# Past, Current and Future Accident Rates: Achieving the Next Breakthrough in Accident Rates

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## INTRODUCTION

A common consensus among aviation professionals holds that fatal accident rates have stabilized at such low levels that additional improvements in the rate will be more incremental than in the past. Even when we define air carrier operations broadly enough to capture aircraft with just 15 passenger seats, the rich countries of the world now combine for an average of just 2 major fatal accidents each year, despite more than 50,000 flights per day. Today's low accident rates often lead us to conclude that we simply do not have much arithmetic space for dramatic improvement.

However this paper argues that we have entered another period of significant reduction in the fatal accident rate, and the improvement will accelerate over the next decade or more. This improvement has been and will continue to be driven by major changes in the air carrier fleet and by the application of new technologies, some of which are already coming on line and some of which soon will do so. These changes will be built on technology and will be connected by two primary themes.

> Ever increasing precision – in navigation, aircraft handling, engine tolerances, etc.
>
> Economic Benefits. Technological breakthroughs in safety have always been implemented most quickly and pervasively when the economic benefits are so compelling that carriers must incorporate them to compete on important routes. Soon airlines will be compelled to have the precise navigation capabilities associated with GPS and "Required Navigation Performance" if they hope to compete in key markets. This, in turn, will encourage carriers to accelerate the modernization of their fleets.

To build its case, this paper first reviews several past breakthroughs in accident rates. Part Two then addresses significant changes in the civil aviation system that are underway, or will soon be underway, and outlines how those changes will lead to sustained improvements in fatal accident rates. Note that the data and examples used in this paper come primarily from the United States. That is for the sake of convenience. However, since no meaningful differences exist in long-term air carrier accident rates among the world's richer countries, the story outlined in this paper applies elsewhere in the world as well.

## PART ONE: PAST BREAKTHROUGHS IN AVIATION SAFETY

While many incremental improvements have helped to deliver today's low fatal accident rate, a relative handful of major technological innovations explains most of the advances that have transformed aviation from a relatively risky post-World War II system into today's very safe system. Part One outlines several sudden advances in the accident rate which share a number of basic characteristics with changes that are underway today or soon will be underway

## CHANGES IN THE AIR CARRIER FLEET AND NAVIGATIONAL AIDS

From 1946 through 1950, U.S. air carriers averaged a major accident[1] every 16 days and a major CFIT accident every 12 weeks. If such frequencies had continued, the industry could never have evolved into the industry that we know today. However, as Figures 1 and 2 illustrate, accident rates fell by half over the next several years. The same figures illustrate that other rapid and significant improvements would follow.

That first breakthrough, from the late 1940s to the early 1950s, was driven by major changes in the civil fleet and by the deployment of new navigational aids (navaids). In the immediate post-war years, larger aircraft and, more importantly, pressurized aircraft entered the civil fleet in large numbers. The Lockheed L-049, with up to 81 passenger seats, entered service in February 1946. In April 1947, the DC-6 (up to 52 seats) entered service, and the Boeing 377 (up to 112 seats) entered service in April 1949. These aircraft instantly extended flight ranges from 350 or 400 miles that typified the era of the DC-3 to 750 and 1000 miles.

Because they were pressurized, the new aircraft also could fly up to 20,000 feet, which put them above much of the terrain and much of the weather, at least while enroute. The longer range of this fleet also opened new markets to non-stop service, thereby reducing the number of landings and takeoffs required for a typical city pair. Though older aircraft remained in the fleet for some time, the pace of change was dramatic. In just 3 years (June 1950 to June 1953) the number of aircraft in the US fleet increased by 17 percent but lift capacity increased 42 percent.[2]

Navaids also changed rapidly and accelerated the pace at which new aircraft penetrated the fleet. In April 1947 the US CAA, a predecessor of the FAA, introduced instrument landing systems (ILS), which included a VHF directional localizer, UHF glideslope transmitters, and, usually, outer, middle, and inner beacons. CAA said that with an ILS, properly trained crews in properly equipped aircraft could make approaches when ceilings were 100 feet below minimum (then normally 400 feet) and when visibility was 3/4 of a mile (versus A minimum of 1 mile at the time). After an airline had 6 months of satisfactory experience with ILS, minima could drop to 200 feet and a half-mile.

The new aircraft and ILS provided a quantum leap in safety by reducing the frequency of controlled flight into terrain (CFIT), in-flight loss of control, and approach-and-landing accidents. Though all three of these accident categories remained far too common, their frequencies fell sharply at the time.

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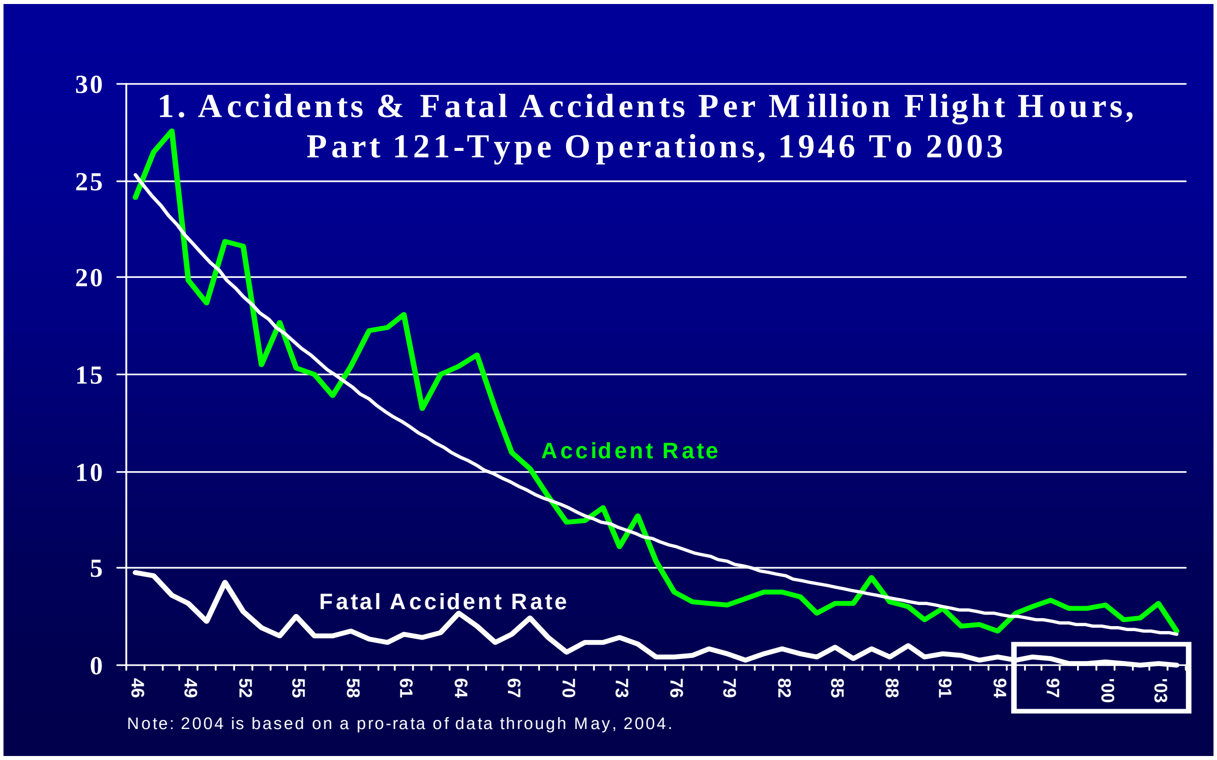
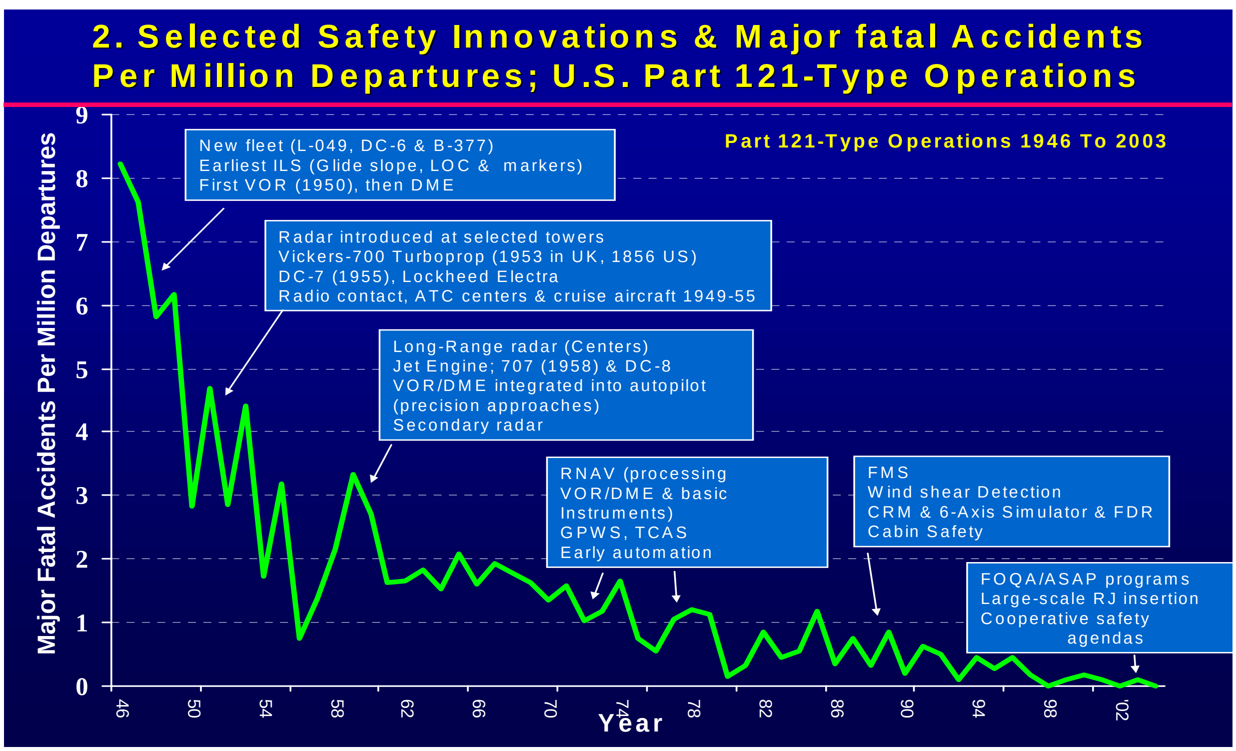
[1] "Major accidents" involve (1) either a hull loss or multiple fatalities, or both; <u>and</u> (2) a scheduled passenger flight with 10 or more seats, or a non-scheduled passenger flight with 30 or more seats, or a cargo aircraft with at least 7,500 pounds of payload.
[2] FAA Historical Chronology, page 51.


1. Accidents & Fatal Accidents Per Million Flight Hours,
Part 121-Type Operations, 1946 To 2003
30
25
20
15
10
5
0
Accident Rate
Fatal Accident Rate
46
49
52
55
58
61
64
67
70
73
76
79
82
85
88
91
94
97
'00
'03
Note: 2004 is based on a pro-rata of data through May, 2004.


