diversifying Defensively—Debate over All-New Plane*, Wall St. J., Apr. 21, 2003, at A1.

[512] *Lucky 8 Pays 60 in Boeing Deal*, N.Y. Times (Jan. 29, 2005), http://www.nytimes.com/2005/01/29/business/worldbusiness/29boeing.html.

[513] Christopher Drew, *Boeing Posts Strong Profit but Cuts Delivery Forecast*, N.Y. Times (Oct. 26, 2011), http://www.nytimes.com/2011/10/27/business/boeing-posts-strong-profit-but-cuts-delivery-forecast.html.

[514] Andrea Rothman & Mary Jane Credeur, *United Said to Study Biggest Airbus A350 to Replace 747s*, Bloomberg (Nov. 1, 2012), http://www.bloomberg.com/news/2012-10-31/united-said-to-study-biggest-airbus-a350-to-replace-boeing-747s.html.

[515] *Airbus Unveils Jet and Broadens Rivalry with Boeing*, N.Y. Times (June 14, 2013), www.nytimes.com/2013/06/15/business/global/airbuss-latest-jetliner-takes-its-first-flight.html; *Airbus Delays A350 XWB Entry as EADS Profits Triple*, BBC News (July 27, 2012), www.bbc.co.uk/news/business-19010202.

tion to both 787 engine options, the General Electric GEnx-1B engine and the Rolls-Royce Trent 1000.[516] The 787, however, entered service with only 180-minute certification; 330-minute certification was delayed due to a new regulatory requirement that additional low-fuel-alerting messages be incorporated to consider abnormal fuel contingencies.[517] This likely caused United Airlines to cancel its planned 787 service from Houston to New Zealand.[518]

The 787 was designed for efficiency. To save weight, it was the first commercial passenger jet to be built primarily of carbon fiber composites, a lighter and stronger alternative to aluminum.[519] But most of the increased fuel efficiency derived from the 787's next-generation engines; customers could choose either General Electric GEnx or Rolls Royce Trent 1000 engines. Further improving efficiency, the 787 used more electricity for critical systems in lieu of pneumatic (air pressure bled from the engines) or hydraulic power.[520] This additional energy use required a larger capacity battery for backup and ground power.[521] To avoid the weight penalty of a larger, traditional nickel-cadmium (Ni-Cad) or lead-acid battery (a Ni-Cad battery would have added 200 pounds to the plane), the 787 was the first Boeing jet to use a lithium-ion battery.[522]

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516 *GEnx-1B Engine Receives U.S. FAA 330-Minute ETOPS Approval*, GE AVIATION, www.geaviation.com/press/genx/genx_20111201.html (last visited July 11, 2013); *Rolls-Royce Trent 1000 Awarded ETOPS Approval*, ROLLS-ROYCE (May 9, 2011), www.rolls-royce.com/news/press_releases/2011/110509_trent_1000_etops_approval.jsp.

517 Guy Norris, *Back on Track*, AVIATION WK. & SPACE TECH., Dec. 10, 2012, at 52.

518 *See* Jon Ostrower, *Boeing Nears 787 GEnx and 330 min ETOPS Certification*, FLIGHTGLOBAL (Mar. 13, 2012), www.flightglobal.com/news/articles/boeing-nears-787-genx-and-330min-etops-certification-369474; Michael Field, *Air NZ's Dreamliner Plans Hit Turbulence*, STUFF.CO.NZ (Apr. 19, 2013, 5:00 AM), www.stuff.co.nz/business/industries/8569548/Air-NZs-Drealiner-plans-hit-turbulence.

519 Jason Paur, *How a Batter Grounded Boeing's Revolutionary Dreamliner*, WIRED (Jan. 17, 2013), http://www.wired.com/autopia/2013/01/boeing-787-electric-fire-grounding/.

