Aircraft Accident Investigation in the Jet Age

This “Aircraft Accident Investigation in the Jet Age” essay is published on the ISASI web site as a memorial tribute to Stephen R. Lund who “flew west” on October 14, 2014. He was an ISASI member for more than 33 years, served as President of the Los Angeles Regional Chapter, participated in the ISASI annual seminars and contributed safety investigation articles to the ISASI Forum. Steve authored this work for a major television production, but much of it was not used. It is an excellent historical record of the era and well worth reading for the many memories it will bring some readers and for the new information it will give other readers.

Aircraft Accident Investigation in the Jet Age

By Steven R. Lund

--Flight Deck reconstruction of Swissair MD-11 following its crash into the N. Atlantic; Sept 1998. [TSB Canada photo]

ONA DC-10 RTO at JFK; Nov. 1975

The investigation of jet transport accidents has played a major role in the successful development of commercial aviation since the beginning of the era of passenger flying in jet powered aircraft in the early 1950s.

The development of jet engines during WW2 foreshadowed important milestones in commercial air transport. The first was the development of the De Havilland DH-106 Comet; the first large passenger transport aircraft powered by jet engines.

The jet engine's relatively simple, smooth operation and high thrust to weight ratio made it far superior to the previous reciprocating piston engines for use in transport aircraft because the jet engines enabled airliners to:

1. Fly much faster and higher: jets fly as high as 7—miles above the earth at speeds of 80 to 90 % the speed of sound;
2. Being much more reliable, jets required far less maintenance, therefore were far more economical for airlines.
3. Operating with fewer moving parts, at much lower vibratory stresses, jets were less likely to fail; hence, were also much safer.

The first jet powered aircraft were developed and flown by the Germans and English during the last years of WW2. Surprising as it was for Allied pilots to see Nazi fighter-bombers buzzing their aircraft at more than twice their piston powered aircraft's speed, there apparently were not enough Nazi jets to affect the outcome of the war.

Even though the jet engine technology was available to the Allies, the number and demonstrated successes of both the 12-cylinder Rolls-Royce Merlin, piston powered *Spitfires* and the Merlin retrofitted American P-51s did not require the addition of any jet fighter use to win the war. The Supermarine designed *Spitfires* alone mortified the self-proclaimed Nazi Luftwaffe's air superiority during the battle of Britain; thus, halting any further German plans for an invasion of the British Isles.

Not surprisingly, the British, the first to refine the post-war jet engines initially developed and flew a jet powered commercial airliner.

The De Havilland Co., formed in 1920 by Geoffrey de Havilland, was first in developing and flying the jet powered De Havilland Comet. Design work began in 1946 with the intention to have a commercial aircraft by 1952. The DH-106 Comet first flew on July 27, 1949. The design was similar to other airliners except for the sleek swept-back wings; the pressurized cabin; and that four of the new, albeit underpowered, de Havilland Ghost -50 engines were mounted in pairs within each wing root. The airliner underwent approximately three years of tests and development enhancements; so the first commercial flights did not begin until January 22, 1952 with BOAC. The first long-range passenger flight was in May from London Heathrow Airport to Johannesburg. The airliners proved to be around twice as fast as contemporary piston-powered craft. Over fifty Comets were ordered after safely carrying approximately 30,000 in its first year.

Figure 1--Comet Mk1 G-ALYP during flight tests. It was destroyed in 1954 after crashing into the Sea near Elba Is. on a flight from Rome to London when it broke up in flight [British Airways photo].

The first accidents involving the Comet came on May 2, 1953 when a Comet crashed soon after take-off from Calcutta; followed by further crashes in January and April 1954. Investigators first attributed the Calcutta accident to an in-flight breakup from turbulence of a thunderstorm in which it was flying; but, with no clear cause of the subsequent two mysterious in-flight breakups, this led to the entire fleet being grounded for investigation. Following an intensive investigation by the Official British Investigators, including:

1. Wreckage recovery and reconstruction showing gouge marks across the upper surface of the reconstructed wing, which matched a jagged piece of fuselage structure being blown out across the upper wing surface;
2. Ground tests of fuselage pressure cycling eventually revealed the beginning of fuselage fatigue cracks emanating from stress concentrations at the sharp corners of the Comet's large rectangular windows in the fuselage.

It was unavoidably concluded in February 1955 that metal fatigue was the reason the fuselage structure failed in flight; after thousands of pressurized climbs and descents the aluminum fuselage metal around the Comet's right-angled large windows would begin to crack, which grew; eventually resulting in an weakening the fuselage to the point where the cabin pressurization loads caused an explosive structural failure.

All the remaining Comets were either scrapped or modified and the program to produce a Comet 2 with more powerful Rolls-Royce Avon engines was put on hold. Some Comet 2s were modified to alleviate the fatigue problems and served with the RAF as the Comet C.2, but the Comet did not resume commercial airline service until 1958, when the much improved Comet 4 was introduced.

Lessons Learned

Even though the original Comet designers were no doubt aware of metal fatigue; they might not have known over what time period or to what extent repeated pressurization cycles would have had on the overall crack strength of the fuselage.

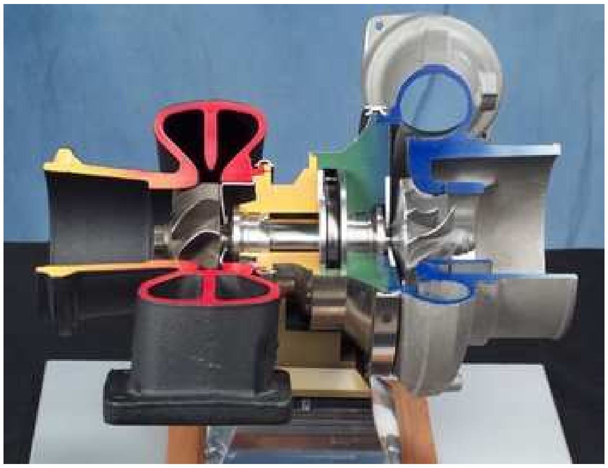
However, it is now a requirement for airliner manufacturers to conduct ground pressure tests demonstrating fuselage structural integrity after a number of pressurization cycles equal to two complete design lifetimes of the aircraft in order to certify any new aircraft for airline use.

In addition, frequent, periodic, detailed maintenance inspections designed to detect the beginnings of fatigue cracks are required during the operational life of all airliners.

Once the structural fatigue cracking problem became well understood as a direct result of the investigation of the DH Comet's tragic accidents, future jet transport structural designers developed elaborate new design features to deal with the problem by adding "crack stopping" structure and "double skins" in suspected highly stressed areas of the fuselage; such as around passenger window openings, to support loads in the event one skin layer began to fatigue.

American Jet Engine Development

When the United States entered World War I in 1917, the U.S. government searched for a company to develop the first airplane piston-engine "booster" for the fledgling U.S. aviation industry. This booster, or *turbosupercharger*, installed on a piston engine, used the engine's exhaust gases to spin a turbine driving an air compressor to boost power at higher altitude.



A turbocharger is a device used in internal-combustion piston-engines to increase the power output of the engine by increasing the mass of oxygen and fuel entering the cylinders. A key advantage of turbochargers in aircraft is that they offer a considerable increase in engine power with little weight increase.

General Electric accepted the challenge first, but another team also requested the chance to develop the *turbosupercharger*. Contracts were awarded in what was the first military aircraft engine competition in the U.S.A. Under wartime secrecy, both companies tested and developed various designs until the Army called for a test demonstration. General Electric demonstrated a 350-horsepower, *turbosupercharged* Liberty aircraft engine and entered the business of making airplanes fly higher, faster, and with more efficiency than ever before. That high altitude demonstration of the first *turbosupercharger* landed GE's first aviation-related government contract and paved the way for GE to become a world leader in jet engines. Because engineering principles and manufacturing techniques required for *turbosuperchargers* apply to gas turbines engines as well, GE was a logical choice to build America's first jet engine.

During the final years of WW2, England solicited Allied help in developing its newly patented jet engine. So, the British secretly shipped its jet engine, designed by Frank Whittle, to the U.S. Army. In 1941, the U.S. Army Air Corps selected GE's Lynn, Massachusetts, plant to build a jet engine based on the design of Britain's Sir Frank Whittle. Six months later, on April 18, 1942, GE's engineers successfully ran the I-A engine.

In October, 1942, at Muroc Dry Lake, California, [now Edwards Air Force Base] two I-A engines powered the historic first of a Bell XP-59A Airacomet aircraft, launching the United States into the Jet Age. (The thrust rating of the I-A was 1,250 pounds; the thrust rating of the GE90-115B engine on today's Boeing 777 is more than 90 times as great at 115,000 pounds.

Over the next two years GE developed improved engines, culminating in the J33 engine, which was rated at 4,000 pounds of thrust. The J33 powered the U.S. Army Air Corps' first operational jet fighter, the Lockheed P-80 Shooting Star, to a world's speed record of 620 miles per hour in 1947. Before the end of that year, however, a GE J35 engine powered a Douglas D-558-1 Sky streak to a record-breaking 650 miles per hour. The J35 was the first GE turbojet engine to incorporate an axial-flow compressor--the type of compressor used in all GE engines since then.