2. Selected Safety Innovations & Major fatal Accidents
Per Million Departures; U.S. Part 121-Type Operations
Part 121-Type Operations 1946 To 2003
Major Fatal Accidents Per Million Departures
New fleet (L-049, DC-6 & B-377)
Earliest ILS (Glide slope, LOC & markers)
First VOR (1950), then DME
Radar introduced at selected towers
Vickers-700 Turboprop (1953 in UK, 1856 US)
DC-7 (1955), Lockheed Electra
Radio contact, ATC centers & cruise aircraft 1949-55
Long-Range radar (Centers)
Jet Engine; 707 (1958) & DC-8
VOR/DME integrated into autopilot
(precision approaches)
Secondary radar
RNAV (processing
VOR/DME & basic
Instruments)
GPWS, TCAS
Early automation
FMS
Wind shear Detection
CRM & 6-Axis Simulator & FDR
Cabin Safety
FOQA/ASAP programs
Large-scale RJ insertion
Cooperative safety
agendas
Year
46
50
54
58
62
66
70
74
78
82
86
90
94
98
'02

Pressurized aircraft and ILS are good examples of safety improvements that airlines could not afford to be without. The increased power, range and comfort of the new aircraft opened a matrix of new, non-stop city pairs and introduced a level of service that made aviation much more attractive for inter-city travelers. To compete in important markets airlines had to have the new aircraft, even though a glut of military versions of less capable civil aircraft was available at bargain prices. Economic benefits also made ILS equipment and ILS training a must if a carrier was to remain competitive. No airline could afford to be frequently locked out of key airports due to weather while competitors maintained reliable access. The new fleet was instrumental in the growth of aviation in the U.S. For the first 10 years after WW II, revenue passengers increased by an average of 19 percent per year.[3]

ILS and pressurized aircraft can easily be taken for granted today or even overlooked as major safety advances. In their time, however, as illustrated in Figures 1 and 2, their impact was dramatic and immediate. Yet the new, larger aircraft had some trade offs in public perceptions of safety. First, though these aircraft in fact improved safety, their accident rates remained remarkably high by today's standards. Second, their increased size suddenly introduced a quantum leap in the number of fatalities associated with any single accident.

Before the introduction of pressurized aircraft, accidents rarely involved more than 20 to 25 fatalities. Then, in October 1946, a CFIT accident in a DC-4 killed 39 people. The following spring, 3 major DC-4 accidents occurred within just 15 days. On May 29, 1947, a DC-4 crashed on takeoff at LaGuardia in New York, killing 43 occupants. The next day, a DC-4 crew lost control on decent toward Washington; 54 people died. Two weeks later, another CFIT in a DC-4 killed 50 people. Later that same year, an on-board fire killed 52 people on a DC-6. In short, fatal accidents on pressurized aircraft suddenly involved unprecedented numbers and, despite improvements compared to the pre-existing fleet, those accidents remained alarmingly common.

Also in 1947 the CAA commissioned its first very-high frequency omni-directional beacon (VOR) at Nantucket, Massachusetts. This was a significant improvement on the non-directional radio beacon (NDB), which was the only common navaid system at the time. A VOR was more accurate and less prone to interference. The VOR signal was transmitted to a 360-degree universe from a particular angle to magnetic north. Pilots could determine bearings and "home" on the station. The pilot also could determine how far the aircraft was off a proper course. The CAA followed the VOR with a program to deploy 425 distance measuring equipment systems (DME). Procurement began in 1950 and installation began in 1951. Now a flight crew not only knew the proper heading to a signal relative to magnetic north, but the crew also knew the distance to that signal.

The combination of VOR/DME improved safety through more reliable navigation. However, substantial time was required before receivers for this equipment, especially DME equipment, penetrated the fleet. They help to explain the sharp decrease in accident rates experienced in the mid-1950's more so than the sharp decrease that began around 1948 (see Figures 1 and 2).

[3] Civil Aeronautics Board, USA.

Again, new technology is incorporated most rapidly when it provides a compelling economic benefit. As that economic case weakens, implementation slows down and the likelihood of, or the need for regulatory action increases. However DME lacked the compelling economic case of new fleets and ILS. Though airlines began adding DME receivers in some aircraft, many aircraft in the fleet did not have DME receivers. FAA later mandated DME equipment. Effective July 1, 1963, DME equipment was required for all jets and any other aircraft capable of operating above 24,000 feet. One year later, DME was required on all aircraft operating in the IFR system and all aircraft over 12,500 pounds. By November 1964, FAA commissioned its first ILS-DME combination at JFK in New York.

By the late 1960s and early 1970s, the VOR evolved into the first RNAV systems, which became widely available in the fleet in the 1980s. On properly equipped aircraft, crews could create waypoints using a VOR radial and DME distance. A waypoint is defined by latitude and longitude coordinates and is most often used to identify a point at which a crew begins to change direction, speed, or altitude. The VOR quickly became and remains the backbone of the enroute IFR system. Essentially, an enroute IFR aircraft flies to a VOR, makes and then makes any required change in direction required to reach the next VOR. This system of navigation provided the first real analogy to a highway in the sky.

Eventually the VOR would be adapted to area navigation (RNAV), as discussed below. RNAV enabled the ATC system to offer "direct-to" clearances, letting crews define and fly the shortest distance between two points, rather than flying less direct routes to and from interim waypoints.

Even without these later evolutionary developments, the new post-war aircraft and the introduction of ILS provided a quantum leap in safety by reducing the frequency of controlled flight into terrain (CFIT), in-flight loss of control, and approach-and-landing accidents. Though all three of these accident categories remained far too common by today's standards, their frequencies collapsed in relative terms.

## IMPROVEMENTS IN AIR TRAFFIC CONTROL (ATC)

**Post-War ATC, Communications and Navaids.** The post-war era in the U.S. began with a very rudimentary ATC system. The system, such as it was, relied primarily on standard procedures, such as landing aircraft had the right of way, see and avoid, etc. The relatively few ATC towers that existed were limited to visual fields of about 1 mile. The enroute system was even weaker. Prior to the war, the Federal Government had just begun to operate three "Air Traffic Control Stations" formerly operated by a consortium of large air carriers. Pilots could get weather information and could report their positions, as determined by the crews. Controllers separated enroute aircraft flight strictly by complex manual computations based on locations, headings and airspeeds that pilots had reported some time earlier.

This system of telephone-radio-blackboard separation was labor-intensive, and could not hope to make efficient use of the airspace. The system was too much of an art to be safe and it, too, was quickly overwhelmed with continued growth and technological changes in commercial air travel. Clearly, the new aircraft coming on line and the rapidly increasing volume would require more viable ATC technology.

The technical innovation, developed by Great Britain during World War II, was radar. For the first time, ATC could separate aircraft based on actual radial position. This would immediately increase airspace efficiency and greatly improve safety by anticipating conflict between enroute aircraft without waiting for complex manual computations based on locations and headings that had been reported some time earlier.

The technical innovation came from Great Britain in World War II: radar, which determines a target's location by measuring the time needed for the echo of a radio wave to return, and by identifying the direction of the return signal. Radar would allow controllers to separate aircraft based on actual position. This would increase airspace efficiency, and greatly improve safety by anticipating conflict between enroute aircraft.

However, implementing radar nationwide took years. CAA first demonstrated civilian use of radar at Indianapolis in May 1946. It would be 3 more years before the first radio contact was established between an ATC center and an enroute aircraft. Six more years would pass before all en route centers even had direct radio contact with aircraft. By mid-1956, the U.S. had radar at just 32 towers and long-range radar at only 2 centers.

**Post-War Midair Collisions.** Radar was first used in terminal airspace at major airports, where the technical demands were less complex. However, rapid growth in air travel, without the benefit of enroute radar, quickly led to an eruption of midair collisions, which created intense and sustained concern by the public and Congress.

The first post-war fatal midair collision occurred in April 1947 over Columbus, SC, as a Delta DC-3 and a Piper approached Columbus. The Piper turned onto final and struck the tail of the DC-3. The DC-3 went full power to climb, then crashed with the Piper embedded in the DC-3's tail. All 7 people onboard the DC-3 and the lone pilot on the Piper were fatally injured. This was followed by 3 more midairs in 1949 and 3 in 1951, 1 of which involved 15 fatalities on a commercial aircraft, while others involved fatalities on general aviation (GA) and military aircraft. Public concern quickly led to Congressional hearings on midairs. Two more midairs with GA, 1 each in 1952 and 1954, saw both air carrier aircraft land safely but 2 people were killed in each of the 2 GA aircraft.

Then came the June 30, 1956 midair over the Grand Canyon; everything changed--fast! A TWA L-1049 (Super Constellation) and a United DC-7 had left Los Angeles 3 minutes apart on eastbound flights. The L-049 was at 19,000 and the DC-7 was at 21,000, as assigned, when the L-1049 crew asked for clearance to climb from 19,000 over turbulence. Shortly before both aircraft were about to leave controlled airspace, the L-1049 crew was advised that the DC-7 was nearby, but the DC-7 crew was not advised of the Constellation's climb. Both aircraft then left the airspace controlled by the Los Angeles ARTCC and entered uncontrolled airspace near the Grand Canyon. At that point, the flights were VFR, and were not under positive control, since only 2 ARTCCs had long-range radar. The aircraft struck at about 21,000 feet. All 58 occupants on the DC-7 and all 70 occupants on the Constellation were killed. The total of 128 fatalities was nearly twice the largest number of fatalities (66) in any previous accident.

The numbers truly shocked both the public and Congress. Within weeks of the Grand Canyon accident, Congress had funded 82 long-range radars for Centers. The first of these second-generation radars came on line in September 1959, with 20 new tower radars on line by May 1960.

Yet the rash of midairs continued, with 1 each in 1957 and 1958 between airliners and military aircraft. They took the lives of 58 people on air carrier aircraft, 1 military pilot and 1 person on the ground. These accidents not only sustained public apprehension about aviation safety, but also brought public attention to long-standing disputes between CAA and the military about jurisdiction over airspace.

The same midair also led directly to the Federal Aviation Act of 1958 and the creation of the Federal Aviation Agency (FAA), later changed to the Federal Aviation Administration. Aviation responsibilities had been divided between the Civil Aeronautics Board (CAB) and the Civil Aeronautics Administration (CAA). CAB was responsible for rulemaking, accident investigation and economic regulation. CAA was responsible for enforcement of CAB rules, certification and ATC. The 1958 Act assigned CAA's functions to FAA, added the CAB's safety rulemaking function, and made FAA solely responsible for civil and military air navigation and ATC.

The primary focus of the t958 Act was to establish a national system of positive ATC. By making FAA solely responsible for the management of domestic airspace, the 1958 Act resolved a long-standing jurisdictional dispute between CAA/FAA and the military. Positive air traffic control would separate IFR traffic from VFR traffic, and fast traffic from slow traffic. Positive control was established over all continental airspace above 24,000 in 1957.

In June 1958, CAA established the first 3 positive control routes on designated airways between 17,000 and 22,000 MSL. Airways were 40 miles wide and excluded all VFR traffic. Since these altitudes required pressurization or oxygen, this was no burden to most VFR aircraft, but it forced carriers who wanted to use less crowded airspace to fly IFR. When this narrowly defined system of airways showed serious operational limitations, FAA went to area control. By October 1971, all airspace between 18,000 and 60,000 MSL was reserved for IFR aircraft with transponders.

Midairs continued after 1956 and 1958, with 4 more in 1960. The first 3 that year involved no fatalities on commercial aircraft, but did involve fatalities among military and GA pilots. Their real effect was to keep midairs before the public as a major safety issue. Then the New York midair in December 1960 put the issue back on page one.