520 *Id.*

521 *Id.*

522 *Id.*; Andrea Rothman & Robert Wall, *Airbus May Switch A350 Battery to Avoid 787 Woes*, SEATTLE TIMES (Feb. 8, 2013), http://www.seattletimes.com/html/businesstechnology/2020316334_airbusbatteryxml.html.

B. The Grounding of All 787s

On January 7, 2013, a Japan Airlines 787 landed at Boston's Logan International Airport from Narita, Japan.[523] As the 787 taxied to the gate, the crew started the auxiliary power unit (APU).[524] Arriving at the gate, the passengers and crew deplaned, and cleaning and maintenance crew boarded.[525] The maintenance crew noticed "an electrical burning smell and smoke in the aft cabin" followed by a power loss to systems powered by the APU.[526] A mechanic went to the cockpit and saw the APU had shut down.[527] He then went to check the aft electronic equipment bay, which holds the battery used to start the APU.[528] He opened the bay to see smoke and flames coming from the front of the battery case.[529] He tried unsuccessfully to extinguish the fire with a dry chemical extinguisher.[530] Other crew members saw "intense" smoke in the cabin.[531]

Airport firefighters soon responded.[532] They applied Halotro (a fire-extinguishing agent) to the battery several times—at this point the smoke was so heavy the fire could only be seen by infrared camera.[533] Smoke could soon be seen outside the airplane as well.[534] At one point, the battery hissed loudly and liquid flowed down the side of the case; a "pop" sound followed.[535] A firefighter sufffered a burn on his neck when the battery, as he described it, "exploded."[536] One hour and forty minutes after being notified of the fire, the firefighters "controlled" the fire.[537] Controlling the fire involved removing the battery from the plane—a task made difficult because the quick disconnect knob had "charred and melted."[538]

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523 *Boeing 787 Suffers a Battery Fire in Boston, supra* note 47.

524 Nat'l Transp. Safety Bd., Case No. DCA131A037, Interim Factual Report 1 (2013), *available at* www.ntsb.gov/investigations/2013/boeing_787/interim_report_B787_3-7-13.pdf.

525 *Id.* at 2.

526 *Id.*

527 *Id.*

528 *Id.*

529 *Id.*

530 *Id.*

531 *Id.*

532 *Id.* at 3.

533 *See id.* at 3–4.

534 *Id.* at 3.

535 *Id.* at 4.

536 *Id.*

537 *Id.*

538 *Id.*

The fire damaged an area roughly fifty centimeters from the battery.[539] An NTSB investigation determined that one of the eight individual lithium-ion battery cells short circuited, leading to a thermal runaway that cascaded to other battery cells.[540] "[T]he temperature inside the battery case exceeded 500 degrees Fahrenheit."[541] Boeing had delivered the 787 to Japan Airlines on December 20, 2012, eighteen days before the incident.[542] The 787 had completed twenty-two flights and 169 flight hours.[543] The battery that caught fire was installed on October 15, 2012.[544] Two days before the fire, the battery had been disconnected while an electrical panel was inspected.[545] "The battery was reconnected the next day."[546] Japan Airlines reported that it had experienced "'several cases' in which maintenance crew members needed to replace 787 batteries after irregularities," but added that the replacements were "conducted 'within the scope of regular maintenance.'"[547]

Nine days after the Boston fire, an All Nippon Airways 787 with 129 passengers departed Ube, Japan, bound for Tokyo.[548] An in-flight alarm in the cockpit warned that the main battery was overheating; this was followed by a burning smell in the cabin.[549] The 787 diverted to Takamatsu, and passengers evacuated the plane using emergency slides.[550] Prior to takeoff, the

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539 *JAL 787 Battery Fire Fails to Unsettle Faith in Lithium-Ion*, FLIGHT INT'L, Jan. 15, 2013, at 1.

540 *NTSB Identifies Origin of JAL Boeing 787 Battery Fire; Design, Certification and Manufacturing Processes Come Under Scrutiny*, NTSB (Feb. 7, 2013), http://www.ntsb.gov/news/2013/130207.html.