Figure 2-- a GE J35 engine powered a Douglas D-558-1 Sky streak to a record-breaking 650 miles/hour

Meanwhile, Back in Britain; BOAC ordered 19 Comet 4s in March 1955, despite the Comet 1's problems. The Comet 4 first flew on April 27, 1958, and deliveries to BOAC began that September. BOAC initiated Comet 4 service with a flight from London to New York via Gander on October 4, 1958. That flight was the first scheduled trans-Atlantic passenger jet service, beating Pan American's inaugural Boeing 707 service by three weeks.

Two other variants of the Comet 4 were developed. The Comet 4B included a stretched fuselage and shorter wings; it was targeted to the fairly short-range operations of British European Airways, which placed an initial order for it in 1958. The Comet 4B first flew on June 27, 1959, and BEA inaugurated services with in April 1960. The final Comet 4 variant was the Comet 4C, with the longer fuselage of the Comet 4B but the larger wings and fuel tanks of the original Comet 4, which gave it a longer range than the 4B. It first flew on October 31, 1959, and Mexicana started Comet 4C services in 1960.

In total, 76 Comet 4 family airplanes were delivered from 1958 to 1964. Although BOAC retired its Comet 4s from revenue service in 1965, other operators (of which Dan-Air was the largest and last) continued flying commercial passenger services with the planes until 1980. The last Comet flight was conducted in 1997 by a Comet 4C that had been owned by the British government.

Although the Comet was the first jetliner in service, the interruption of commercial service and the damage to the aircraft's reputation caused by the Comet 1 fatigue failures meant that the jetliner market became dominated by Boeing and Douglas; Boeing flew the first prototype 707 in 1954, and Douglas, which launched the DC-8 program in 1955. Only fifteen airlines ever used the Comet, the proposed Comet 5 was never built, and the Comet 4s were withdrawn from service.

The tragic accidents involving the first generation Comet notwithstanding, the legacy of the Comet remains with us even today. Not only were Boeing, Douglas, and other designers forewarned about the insidious "high-cycle" fatigue problems; but, the British accident investigators began to literally write the book on jet transport accident investigations techniques. The first International Civil Aviation Organization's (ICAO) [the aviation branch within the United Nations] ***ICAO ACCIDENT INVESTIGATION MANUAL*** contains detailed instructions for today's investigators, which is still in use world wide; including items as:

1. Methods of wreckage reconstruction and how to analyze the reconstruction;
2. Differences between pre and post impact fire evidence;
3. Methods to discern the cockpit instrument readings at impact.
4. Microscopic analysis of metal fractures;
5. Flight Data and Cockpit Voice Recorder data reduction techniques;
6. Engine failure analysis;
7. The importance of crash victim forensic and toxicological evidence.

Modern computer analysis and other laboratory techniques coupled with those original methods used in the Comet investigations are widely used in today's investigations.

Except for the accidents caused by fatigue cracking on the DH Comet, the accident frequencies during the initial years of operation of the B707 and DC-8 were comparable to the early Comet record of accidents.

The British Aircraft Corporation began the next innovative jet transport design; a 79 seat, short range airliner with two Rolls Royce Spey engines rated at 10,400 pounds of thrust. It was to be the successor to the Vickers Viscount[1] of the 1950's. Production was undertaken at Bournemouth, where the prototype flew on 26th August 1963. The design incorporated the horizontal tail on top of the vertical tail. This "T" tail configuration was quite new and was mainly used to accommodate both engines mounted on the aft fuselage, behind the passenger cabin. This T-tail kept the horizontal tail was well away from the hot engine exhaust and had other performance advantages. However the T-tail configuration caused serious pitch control difficulties with the airplane at high pitch angles because the turbulent wing wake would tend to "blank" out the horizontal tail's control surfaces; rendering pitch control ineffective with the craft at high angle of attack, such as during an aerodynamic stall maneuver, which was not normally made in normal operation; but had to be demonstrated during flight test certification, which was the case in Oct.1963 when the One-Eleven prototype was engaged in a series of test fights to

[1] [1] The **Viscount** was a medium-range turboprop. A **Turboprop** or **turboshaft** engine is a type of gas turbine. It differs from a jet engine in that the design is optimized to produce rotating shaft power, instead of thrust from the exhaust gas.

assess stability and handling characteristics during the approach to, and recovery from the stall with a centre of gravity in varying positions. On the fifth stalling test, at a height of about 16000 feet and with 8deg of flaps, the plane entered a stable stall. The 1-11 continued to descend at a high vertical speed, and in a substantially horizontal attitude and eventually struck the ground with very little forward speed.
PROBABLE CAUSE: "During a stalling test the aircraft entered a stable aerodynamic stalled condition, [*Deep Stall*] recovery from which was impossible."

Once again a jump in aeronautical technology by the British Aerospace Industry forewarned the World's aeronautical community of a design trap they must deal with extreme caution. The accident investigation of the BAC1-11 flight test accident provided future designers with a rigid set of design parameters in order to safely deal with the *Deep Stall* situation should the design include a T-tail.

The Douglas DC-9 Series aircraft happened to be in the final design stage when the BAC 1-11 accident investigators clearly identified the T-tail with the *Deep Stall* control problem; so, design enhancements were necessary to continue with the program.

The DC-9 was designed specifically to operate from short runways and on short- to medium-range routes so that the speed, comfort and reliability of jet transportation could be extended to hundreds of communities previously served only by propeller-driven airliners.

Smaller than the DC-8, the trim DC-9, like the One-Eleven, has a distinctive high-level horizontal stabilizer atop the rudder, commonly called a "T" tail. Two engines mounted on the aft fuselage power the aircraft at cruising speeds exceeding 500 mph (800 km/h) and altitudes over 30,000 feet (9,144 m).

Design, development and production of the DC-9 were centered in Long Beach, California where 976 of the twin jets were built during an 18-year production run. The first flight was Feb. 25, 1965, about one year after the One Eleven Accident findings were released. In the interim, Douglas changed the original design to add a vortex generator under the leading edge of the wing, among other enhancements to ameliorate a deep stall. The vortex generator was designed to produce a tornado-like vortex that would sweep over the horizontal tail and elevator control surfaces with the aircraft at high angles of attack; thus enhancing the pitch control afforded by elevator deflection during the airplane stall maneuver, preventing a deep stall condition on the first DC-9s.

There are five basic DC-9 versions, designated Series 10, Series 20, Series 30, Series 40 and Series 50. Several models in each series provide operators maximum efficiency for diverse combinations of traffic density, cargo volume and route distances to more than 2,000 miles (3,218 km). All models use variants of the reliable workhorse Pratt & Whitney JT8D engine.

Series 10: The first in the twinjet family, the fuselage length of the Series 10 DC-9 is 104.4 feet (31.8 m), accommodating up to 90 passengers with 600 cubic feet (16.9 m^3) of cargo space below the floor. Wingspan is 89.4 feet (27.2 m). Engines can be JT8D-5s or JT8D-7s, with takeoff thrust ratings up to 14,000 pounds.

Series 20: The DC-9 Series 20, although numbered second in the sequence of models, actually is the fourth member of the family. This high-performance version was announced in December 1966, and the first delivery was made in December 1968. The Series 20 is designed for operation from very short runways. It combines the fuselage of the DC-9 Series 10 with a high-lift wing developed for the Series 30. Power is provided by two JT8D-9s with 14,500 pounds thrust each, or 15,000-pound JT8D-11s.

Series 30: Fuselage of the Series 30 DC-9, actually second developed, is nearly 15 feet longer than the Series 10, at 119.3 feet (36.3 m), providing seats for up to 115 passengers and cargo space to 895 cubic feet (25.3 m^3). Series 30 wingspan was increased to 93.3 feet (28.4 m), and a high-lift wing system of leading edge slats gives the Series 30 excellent short-field performance. The first of the type began airline service in February 1967.

Series 40: To again meet airline demands for a DC-9 with more capacity, the Series 40 was developed with a fuselage length of 125.6 feet (38.3 m). Seating is available for up to 125 passengers, 10 more than the popular Series 30s. Below-floor cargo space totals 1,019 cubic feet (28.8 m^3). The Series 40 uses the same wing as the Series 30. Series 40 engines are JT8D-9s, JT8D-11s or JT8D-15s. The model entered service in March 1968.

Series 50: The fifth DC-9 version is extended to 133.6 feet (40.7 m) long, permitting installation of five more rows of seats than the Series 30. Maximum passenger capacity is up to 139, with cargo capacity increased similarly. Wingspan is the same as for the Series 30. Engines are either JT8D-15s or JT8D-17s, which are rated at 16,000 pounds. Airline operations with the Series 50 began in August 1975.