A United DC-8 and a TWA Constellation were on approach to Idlewild Airport (now JFK) and LaGuardia, respectively. The ground controller instructed the DC-8 to hold near a navigation fix until he could be cleared to Idlewild. However, the DC-8 had lost much of its navigation equipment, and could not establish its fix. The DC-8 then entered its holding area at too high a speed, over shot its designated airspace and, over Staten Island, struck the Constellation that was awaiting clearance to LaGuardia. All 44 people on the Constellation and all 84 on the DC-8 died. Five more people on the ground were killed -- a total of 133 fatalities. The Staten Island accident quickly shifted the focus on midairs from the enroute environment to the terminal environment, where IFR and VFR aircraft mixed in close quarters.

Though the commercial system got a 3-year reprieve from fatal midairs after Staten Island, midairs resumed in February 1965, with a non-fatal midair over Long Island. This was followed in December by a fatal accident with 84 fatalities due to an evasive maneuver by an Eastern DC-7 trying to avoid a midair 7 miles off Jones Beach in New York. In that accident, a Pan Am 707 captain, inbound to JFK from Puerto Rico advised ATC of a near miss and reported that the other aircraft had “winged over” and "it looks like he's in the bay."

In 1967, a midair over west central Ohio between a GA aircraft and a DC-9 (26 fatalities), then a midair in North Carolina between a GA aircraft and a Piedmont 727 (82 fatalities) kept the midair issue before the public. Three more midairs followed in 1968 with no fatalities on the commercial aircraft, but 7 fatalities on GA aircraft, and 2 more non-fatal midairs in 1969.

FAA responded to midairs by developing the ATC Radar Beacon System, starting in the late 1950s. The CAA/FAA understood as early as 1950 that positive control based on radar soon would fall short of the system's needs. The shortcoming was that primary radar simply "painted" a target on a given radial. Altitude could not be identified, nor could the aircraft or, therefore, the aircraft's capabilities. A second-generation radar system would be required, particularly with the birth of the jet age. The desired system would be based on an airborne transponder that transmitted unique signals from which ground interrogators could display aircraft identity on an ATC screen.

FAA clearly needed a new generation ATC system to reduce or eliminate midairs and to manage the growth in traffic efficiently. That new system would have to be based on computers. It would have to identify each aircraft and display each aircraft's identity, speed and altitude on ATC screens. The new system also would have to anticipate conflicts with traffic or terrain, and perform all these tasks quickly and accurately. Simultaneously, the new system would reduce ATC paper work, which, as late as 1965, still consumed 75 percent of a controller's time.

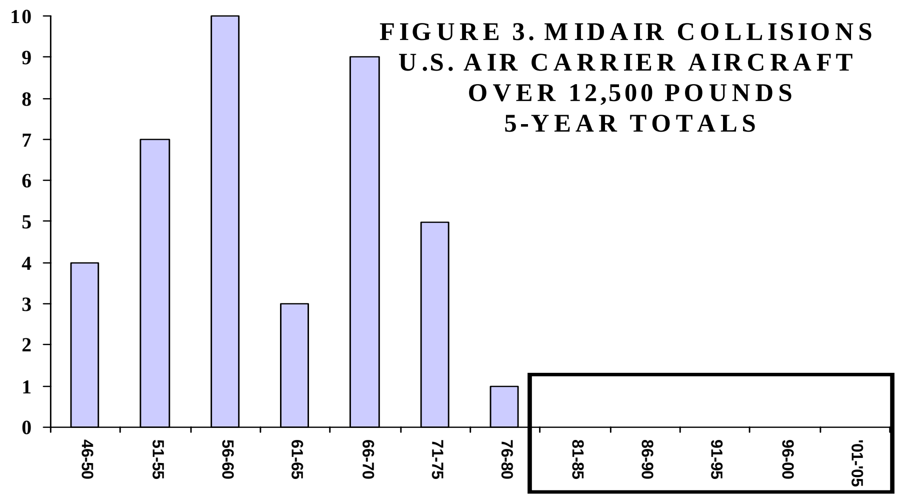
Terminal automation would be less complex than enroute automation, so FAA began its automation program in terminal areas in 1965 with the Area Radar Terminal Systems. These systems combined radar and mode C in order to paint and identify aircraft. The system later added conflict alert software and altitude warning systems to warn controllers if aircraft were too close to terrain or to each other. Nevertheless, in September 1969, while the new terminal system was being implemented in stages, an Allegheny DC-9, descending from 6,000 to an assigned altitude of 2,500 feet, collided over Indiana with a student pilot in a PA-28. All 82 people onboard the DC-9 and the GA pilot died. This was followed by still more midairs, including a midair between a DC-9 and a military F-4B over Duarte, California in June 1971, with 50 fatalities.

All these fatal midairs, from Staten Island in 1960 to Duarte in 1971, occurred in terminal airspace. The sustained frequency of midairs led FAA to restrict access to airspace around the busiest terminals. On September 29, 1969, FAA proposed to establish Terminal Control Areas (TCAs), later Class B Airspace, around selected airports. Implementation began in May 1970. The rule initially required two-way radio, a beacon transponder and a VOR or TACAN receiver in order to enter a designated TCA. FAA then added an altitude reporting transponder requirement in 1974. (See Figure 3.) The objective was to limit the mixing of VFR with IFR traffic, and small aircraft of limited capability with faster jets in congested terminal areas (as the Safety Board, then still part of CAB, had been recommending since Staten Island).

Simultaneously, the entire en route system was being upgraded. Automation of enroute ATC began with the installation of IBM's prototype 9020 system at the Jacksonville Center in 1967. The system was designed to provide automated flight data processing and radar tracking at all enroute centers and major terminals. The system was delivered behind schedule, which created significant frustration within FAA, the aviation community and IBM. The system would not be in place at all 22 enroute centers until the end of the 1970s. However, indicative of the complex nature of automating the enroute environment, the 9020 system proved to be the most complex computer application in the world at the time. IBM more than doubled the amount of memory first estimated in order to handle the program's half million commands.

Since the 1971 midair over Duarte, only one large American passenger aircraft has been involved in a midair in the United States (San Diego in 1978). The only other midair involving a large passenger aircraft in U.S. airspace occurred in August 1986 when a GA aircraft and an Aeromexico DC-9 collided over Cerritos, California. That accident led to an expansion in the number of TCAs, plus the requirement for a Mode-C transponder on board before entering a TCA. Upon implementation of TCA's, the altitude-reporting transponder in 1974 and a Mode-C transponder, the number of midairs immediately collapsed. (See Figure 3.)

Midairs involving large commercial aircraft, which were the driving force that led to the creation of today's ATC system in the U.S., have changed from relatively common events to extremely rare events. Yet, the risk is not zero, as illustrated by the midair in December 1996 in India between a Saudia 747 and a Kazakhstan IL-76 with 349 fatalities, or the July 2002 midair over Germany between a DHL 757 and a Bashkirskie TU-154, with 73 fatalities. Yet these two exceptions help to prove the rule: when aircraft are properly equipped and when crews respond to TCAS alerts (rather than possibly conflicting directions from ATC), midair collisions have become very rare indeed, as illustrated in Figure 3.




## THE JET

The jet often cited as the single most significant improvement in airline safety, though the earliest years of civilian jet travel were difficult. British Overseas Airways (BOAC) introduced commercial jet travel with the Comet in the early 1950's, only to suffer three especially puzzling accidents in which Comets seemingly disappeared from the sky. On May 2, 1953 a BOAC Comet took off from Calcutta with 43 occupants and disappeared in flight after passing through 19,000 feet. Eight months later, a second BOAC Comet disappeared at 26,000 feet after takeoff from Rome (35 fatalities). The United Kingdom then grounded the Comet but, under intense pressure, the government allowed the Comet to resume service on April 1, 1954. One week later, another BOAC Comet disappeared at 35,000 feet (21 fatal), also after departing Rome.

These events led to what many people recognize as the birth of modern accident investigation. Investigators in the U.K. employed the scientific method in various experiments to establish that the Comets in fact had broken up in flight. The U.K. investigators established that, as the Comet operated at unprecedented altitudes, the aircraft's frame expanded and contracted during every pressurization cycle, which caused metal fatigue. Designs changed abruptly to avoid points of added stress, such as sharp corners or square openings, and included fewer but stronger joints.

The next generation of commercial jets, such as the Boeing 707 and the DC-8, were the primary beneficiaries of this knowledge. When Pan Am introduced revenue jet service to the U.S. industry in October 1958, BOAC was still operating jet jets in its fleet, and Aeroflot already had 62 TU-154's.[4] Nevertheless, it was the Boeing 707 and then the DC-8 a year later that truly established the jet age.

Piston engines had continued improve through the 1930s and 1940s, with much more powerful engines entering the civil fleet after World War II in the DC-6, the Constellation, etc. Yet, even by the standards of the time, the most sophisticated piston engines did not offer the reliability the industry sought. Most of those engines were developed during the war for military use. They were

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[4] Fleet data from Airclaims.

built with a conscious notion of "use it and throw it away." Performance and power, not reliable endurance, were the wartime objectives.

In fact, as piston-driven aircraft increased in power, the rate of engine failure often increased. At their peak, 4-engine piston air transports in effect operated with 4 rows of 7 pistons. All those moving parts invited some degree of common failure. By the early 1950s, the top of the line piston engines could run a maximum of only 1,500 hours time between overhauls (TBO). In practice, TBO's of 800 hours were a luxury.

At such levels, arithmetic suggests that every flight had a very real risk of losing an engine, especially on a 4-engine aircraft. The chances of losing two engines also were real on every flight. From 1946 to 1958, US air carriers averaged 4.5 major accidents and about 50 fatalities in engine-related accidents. On average, 1 of these 4.5 involved the failure of two engines. Due to the frequency of piston-engine failure, in 1953 the U.S. prohibited twin- and triple-engine commercial airliners from flying routes that were more than one hour from an adequate airport.

The earliest turbofans quickly extended the TBO from about 800 hours to 6200 hours, then trebled the TBO again to 18,000 and 20,000 hours by the early 1960's. Soon the FAA abandoned the TBO as a meaningful regulatory standard and replaced it with a standard of "on condition." By that standard, an engine can be operated indefinitely, provided that it satisfies certain performance criteria, though various parts of the jet engine still have defined life cycles. Less than 6 years into the jet age in the US, the FAA in 1964 exempted the 3-engine 727 and Trident from the limitation of having to remain within 60 minutes of an alternate airport.

Of necessity, technological advances in materials accompanied the introduction of the jet. The industry moved to nickel alloys and titanium for greater strength under heat, then to composites, such as spun glass and resins, to resist impact and stress. Fiberglass resins and reinforced plastics followed and, by the mid-60s, aircraft manufacturers began to incorporate developments in carbon fiber (graphite) and graphite-reinforced plastic. Similarly, the jet demanded a quantum leap in manufacturing processes to ensure the precision that jet engines required.

In the latter 1980s, FAA clearly recognized a new order of magnitude in engine reliability when the agency began approving extended range operations (ETOPS) over water for two-engine aircraft, based on performance requirements. Multi-engine aircraft had been required since 1936 to demonstrate that, with one engine out, safe flight could be continued long enough to reach an alternate airport. However, that requirement had been set in an era when commercial aircraft could not be more than 100 miles from an alternate airport at any time during a flight. Though the rule was amended over the years, the rule continued to exclude 2-engine aircraft from oceanic flight (defined as flight for at least one hour over water).