541 *Id.*

542 *NTSB Issues Seventh Update on JAL Boeing 787 Battery Fire Investigation*, NTSB (Feb. 1, 2013), http://www.ntsb.gov/news/2013/130201b.html.

543 Matthew L. Wald, *No Defect is Found in Another 787 Battery*, N.Y. TIMES (Jan. 27, 2013), http://www.nytimes.com/2013/01/28/business/backup-battery-in-787-had-no-obvious-anomalies-report-says.html.

544 NAT'L TRANSP. SAFETY BD., CASE NO. DCA131A037, *supra* note 524, at 5.

545 *See id.*

546 *Id.*

547 Christopher Drew et al., *Boeing 787 Battery Was a Concern Before Failure*, N.Y. TIMES (Jan. 29, 2013), http://www.nytimes.com/2013/01/30/business/boeing-aware-of-battery-ills-before-the-fires.html.

548 Yoree Koh et al., *Another 787 in Emergency Landing*, WALL ST. J., Jan. 16, 2013, at B1.

549 Jon Ostrower et al., *All Boeing Dreamliners are Grounded World-Wide*, WALL ST. J., Jan. 17, 2013, at A1.

550 Hiroko Tabuchi & Jad Mouawad, *Top Airlines in Japan Grounding Boeing 787s*, N.Y. TIMES (Jan. 15, 2013), http://www.nytimes.com/2013/01/16/business/emergency-landing-for-boeing-787.html.

plane's computers indicated a battery fault, but the warning was displayed in a part of the cockpit's data system that pilots do not routinely scan immediately before takeoff.[551] The battery experienced an unexpectedly low charge.[552] "Subsequent examination of the main battery, located in the aircraft's forward electronic equipment bay, revealed it was 'discoloured and the electrolysis solution had leaked.'"[553] The Japan Transport Safety Board (Board) investigators found ten holes in the battery case that were caused by sparks—the steel "battery case melts at around 1,400 degrees."[554] The Board also found that the 787's aft APU battery showed signs of failure.[555] Tomography scans revealed that two cells in the aft APU battery were slightly swollen.[556] The 787 had received a new battery approximately two months before the failure.[557] In fact, in the months before the fire, All Nippon Airways (the largest operator of the 787) had replaced ten batteries.[558] In five of the replacements, the main battery "showed an unexpectedly low charge."[559]

Following the All Nippon diversion in Japan, all fifty 787s in service with eight different carriers were grounded by global regulators, including the FAA.[560] The battery incident followed a series of smaller incidents, including a December 2012 diversion of a United Airlines 787 following an electrical incident.[561] A fuel leak and windshield crack also plagued early customer flights.[562] And during testing in November 2010, a 787 test flight suffered a serious in-flight electrical fire.[563]

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551 Ostrower et al., *supra* note 549, at A1.

552 Drew et al., *Boeing 787 Battery*, *supra* note 547.

553 Mavis Toh & Stephen Trimble, *Boeing Faces Multiple Safety Investigations as Crisis Intensifies*, FLIGHT INT'L, Jan. 22, 2013.

554 *No Faults Found in ANA 787 Electrical System: Transport Safety Panel*, JAPAN TIMES (Mar. 29, 2013), http://www.japantimes.co.jp/news/2013/03/29/business/no-faults-found-in-ana-787-electrical-system-transport-safety-panel.

555 *Crunch Time*, AVIATION WK. & SPACE TECH., Feb. 25, 2013, at 33.

556 *Id.*

557 Toh & Trimble, *supra* note 553.

558 Drew et al., *Boeing 787 Battery*, *supra* note 547.

559 *Id.*

560 Christopher Drew et al., *Regulators Around the Globe Ground Boeing 787s*, N.Y. TIMES (Jan. 17, 2013), http://www.nytimes.com/2013/01/18/business/regulators-around-the-globe-ground-boeing-787s.html.