The engineering fixes to keep the DC-9-10 Series out of a *Deep Stall* notwithstanding; these models had other problems involving accidents throughout the operational life from a different problem: the accumulation of a small amount of ice on the leading edge of the wing during takeoff. This problem was shared with the DC-8, which had a similar wing design leading edge. Later model DC-9s and the DC-10 had no such difficulties because those planes had high-lift devices called slats across the leading edge of the wings that substantially increased the wing's lifting capability at a given angle-of-attack and speed. The DC-9-10 has a fixed leading edge, which was more susceptible to contamination from ice or other things; such as dents from hail encountered in-flight, or even insects. Any of which would disturb the flow over the wing to inhibit the normal lifting capability at a given angle. So, when takeoffs were attempted with a contaminated wing the plane would roll rapidly from an uneven lift generated across the wing. This rapid rolling tendency resulted in many accidents on the DC-9-10, DC-8, and other jet transports with similar wing designs:

Table I

Accidents with Wing Ice on takeoff

Day/month/year	Aircraft Type-Model	Location	Casualties Fatalities/# Aboard	Remarks
27/Dec./1968	DC9-15	Sioux City-, Iowa	0/68	Wing stall near the upper limits of ground effect, with loss of control because of aerodynamic and weight penalties of airfoil icing.
05/Feb/1985	DC9-15	Philadelphia	0/2	Wing stall with loss of control because of aerodynamic penalties of airfoil icing.
17/Feb/1991	DC9-15RC	Cleveland-Hopkins International Airport	2/2	Wing ice contamination led to wing stall and loss of control during the attempted takeoff.
22/Mar/1992	Fokker F28	New York-La Guardia Airport, NY	27/51	During take-off with ice accumulated on the wings. The captain rotated 5kts early, causing the F-28 to enter a stall. The aircraft crashed and came to rest partially inverted and submerged in the bay.
13/Jan./1977	DC8-	Anchorage	5/5	Wing stall that

Day/month/year	Aircraft Type-Model	Location	Casualties Fatalities/# Aboard	Remarks
	62AF	IAP, AK		resulted from the pilot's control inputs aggravated by airframe icing while the pilot was under the influence of alcohol.
13/Jan/1982	B737-200	Potomac River, Washington, D.C.	74/79+4 ground fatalities	Crashed after takeoff due to wing & engine instrument icing
12/Dec/1985	DC8-63CF	Gander, Newfoundland	256/256	Wing stall at low altitude because of ice contamination on the leading edge and upper surface of the wing

To fully understand what can happen in these accidents, especially in the icing cases it would help to know some basic aerodynamic principles: Namely, Lift and Thrust, which are both based on the same law of physics. No, it's not "What goes up, must come down"! But that's part of overall system of laws involved. What I am specifically referring to here is the third law of motion by the Englishman, Sir Isaac Newton from his book Mathematical Principles of Natural Philosophy, published in London on July 5, 1686, which states:

"To every action there is always opposed an equal reaction; or, the mutual actions of two bodies on each other are always equal, and directed to contrary parts. . .

If a body impinges upon another, and by its force changes the motion of the other, that body also (because of the equality of the mutual pressure) will undergo an equal change, in its own motion, towards the contrary part. The changes made by these actions are equal, not in the velocities but in the body motions; that is to say, if the bodies are not hindered by any other *impediments. For, because the motions are equally changed, the changes of the velocities made towards contrary parts are inversely proportional to the bodies".*[2]

In other words, Newton's third law states: "For every action there is an equal and opposite reaction". Because of his Third Law of Motion, Newton must be credited with first theorizing Jet and Rocket propulsion; he was the first to theorize that a rearward-channeled explosion could propel a machine forward at a great rate of speed. This theory was based on his third law of motion. As the hot air blasts backwards through the nozzle the plane moves forward. This is shown quite vividly when a rocket is fired upward as the hot gases are expanded out of the back of the rocket's motor; this action pushes the rocket upward in the opposite direction. Similarly, in an airliner's turbo-jet engine, Thrust is produced as the engine's exhaust is forced out the back of the engine, pushing the engine and the airplane to which the engines are attached forward in the opposite direction as the engine exhaust. The aircraft wing generates lift in a similar fashion by changing the direction of the air flowing around the wing in the downward direction, thus producing Lift in the upward and opposite direction as the downward flow directed by the wing as it is pushed forward through the air by the engines.

Aerodynamicists realized that the amount of lift generated by a wing is dramatically changed by the speed of the air flowing over it, by the shape of the wing, and by the angle the wing is placed relative to the air flowing over and under the wing's surface. As every airline passenger has experienced during takeoff, when the plane speeds up, it leaves the ground after reaching the takeoff speed and the pilot has "rotated" the plane's nose upward during the takeoff roll. The larger the angle, the more lift is generated, but only up to a point! When this maximum lift angle is reached, the wing can no longer efficiently deflect the air downward to produce the opposite, upward lift and the wing will "Stall". It was found that a particular wing "stall" angle could be increased by placing movable flaps on the front or leading edge of the wing. More lift can be generated at a given angle by movable flaps on the trailing edge of the wing as well. These leading and trailing edge flaps are movable so they can be retracted when not needed, during most of the flight, to reduce the airplane's Drag or air resistance, which saves the engine from working so hard to move the plane forward through the air and, most importantly, saving costly fuel. The leading and trailing edge devices are generally only used when the plane flies slowly as during takeoff and landing. If you've ever had a window seat over the wing, you've probably noticed the wing looking like it's coming apart just before the start of the takeoff as the leading and trailing edge flaps are deployed for takeoff. The angle and speed at which all airliners wing's stall is carefully and accurately measured during the airplane's FAA Certification tests prior to entering airline

[2] Newton, Isaac, *Mathematical Principles of Natural Philosophy,* London, 1686 Translated from the original Latin by Andrew Motte

service to ensure these limits are never reached when calculating the normal operating performance into the airports the airline flies. As the wing angle is increased and/or the airplane speed is reduced to the point of wing "stall" the flow over the top of the wing can actually stop and reverse direction, thus separating from the wing surface. When this wing stall occurs, wing lift is abruptly reduced and the airplane starts to drop due to gravity.

There was a case where a DC-9-10 wing's (not equipped with wing leading edge flaps) stall speed and angle were severely degraded by flying through a swarm of insects that adhered to the leading edge of the wing causing enough roughness to degrade lift. The DC-9-10 Maintenance instructions contain a section about the critical areas of the airfoils that must be kept extra clean and free of dents/debris to maintain adequate aerodynamic performance. Because pilots are not normally aware of all maintenance instructions, they might not be aware of the fact that a wing leading edge roughness may be hazardous, as the following accidents have shown:

The weather at Sioux City was poor On Dec.27, 1968: 800ft overcast, 3 miles visibility in fog and light freezing drizzle. The DC-9-15 took off from Runway 35 and, upon gear retraction, rolled violently 90 to the right. The roll was overly counteracted, and the left wing struck the runway. The DC-9 crashed and came to rest in a grove of trees, 1181ft past the runway end. PROBABLE CAUSE: "A stall near the upper limits of ground effect, with subsequent loss of control as a result of aerodynamic and weight penalties of airfoil icing. The flight crew failed to have the airfoil ice removed prior to the attempted take-off from Sioux City. The Board also finds that the crew selected an improper takeoff thrust for the existing gross weight condition of the aircraft."

Ground Effect means, as the term implies, an increased lifting capability when the wing is in close proximity to the ground. As the plane gains altitude, this increased lifting capability gradually goes away. So, if the lift of the wing is degraded by roughness due to ice formation, the wing lift might not be able to support the plane when the "ground effect" goes away. This usually happens unevenly across the plane's wing span because of the uneven nature of wing roughness due to ice formation, resulting in the plane's tendency to roll left or right abruptly when the lift benefit from the "ground effect" ceases.

There have been at least 7 accidents since 1968 where wing roughness due to ice has either been the root cause or a substantial contributing factor: 4 DC-9-10s, 2 DC-8s, and one Fokker F-28, (a European manufactured jet, similar to the DC-9-10 Series.)

The second DC-9 Series 10 wing icing accident, occurring after the Sioux City case in 1968 is described below.

Just after liftoff, on 05 FEB 1985, at Philadelphia, a cargo DC-9-15 snap rolled left just after main gear liftoff. The takeoff was abandoned and the aircraft landed back on its tail and right wingtip about 5600ft from the runway threshold. The aircraft skidded for 2025ft, hitting runway signs. A thin layer of ice (0.15 inch) had accumulated on the wings. Both Pilots were injured, there were no fatalities **PROBABLE CAUSE**: "wing ... ice: ice/frost removal from aircraft ... not performed.

In the third DC-9 Series 10 case, on 15 NOV. 1987, the DC-9 Passenger Flight 1713 was cleared for a Runway 35L take-off at Denver, CO., 27mins after deicing. On take-off, the DC-9 over rotated. The aircraft descended back and the left wing struck the ground, causing it to separate from the fuselage. The left side of the cockpit and forward fuselage struck the ground next and the aircraft continued to skid inverted. Both pilots were relatively inexperienced in DC-9 operations (Captain: 166hrs on type; First Officer: 36hrs on type).Twenty eight of the 82 passengers and crew on board were fatality injured. PROBABLE CAUSE: "The captain's failure to have the airplane de-iced a second time after delay before take-off that led to upper wing surface contamination and a loss of control during rapid take-off rotation by the First Officer. Contributing was the absence of regulatory or management controls governing operations by newly qualified flight crew members and the confusion that existed between the flight crew and air traffic controllers that led to the delay in departure." [3]

The forth DC-9 Series 10 case on 17 Feb. 1991, the DC-9 cargo Flight 590 landed at Cleveland at 23.44h and taxied to the mail ramp. Snow (dry and blowing) fell throughout the 35 minutes that the DC-9 was on the ground. The deicing service was not requested during this period. Clearance to taxi to Runway 23 was received at 00.09h. Takeoff clearance was given at 00.18h. The aircraft stalled during take-off and rolled 90 degs., at a height of 50-100ft. The engines then began to experience compressor stalls because the engine inlet air flow was disturbed by the turbulent wake of the stalling wing , the left wing contacted the runway and the aircraft cart wheeled. The DC-9 came to rest inverted 6500ft from the threshold. PROBABLE CAUSE: "The failure of the flightcrew to detect and remove ice contamination on the airplane's wings, which was largely a result of a lack of appropriate response by the Federal Aviation Administration, Douglas Aircraft Company, and Ryan International Airlines to the known effect that a minute amount of contamination has on the stall characteristics of the DC-9 series 10 airplane. The ice contamination led to wing stall and loss of control during the attempted takeoff."[4]

Even though the hazard associated with airframe and propeller icing had been well known for years; long before the age of jetliners; the insidious effect of attempting a takeoff with such a miniscule amount of wing contamination did not become apparent until the investigation of accidents which could be attributed to aerodynamic penalties caused by wing leading edge roughness.