In 1983, discussions began to ease the 60-minute rule for twin-engine jets such as the A300, 767 and 757. In 1985, FAA amended the rule to permit selected aircraft to operate two hours from an alternate airport that could handle the aircraft, provided that carriers and engines met performance parameters over 12 consecutive months of operations. Aircraft also had to be fitted with additional back-up systems. ETOPS was extended to three hours from an airport in 1988 as turbofan engines were demonstrating reliability 50 times that of piston engines. As stated in a subsequent Advisory Circular on December 30, 1988, FAA based that action on the reliability achieved by newer generation aircraft, and by the use of propulsion systems that had established an in-flight shutdown rate of just 1 per 50,000 hours in the preceding 10 years. The FAA's Advisory Circular of December 30, 1988 went on to add:

> Some of the new generation [2-engine] airplanes have a range/payload capability equivalent to many previous generation three- and four-engine airplanes. The demonstrated range/payload capabilities of the new generation airplanes, including their provisions for achieving a higher degree of reliability, *clearly indicates there is a need to recognize the capabilities of these airplanes* and to establish the conditions under which extended range operations with these airplanes can be conducted over oceanic and/or desolate land areas.
> (Emphasis added.)

To illustrate the reliability of today's jet engines, by early 2004, the FAA's Engine Directorate reported an average of just .09 serious engine failures (high-risk outcomes) per million flight cycles for the preceding 3 years, or an average of just 1 per 11 million cycles. The objective now is to reduce the rate of serious engine failures from .09 per million cycles by half, to .045 or 1 per 22 million cycles, by 2007.

In the past 20 years, the U.S. air carrier industry has had just 2 fatal jet accidents that can be attributed directly to engine failure: uncontained engine failures at Sioux City, Iowa in July 1988 (111 fatalities) and at Pensacola, Florida in July 1996 (2 fatalities). Today most engine failures are inherently low-risk events, as aircraft can function well enough on a single engine to make a safe return or safe diversion to an airport. Even if an engine fails on initial climb after takeoff, a crew simply continues to apply full power, completes the climbout, and then returns to the airport. In fact the primary safety threat from an engine failure now is the risk that a crew might respond improperly to a perfectly survivable event. For example, a crew might turn into the failed engine or become so pre-occupied with the engine that they fail to fly the airplane. The bottom line is that engine failure, by itself, is no longer a common cause of catastrophic accidents in commercial aviation.

## AUTOMATION

At their core, automation and other cockpit advances assist pilots in flight by enabling the aircraft to perform maneuvers automatically and precisely, and by providing more information to the crew on the status of the flight, the aircraft, and the environment. When the jet age abruptly introduced aircraft that were much faster and that operated at much higher altitudes than all preceding civil aircraft, the need for such information instantly increased by orders of magnitude.

In the era of the DC-6, the Constellation and Boeing Stratocruiser, the most sophisticated piston-powered aircraft had one or two analog computers that controlled pressurization or heaters. Even the autopilot was analog and rudimentary. In comparison, the first Boeing 777 had 1,000 digital computers and then the Airbus A320 family and subsequent aircraft exceeded that level. In short, we not only have more computers onboard to automate more and more functions, but each computer is immeasurably more powerful than either the old analog systems or the earlier digital systems.

In the enroute environment, primary flight information had been limited to just 6 instruments: airspeed indicator; artificial horizon; three-pointer altimeter; turn and bank indicator; directional gyro; and vertical speed indicator. The basic display and range of information available remained essentially static for years preceding the introduction of the jet. Because routine events occur much more rapidly in jets than in earlier fleets, more information and more precise information was required on the state of flight, especially at high altitudes and on approach.

Electro-mechanical and analog devices were used through the 1960s to automate a number of aircraft functions. In the 1970s, the use of digital electronics in the design of avionics systems enabled more aircraft functions to be automated with higher levels of reliability. However, automation did not come into its own until the 1980s, when the micro-computer and cathode ray tube (CRT) displays were introduced into cockpits. This was the era in which automation first provided optimized flight path control, engine power control, and aircraft subsystem control.

**TCAS and GPWS: Early Safety Breakthroughs from Automation.** As outlined earlier, TCAS was a major defense against midair collisions. The first generation TCAS identified and aurally warned pilots when separation from another aircraft was inadequate. Since the introduction of TCAS, midair collisions have virtually ceased with large American commercial aircraft operating in the United States.

The ground proximity Warning System (GPWS) emerged in the same era as a defense against controlled flight into terrain (CFIT). GPWS brought even greater advances in safety than did TCAS, if only because CFIT was a far more common accident scenario than were midairs and because severe outcomes were even more likely in CFIT accidents than in midairs.

Today we can easily forget just how frequently major CFIT accidents occurred. For the first decade after World War II (1946-1955), Part-121-type operations in the U.S. averaged 3.5 a major CFIT accidents per year, or 1 every 15 weeks, with nearly 750 fatalities. The pace slowed to "only" 2 such accidents per year for the next two decades with the improvements that already have been noted, such as the post-war fleet, the jet, improvements in ATC services, etc. Nevertheless, at a steady average of 2 major accidents per year, and a total of 1900 fatalities among U.S. operators, CFIT remained a critical safety issue.

The major change in the risk of CFIT began to change on December 1, 1974, when a TWA 727 approached Dulles Airport in heavy rain on an absolutely miserable day. The approach seemed normal to the crew, but the aircraft slammed into Round Hill about 35 miles northwest of Washington, killing all 92 people onboard. That accident involved several key causal factors, one of which was the absence of a definitive alerting system to warn the crew that they were dangerously close to terrain.

As a result of that accident, in 1975 all commercial aircraft with more than 30 were required to operate with GPWS. The system sounded an alert whenever an aircraft was flown too close to the surface. Since then, no large U.S. passenger aircraft have had major CFIT accidents in airspace with radar coverage, though 3 such aircraft have suffered fatal accidents elsewhere in the world where terrain precluded radar coverage. Those 3 exceptions were: Eastern Airlines in Bolivia on 1 January 1985 with 29 fatalities; Independence Air at Tenerife on 8 February 1989 with 144 fatalities; and American Airlines on 20 December 1995 with 160 fatalities.

The 3 exceptions noted here are rather clear indications that GPWS cannot reduce the risk of CFIT to zero. GPWS had an important shortcoming, as it was limited to looking ahead of the aircraft. Enhanced GPWS (EGPWS), or the "Terrain Alert Warning System" (TAWS) adds the capacity of vertical sensing. In addition, the eventual adaptation of GPWS and the development of extensive on-board topographical databases have reduced the risk even further.

Note, too, that CFIT accidents continued in smaller passenger aircraft and in cargo aircraft, which were not addressed by the 1975 requirement to have GPWS onboard. In March 1992, FAA required that all aircraft with more than 20 seats and all turbine-powered aircraft in air taxi or commercial service be equipped with GPWS by April 1994. Once again, CFIT virtually disappeared as an accident scenario.

Finally, both TCAS and GPWS support the theme of safety advances being incorporated most quickly when they provide a compelling economic case for operators. Unlike most other advances in automation, TCAS and GPWS were designed explicitly to improve safety. Each had been strongly resisted for years and the resistance continued for several years after each was required. The use of VOR/DME equipment in the cockpit also was resisted into the early 1960s and briefly after that, when the equipment was required in the cockpit. These examples suggest that the coercive power of government to require certain equipment or practices remains an important tool in safety.

In the end, GPWS has proven itself to be an enormously important tool in safety. Again, the risk of CFIT is not zero, as we have been reminded by American Airlines at Cali in 1995 and by Spain's Paukn Air in 1998. Nevertheless, CFIT has become a very rare event, at least among the world's richer countries. Yet, CFIT consistently remains among the top several fatal accident scenarios elsewhere in the world.

**Engine Power:** Automatic propeller feathering systems, introduced after WW II, were the first significant automatic control of engine power. The autofeather was made obsolete by jet engines, which include autothrottle systems to control fuel flow. By the 1980s, this had evolved into full-authority digital engine control, which has further improved the precision with which jet power plants can be controlled. Autothrust systems now set engine power to automatically determined parameters even during takeoff roll.

Information on engine power and performance was first displayed in the cockpit on electromechanical instruments. This has since been replaced with easier-to-read electronic displays. Since then, variations in the display formats have been added, including analog tapes and alphanumeric data.

**Aircraft Systems:** In the earlier commercial jets, a variety of lights and gauges monitored aircraft subsystems (e.g., electrical, hydraulic, pneumatic, and fuel) and showed the configuration of landing gear, flaps and slats, control surfaces, aircraft doors, and other flight-critical systems. Pilots needed rather detailed knowledge of all onboard systems to ensure that they understand that a certain reading on some gauge indicated a problem or a failure.

This became a problem when subsystems. Pilots had to interpret readings quickly, had to integrate those readings with their own understanding of the various onboard systems, and then had to act quickly enough to reconfigure the aircraft safely.

In the early 1980s, CRT displays of systems information were guided by a less confusing "need-to-know" principle; the early CRTs would display pictorial and alphanumeric alerts in the cockpit. For example, if a particular failure did not require reconfiguration, or if the pilot could not respond to a failed light on the wing, the pilot received no indication of a problem.

By the late 1980s, CRTs added synoptic diagrams that provided a picture of the aircraft and showed the location of problems within aircraft subsystems more accurately and more succinctly. In today's aircraft, flight management computers and CRTs offer a display of aircraft configuration, along with additional flight planning and navigational information. These systems simplified the information pilots need, and provide a resource in times when the aircraft needs to be operated in abnormal conditions.

**Flight Path.** In the 1970s, onboard computers began using data from static and dynamic air pressure to control aircraft speed and altitude, thereby permitting precision climbs and descents. Flight directors were added to provide computerized pitch and roll commands on displays that were much easier to fly than the VOR/DME/ILS displays. The inertial navigation system (INS) also was added in the 1970s for precision navigation over the ocean and other areas outside the range of ground-based navaids. Other advances of the 1960s and 1970s reduced aerodynamic drag (trim control) and adverse yaw (yaw damper). The first systems were built of mechanical gyros, which required complicated constructions and substantial power supplies, all of which were prone to failure. Later on 'solid state' solutions employed discrete integrated electro-mechanical or electro-optical sensors. These 'solid state' systems had no moving parts, but consisted of expensive laser-gyros and integrated sensor devices in Micro Electro-Mechanical Systems.[5]

Important though these advances were, the pace and scope of automation and simplified cockpit displays took off in the late 1970s and early 1980s with the introduction of the cathode ray tube (CRT) into the cockpit, along with onboard computers that quickly processed new information as a flight progressed. Today, large commercial jets have automated flight path and aircraft management with up to 100 high-speed computers and CRTs that are reconfigured in flight to display different types of information. Visual displays show bearing and distance to specific "fixes," visual information on deviations from localizer and glide slope centerlines on approach, actual versus planned route of flight, weather, traffic avoidance information, systems updates, etc.

Primary flight information first was integrated on several electro-mechanical displays. By the late 1980s, all primary flight information, such as the location of navaids, actual versus planned route of flight, and weather were displayed on a single CRT to increase situational awareness and reduce pilot workload.

**Flight Management System.** Many of the advances noted above, plus additional advances, evolved into or have been incorporated into the Flight Management System (FMS), which was first introduced in the early 1980s. The FMS is a system of airborne sensors, receivers, computers, and a navigation database that integrates the control display unit with raw navigation data and inputs from multiple sources such as DME, VOR, localizers, and, now, GPS. These systems now also provide performance and RNAV guidance to displays and automatic flight control systems. The FMS then soon added the capability of detecting and isolating faulty navigation information.