561 *Timeline: The Dreamliner's Nightmares*, FLIGHT INT'L, Jan. 22, 2013.

562 Hiroko Tabuchi & Bettina Wassener, *Deepening Crisis for Boeing 787*, N.Y. TIMES (Jan. 16, 2013), http://www.nytimes.com/2013/01/17/business/global/deepening-crisis-for-the-dreamliner.html.

563 *Timeline: The Dreamliner's Nightmares*, *supra* note 561.

C. Returning the 787 to Service

Three months later, on April 27, 2013, Ethiopian Airlines Flight 801 departed from Ethiopian capital Addis Ababa bound for Nairobi, Kenya.[564] Flight 801 was the first 787 to return to service.[565] By May 2013, four other 787 operators had returned their dreamliners to service, though the cause of the previous battery failures had still not been discovered.[566]

To ensure safe operation of the batteries and resume 787 flights, Boeing developed a new battery design and enclosure.[567] The new battery includes "improved separation of the individual lithium-ion cells to minimize the chance of . . . thermal propagation" should one of the eight cells overheat.[568] The battery is now encased in a one-eighth-inch thick steel box that has a vent to the aircraft exterior.[569] The enclosure is "designed to eliminate oxygen," starving any fire.[570] The battery charging system was also redesigned to reduce the maximum charge allowed, and increase the minimum charge allowed.[571]

D. The FAA's 2007 Approach to Lithium-Ion Batteries

The use of lithium-ion batteries on aircraft is a novel technology. Accordingly, on October 11, 2007, the FAA published, in the Federal Register, a final, special condition approving Boeing's inclusion of lithium-ion batteries in the 787.[572] The special condition noted that the 787 would incorporate a number of novel design features including "[l]arge, high capacity, rechargeable" lithium-ion batteries.[573] Lithium-ion batteries have failure, operational, and maintenance characteristics that

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564 *See* Jon Ostrower & Hiroyuki Kachi, *Boeing's Dreamliner Returns to Commercial Service*, Wall St. J. Online, Apr. 28, 2013.

565 *Id.*

566 *See* Jon Ostrower, *United Puts Dreamliner Back in Service*, Wall St. J. Online, May 20, 2013.

567 *See* Jason Paur, *Boeing Completes Final 787 Battery Text, Awaits FAA Approval*, Wired (Apr. 8, 2013), http://www.wired.com/autopia/2013/04/boeing-787-final-battery-flight-test.

568 *Id.*

569 Michael Mecham, *Fit for the 'Worst Case'*, Aviation Wk. & Space Tech., Apr. 29, 2013, at 24.

570 Keith Campbell, *The Resolution of the Boeing 787 Dreamliner Battery Crisis*, Engineering News Online (May 17, 2013), http://engineeringnews.co.za/article/the-resolution-of-the-boeing-787-battery-crisis-2013-05-17.

571 *Id.*

572 *See* Special Conditions: Boeing Model 787-8 Airplane, 72 Fed. Reg. 57,842, 57,842 (Oct. 11, 2007) (codified at 14 C.F.R. pt. 25).

573 *Id.*

differ significantly from the Ni-Cad and lead-acid rechargeable batteries that were approved for large airplanes.[574] Ni-Cad batteries had sparked battery fires and failures, leading the FAA to promulgate rules in 1977 and 1978 governing Ni-Cad installations on large transport airplanes.[575] The FAA acknowledged the limited experience with rechargeable lithium-ion batteries in aviation.[576] But other users of lithium-ion technology, including cell phones and electric vehicles, have uncovered safety problems with lithium-ion batteries including "overcharging, over-discharging, and flammability of cell components."[577]