These and other takeoff icing accidents around the world prompted the industry to develop different types of de-icing fluids, ones that would not allow ice to reform so soon after de-icing during a long taxi before takeoff. But, all these de-icing fluids were expensive and not very environmentally friendly. So, they are not always readily

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[3] NTSB/Aircraft Accident Report AAR-88/09
[4] NTSB/AAR/91-09

available for use. However some icing prone airports have special de-icing locations where the fluids are captured after use then recycled to prevent contaminating the local environment.

In the two DC-8 cases mentioned in Table I, in Anchorage and Gander, the planes were not de-iced at all before the takeoff was attempted in icing conditions.

It wasn't until the new, state-of-the-art, wide-body aircraft introduction into service did more complicated causes of accidents begin to surface in direct proportion to the complexity of aircraft systems and the environments in which they operated. Some of these accidents were experienced during an attempt to reject the takeoff; a maneuver required in the event one engine loses power before reaching a predetermined speed and distance for the existing plane's takeoff weight and runway length. If the plane has not reached this critical speed before loosing power in one engine it will not be able to generate sufficient lift to safely completely the takeoff; so, the pilot must reject and attempt to stop on the runway remaining.

Figure 3--Fiery aftermath of the ONA DC-10 following an unsuccessful RTO on Nov. 12, 1975 at New York's JFK airport

One of these Rejected Takeoff (RTO) accidents occurred when a crew member's home movie camera documented the accident sequence at about 15-frames per second leading up to the aircraft exiting the runway, catching fire and burning. Which, fortunately, did not involve any serious injuries to anyone aboard, but the multi-million dollar aircraft was destroyed. All the occupants were airline employees being repositioned to conduct special flight operations in a foreign country. This unfortunate accident amounted to not much more than a very expensive (and very realistic) training exercise in emergency evacuation!

The sequence of events on this RTO accident could be considered to begin when the pilots first noted something going wrong as large birds were ingested into the right wing engine, resulting in severe fan blade damage and fan rotor imbalance, with accompanying heavy airframe vibration, presumably inducing the Captain to begin to bring the heavy (555,000-lbs.) airplane to a safe stop on the wet runway. After the RTO initiation, things when from bad to very bad in a short time:

- The vibrating engine began throwing high energy parts into aircraft structure severing fuel lines to the engine and showering hot, jagged, debris toward the right main landing gear tires and brakes.
- The engine caught fire
- At least 3 of 4 tires and wheels on the right man landing gear (RMLG) began to disintegrate.
- The hydraulic lines to the RMLG brakes were severed, depleting that hydraulic system of its fluid as brakes were applied for stopping.
- Aircraft deceleration and steering control were degraded because of asymmetric braking, asymmetric engine thrust, and the loss of some wing lift spoilers, normally operated by the inoperative hydraulic system
- The aircraft veered to the right off the hard surface into soft ground.
- The RMLG collapsed
- The fire spread to engulf the entire aircraft.

In another, very similar accident, about 3-years after the ONA RTO at JFK, another DC-10 experienced an RTO at LAX after one tire lost pressure during taxi to the takeoff runway. Even though there are 4 main landing gear wheels on both the left and right main landing gears, when one tire/wheel fails, this overloads the other on the same axel, causing it to fail in turn, Which is apparently what happened during the takeoff roll while approaching the V1 speed (156kts) a loud "metallic bang" was heard, followed by a quivering. As rejected takeoff (RTO) procedures were begun, the airspeed continued to increase to 159kts. The aircraft appeared to be decelerating normally, but with 2000ft of runway remaining, the flight crew became aware that the rate of deceleration had decreased and they believed that the aircraft would not be able to stop on the runway. The aircraft was steered to the right and departed the right corner of the runway end. About 100ft beyond the runway, the left main gear broke through the non load-bearing tarmac surface and failed. A fire erupted in this area as the aircraft turned to the left, coming to rest 664ft from the runway end and 40ft right of the extended centerline in a 11deg left wing low and 1,3deg nose-up attitude.

Figure 4--Continental DC-10 RTO overrun accident at Los Angeles International Airport (LAX) on March 1, 1978.

Table II
Accidents involving Rejected Takeoff (RTO)

Date	Aircraft Type-Series	Airline	Location	Casualties Fatalities/occupants	Remarks
12/Nov/1975	DC10-30	Overseas National	JFK, New York	0/139	The aircraft struck many birds and the take-off was rejected. Bird strikes damaged the No.3 engine's fan blades, causing rotor imbalance.
16/Nov/1976	DC9-	Texas	Denver,	0/86	A false stall

Date	Aircraft Type-Series	Airline	Location	Casualties Fatalities/occupants	Remarks
	10	International	Co.		warning prompted an unsuccessful attempt to reject the take-off after the aircraft had accelerated beyond refusal and rotation speed.
01/March/1978	DC10-10	Continental	Los Angeles	2/200	The sequential failure of two tires on the left main landing gear and the resultant failure of another tire on the same landing gear at a critical time during the take-off roll, resulting in the captain's decision to reject the take-off.
26/June/1978	DC9-30	Air Canada	Toronto	2/107	Tire debris damaged the gear 'down and locked' switch, causing a gear unsafe indication in the cockpit and RTO overrun
13/Sept./1982	DC10-30	Spantax	Malaga, Spain	50/394	Right nose gear tire tread separation prompted Capt to attempt an

Date	Aircraft Type-Series	Airline	Location	Casualties Fatalities/occupants	Remarks
					RTO after rotation
21/May/1988	DC10-30	American Airlines	Dallas	0/254	RTO overrun when the slat disagree light Illuminated
08/June/1995	DC9-30	ValuJet	Atlanta	0/62	RTO when shrapnel from an uncontained engine failure penetrated the right engine main fuel line.
13/June/1996	DC10-30	Garuda	Fukuoka, Japan	3/275	RTO overrun after rotation when a No.3 eng. 1st stage HP turbine blade separated.

The reasons for these repeatable jetliner accidents due to wing icing and rejecting the takeoff under adverse conditions could be explained and easily rectified:

1. The timely application of the proper de-icing fluids, in the icing cases.
2. More detailed attention to the condition of the tires and a better understanding of overall RTO maneuver and how the planes were certified in the RTO cases.

All of the above can be accomplished through better training of the maintenance and flight personnel.

However, the same can not be said of another series of repeatable jetliner accidents, namely: those involving severe in-flight fires and controlled flight into terrain (or the so-called CFIT accidents).

In-Flight Fires

There is nothing like the scent of something burning on the flight deck of a modern airliner to have an intensely sobering effect on pilots. Fire, especially an electrical fire--with its potential to directly attack the "nervous system" of a modern jet - is at the very top of the typical pilot's primal fears.

In a survey of nearly 100 reports of in-flight fire and smoke[5], the pilots' hit upon predictably consistent themes: notably,

- The need to cut power to the perceived source of an electrical malfunction. Indeed, most modern airliners are fitted with redundant electrical power systems. So pilots can use emergency procedures to immediately isolate a possible burning system by selectively turning off, each system, and back on, one at a time, until power is removed from the affected system; leaving the other system(s) to safely take over the load.
- the imperative to land as soon as possible
- and, the need for more realistic, rigorous simulator training while wearing emergency equipment with possible multiple system failures caused by the electrical fault.

In a tragic accident, on 2 September 1998, involving a Swissair MD-11 passenger flight 111 from New York to Geneva, which killed all 229 persons aboard, an electrical fire apparently did, indeed, attack the plane's "nervous system", resulting in the loss of control and crash into the North Atlantic off the coast of Nova Scotia, Canada, during an attempted precautionary landing at Halifax, because the pilots smelled smoke in the cockpit.

Approximately 40 minutes after takeoff, sixteen minutes after contacting the High Level Air Traffic Controller upon reaching 33,000 feet altitude, the crew issued a notice of trouble, but not an emergency ('Pan'-call) reporting smoke in the cockpit and requesting prompt directions to the nearest airport, which they thought was Boston. The High Level controller cleared the flight to descend to FL310 (31,000 ft.) and offered Halifax as the closest airport available, which was accepted by the crew. Shortly thereafter, at about one-hour after takeoff, the flight was handed over to Moncon Centre and was vectored for a back course approach to Halifax runway 06. One-minute later, Flight 111 was just 30 miles from the landing threshold, so Moncton Centre directed the plane for a 360-degree turn to lose some altitude and to dump fuel off the coast. Five minutes later, the autopilot dropped off and the situation in the cockpit apparently became worse, because the crew declared an emergency and reported that they were starting the fuel dump and that they had to land immediately. There were no more radio communications and the aircraft transponder ceased transmitting any altitude information

[5] *In-Flight Fires Wreak Havoc With Systems Reliability.* **Air Safety Week,** 26 September 2003

to the ATC radar approximately 35nautical miles from the airport off the Nova Scotia coast, near Peggy's Cove.