The FMS provides strategic control of the overall flight and overall aircraft performance rather than tactical control. The system is loaded with data files on airport locations, VOR locations and frequencies, specific ATC constraints, and aircraft operating characteristics, so the aircraft knows when flaps can be up or down, etc. The pilot then adds data for each flight, including winds, temperature, standard temperature deviation, whether the pilot wants a full flap takeoff, desired cruising speed, etc.

The FMC computes the rest (maximum gross weight, center of gravity, flight path with climb and descent profiles, pitch and thrust commands that control aircraft speed and altitude, etc.). The system also adjusts all these computations if necessary during the flight, based on data gathered from onboard sensors (for example, actual winds may differ from the data on winds entered by the pilot).

These advances in fact have changed the pilot's basic role on an aircraft. Today's pilot becomes a strategic planner and flight manager, rather than a traditional "stick and rudder" operator. As

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[5] Description adapted from Electronics Laboratory of the Swiss Federal Institute of Technology, Zurich.

manager and monitor, the pilot has time to anticipate problems, and enjoys the benefits of onboard back up systems that accurately, dependably, and safely operate the aircraft.

In the end, automation enables the aircraft to perform routine maneuvers more precisely and more safely than those maneuvers might have been performed in the past. Automation has further evolved to include flight envelope protection, which maintains flight controls, speed and attitude within certain profiles. Envelope protection restricts the aircraft to remain within maximum and minimum speeds, avoid excessive G loads, and minimizes risk of stall, excessive pitch or bank, etc.

Automation has introduced some tradeoffs. So-called mode confusion can get crews into trouble. Crews may expect the aircraft to perform in a specific way that is associated with the logic of one mode, but the mode of automation that actually has been selected may use a different logic from that which the pilot anticipates. For example, depending on the software logic, if a pilot selects flaps at too high a speed, the aircraft may default to a go-around, which the crew does not anticipate. Pilots also must understand the basic design of some automation subsystems. For example, if the Captain's pitot static tube is blocked, the crew must understand that the back-up airspeed indicator (ASI) in some aircraft reflects data received from the Captain's system. Consequently, the crew must recognize that they need to use the First Officer's ADI, since the back-up system would provide the same erroneous data that the Captain's ADI displays..

Pilots also must recognize the conditions under which they should disengage the autopilot. The risk is that the crew fails to recognize when the autopilot adjusts to inflight problems without informing the crew, then reaches one or more maximum parameters and suddenly disengages. The crew then may be unprepared to respond properly and quickly, as all the correcting configurations selected by the autopilot suddenly disengage, and the aircraft is thrown into some severe maneuver. In the end, automation often requires that pilots combine basic flying skills with the skills of a systems analysts, and can combine those sometimes disparate skills in an environment that might require instant decision making. These issues remain real, but they have been reduced by concentrated training and by the benefits of time, which has increased pilot experience with automation and has made pilots much more comfortable with contemporary systems. Those systems have evolved from the glass cockpit to fly-by-wire aircraft, as aircraft increasingly manage flight controls electrically, without the use of cables and pulleys.

In the end, the net benefit to safety has been substantial. To appreciate the scope of advances and their meaning for safety, we need only to look at the cockpit of a DC-7 or Constellation, or even that of a first-generation jet. We would see remarkably stark cockpits that offered limited information and even less assistance to crews. Automation has improved safety by increasing position awareness, by making more precise maneuvers and operations possible, and by eliminating numerous factors that once were common in accident scenarios, such as CFIT, midairs, running out of fuel, getting lost, losing control in flight, landing short, etc. While the risk of such events is hardly zero today, their frequencies have collapsed, as indicated earlier by Figures One and Two.

## SURVIVABILITY AND CABIN SAFETY.

Engines, airframes, ATC technology, onboard automation and avionics have clearly improved the ability to avoid aviation accidents. Not only have we reduced the rate and number of accidents, but also more people can expect to survive the rare occurrence of certain kinds of events due to aggressive changes in regulations governing cabin safety.

Large numbers of people have survived several accidents in recent years that would have been deemed "nonsurvivable" just a few years earlier. In August 1988, a 737 was destroyed by fire after an aborted takeoff; 94 of 108 people onboard survived the intense fire. In its investigation of the accident, NTSB officially found the 94 survivors were saved by the benefits of new cabin safety regulations that required fire-blocking seats.

On March 17, 1991, an L-1011 carried 231 passengers and crew on a transatlantic flight. In mid-flight, a fire started beneath the cabin floor. The crew used a Halon 1211 extinguisher to fight the fire through the air-return grill. The Halon penetrated hidden voids and spaces beneath the floor to extinguish the fire. Those spaces would have been inaccessible with other equipment, and the aircraft would have been lost. Instead of resulting in a catastrophe, the aircraft completed the flight with no injuries among the 231 people onboard. Though Halon has been replaced with other fire-extinguishing agents due to concerns about the ozone layer, the benefit of such systems has been demonstrated several times since the 1991 incident.

Perhaps the most dramatic evidence of the positive effects of changes in cabin safety came from the accident at Sioux City in July 1989. A DC-10 lost an engine that severed the aircraft's hydraulic systems, limiting the crew's control to the use of thrust from the remaining engines. The DC-10 crew became national heroes, as did some air traffic controllers. The crew nearly made a miraculous landing, but the aircraft banked before touchdown and cartwheeled into a ball of fire, which was caught on camera and replayed around the country for days. Tragically, 111 people died in the accident, but, remarkably, 185 people survived what everyone just a few years earlier would have recognized as a non-survivable crash.

The list of heroes could have included FAA and other safety advocates who had worked to increase seat strength, to reduce the speed at which fire could spread through seat materials, to reduce toxic emissions from cabin materials, etc. Other heroes could have included FAA and other safety advocates who were responsible for tougher emergency preparation standards at the Nation's airports.

The 3 events cited above (Sioux City, the L-1011 transatlantic fire, and the August 1988 accident) took a total of 125 lives. However, the 510 people who survived those events offer tangible evidence of the benefits that came directly from improvements in cabin safety.

For years, aviation accident investigators and safety analysts had recognized that people often survived an accident's impact but then succumbed to post-crash fire or smoke. This led to major efforts to improve cabin safety and give crews and passengers crucial extra seconds to evacuate safely after an accident.

Top on the list was the need to reduce the rate at which fire and toxic smoke spread through an aircraft. FAA first targeted seat cushions in 1984 by requiring for more demanding flammability tests on seat bottoms and back cushions. This led to new seat materials and fire-blocking layers that slow the speed at which fire can spread and reduce the emission of toxic smoke. In 1986, then again in 1988, FAA built on these new flammability standards for seats by requiring more demanding flammability tests for all aircraft interiors, such as wall panels, overhead bins, floors, etc.

Seats also have been strengthened to withstand greater impact forces. All seats on aircraft manufactured after June 16, 1988 must withstand an impact of 16 Gs, versus the old standard of 9 Gs. The 9-G seat had performed well, but the 16-G seat established a greater safety margin for passengers.

In December 1984, the FAA took a related step by requiring fire-resistant emergency slides on air transport aircraft, and set radiant testing procedures for that purpose. Two years later (November 26, 1986), FAA required all air transport aircraft to be fitted with emergency floor lighting to lead passengers to emergency exits in the darkness that can accompany emergency evacuations.

Other efforts to slow the pace at which fire or toxic smoke can spread in an aircraft involve some obvious steps: state-of-the-art fire extinguishers and smoke detectors. The FAA began upgrading those requirements in 1986 and 1987. For example, at least two hand-held Halon 121 fire extinguishers were required in the cabin of all aircraft as of April 29, 1986. Lavatories were required to have smoke detectors as of October 29, 1986, and lavatory waste receptacles had to have built-in fire extinguishers as of April 29, 1987. Finally, the FAA required protective breathing equipment, such as smoke hoods, for flight attendants as of July 6, 1989.

Beginning in 1986, FAA took action to strengthen fuel tanks and reduce the risk of rupture in on impact, then began work on standards for more heat-resistant liner panels in cargo and baggage compartments so fires erupting in cargo bays could be better contained. The objective was to replace less heat-resistant aluminum and glass fiber-reinforced resins with more fire-resistant materials. All subject aircraft had to comply by March 20, 1991.

Other recent improvements include restrictions on the amount of carry-on luggage to reduce injuries from debris and the danger of tumbling, heavy objects during an evacuation (1987). FAA then established a maximum distance of 60 feet separating any seat from an exit (July 24, 1989), and required an independent power source for public address systems in large aircraft to assure communication with passengers in an emergency (November 1990).

Though the efforts to improve cabin safety have proven their value, they also offer good examples of how regulatory proposals generate legitimate and politically sensitive differences in perceptions and preferences.  Some in the industry criticized the FAA for going too far too fast on too little definitive evidence.  Simultaneously, some safety advocates criticized FAA for not going far enough fast enough on what they perceived to be compelling evidence.

Yet few now dispute the net benefits from most of the advances made in cabin safety from the mid-1980s through the mid-1990s.  Advances admittedly have slowed since that period, but new efforts continue, with attention focused on evacuations, the circulation of potentially noxious fumes within the aircraft, etc.  The strength of seats also continues to get some attention.  The debate wrestles with a desire for still stronger seats than today's 16-G standard versus the possibility of strengthening seats beyond any meaningful benefit to an occupant.

However the net result of the advances in cabin safety, again, have been tangible.  Many more people survive the increasingly rare life-threatening accident when it occurs.

## SIMULATION & TRAINING.

Advances in simulators have been the single most important safety advance in the field of training.  Basic simulators have been in fairly common use since WW II, when the military developed them to help train large numbers of new pilots quickly.  However, at their best, early simulators gave pilots very limited practice in prescribed procedures for selected maneuvers and emergencies, and did so , under sterile conditions,.

The first modern simulators essentially were boxes with single-channel, 3-axis systems (pitch, yaw and roll).  This first generation could try to replicate only a fixed airport and fixed terrain, and could not realistically replicate a given approach path and landing.  Visual scenes, based on movies of final approaches, were greatly improved with the introduction of video map models.  This began the representation of "real" terrain.  However, the scanned map projected TV screen images, which were less than sharp, and they provided only limited depth perception by presenting the image with angular mirrors.  This system was followed with digitized visual systems, which created more accurate and varied visual fields, but the system was limited to lighted points in a nighttime field.

This was the state of aircraft simulation as recently as the second oil crisis in the late 1970s.  "Training" still meant preparing for flight checks that included several steep turns, some engine-out procedures, and other limited exposure to prescribed procedures.  However, pilots could not gain airborne experience either in training or in a check ride in the more challenging and more dangerous scenarios, such as wind shear, severe wake turbulence, or serious events close to terrain.  Those pilots who had experience with such events got it for the first time in normal air carrier operations with people on board.

However, the second oil crisis and a long list of flight training accidents stimulated the demand for more capable and realistic simulators.  With fuel prices abruptly doubling for the second time in just 4 years, the airlines sought some cost relief by petitioning the FAA to substitute certain simulator training for the required airborne training. FAA agreed that this made sense, provided that simulators accurately represented real aircraft behavior in actual line operations. Disciplined testing quickly revealed they did not. FAA then identified the standards that a simulator would have to meet in order for a pilot to receive full training credit in a simulator. FAA established three phases of capability, in which simulators that included an increasingly comprehensive range of real aircraft behavior in real scenarios could satisfy different levels of training. The requirements went well beyond the state-of-the-art in simulators at the time, but created a set of performance requirements that simulator manufacturers around the world immediately scrambled to meet with new product development.