Compared to Ni-Cad and lead-acid batteries, lithium-ion batteries are significantly more susceptible to internal failures that can result in self-sustaining temperature and pressure increases (i.e., thermal runaway).[578] Overcharging, in particular, can cause heating and destabilization of the components of the cell.[579] "The metallic lithium can ignite, resulting in a self-sustaining fire or explosion."[580] And the severity of thermal runaway "increases with increasing battery capacity, because of the higher amount of electrolytes in large batteries."[581] Discharge of some lithium-ion batteries over a certain voltage can corrode cell electrodes, causing irreversible loss of battery capacity.[582] This capacity loss "may not be detected by the simple voltage measurements commonly available to flightcrews."[583] This issue is also present in Ni-Cad batteries.[584] But unlike Ni-Cad and lead-acid batteries, some lithium-ion batteries use liquid-flammable electrolytes, which "can serve as a source of fuel for an external fire[ ] if there is a breach of the battery container."[585]

The FAA conditioned the use of lithium-ion batteries by requiring that (1) all characteristics of the lithium-ion battery and its installation that could affect safe operation of the 787 be addressed, and (2) appropriate maintenance requirements be established to ensure the availability of electrical power from the

574 *Id.*
575 *Id.*
576 *Id.*
577 *Id.*
578 *Id.*
579 *Id.*
580 *Id.* at 57,842–43.
581 *Id.* at 57,843.
582 *Id.*
583 *Id.*
584 *Id.*
585 *Id.*

batteries when needed.[586] It specifically applied 14 C.F.R. § 25.1353, regulating electrical equipment and installation, and 14 C.F.R. § 25.863, regulating flammable fluid fire protection to lithium-ion batteries.[587] Applying 14 C.F.R. § 25.863 was necessary because the electrolytes used in lithium-ion batteries are flammable, while those in lead-acid and Ni-Cad batteries are not.[588] The FAA also imposed new requirements to address the hazards of overcharging and over-discharging that are unique to lithium-ion batteries and to ensure that batteries used as spares are maintained in an appropriate state of charge.[589] The FAA noted that these changes were similar to those adopted for the Airbus A380, which also utilized lithium-ion batteries—though to a lesser extent.[590]

In response to the proposed special conditions, the ALPA requested modifications to the conditions.[591] The ALPA attached to its comments a 2003 FAA publication, "Flammability Assessment of Bulk-Packed, Rechargeable Lithium-Ion Cells in Transport Category Aircraft."[592] The report's executive summary noted the following:

> A relatively small fire source is sufficient to heat the lithium-ion cell above the temperature required to activate the pressure release mechanism in the cell. This causes the cell to forcefully vent its electrolyte through the relief ports near the positive terminal. The electrolyte is highly flammable and easily ignites when exposed to an open flame or hot surface.[593]

The ALPA requested several modifications to the conditions to ensure no explosive or toxic gases emitted by a lithium-ion battery would enter the cabin, that fires could be extinguished by the crew, and that the batteries would not overheat or overcharge.[594] The FAA did not modify the special conditions in re-

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586 *Id.*

587 *Id.*

588 *Id.*

589 *Id.*

590 *Id.*

591 *Id.*

592 FAA, U.S. DEP'T OF TRANSP., DOT/FAA/AR-06/38, FLAMMABILITY ASSESSMENT OF BULK-PACKED, RECHARGEABLE LITHIUM-ION CELLS IN TRANSPORT CATEGORY AIRCRAFT (2006).

593 *Id.* at vii.