According to the Canadian Transportation Safety Board (TSB) official report, "At approximately 2231 Atlantic Daylight Time" the aircraft crashed into the sea near Peggy's Cove, Nova Scotia, fatally injuring all 229 occupants. About 13 minutes after the abnormal odor was detected, the aircraft's flight data recorder began to record a rapid succession of aircraft systems-related failures; presumably due to a fire attacking these systems. Both the Digital Flight Data Recorder (DFDR) and the Cockpit Voice Recorder (CVR) then stopped recording when the aircraft was at approximately 10,000 feet above the sea, about six minutes before the aircraft struck the water." Because the aircraft plunged into water, virtually eliminating any severe post-crash fire damage adding to the in-flight fire damage was minimized. Thus, giving investigators reasonable assurance that any recovered fire damaged parts occurred in flight before impact. The initial investigation revealed heat damage consistent with a fire in the ceiling area covering about one meter forward and several meters aft of the bulkhead between the flight deck and the cabin area. Physical evidence recovered from the sea floor showed numerous wires from this area exhibit charring and burnt insulation. Examples of electrical arcing damage were found. But, it was not immediately obvious whether the arcing was the ignition source for the fire or whether arcing was the secondary result of a fire that originated elsewhere and damaged the wiring insulation, which subsequently caused the arcing to occur.

A review of a number of previous in-flight fire accidents was made by TSB investigators looking for fire events that had similarities to the sequence of events in Flight 111. Fifteen such events were identified. For these events, the time from when fire was first detected until the aircraft crashed ranged from 5 to 35 minutes. Each of these accidents had the same characteristic: the in-flight fire spread rapidly and became uncontrollable. In the case of Flight 111, approximately 20 minutes elapsed from the time the crew detected an unusual odor until the aircraft crashed, and about 11 minutes elapsed between the time the presence of smoke was confirmed by the crew and the time that the fire is known to have begun to adversely affect aircraft systems. In the case of Flt. 111, The TSB Report made the following findings as to the fire's ignition source:

- "*The type of circuit breakers (CB) used in the aircraft were similar to those in general aircraft use, and were not capable of protecting against all types of wire arcing events. The fire most likely started from a wire arcing event*.
- *A segment of in-flight entertainment network (IFEN) power supply unit cable (1-3791) exhibited a region of resolidified copper on one wire that was caused by an arcing event. This resolidified copper was determined to be located near manufacturing station 383, in the area where the fire most*

likely originated. This arc was likely associated with the fire initiation event; however, it could not be determined whether this arced wire was the lead event."

Another severe airliner in-flight fire, occurred in June 1983, which also involved aircraft electrical system faults, was first brought to the pilots' attention by circuit breakers tripping on the flight deck involved an Air Canada DC-9 cruising at 33,000 feet, over Ohio. The circuit breakers were for the aft lavatory flush pump motor. The captain thought the flush motor had probably seized and wisely waited for about eight minutes before (unsuccessfully) trying to reset the circuit breakers, to refrain from immediately applying electrical energy onto an already faulted system. At about the same time a strange odor was noticed at the back of the plane, near the aft lavatory. After suspecting that the lavatory was full of smoke, a cabin attendant briefly opened the lavatory door and discharged a CO_2 bottle into the lavatory in an attempt to put out the fire while minimizing the amount of smoke/toxic fumes released into the passenger cabin (reportedly because black smoke was seen coming out of the seams of the lavatory's walls. The first officer was sent back to investigate, but had to return to the flight deck to get his smoke goggles. Upon returning to the flight deck, the 1st officer told the captain he thought it best to descend. Around that time the aircraft started developing electrical faults and an emergency call was issued. The flight started to descend and contacted Cincinnati for an emergency about 3-minutes after the first officer's return to his seat. During the descent smoke began to fill the passenger cabin. The emergency landing was carried out on Cincinnati's runway 27L 10-minutes later. The Cincinnati fire services responded with fire retardant foam immediately after the aircraft stopped on the runway. But, they were not able to extinguish the fire, which eventually gutted the fuselage. Of the 41 passengers and 5 crew members on board, 23 passengers were fatally injured in the fire. All cabin crewmembers safely evacuated via the cabin emergency exits while the pilots escaped through the manually opened flight deck windows, which were designed, tested, and certified to be opened in flight to clear smoke/fumes from the flight deck during an air conditioning or electrical smoke/fume event. The official cause of the accident was:

"A fire of undetermined origin, an underestimate of fire severity, and conflicting fire progress information provided to the captain. Contributing to the severity of the accident was the flight crew's delayed decision to institute an emergency descent."[6]

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[6] National Transportation Safety Board Aircraft Accident Report (NTSB/AAR-84/09)

The investigation showed that many passengers were overcome by smoke/fumes. So, it was concluded that many passengers may have been physically unable to egress the smoke filled fuselage. This, and other in-flight fire accidents, prompted the FAA and the aircraft manufacturer to attempt to mitigate this hazard by devising a means of rapidly evacuating the smoke/fumes from the aircraft in flight in the event of fire in the cabin. One method proposed by the aircraft manufacturer was to simply depressurize the airplane and open the flight deck windows. However, this was discarded for two convincing reasons: 1) not all commercial airliners were designed to open flight deck windows; 2) more importantly, flight test clearly demonstrated that when the flight deck windows were opened in flight, the smoke/fumes generated in the cabin immediately intensified on the flight deck to the extent of severely impeding the pilots ability to control the plane for landing!

Undaunted by the failure of the flight deck window procedure, the manufacturer continued flight tests to develop a "cabin smoke/fume evacuation" emergency procedure on both the wide-body and narrow-body airliners in their product line. This resulted in a procedure, in the narrow-body case whereby the forward and aft cabin doors were opened slightly, with the cabin depressurized. The in-flight pressure distribution around the airplane caused the cabin smoke/fumes to immediately be purged from the cabin, thus removing any hazard due to toxic fumes affect on passengers and crew. The cabin door opening procedure was not required in the wide-body aircraft because analytical calculations and flight tests proved that the normal air conditioning system designed for these larger aircraft provided more than adequate ventilation rates to continuously purge the cabin of harmful smoke/fumes.

However, this was not the case in the smaller narrow-body airplanes. So, the cabin door opening emergency procedure was believed to be necessary by the manufacturer; however, the procedure was not adopted by airlines for several reasons: 1) by definition, an emergency procedure must be accomplished by a member of the flight crew, requiring one of the pilots, in most cases a member of a two-person flight crew, to abandon the flight deck in an emergency situation, leaving the other pilot to simultaneously accomplish all other emergency checklist tasks in addition to operating the radio and controlling an airplane, in the presents of possible multiple system faults. 2) Furthermore, the cabin crew already had other important duties to prepare passengers for the emergency situation, the subsequent landing, and emergency evacuation. 3) Some cabin crew members were not keen on opening doors in flight, claiming that they had best be taking the precious time to **extinguish the fire** to eliminate the source of smoke/toxic fumes, rather than attempting to reduce the smoke effects after being generated. 4) The FAA could not approve the procedure on similar grounds.
Whether the procedure was adopted or not became moot about 13 years after the Cincinnati accident because of an in-flight fire that was so intense no conceivable procedure could have mitigated the fire's threat to the airplane or its occupants! This

case involved another narrow-body DC-9, operated by ValuJet, which crashed into the Florida Everglades, killing all 110 passengers and crew aboard, in May 1996, following an intense fire in the forward cargo compartment. The extreme fire reportedly resulted from unauthorized, hazardous cargo in the form of spare passenger chemical oxygen generators, designed to be fitted in the cabin to produce emergency supplemental passenger O_2 by a chemical reaction involving the production of extreme heat along with oxygen. When properly fitted the heat generated was designed to be well insulated from any combustibles while generating a supply of passenger supplemental oxygen to masks during an emergency decompression. The unexpended O_2 generators must be removed and replaced once a predetermined useful life has elapsed to ensure proper operation. The removed units must be shipped to a certified overhaul facility to determine proper operation, and these units were deemed hazardous cargo by authorities because of the extremely high temperatures generated during the combustion process that produces the oxygen; and, the units were designed to be self-activated by a spring-loaded hammer striking a firing pin to begin the chemical reaction. This self activation feature required a safety cap be installed over the firing pin to prevent inadvertent activation during shipping.

The investigation of the Everglades accident showed that at approximately 6-minutes after takeoff from Miami, while flying just above 10,600-feet, Valujet's flight 592 flight recorders indicated the altitude dropped 815ft and the indicated airspeed decreased 34kts in 3secs. At the same time the Voice Recorder recorded the captain responding to an unusual noise. Five-seconds later the captain first noticed multiple electrical system faults; immediately prompting the decision to return to Miami. Six seconds later, excited female voices in the cabin shouting "fire, fire" were recorded.

From then on, the FDR recorded intermittent data dropouts, presumed to be caused by the fire impinging on the FDR signal or electrical power wires routed under the cabin floor. Shortly thereafter the crew requested to return to Miami due to smoke in the cabin. Flight 592 was vectored for a runway 12 approach. At 7207ft, descending at 260kts on a 210 heading, the FDR stopped recording. Fifty seconds later ValuJet 592 struck a swamp with the nose pitched down 75-80 degrees and disintegrated. It was concluded that there had been a very intense fire in the middle of the forward cargo hold, which burned through the electrical wiring under the floor and ultimately through the cabin floor left side at seat rows 5 and 6 within only about 6-minutes, 35-seconds after takeoff.