As a result, the regulatory process proved to be the catalyst that transformed simulators and training. In order to realize the efficiencies associated with reduced training costs that simulators might offer, air carriers immediately negotiated orders for increasingly sophisticated simulators that would meet the next increment in accurate aircraft simulation.

This required a burst of research into actual aircraft behavior in all flight conditions needed for training. The massive effort, accompanied by rapid advances in computer technology, led relatively quickly to the upgrade of late-model existing simulators. These Phase I simulators (later called "Type B") included improved aerodynamic modeling and 6-axis motion systems that more accurately replicated real aircraft behavior in many line operations.

These Type B simulators were a major advance in training technology, but still were quite limited as substitutes for airborne training requirements. Accredited training in this generation simulator was limited to landing and approach maneuvers necessary for pilots to meet currency requirements. All other airborne training previously required for a pilot to be rated in a new aircraft, to upgrade from the right seat to the left seat in an aircraft type still had to take place in an airborne aircraft.

The air carriers' desires to substitute simulator training for more training requirements, and eventually a full range of requirements, led to the development and purchase of new "advanced simulators." These simulators (later "Type C") included dusk vision with actual terrain, and actual runways, complete surface conditions, structures, and other ground obstacles. Type C also added weather conditions and other environmental factors, such as ice on runways, variations in wind velocity and direction, windshear, etc., plus a comprehensive range of other emergency scenarios.

This was the leap in realism the industry sought. Type C simulators were authorized to substitute for most training requirements, except initial training. That is, a pilot would still have to learn to fly an aircraft type by indeed flying it. Nevertheless, all other training requirements could be met in a Type C simulator, which achieved substantial savings for the carriers. In addition, pilots could gain real experience in actually handling various emergencies; actual experience with windshear, for example, would no longer have to wait for the pilot's first airborne encounter in a real aircraft with real passengers onboard.

Type D simulator, the most advanced as of this writing, have reached the goal of substituting for all training requirements, including initial training. Pilots no longer must learn to fly in real aircraft, which would carry real risk. Instead, pilots can learn to "fly" a simulator, and can gain a full range of first-person experience with a whole host of actual emergencies.

Type D simulators also have added more realistic, digitized daylight views of airfields around the world. The remaining challenge in simulators rests with "fidelity," or the assurance that the simulator can reproduce actual aircraft behavior in all scenarios. Simulators are routinely auto-checked to test their fidelity, and the fidelity in fact is excellent for most scenarios. However, some issues remain beyond the reach of simulators, such as the sensation of G-loads, extreme scenarios for which actual data has not been or cannot be captured, etc. Nevertheless, with precious few exceptions, flying a simulator is like flying the aircraft; the cockpit of a simulator *is* the cockpit of an aircraft.

The real impact of Type D simulators is the realization of the fundamental goal that helped to drive the remarkable advances in simulation: the simulator has replaced the airplane as the vehicle for flight training. Simulators provide a safe and very realistic laboratory for new approaches in crew resource management. Today, every common aircraft in the commercial passenger fleet is simulated, including regional aircraft with fewer than 30 seats.

Equally important to the flying skills that could be taught in a simulator, the safe laboratory also revolutionized the way in which crews were trained to work together. Because real aircraft had to be used prior to the modern simulator, training programs reflected broader cultural traditions in the industry at the time. Captains were trained only with other captains, while first officers were trained only with other first officers. Flight attendants were not even part of the conversation at the time.

Everyone consciously hoped or subconsciously assumed that these separately trained crewmembers would work well together. However a long history of accidents clearly indicated that crews did not always work well together. At least in selected cases, accident histories identified two extremes in the relationship of a Captain and First Officer during an accident flight. Some First Officers were found to be so passive and/or some Captains were so domineering that the First Officer provided little or no help, and may even have been an added burden during an emergency. At the other extreme, First Officers had provided accurate assessment of emergency situations and had recommended appropriate corrective action during an accident flight, but were utterly ignored by the Captain.

When crew dynamics broke down, the failure essentially was accepted as something about which we could do very little. That passive acceptance changed with simulators. Pilots now are trained to fly aircraft and to work with crewmembers. The effort began in earnest in the late 1970s through the 1980s with Crew Resource Management (CRM), as Captains and First Officers were trained together and trained to work together. By the early 1990s, the "C" in CRM had changed to "Crew" and reflected a broader recognition that entire crews, including cabin crews, needed to work together.   With accurate simulation, trainers suddenly acquired a realistic laboratory in which to address the psychology of safe flight in a realistic operating environment.

The change in cultural values displayed in the cockpit and in the interaction of all crewmembers cannot be overstated.  This does not mean that all Captains and all First Officers now work well together all the time, or that all flight crews work well with all cabin crews.  The change, though, indeed has been enormous.  Captains no longer are expected to know everything about everything, while First Officers and cabin crews are expected to contribute real skills and judgment to the operating environment.   Though issues of crew coordination still appear in accident scenarios, their frequency has collapsed.

Today, crews, get hands-on experience with real-time problems, complete with acceleration, full motion sensations, and real aircraft behavior.  Simulators let us practice and train in maneuvers and scenarios that really happen, but would be far too dangerous to practice in a real aircraft, such as getting out of windshear, losing one or more engines on rotation, etc.

Simulators also have added a realistic laboratory to accident investigation.  With the use of digital flight data recorders, accident flights can be recreated and "flown" in simulators.  Actual flight behavior and conditions then can be analyzed to identify chains of events we might never have considered before, or at least never have been able to confirm in the past.  The end result for accident investigation has been that simulators offer the best source in some cases for testing or even discovering how accident chains can be broken.

## WINDSHEAR

A 1975 accident at JFK was the definitive accident in which the aviation community established the way in which windshear interacted with large aircraft.  Windshear had been a primary factor in at least 2 other hull losses involving large passenger aircraft (a Pan Am 707 in January 1974 at Pago Pago, with 97 fatalities, and a non-fatal DC-9 accident at Chattanooga in November 1973). Other examples may have existed, but windshear was seldom identified with accidents at the time, because the aviation community had only a limited understanding of precisely how windshear and, especially, microbursts interacted with large aircraft.  Investigation of that accident eventually established the scientific evidence that significantly improved the understanding of that interaction.

However, windshear accidents continued to occur.  Just 11 days after JFK, Continental Airlines lost a DC-9 at Denver in a non-fatal windshear event.  The following June, an Allegheny DC-9 was destroyed on approach to Charlotte in another non-fatal windshear event.  Several years later, in July 1982, Pan Am lost a 727 on takeoff from New Orleans with 145 fatalities.  The watershed event, however, occurred in Dallas on August 2, 1985 (134 fatalities).  That accident led to immediate and sustained efforts to develop or to accelerate ground-based and on-board windshear detection systems, Doppler radar, better weather forecasting and dissemination of weather information, plus windshear escape procedures and training programs.

While each of the improvements was significant in its own right, together they illustrate the potential benefits from coordinated and focused actions by government and industry. That is an important idea in current and future efforts to drive the fatal accident rate even lower than it is today. The procedures and training programs also illustrate the significance of contemporary simulators, which enabled crews to experience how real aircraft behave in real windshear and to experience real escape maneuvers. Such realistic training would not have been remotely possible just a few years earlier.

## CONCLUSION, PART ONE

If accident rates of just 20 years ago had remained place, let alone those of 40 years ago, the demand for public action would have been so great that governments would not have been permitted to let the industry develop to the state that most of us take for granted today. Instead, the advances noted above, plus steady and on-going incremental improvements over the past 5 or 6 decades, have brought us to today's low accident rates. The challenge now, of course, is to achieve major and sustained reductions in an already low rate.

## PART TWO: RECENT AND FUTURE IMPROVEMENTS IN AIR CARRIER SAFETY

The challenge now is to ensure a sustained decrease in the already low fatal accident rate in much of the world. The reasons are both complex and simple. The simple reason is the self-evident value and virtue of saving lives. The more complex reasons ironically are the result of the aviation community's past success. Major accidents have become such rare events that they are no longer acceptable to the public. The public assesses the safety of commercial aviation by a de factor standard of zero accidents. Both industry and governments must respond to that de facto standard. At the same time, when the rare major accident does occur, it can threaten the survival of any air carrier. As a result, everyone in the aviation community, whether in government or industry, is damaged when a single carrier suffers a single major accident. Everyone in the industry is truly a hostage to everyone else.

So, how do we drive the already low rate even lower? One answer will be the cumulative effects of incremental improvements, such as a new or revised rule procedure or piece of equipment here and a revised rule there. That has always been the source of significant progress, at least in the long-term aggregate. However the challenge is to achieve a significant and sustained reduction in the already low fatal accident rate rather than imperceptibly gradual improvements. At least four factors may produce just such a reduction: (1) fleet turnover; (2) new analytical capabilities with routine operational data; (3) a change in the industry-government relationship that enables the entire community to focus on those areas with the highest risk; and, (4) perhaps most revolutionary of all, Required Navigation Performance. Each of these changes is already underway to varying degrees. The sum of their impacts have begun and will continue to accelerate the next significant reduction in the fatal accident rate.

## One Level of Safety and the Regional Jet Revolution.

As of the early 1990s, the "commuter industry" (FAR Part 135) was dominated by turboprop aircraft with 30 or fewer seats. That segment suffered an unusually high number of major accidents from the late 1980s through 1992. This led the FAA in 1994 to mandate that all scheduled passenger operations on aircraft with 10 or more passenger seats would be subject to the more demanding rules of Part 121 operations as of spring 1997. The rationale was two-fold. First, FAA asserted that any passenger buying a ticket on a scheduled air carrier was entitled to the same level of effort by the Federal Government. Second, that ear had witnessed the growth of codesharing between established mainline operators and less well-known regional operators in which the regional airline operated under the name of the better known mainline carrier. More than a few passengers were buying tickets with the assumption that they indeed would be flying the mainline carrier for their entire trip, only to discover that they were not. Though the regional carriers were inherently quite safe, a significant share of the traveling public felt something was amiss.

One of the effects was to eliminate what had been an unintended distortion of the older regulatory regime. Under FAR Part 135, training requirements were less demanding and therefore less costly, and aircraft could operate without certain equipment. Carriers also could operate without dispatch services and other requirements faced by carriers that operated under FAR Part 121.