594 *See* Special Conditions: Boeing Model 787-8 Airplane, 72 Fed. Reg. at 57,843.

sponse, reasoning that the proposed conditions would address the ALPA's concerns.[595]

In 2006, a 787 prototype battery exploded in a lab; despite firefighters' efforts, the explosion resulted in the destruction of a 10,000 square-foot Arizona building.[596] In 2010, three years after the special conditions were finalized, a UPS Boeing 747 crashed in Dubai, killing both pilots, when its shipment of 81,000 lithium-ion batteries burst into flames.[597] At the time of writing this article, the ICAO dangerous goods committee had proposed revoking an exemption that permitted lithium-ion aircraft batteries weighing up to seventy-seven pounds to be shipped on passenger planes.[598] Industry groups argued that it was inconsistent to ground the 787 because of its batteries but allow the same batteries to fly as cargo on passenger planes.[599]

E. THE 787 DEMONSTRATES THE NEED TO APPLY ETOPS PRINCIPLES TO NOVEL AVIATION TECHNOLOGY

ETOPS depends on several concepts. First, engines mature over time, and engines that derive from existing designs enter service as a mature product, experiencing few issues. Second, by monitoring and resolving problems that lead to shutdowns, reliability increases. Third, by anticipating risks and taking adequate precautions, safety improves. Mandating sufficient cargo hold fire suppression capabilities for the length of a diversion is a notable example.

But lithium-ion batteries, along with the FAA's initial attempt to regulate them, fall outside the scope of the larger ETOPS concept. Lithium-ion batteries do not derive from proven and reliable aviation technology. Though they experience extensive use in consumer electronics, the consumer electronics field

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595 *Id.*

596 Dominic Gates, *787 Battery Blew Up in '06 Lab Test, Burned Down Building*, SEATTLE TIMES (Jan. 29, 2013), http://seattletimes.com/html/businesstechnology/2020199686_787batterysafetyxml.html.

597 Matt Molnar, *How a Small Fire Could Spell Big Trouble for the Boeing 787*, POPULAR MECHANICS (Jan. 8, 2013), http://www.popularmechanics.com/technology/aviation/safety/how-a-battery-fire-could-spell-big-trouble-for-the-boeing-787-14954495; Bart Jansen, *FAA Focuses on Safety of Boeing 787 Dreamliner's Batteries*, USA TODAY (Jan. 18, 2013), https://www.ivyexec.com/professionals/insights/article/2722/296.

598 Joan Lowy, *UN Agency Moves to Kill Aircraft Battery Exemption*, SEATTLE TIMES (Feb. 12, 2013), http://seattletimes.com/html/politics/2020340381_apusboeing787batteryshipments.html.

599 *Id.*

does not require the level of maturity and reliability that the commercial aviation industry requires. Thus, unlike a new engine derived from a proven engine, a current generation lithium-ion battery is unlikely to enter the market as a mature product.

Aviation lithium-ion batteries may be better analogized to a first-generation 767: promising, but not a proven mature technology. Accordingly, a conservative approach would require that, like the 767, lithium-ion batteries demonstrate maturity before they are used in a capacity where a failure could threaten a flight. This maturity should be shown through the accumulation of a sufficient number of flight hours and by meeting a target level of reliability. Ideally, such in-flight experience would be obtained through something analogous to non-ETOPS flight. Indeed, it is extremely fortunate that one 787 battery failure occurred on the ground, while the other occurred during a domestic flight—neither occurred three hours from an airport.

And even though the 777 established precedent for delivering a mature product upon entry into service, the adoption of lithium-ion batteries is not analogous. With the 777, there was considerable institutional knowledge and experience with how engines mature. Thus, there was a high degree of confidence that Boeing could simulate the in-service maturing process prior to actual entry into service. With lithium-ion batteries, there is less knowledge about how the technology matures. The industry does not even know—and may never know—how the two 787 batteries failed.[600]

That is not to say that all novel technology requires such a conservative approach to adoption. Indeed, clean-sheet aircraft are expected to incorporate numerous novel design features. The 787, for instance, included significantly more carbon fiber than previous airplanes, and the 777 was the first Boeing jet to incorporate fly-by-wire technology.[601] Incorporating new technologies such as these should not necessarily require demon-