Investigations focused on a fire, possibly caused by oxygen generators carried in the cargo hold. The aircraft carried boxes containing 144 oxygen canisters and two inflated MD-80 landing gear wheel-tires in the forward hold. Several fire-blackened expended oxygen generators were recovered from the wreckage in the swamp which had been completely discharged and which did not have the shipping safety caps installed.

As part of their on-going investigation, N.T.S.B. Investigators reconstructed an arrangement of the cargo reported loaded into the Valujet DC-9's forward cargo hold to simulate the suspected fire at the FAA's fire test facility. The video of the test showed that an extreme conflagration was well underway about 6-minutes after the purposeful initiation one of the oxygen generators packed in cardboard boxes beneath two aircraft tires surrounded by various other combustible passenger bags and cargo items, some other oxygen generators were shown spewing narrow jets of flame onto the tires and other combustibles in the area of the main blaze, in a display of pernicious fire-works eventually requiring the test facility fire extinguishing system several minutes to flood the area and put out the fire. The video also showed one of the tires exploding, forcing large pieces of rubber to rapidly fly away from the fire area, which was consistent with the split open, charred tire recovered from the wreckage; and, which was later suspected to be the source of the noise the captain heard during climb, 6-minutes after takeoff.

Approximately one-minute after the fire burned through the aircraft floor a sound similar to "loud rushing air" was recorded, and continued until the end of the recording. Some thought this sound might have been the pilots attempt to alleviate the smoke on the flight deck by opening one or more flight deck windows, but this was not confirmed.

The official cause of the accident was reported as follows:

> *"The National Transportation Safety Board determines that the probable causes of the accident, resulting in a fire in the Class D cargo compartment from the actuation of one or more oxygen generators improperly carried as cargo, were: (1) the failure of SabreTech to properly prepare, package, identify, and track unexpended chemical oxygen generators before presenting them to ValuJet for carriage; (2) the failure of ValuJet to properly oversee its contract maintenance program to ensure compliance with maintenance, maintenance training, and hazardous materials requirements and practices; and (3) the failure of Federal Aviation Administration (FAA) to require smoke detection and fire suppression systems in Class D cargo compartments. Contributing to the accident was the failure of the FAA to adequately monitor ValuJet's heavy maintenance program and responsibilities, including ValuJet's oversight of its contractors, and SabreTech's repair station certificate; the failure of the FAA to adequately respond to prior chemical oxygen generator fires with programs to address the potential hazards; and the failure of ValuJet to ensure that both ValuJet and contract maintenance employees were aware of the carrier's no-carry hazardous materials policy and had received appropriate hazardous materials training."*[7]

The intense heat and rapid propagation of this oxygen fed fire was tantamount to a slowly propagating explosion; thus, rendering any fire-fighting or smoke/fumes removal procedures woefully inept! The lessons learned from in-flight fire accidents are as numerous as they are obvious:

1. Take positive steps to ensure hazardous material remains out of aircraft, especially those that generate oxygen which will accelerate a fire.

[7] National Transportation Safety Board Aircraft Accident Report (NTSB/AAR-97/06)

2. Provide state-of-the-art fire-fighting equipment to all aircraft crewmembers

3. Train all Crewmembers to aggressively attack any fire in an aircraft with the best available fire fighting equipment to immediately extinguish any on-board fire.

More succinctly, everything that **can** be done to prevent in-flight fires **must** be done; and, in the event a fire does start, it must be completely and immediately extinguished before it can attack the nervous system of the aircraft or the respiratory system of its occupants! Apparently, another lesson was learned, at least by the pilot community, was to "Land As Soon as Possible" because less than 4-months following the ValuJet fire, another fire occurred on a cargo DC-10 where the airplane was on the ground within 18-minutes after the flight crew first noticed a cargo smoke warning light illuminated. This accident occurred in the early morning hours of September 5, 1996, when a Douglas DC-10-10CF, operated by the Federal Express Corporation as flight 1406, made an emergency landing at Stewart International Airport, Newburgh, New York, after the flight crew determined that there was smoke in the upper deck cargo compartment. The flight was operating under the provisions of Title 14 Code of Federal Regulations Part 121 as a cargo flight from Memphis, Tennessee, to Boston, Massachusetts. Three crewmembers and two non-revenue passengers were aboard the airplane. The captain and flight engineer sustained minor injuries while evacuating the airplane. The airplane was destroyed by fire after the landing.

The National Transportation Safety Board determined that the probable cause of this accident was an in-flight cargo fire of undetermined origin.[8]

The captain stated that as the airplane approached the airport, visibility remained good in the cockpit, even though he could smell smoke through his oxygen mask. The airplane was cleared to land on runway 27, and the first officer landed the airplane at 0554:28. The captain then took control of the airplane and brought it to a stop on taxiway A3, where airport aircraft rescue and firefighting (ARFF) trucks were waiting.
The flight engineer said that when he opened the cockpit door after landing, he saw that the foyer area was full of smoke, and he could not see the smoke barrier at the aft end of the foyer. The captain later told investigators that both he and the flight engineer called for an emergency evacuation. The CVR indicates that at 0555:07, the captain stated, "we need to get the [ ] out of here," and that 12 seconds later the flight engineer said, "Emergency ground egress." The captain told investigators that he then pulled all three engine fire handles and attempted to discharge the engine fire agents (he was unsure whether all bottles discharged). After the accident, the captain said that the "Emergency Evacuation" checklist had not been read. The flight engineer confirmed that the "Emergency Evacuation" checklist had not been read, but he stated that he had turned off the battery switch (which is item No. 18 on that checklist). The flight engineer attempted to open the primary doors (doors L1 and R1), but the doors would not immediately open.

[8] National Transportation Safety Board Aircraft Accident Report AAR-98/03.

Meanwhile, the captain attempted to open his cockpit window and felt resistance, and when he broke the air seal he heard air escape with a hissing noise. He shouted to the others that the airplane was still pressurized. The flight engineer then rotated the outflow valve control to the open position (thereby depressurizing the airplane), and again attempted to open the L1 and R1 doors. Both of the evacuation slides deployed; however, the L1 door only partially opened. After the airplane was depressurized, both the captain and first officer opened their cockpit windows. The captain said that at that point the smoke was colored gray to black, and then turned black and had a “horrible acrid” smell. He said he had to hold his breath until his window opened and the smoke “billowed out the window like a chimney.”

Smoke coming out of the cockpit windows and evacuation doors was immediately visible to the firefighters. After the captain and first officer opened their respective sliding windows, they positioned their upper bodies outside the airplane. The captain knelt on his seat with his upper body outside the window. The first officer was seated on the window sill with his feet on his cockpit seat and his upper body outside. They remained in these positions until after the flight engineer and the jump-seat riders had evacuated the airplane (via the R1 evacuation slide) and called to them from the ground beneath their windows. The captain and the first officer then evacuated the airplane using the cockpit windows’ escape ropes. During the evacuation, the captain sustained rope burns on his hands, and the flight engineer received a minor cut to his forehead.

The flight engineer said that while he was in the airplane, the smoke was “oily and sooty” and acrid smelling, and that it made breathing unpleasant and difficult. He said that before he left the cockpit, he used his oxygen mask to fill his lungs with oxygen and then entered the foyer area. He stated during his deposition that he did not consider using the PBE (Portable Breathing Equipment) that was available in the cockpit because he was anxious to open the exit doors, and he thought this could be accomplished relatively quickly. He also indicated that he forgot that the PBE was available in the cockpit.

The investigation revealed that the “seat” of the fire was located in cargo container 6R. A conical “V” burn pattern was observed from right to left and from forward to rear with the lowest (deepest burned) area centered over container 6R. Each of the containers was inspected to assess the degree of its fire damage and the depth to which its contents were burned. A layered inspection of the debris in each cargo container was initiated starting with the top, outermost layer of burned cargo and working inward and down towards the center of the cargo. The examination revealed that container 6R was the only cargo container that exhibited fire damage throughout its debris and down to the container floor. The investigation found four cargo shipments in container 6R: one consisting of industrial metal valves, one consisting of a DNA synthesizer, and two separate computer shipments. All of the contents of 6R were removed and examined. But, no conclusive source of ignition to the fire was found!

It was not known whether the captain was aware of the Valujet accident when he decided to declare an emergency and land at the closest airport. But, the fact that a safe landing and emergency evacuation of all crew members was made in such a timely and professional manner, indicates some knowledge of the hazard of lingering with a fire on board.