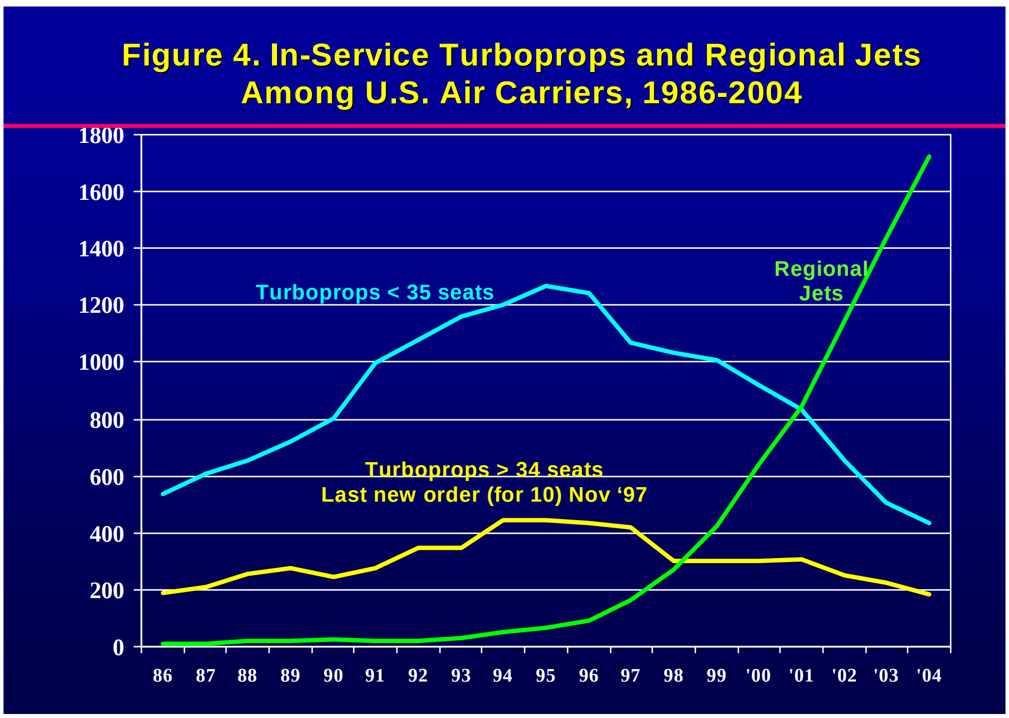
Given the criterion of 30 seats, carriers typically operated aircraft at or near 30 seats, or aircraft with a minimum of 40 or more seats. The marginal benefit of operating aircraft with a capacity in the low to mid-30s would be more than offset by the increase in costs. In the end, the former regulatory regime had posed an economic disincentive against upgrading the commuter fleet.

Since the One Level of Safety rule went into effect in spring 1997, the frequency of accidents among the operators who were forced to migrate into FAR Part 121 has collapsed. Presumably the required changes in training, operating procedures, and the like explain much of the improvement. However, much of the improvement also can be explained by a revolution in the fleet that was partly underway of its own weight, but which was greatly accelerated by the removal of an inadvertent regulatory distortion of the industry's structure. The bottom line has been an explosion in the number of regional jets (RJs) in the U.S. fleet and the simultaneous collapse of the turboprop fleet. The scale and speed of the change in the fleet is hard to overstate, as illustrated in Figure 4.

The net effect has been a thorough change in the structure of the so-called regional industry, to the point where the very label of "regional" is somewhat outdated. Much like the fleet revolutions of the late 1940s and then the jet era, the extended range of the RJ fleet has opened a matrix of new city pairs to non-stop service and has made travel on existing "regional" city pairs faster a somewhat more comfortable. In short, the RJ revolution has changed the structure of the air carrier industry.

It also has influenced safety.  Though turboprops are sophisticated, safe aircraft in their own right, and constituted a major improvement in regional safety from the piston-powered fleet it replaced, RJs indeed are jets.  As such, their power plants are more reliable as they simply have few moving parts, with no props and related transfers of power to the props.  RJs also have more sophisticated avionics than the aircraft they are replacing.

Skeptics can note that RJs also brought some tradeoffs in new safety challenges, such as an unprecedented number of pilots from upgrading all at once into jets, or the use of "hard wings" on first-generation RJs (i.e., no forward-edge slats), which experience had shown were vulnerable to icing.  Nevertheless, the net effect of the fleet change has been a significant improvement in safety.



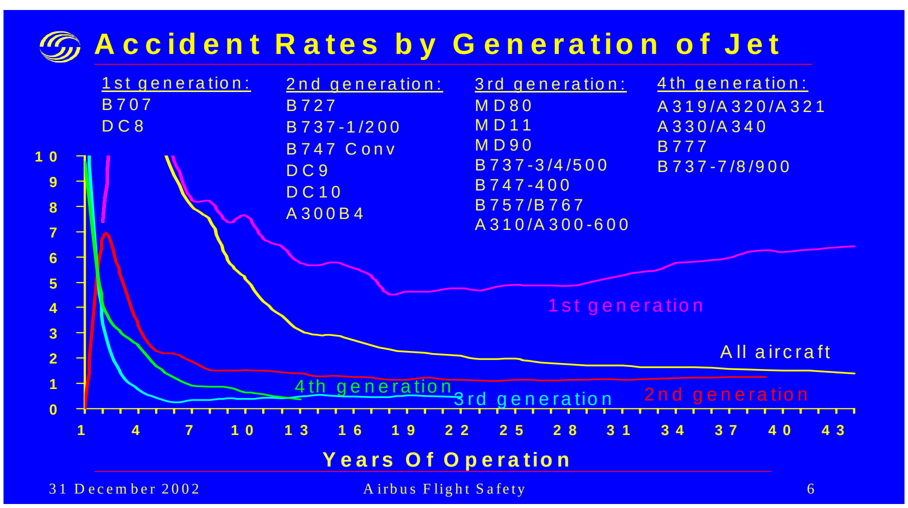

## Fleet Changes Among Large Jets

Changing fleets always have been persistent sources of improved safety, with the RJ adding just one more example.  As already noted, the post-war fleet improved safety significantly.  Shortly thereafter, the jet utterly revolutionized the fleet and safety.   Every generation of jets since the Boeing 707 and DC-8 has improved safety even further with advances in avionics, engine reliability, automation, etc.

Though each new generation of jets has a relatively high accident rate early in its service life, Figure 5 illustrates that each new generation of jets enters service with a lower initial accident experience than each preceding generation. In addition, the learning curve is shorter lived for each new generation compared to preceding generations. Each generation then reaches a stable accident state more quickly and that stable state is lower than for each preceding generation. Note that Figure 5 is a product of Airbus, but Boeing has published comparable charts for years that illustrate the same points.

The bottom line has been that fleet turnover, by itself, typically has led to about a reduction of about a third in fatal accident rates over each 10-year period since the start of the jet age, and even before the jet age. With fourth-generation jets already in service, such as the A320 family and the Boeing 777, other fourth-generation jets will be entering the fleet in the next several years, including the A380 and the Boeing 7E7. At the same time, the Boeing 737-800 and 900, which are recent arrivals, will rapidly increase their presence in the fleet. All these makes/models will constitute the most automated aircraft in aviation's history, only to be surpassed eventually by the next generation of new designs.

**FIGURE 5**




Note: B737-800/900 added by author.

## Analysis of Routine Operational Data

For several decades, the aviation community in the U.S. used operational data only as part of an accident or incident investigation. With cockpit voice recorders and flight data recorders (FDRs), operational data on accident or incident aircraft was relatively complete and helped the community to learn a lot about what went wrong in accidents and incidents. We could study FDR parameters in extreme events, and we could review design criteria that identified the edge of the envelope, which is not unlike knowing the extreme. However, we knew far less about how aircraft were flown on normal flights, on normal approaches or normal departures to and from runways under normal or at least common circumstances. In short, we knew little about what constituted a normal flight.

Though Japan and much of Europe had been using FDR data on selected parameters from normal, safe flights as part of their routine safety analysis for years, several factors precluded that practice in the U.S. until the late 1990s. One major factor was a litigious legal tradition in which the safety data might be obtained and then misrepresented by litigants. Carriers were weary of collecting data that might be used against them in a civil court. Similarly, a traditional of adversarial relations between the government and industry made the carriers weary of collecting data that FAA might use against them in the enforcement of regulations. Finally, an equally adversarial tradition of industry-labor relations made pilots very suspicious of exactly how their employers might use operational data from routine downloads of FDR data.

However, this began to change with rapid advances in the number of parameters that could be recorded and in the frequency with which parameters could be sampled, then equally rapid improvements in tools that were available to analyze this new quantity of data – this new avalanche of data. Early FDRs had a relatively few basic parameters, such as speed, time, altitude, pitch, magnetic heading and climb rate. By the early 1990s, FDRs in the third generation of jet aircraft were recording up to 125 channels. Knowledge about accidents and incidents suddenly got much better, but knowledge about routine flights did not improve.

In May 1995, FAA first began to advocate systematic use of FDR data and voluntary reports from crews when Administrator David Hinson delivered the keynote address at the annual Wings Club meeting in New York.[6] Hinson argued not only that the industry and government needed to make better use of routinely available data, but that the basic premises in the industry-government relationship needed to change. The basic argument was that the command-and-control model of mandating safety improvements by regulation and then inspecting to ensure that those regulations were being followed had produced nearly as much safety as they would ever produce. Conversely, the industry's self-interest in reducing the accident rate made the adversarial relationship between FAA and the industry obsolete. Hinson concluded by arguing that a new model was needed.

The basic premise was that systematic use of operational data from every-day flights that ended safely could define "normal" in a statistically meaningful way. Only then could "abnormal" be identified from the same data source, via statistical outliers or by identifying events that exceeded defined ranges of acceptable performance. The notion came to be identified in the U.S. as Flight

[6] See "A New Paradigm for Aviation Safety;" FAA Administrator David Hinson and Robert Matthews, Wings Club of New York, May 1995.

Operations Quality Assurance (FOQA), while other regions of the world identified the notion as Operational Data Analysis (ODA).

Regardless of the preferred term, to be most useful, the data would need to be shared system-wide, among carriers and between carriers and government. Ideally such data could be strengthened with the use of comparable data from the ATC system and by voluntary crew reports. The key though, as Hinson noted then, was to ensure that the data could not be used for punitive purposes by FAA, employers or even by civil courts, and that it would not be vulnerable to popular misrepresentation.

This stimulated a debate within the U.S. aviation community that only recently approached resolution. Though few challenged the intellectual case that Hinson had presented, debate and opposition were often intense due to the core issues identified above: a lack of trust between employers and employees, and a lack of trust between pilots and FAA and between carriers and FAA. The only "technical" objection focused on the capacity to analyze the mountains of data that daily operations could generate. However, rapid improvements in computer capacity, analytical software and data displays resolved that issue and moved the possibilities well beyond the practices in place among some non-U.S. operators.

**CAST.** In the interim, the industry and FAA entered several significant efforts to build trust by jointly analyzing historical accident data and to identify a single set of accidents that needed to be targeted to reduce the accident rate even further. Efforts were undertaken with engine manufacturers and then airframe manufacturers. However the major advance came in the creation of the Commercial Aviation Safety Team (CAST).

CAST started in 1997 and quickly included representation from FAA and NASA, as well as major carriers, major aviation labor organizations, aircraft manufacturers, engine manufacturers, avionics manufacturers and the International Civil Aviation Organization. Corporate members typically were at the level of vice president, while FAA membership was at the level of Associate or Assistant Administrators.

CAST then employed a structured mechanism, with explicitly defined procedures for joint analysis of selected accident types, then joint assessment and endorsement of interventions, complete with jointly developed and jointly endorsed implementation plans. Teams with professionals from all interested CAST organizations have conducted the analyses and developed proposed interventions and implementation plans. CAST members then review the products and vote yes or no. Unanimous votes are required to endorse plans.

Given the level of these members within their respective organizations among unions, operators, manufacturers and government, unanimous endorsement makes actual implementation a realistic expectation. Though many ad hoc efforts with similar intentions had been initiated for years, this was the first such effort that included a credible mechanism for implementing the results of joint analysis and jointly developed plans, with the respective obligations of all parties clearly identified.

Industry recognized that it needed government involvement to accomplish many of its objectives. Similarly, government recognized that, if indeed the old regulatory model had yielded nearly all it could yield, government needed to work through and with the various segments of the aviation industry to improve safety. Granted, early progress was slow as industry and government officials worked to build trust among themselves, and as competitive rivals got used to sharing what was once considered sensitive corporate information. However, those growing pains subsided and CAST has since evolved into an effective mechanism that indeed has produced results.