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600 Kristen Painter, *NTSB's Two-Day Boeing 787 Battery Fire Investigation*, DENVERPOST.COM (Apr. 24, 2013, 11:30 AM), http://blogs.denverpost.com/thebalancesheet/2013/04/24/ntsb-787-investigation/9319/. And as this article goes to print, an Ethiopian Airlines 787 parked at Heathrow caught fire, damaging the top fuselage. David Kaminski-Morrow, *Ethiopian 787 Fire Probe Urges Lithium ELT Safety Review*, FLIGHTGLOBAL (July 18, 2013), http://www.flightglobal.com/news/articles/ethiopian-787-fire-probe-urges-lithium-elt-safety-review-388455/. The initial investigation has focused on a lithium-powered emergency locator transmitter. *Id.*

601 *See* SABBACH, *supra* note 372, at 47.

strated maturity through in-service experience because these technologies either have fewer dangers in other contexts or their dangers are better understood. Prior to their adoption by the civil aviation industry, carbon fiber and fly-by-wire technology were used extensively in military aviation. But the dangers of lithium-ion batteries are well-documented, and the industry's ability to fail-safe the technology is less developed.

In all likelihood, the new battery fix will ensure safe flight during all portions of a flight. A cell is highly unlikely to fail, overheat, propagate to other cells, fail to vent, and breach the new steel container. But the adoption of the lithium-ion battery did not see the same conservative approach followed during the adoption of ETOPS and its evolutions. Perhaps the lesson for the next adotpion of new technology is to embrace the conservative approach that was so successfully applied to the creation of ETOPS. Indeed, the industry may already be learning from this lesson. Following the 787 grounding, Airbus chose to switch to Ni-Cad batteries for the A350.[602] Airbus added that it will embark on "additional maturity studies."[603]

VIII. CONCLUSION

On June 16, 2011, Flight 277, a four-engine Delta Airlines 747-400 with 359 passengers and 19 crewmembers, departed Honolulu bound for Osaka.[604] En route, over the Pacific, a serious crack formed in the windshield.[605] To reduce the risk of the windshield shattering, the pilots reduced altitude, changed course, and flew for nearly an hour toward a small World War II airstrip: Henderson Field on the Midway Atoll.[606]

While landing, the 747 struck two albatrosses flying near the runway, damaging a wing flap.[607] Passengers remained aboard until a second 747 arrived from Japan, delivering parts and

602 David Kaminski-Morrow, *Airbus to Ditch Lithium-Ion Batteries on A350*, FLIGHTGLOBAL (Feb. 15, 2013, 8:18 AM), http://www.flightglobal.com/news/articles/airbus-to-ditch-lithium-ion-batteries-on-a350-382374/.

603 *Id.*

604 Simon Hradecky, *Incident: Delta B744 over Pacific on Jun 16 2011, Cracked Windshield*, AVIATION HERALD (June 17, 2011), http://avherald.com/h?article=43e52c40.

605 Ben Sandilands, *'Adventures' in Paradise for Two 747s*, CRIKEY (June 19, 2011), http://blogs.crikey.com.au/planetalking/2011/06/19/adventures-in-paradise-for-two-747s/.

606 *Id.*

607 *Id.*

mechanics.[608] Passengers changed planes that night and departed for Osaka at 5 a.m. (nearly twelve hours later).[609] The occupants of Flight 277, a four-engine, ETOPS-exempt 747, had benefited from ETOPS when an emergency occurred over the Pacific. Henderson Field on Midway is kept in operation specifically for ETOPS.[610]

In 1989, the Midway naval base closed, and the U.S. Fish and Wildlife Service took over the base.[611] Phoenix Air, a private company, contracted with the U.S. Fish and Wildlife Service to reopen the airport, intent on expanding Midway as a tourist destination.[612] When the operation became unprofitable, once again threatening closure of the airport, Boeing subsidized Phoenix Air for nearly five years.[613] For Boeing, Midway served as a crucial diversion point for ETOPS flights in the Pacific.[614] Keeping it open ensured the viability of the 777 in the Pacific.[615] In fact, in January 2004, a Continental 777-200ER diverted to Midway following an engine problem.[616]

For the passengers of Flight 277, a non-ETOPS flight, ETOPS very quietly saved the day. And that is the ultimate legacy of ETOPS: very quietly improving safety. Perhaps the most interesting aspect of ETOPS is that it has been so successful, while at the same time, so controversial.