Severe Airliner Fires
1967 to 2002

Aircraft type	Date	Location	Operator	Remarks
BAC111-204AF	23 Jun 1967	Blossburg, Pa	Mohawk	Fire in tail section fueled by hyd. Fluid
Caravelle III	11 Sept 1968	Nice, France	Air France	Fire in the rear of the cabin after takeoff. crashed into the sea off Nice
Boeing 707-345C	11 July 1973	Paris, France	Varig	fire started in the washbasin unit of the aft right lavatory
Boeing 707-321C	03 Nov. 1973	Boston	Pan American	dense smoke in the cockpit seriously impaired the flight crew's vision
Boeing 707-340C	26 NOV 1979	Jeddah, Saudi Arabia	Pakistan Airlines	fire near the aft cabin passenger door
L-1011-200	19 AUG 1980	Riyahd, Saudi Arabia	Saudia	Three minutes after emergency landing, the interior was seen to be engulfed in flames.
DC-9-32	02 JUN 1983	Cincinatti	Air Canada	Fire in aft lav. after crew reset 3 flush motor circuit breakers
Boeing 727-324	31 MAR 1986	La Mesas, Mexico	Mexicana	tire on the LMLG exploded. Fuel and hydraulic lines were ruptured and electrical cables severed fuel ignited and caused a massive fire on board.
DC-10-40	10 AUG 1986	Chicago	American	solid-state

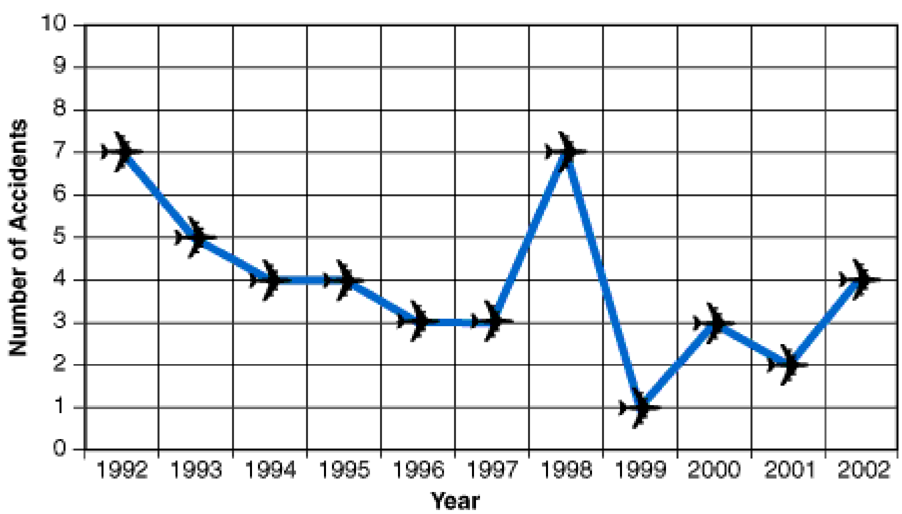
Aircraft type	Date	Location	Operator	Remarks
			Transair	chemical oxygen generators) in the lower forward cargo hold with seat covers and oil caught fire on ground
Boeing 747-244B	28 NOV 1987	Indian Ocean	So. African Airways	Upper deck cargo fire
B737-400	08Jan.'89		British Midland Airways - BMA	smell of fire in the cockpit following left engine fan blade failure
B737-289	30 Dec'89	Tucson International Airport, AZ	America West Airlines	During approach a fire erupted and burned through to the electrical power wires to the standby hydraulic pump.
DC8-61	11Jul'91	Jeddah, Saudi Arabia	Nigeria Airways	two tires may have failed during the first 500ft of take-off and one had caught fire burning through to the cabin after gear retraction.
DC-10-30	5 SEPT 1996	Newburgh, N.Y.	FEDEX	Upper deck cargo fire
DHC-6 Twin Otter	12July'95	Dagura, Papua, New Guinie	Milne Bay Air	in-flight fire accidentally began behind the rear cargo locker. It is believed that some flammable liquid from the passengers' luggage had ignited.
DC-9-30	11 MAY 1996	Miami. Florida	Valujet	Fwd. cargo fire
DC-8-61	11 JUL 1991	Jeddah	Nationair	MLG wheel well fire after tire failed on T.O. roll
MD-11	02 Sept. 1998	Halifax, N.S.	Swissair	Cockpit fire
MD82	07May2002	20 km E off Dalian, China	China Northern	aircraft crashed into the sea after the pilot reported a fire in the cabin.

Controlled Flight into Terrain C.F.I.T. Accidents

CFIT occurs when an airworthy aircraft under the control of the flight crew is flown unintentionally into terrain, obstacles or water, usually with no prior awareness by the crew. This type of accident can occur during most phases of flight, but CFIT is more common during the approach-and-landing phase, which begins when an airworthy aircraft under the control of the flight crew descends below 5,000 feet above ground level (AGL) with the intention to conduct an approach and ends when the landing is complete or the flight crew flies the aircraft above 5,000 feet AGL en route to another airport.

CFIT accidents certainly were not new to jet airliners. Numerous small general aviation and propeller driven airliners were lost in this manner over the decades. Consequently, an international CFIT Task Force, created in 1992, set as its five-year goal a 50 percent reduction in CFIT accidents. Among large commercial jet airplanes, seven CFIT accidents occurred in 1992; five CFIT accidents occurred in 1993; four CFIT accidents occurred in both 1994 and 1995; three CFIT accidents occurred in 1996 and 1997; seven CFIT accidents occurred in 1998; one CFIT accident occurred in 1999; three occurred in 2000; two occurred in 2001; and four (data through Sept. 1, 2002) occurred in 2002.

Worldwide Controlled-flight-into-terrain Accidents
Large Commercial Jets (>60,000 pounds, non-CIS) 1992–2002*



CIS = Commonwealth of Independent States
60,000 pounds = 27,000 kilograms (maximum gross weight)
*Through Sept. 1, 2002

Source: Boeing Commercial Airplanes

The task force included more than 150 representatives from airlines, equipment manufacturers, aircraft manufacturers, and many other technical, research and professional organizations. The task force believed that education and training are readily available tools to help prevent CFIT accidents.

One ominous CFIT accident investigation in which this author was intimately involved occurred when an Air New Zealand DC-10 crashed into the ice covered slopes beneath Mt. Erebus, on Ross Island, Antarctica in November 1979.

This DC-10 Accident investigation was unique because:

1. it required an odyssey to Antarctica to work on the ice covered slope near an active volcano (Mt. Erebus),
2. it was the third fatal DC-10 accident within 6 months
3. it was the first investigation in history where the information contained in the plane's Navigation Computer memory chips were retrieved to substantiate the Digital Flight Data Recorder information for the flight path reconstruction just before the accident. This non-volatile or *flash* memory is designed to hold data stored in the memory chips even when electrical power is removed to ensure data integrity in the event of a momentary power transient in normal operation. So, the chips can be removed from the Nav computer and the data within the memory can be extracted to show the plane's past position as a function of time, among many other parameters. This enables investigators to reconstruct a 3-dimentional path the aircraft traveled.
4. Under International agreement, the Country where the accident happens is normally responsible for the Official Investigation, but, because no single Country posses Antarctica, The Country of the Airline involved is Responsible, under the same international agreement. So, in this case I provided assistance to the New Zealand Government Authorities, which was both the airlines' home country and the country that held the claim in the area of Antarctica where the crash occurred.

Polar tents provided by NZ Recovery personnel
NZ Police photo

5. Because of the remoteness of the crash scene, Ross Island, the investigation team was required to "camp out" on the ice near the wreckage. Upon arrival, I was given a sleeping bag and shown to a polar tent to stow my gear. Inside the tent was an ice floor about 12-feet in diameter with a central tent pole forming an inverted cone of canvas. Fortunately for this native Californian, we had received cold weather training before leaving New Zealand for Antarctica. In the coldest place on earth with recorded winter temperatures of –88°C (–126°F), the accident site temperature remained a balmy -20 deg. C and the wind was calm, most of the time. However, the agreed upon work schedule of 12-hour shifts stopped while I was on duty at the scene because of the poor en-route visibility from blowing

snow stopped the helicopters from moving safely to/from the crash scene. So, I began to experience what Sir Ernest Shackleton's stranded crew must have felt, when we paradoxically began to run short of water on the continent where about 1/3 of the earth's fresh water is stored in the ice. We began running low on fuel for a fire to melt the ice! The cans of beer we salvaged from the plane's galley carts helped somewhat, but, as I learned later, the alcohol in the beer actually increases your thirst because it is a diuretic. Like Shackleton's crew, we survived. Unlike his crew, we were rescued by helicopters that finally returned me, when the weather cleared, to my warm bed at the U.S. Navy Base in McMurdo. I made the mistake of including aerial photos of our "camping" area next to the debris field in my investigation status presentation to Company Managers, prompting sarcastic remarks about "putting in for vacation time for this fun trip" from my friend, the V.P. of Engineering after my comment that Management should be pleased about the lack of hotel expenses on our expense reports while on the accident scene. I thought I'd been at some primitive camp sites during my previous summer jobs as a wrangler on a ranch in Montana. However, those camps on the Rocky Mountain peaks of the Continental Divide in southern Montana's summer months were the Ritz compared to Ross Island, especially in the area of latrine accommodations. The New Zealand Police and volunteers with us on the ice were true "Mountain Men" (as I used to refer to my more rugged Montana campers). Our New Zealand helpers in Antarctica had fashioned a latrine out of a cave hacked into the ice with little more than a shelf of ice with a bowl carved depression in which to place a plastic bag to facilitate clean-up after using the facility. Needless to say, the thought of sitting on the ice with nothing more than a thin plastic bag between you and the blue ice, did not conjure up many thoughts of comfortable reading time! So, a "light bulb" appeared above the head of my colleague and I almost simultaneously as we thought of retrieving the fiberglass cover fitted above the DC10 wreckage's lavatory waste tank, complete with plastic toilet seat and toilet roll dispenser, we had just seen in the debris field and installing it in the "ice cave" as the latrine became known to us. After mentioning this modification, I think we were considered as softies by our New Zealand colleagues. I did <u>not</u> include any photos of this unmodified ice cave facility in my presentation to my management.