All CAST members have taken some risk in cooperating with each other. FAA risks being criticized for being too close to the industry it regulates. Officials from pilot unions face a similar risk of being perceived as too close to management or to the FAA. Companies risked airing some of their dirtier laundry with competitors and with FAA. Everyone risked having priorities re-arranged. Yet, the effort has been successfully addressed CFIT accidents, loss of control, approach and landing accidents, turbulence, and runway incursions, with work underway to on maintenance, near midair collisions and issues that are unique to cargo. In 7 years, CAST has managed to build both intellectual and professional trust that simply did not exist in the past between FAA and the industry.

**FAR 193 and FOQA.** CAST added both some level of trust and its own analytical findings to the case for FOQA and ASAP programs. Simultaneously, with improvements in analytical tools, the economic benefits of using FOQA data became self-evident. Carriers could now monitor the health of various aircraft systems and perhaps reduce premature replacement of parts and systems. Carriers could also hope to manage inappropriate and inefficient use of control surfaces in flight (such as high-speed slat deployment during approach), or the use of approach profile that regularly resulted in high g-loads at landing, or inefficient flight profiles that needlessly burned fuel, etc.

Efforts to use FOQA data internally within various air carrier properties (not among air carriers) started to build some level of trust with pilot groups. Typically, carriers and their pilot unions entered formal agreements on exactly how such data could be used and typically ensured a role for the unions in analyzing the data and/or in recommending any remedial training, but with the absolute assurance that the data could not be used for punitive purposes. However, efforts to get carriers to share the data among themselves and with FAA progressed much more slowly.

Finally in April 2003, under statutory authority granted by Congress and after several years of negotiating with the industry to ensure a workable system, FAA issued a new rule (FAR Part 193). The rule protected any data voluntarily shared with the FAA from punitive uses, “discovery” during litigation, or from public disclosure under Freedom of Information requests. Yet, exact procedures for sharing the data with FAA remained the subject of negotiation for another year.

As of this writing, the carriers and FAA are about to implement an agreement by which the carriers can share data with each other (which some carriers had already been doing) and with FAA through NASA as the honest third-party broker. Integration with voluntary crew reports, typically known as an Aviation Safety Analysis Program (ASAP), which is also protected by FAR 193, and operational data from ATC could augment existing databases to provide a truly comprehensive understanding of risks in the system and offer the opportunity to resolve them before they lead to accidents.

Early efforts to use FOQA and ASAP data cooperatively and without threat of punitive misuse have produced some positive early results. ATC data has been integrated with FOQA data to identify several approaches and departure routes where TCAS resolution alerts were especially common and, therefore, where the threat of midair collisions was unusually high. Similarly, operational data has been used to identify particularly difficult approaches where flight crews must remain high until very close to the runway, then descent quickly to the runway. Though each case thus far has been localized and not exactly page-one news, the improvements in systems safety have been real.

Similarly, many carriers have used FOQA data to analyze unstable approaches, a key pre-cursor in CFIT and approach-and-landing accidents. Based on these analyses, the carriers are emphasizing standard procedures during approach in their training programs and in their safety education efforts, in cooperation with their pilot unions. More challenging issues likely will emerge as candidates for joint analysis with the use of data from FOQA and ASAP programs, and from ATC data.

The potential for long-term safety benefit is enormous. Eventually, the knowledge gained on normal ATC operations could lead to new system models that account for different weather conditions, seasonal variations, unique (and newly recognized) characteristics of different aircraft types, etc. Ultimately, the knowledge gained from analyzing operational data could be added to the next generation of aircraft, ATC software and air-ground-air digital communications to account for any newly defined interrelationships. At the same time, everyone understands fully that the system must remain non-threatening to the sources of the data. If the system is misused just once or if it comes to be perceived as threatening by any of the interested parties, it will be doomed to fail.

## Required Navigation Performance (RNP)

Notwithstanding all the advances noted above, Required Navigation Performance (RNP) may be the best example of a contemporary safety advance that will offer compelling economic benefits to carriers. Consequently, the technology will penetrate the fleet rather rapidly.

RNP is an evolution of Area Navigation (RNAV). Consistent with the International Civil Aviation Organization's (ICAO) definition of RNAV, FAA defines RNAV as "a method of navigation that permits aircraft operation on any desired flight path within the coverage of stationreferenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these." RNP applies to "self-contained aids, or a combination" of self-contained and ground-based navaids.

With RNP, an aircraft essentially brings its own self-contained ILS system to all phases of flight and to any point in the world. Any airplane with dual inertial navigation, dual GPS and dual FMS will be able to go anywhere, provided the aircraft has an adequate database. Conceptually, the airplane will be able to find a prescribed piece of sidewalk, provided that the database has the sidewalk incorporated or the flight crew knows the precise coordinates for locating it. If the crew must enter coordinates, the aircraft basically will fly "dead reckoning" with its inertial system (i.e., the aircraft will know how long it has been flying various headings from a starting point and at what speeds and therefore will be able to compute its precise position).

The existing ground-based system has been improved incrementally over the years to deliver huge improvements in safety. Nevertheless, the system remains expensive, demands effective security, and still has relatively high failure rates. RNP allows the civil aviation system to reduce or, at some point, even eliminate its dependence on ground-based navigational aids.

In the terminal environment, the ground-based system is restricted by runways that are not equipped with ILS, and by the large, cone-shaped containment zones that spread out as we move back from the runway in order to ensure safe separation in lieu of possible navigational failures. As a result, maximum runway capacity remains relatively modest.

The enroute environment faces comparable limitations on accuracy and dependability. Aircraft still basically fly fixed routes from one navaid to the next. This is true, at some point, even with direct routing. Those limitations put enroute aircraft on fixed paths that require significant separation. This is especially true in the oceanic environment, which is beyond the service range of ground-based systems and therefore require enormous separation. Without RNAV and its next iteration of RNP, the efficient use of airspace in much of the world approached its conceptual limits several years ago.

At its core, RNP provides more precise navigation and tight "containment" within the airspace. An aircraft's capacity to take advantage of RNP will depend on the specific navigation sensors and equipment on the airplane, the precision and dependability of that equipment, plus the type, accuracy and dependability of ground-based systems.

ICAO has defined various RNP values for oceanic, en route, terminal, and approach and expresses "RNP Level" or RNP Type as a function of navigational precision (nautical miles from the intended centerline of a route, or flight path) and reliability. The required RNP level is shown on navigational charts and procedures. For example, an RNAV departure procedure may define eligible aircraft by citing "RNP-0.3" or "RNP-10." As the number associated with the RNP Level decreases, the required precision and reliability of on-board equipment and ground-based systems increases. A fully equipped aircraft can be expected to execute CAT III approaches to a decision height (DH) of 100 feet if the precision criterion satisfies .003 nautical miles (18 feet) and meets a reliability criterion of 99.999 percent of the time with RNP/RNAV.

RNP also is consistent with and supported by several key actions led by CAST. For example, CAST and its members, along with the Flight Safety Foundation, have focused on stabilized approaches, minimizing the use of non-precision or step-down approaches, establishing constant-angle approaches where precision approaches are not available, and establishing go-around gates in which the failure to meet several basic criteria will require the crew to go around rather than to continue and try to recover what is likely to be an unstable approach.

RNP is the product of innovations in communications and computing capacity. The communications link of course is based on satellite technology. However changes in computer capacity help to explain the rapid onset on RNP. Computer capacity required for the on-board database and data processing of GPS signals, FMS data, etc., would have precluded an aircraft from getting off the ground just 15 years ago. Instead, the fleet already includes aircraft that are fully RNP-capable.

Yet some barriers could limit or delay the full benefits of RNP. For example, large segments of the aviation community will still require ground-based navaids. This will hardly stop RNP, but it will limit the fiscal benefits for air traffic service providers. In addition, concerns about wake turbulence will limit the application of RNP on closely spaced parallel runways with simultaneous operations. Similarly, some controls may be required to ensure that a light jet does not position itself behind and below a heavy jet on approach or departure.

Perhaps the most significant barrier or source of delay could be the pace at which some carriers incorporate RNP requirements into their fleets. If a majority or even a significant minority of the fleet were to have limited RNP capability well into the future, the mix of traffic could restrict the availability of RNP procedures in the airspace system. This, in turn, would negate benefits to carriers that are anxious to use RNP procedures and thereby perhaps slow the pace at which those carriers choose to add RNP capabilities. In the end, this domino effect would substantially slow the pace at which airspace efficiency improves.

In the end, civil aviation authorities (CAA) may have to exercise their regulatory powers to ensure that the economic incentives inherent in RNP remain compelling. At busy airports during periods of congestion, CAAs may have to limit access to aircraft with RNP capability. For example, landings and departures at, say, Chicago O'Hare or San Francisco between 0600 an 1000 or 1530 through 1930, might be restricted to aircraft that meet a specific level of RNP capability. Carriers that expect to compete at such airports during peak periods then would indeed have a compelling economic interest in RNP.

However, none of the above barriers will stop RNP and very likely will not be permitted to cause significant delays in the application of RNP. In fact RNP is already underway. ICAO and some Member States have designated a number of RNP procedures. For example, RNP-10 routes have been established in the North, Central-East and South Pacific in which lateral separation of flight tracks has been reduced to 50 nautical miles. Granted, 50 miles of separation remains a lot of airspace, but it is a major improvement in the efficient use of oceanic airspace. States in Europe also have designated RNP-5 procedures and most arrivals in many countries already have designated RNP Levels.

When RNP is fully implemented, it will establish precise lateral and vertical guidance to and from any runway or any other targeted spot in the world. It will improve situational awareness for pilots and ATC, and it will smooth out traffic flow even while significantly reducing required separation buffers. It will reduce workload for both pilots and controllers as pilots and, more significantly, the aircraft will know precisely where the aircraft is within a tightly defined 3-dimensional piece of airspace.

The changes will greatly improve stabilized approaches, reduce the need for ATC to issue close-in changes in speed or heading, and will reduce the need for keeping aircraft high until they are close to the runway in order to keep traffic moving. Time and time again, a flight crew can expect to touch down with the nose wheel splitting the centerline. Yet, impressive as the arrival, approach and landing functions are, the precision that RNP brings to departure procedure is equally impressive. Departure becomes very precise, as in effect aircraft climb out on a reverse glide slope.

In the not-too-distant future, RNP will open huge portions of terminal airspace that is now obligated to separation. As a result, terminal capacity will increase by orders of magnitude, as will air carrier access. Simultaneously, carriers can expect more precise flight profiles, fewer go-arounds, etc. The promise of fuel savings, schedule reliability, consistently lower G loads, less frequent deployment of flight controls at inappropriate speeds, less frequent efforts to capture a glide slope or localizer at the last minute, plus the benefits of accident-avoidance already have made many air carriers anxious to implement RNP. Safety benefits will include lower risk of CFIT, loss of control or other types of approach-and-landing accidents, as well as accidents on takeoff and climbout. In short, RNP is on its way.

## CONCLUSIONS

The fatal accident rate has undergone several sharp and sudden reductions in the past half-dozen decades. Most of those sudden and sustained reductions have been driven by technological innovation, including constant fleet turnover, improvements in navaids, automation, etc. The fatal accident indeed has reached such low levels that trying to push it even lower can sometimes seem impossible or at least very challenging.

However, the next significant and sustained reduction in the fatal accident rate in fact is already underway and it will accelerate over the next decade or so. The sources of that reduction will include some factors that are familiar in their core attributes: technology and fleet turnover. However, some new factors also will help to drive the fatal accident rate ever lower, including fundamental changes underway in analytical tools and in the relationship between the industry and regulators.