Indeed, ETOPS has often been on the receiving end of kneejerk responses. Boeing's original proposal that twins fly routes restricted to three- and four-engine planes met nearly universal opposition. Opponents quipped, "The only reason I fly in a four-engined plane . . . is because there are none with five."[617] Opposition to ETOPS even found its way into popular

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608 *Delta 747 Leaving Hawaii Forced to Land at Midway Atoll After Windshield Cracks*, HAW. NEWS NOW (June 17, 2011), http://www.hawaiinewsnow.com/story/14932452/crack-windshield-forces-unscheduled-landing.

609 Ben Mutzabaugh, *Delta 747 Makes Emergency Landing on Remote Pacific Island*, USA TODAY (June 20, 2011), http://travel.usatoday.com/flights/post/2011/06/delta-747-midway/175009/1%20target.

610 *Id.*

611 Michael Mecham, *Midway Island Takes on New Aviation Role*, AVIATION WK. & SPACE TECH., June 21, 1999, at 52.

612 *Id.*

613 PANDEY, *supra* note 46, at 127–28.

614 *Id.* at 121.

615 *Id.* at 128.

616 Matthew L. Wald, *Threat to Close Emergency Airfield in Pacific Upsets Airlines*, N.Y. TIMES (Oct. 30, 2004), http://www.nytimes.com/2004/10/30/politics/30airport.html.

617 THOMAS BECHER, BOEING 757 AND 767, at 145 (1999).

culture. Tom Clancy's 1999 thriller *Rainbow Six* begins: "John Clark had more time in airplanes than most licensed pilots, and he knew the statistics as well as any of them, but he still didn't like the idea of crossing the ocean on a twin-engine airliner. Four was the right number of engines . . . ."[618]

But the data did not support the kneejerk response. Modern jet engines fail so infrequently (particularly during the cruise portion of the flight) that the redundancy provided by three- and four-engine planes is insignificant. Boeing showed that the well-taken argument against ETOPS—that a plane's critical subsystems could not be powered by a single engine—could be solved by sufficient redundant power sources. Regulators, manufacturers, and carriers collectively proved that ETOPS was not only safe, but also potentially safer than the status quo.

When carriers and manufacturers proposed 180-minute ETOPS, the same arguments were raised. But again, the data did not support the opposition. Rather, the data supported a counterintuitive conclusion: 180-minute ETOPS could be safer than 120-minute ETOPS because it allowed pilots more discretion in plotting routes and increased the number of suitable landing sites in the event of an emergency. Three-hour ETOPS also required significantly greater engine reliability.

Early ETOPS gained similar vocal opposition. Yet the 777's safety record demonstrated that manufacturers (under the watchful eye of regulators) could develop a mature product upon service entry.

The success of ETOPS is attributable to several factors: a strong and engaged regulatory entity, the FAA, industry players with a vested interest in improving safety and reliability, and the technical wherewithal to accomplish ETOPS. ETOPS has had an enviable success record, but the 787 has, in some respects, brought this record into question. With respect to the 787's battery issues (though the precise reason for the failure remains unknown), the industry would do well to re-embrace the principles that have made ETOPS a success.

Most analysts believe that the grounding of the Boeing 787 will simply be a rocky beginning for an ultimately successful aircraft. The author agrees that the problems will ultimately be resolved, but if the 787 is indeed a success in the long term, it will have ETOPS to thank.

618 Tom Clancy, Rainbow Six 1 (G.P. Putnam's Sons 1998).