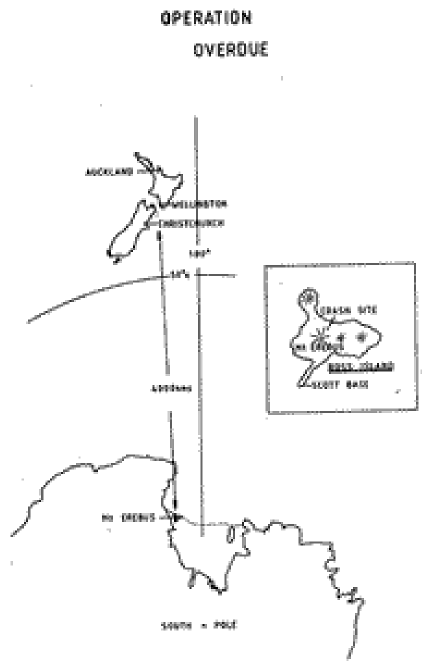
6. This investigation was also unique because of the fact that the accident flight's purpose was sight-seeing; the number of passenger's cameras found intact within the debris field was extraordinary. Those cameras were carefully collected in anticipation of processing the film, which was accomplished with some success.
7. A large number of passengers were standing in a queue for a turn on the flight deck for viewing out the forward windows. Consequently, very few seat belts

> were found fastened in the wreckage and a disproportionate number of passenger remains were found some distance from the main debris path. This prompted speculation than some may have survived the impact and fire by being thrown clear when the fuselage split open at impact. However, this was not confirmed during the investigation.

At first arrival on an accident scene it is useful to perform an initial “walk through” of the wreckage debris field to obtain an overall mental picture of how best to deal with the factual investigation. This procedure is always hindered by the weather, terrain, and overall general conditions at the accident site. Usually, the identification/recovery of the crash victim’s human remains takes priority over the technical investigation, but, in this case, because of the site’s inaccessibility, the victim ID and recovery process and accident investigation was simultaneously accomplished. The initial “walk through” and overall accident site accessibility was further hindered by the fact that the wreckage was scattered up a 20 degree slope of solid ice crisscrossed by several 300 ft. deep snow covered crevasses. The coverings of which were weakened by the burning wreckage passing over the crevasses during the crash. So, in order to safely traverse the entire debris field, each of us had to be accompanied by a guide tied together with a long safety line for recovery should one disappear into a crevasse.

The Accident Flight

On 27 NOV 1979**,** at 19:17h DC-10 Flight TE901 took off for an Antarctica scenic flight from Auckland, N.Z. proceeding over South Island, Auckland Islands, Baleny Islands and Cape Hallett to McMurdo (Antarctica) The flight would then return via Cape Hallett and Campbell Island to Christchurch. After being notified that the flight was overdue in Christchurch, I had to wait before taking action until the requisite time that all fuel reserves were exhausted and to hopefully, learn the aircraft was on the ground somewhere else. After a period of about 12 to 14—hours, I was informed that the wreckage had been located on the ice-covered slopes beneath Mt. Erebus, Ross Island.



Approaching Ross Island it appeared that the area which was approved by the operator for descents below 16000ft only under **V**isible **M**eteorological **C**onditions (VMC), which permit a clear view of the terrain. Apparently, the surface was obscured by cloud. The crew decided to descend in an apparent clear area to the (true) North of Ross Island in two descending orbits. The aircraft's descent was continued to 1500ft on the flight planned track back toward Ross Island for its next turning point, Williams Field, McMurdo. The aircraft however, was actually flying 1.5miles east of its flight-planned track. Shortly after reaching 1500ft, during the descent, the cockpit voice recorder indicated a Ground Proximity Warning System (GPWS) sounded. Go around power was applied about six-seconds later with an increase in pitch attitude but the aircraft struck the ice covered slope beneath Mt Erebus at 1465ft., at an airspeed of about 253 knots. The aircraft broke up and caught fire.

Investigator amidst the DC-10 wreckage with Mt. Erebus in the background
NZ Police Photo.

Intact DC-10 Fuselage section with NZ Police locating victims remains; marked with green flags.
NZ Police Photo.

The OFFICIAL CAUSE as submitted by the technical Commission of Inquiry read: "The decision of the captain to continue the flight at low level toward an area of poor surface and horizon definition when the crew was not certain of their position and the subsequent inability to detect the rising terrain which intercepted the aircraft's flight path."

Presumably due to the adverse publicity; ostensibly blaming the Captain for the accident that resulted from the technical Commission of Inquiry report, an investigation by a subsequent Royal Commission of Inquiry led by a New Zealand high court Judge revealed additional facts. It appeared for instance that in three years of Antarctic flights, the final navigational waypoint had been changed from longitude 166deg 48.0' E (the Williams Field Non-Directional-Beacon[NDB]) to 164deg 48.9' E by mistake, routing 7 flights down the middle of McMurdo Sound. But, on the day of the accident, by misunderstanding, the waypoint was set to 166deg 58.0' E (the TACAN close by the NDB) routing the planned track directly over Mount Erebus on Ross Island. "The dominant cause of the disaster was the act of the airline in changing the computer track of the aircraft without telling the air crew." Contributing were the lack of any charts showing a printed route, the change of the co-ordinate without the knowledge of the crew and the effects of sector whiteout.[9]

The DC-10 involved was capable of navigating with the autopilot engaged to fly the entire trip from waypoint to waypoint, the coordinates of which are loaded into the Navigation computer via a pre-recorded cassette tape before the flight. So, unless the pilots take the time to plot each waypoint on a chart, they would have little knowledge of the terrain below the flight path in poor visibility. This coupled with the visual illusion caused by the “whiteout” condition, (ice crystals blown up into the air looking like a flat plane below) presumably deceived the pilots into believing the descent was not hazardous. This was one of many cases, in my experience, where an accurate technical finding of the most probable cause of the accident was misinterpreted by the media as assessing blame for the tragic loss of so many lives. Although this is a natural human tendency, it is counterproductive. It accomplishes absolutely nothing to prevent future accidents.

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[9] ICAO Circular 173-AN/109 (110-159)

The technology which is tending to alleviated the CFIT problem was the installation of the Ground Proximity Warning System (GPWS) required on all airliners.

The GPWS senses the airliner position relative to the ground and any rising terrain ahead using a very sensitive height measuring device called a Radio Altimeter (RA). The RA sends a radio wave pulse to the ground; then receives the reflected wave while very accurately measures the time interval between sending and receiving the reflected wave. This time interval is then used to compute the planes distance from the terrain to an accuracy within one foot of altitude. The GPWS computer uses the altitude information as a function of time to instantaneously warn the pilots to take the appropriate action to avoid the rapidly approaching terrain.

When the DC-10 on TE Flight 901 passed over the 300-ft. ice cliff on Ross Is. just before impact; the GPWS began sounding about 6-seconds prior to the pilot taking action to pull up the plane; ultimately resulting in an aircraft pitch attitude equal to the slope of ice upon impact. This prompted some to speculate that the impact might have either been avoided or simply impacting further up the slope, neither of which could be accurately determined.

The CFIT Task Force made the following recommendations to the International Civil Aviation Organization (ICAO):

- That requirements for the use of ground-proximity warning system (GPWS) be broadened. ICAO in 1998 amended its requirement for GPWS to include all aircraft with maximum takeoff weights above 5,700 kilograms/12,500 pounds or authorized to carry more than nine passengers;

- That early model GPWS equipment be replaced. ICAO in 1999 introduced an amendment requiring predictive terrain hazard warning functions in GPWS equipment (enhanced GPWS or terrain awareness and warning systems) in turbine airplanes certified on or after Jan. 1, 2001, and with maximum takeoff weights above 15,000 kilograms (33,069 pounds) or authorized to carry more than 30 passengers;

- That color-shaded depictions of terrain heights be shown on instrument approach charts. ICAO said that requirements for such depictions are scheduled to be introduced in November 2001;

- That aircraft operators be warned against using three-pointer altimeters and drum-pointer altimeters. ICAO in November 1998 adopted amendments prohibiting the use of these altimeters in commercial aircraft operated under instrument flight rules and warning that “due to the long history of misreadings, the use of drum-pointer altimeters is not recommended” in other aircraft;

- That the design and presentation of nonprecision instrument approach procedures be improved with a standard three-degree approach slope, except where prohibited by obstacles. ICAO said that requirements for such improvements are scheduled to be adopted in November 2001;

- That automated altitude call-outs be used. ICAO in 1998 amended the standards for operations manuals to require that they include "instructions on the maintenance of altitude awareness and the use of automated or flight crew call-out"; and,

- That the important CFIT-avoidance benefits provided by the global positioning system/global navigation satellite system (GPS/GNSS) be recognized. ICAO in 1995 cited the urgent need for progress in applying satellite navigation to nonprecision instrument approach procedures. In 1998, ICAO introduced GNSS area navigation procedures. ICAO said that criteria to support basic GNSS operations in all phases of flight are scheduled to be introduced in November 2001.

The task force also recommended that all civil aviation authorities adopt the use of hectopascals for altimeter settings. (ICAO and the World Meteorological Organization both introduced requirements in 1986 for the use of hectopascals for altimeter settings.)