Air Safety Handbook

Jody Kilgore

First Edition, 2012

ISBN 978-81-323-4339-4

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1

Air Safety

NASA air safety experiment (CID project)

Air safety is a term encompassing the theory, investigation and categorization of flight failures, and the prevention of such failures through regulation, education and training. It can also be applied in the context of campaigns that inform the public as to the safety of air travel.

Institutions

United States

During the 1920s, the first laws were passed in the USA to regulate civil aviation. Of particular significance was the Air Commerce Act 1926, which required pilots and aircraft to be examined and licensed, for accidents to be properly investigated, and for the establishment of safety rules and navigation aids, under the Aeronautics Branch of the Department of Commerce.

Despite this, in 1926 and 1927 there were a total of 24 fatal commercial airline crashes, a further 16 in 1928, and 51 in 1929 (killing 61 people), which remains the worst year on record at an accident rate of about 1 for every 1,000,000 miles (1,600,000 km) flown. Based on the current numbers flying, this would equate to 7,000 fatal incidents per year.

The fatal incident rate has declined steadily ever since, and, since 1997 the number of fatal air accidents has been no more than 1 for every 2,000,000,000 person-miles flown (e.g., 100 people flying a plane for 1,000 miles (1,600 km) counts as 100,000 person-miles, making it comparable with methods of transportation with different numbers of passengers, such as one person driving a car for 100,000 miles (160,000 km), which is also 100,000 person-miles), making it one of the safest modes of transportation, if measured by distance traveled.

A disproportionate number of all U.S. aircraft crashes occur in Alaska, largely as a result of severe weather conditions. Between 1990-2006 there were 1441 commuter and air taxi crashes in the U.S. of which 373 (26%) were fatal, resulting in 1063 deaths (142 occupational pilot deaths). Alaska accounted for 513 (36%) of the total U.S. crashes.

Another aspect of safety is protection from attack currently known as *Security* (as the ISO definition of safety encompasses non-intentional (safety_safety) and intentional (safety_security) causes of harm or property damage). The terrorist attacks of 2001 are not counted as accidents. However, even if they were counted as accidents they would have added only about 2 deaths per 2,000,000,000 person-miles. Only 2 months later, American Airlines Flight 587 crashed in Queens, NY, killing 256 people, including 5 on the ground, causing 2001 to show a very high fatality rate. Even so, the rate that year including the attacks (estimated here to be about 4 deaths per 1,000,000,000 person-miles), is safe compared to some other forms of transport, if measured by distance traveled.

Safety improvements have resulted from improved aircraft design, engineering and maintenance, the evolution of navigation aids, and safety protocols and procedures.

It is often reported that air travel is the safest in terms of deaths per passenger mile. The National Transportation Safety Board (2006) reports 1.3 deaths per hundred million vehicle miles for travel by car, and 1.7 deaths per hundred million vehicle miles for travel by air. These are not passenger miles. If an airplane has 100 passengers, then the passenger miles are 100 times higher. The number of deaths per passenger mile on commercial airlines in the United States between 1995 and 2000 is about 3 deaths per 10 billion passenger miles.

Navigation aids and instrument flight

One of the first navigation aids to be introduced (in the USA in the late 1920s) was airfield lighting to assist pilots to make landings in poor weather or after dark. The Precision Approach Path Indicator was developed from this in the 1930s, indicating to the pilot the angle of descent to the airfield. This later became adopted internationally through the standards of the International Civil Aviation Organization (ICAO).

In 1929 Jimmy Doolittle developed instrument flight.

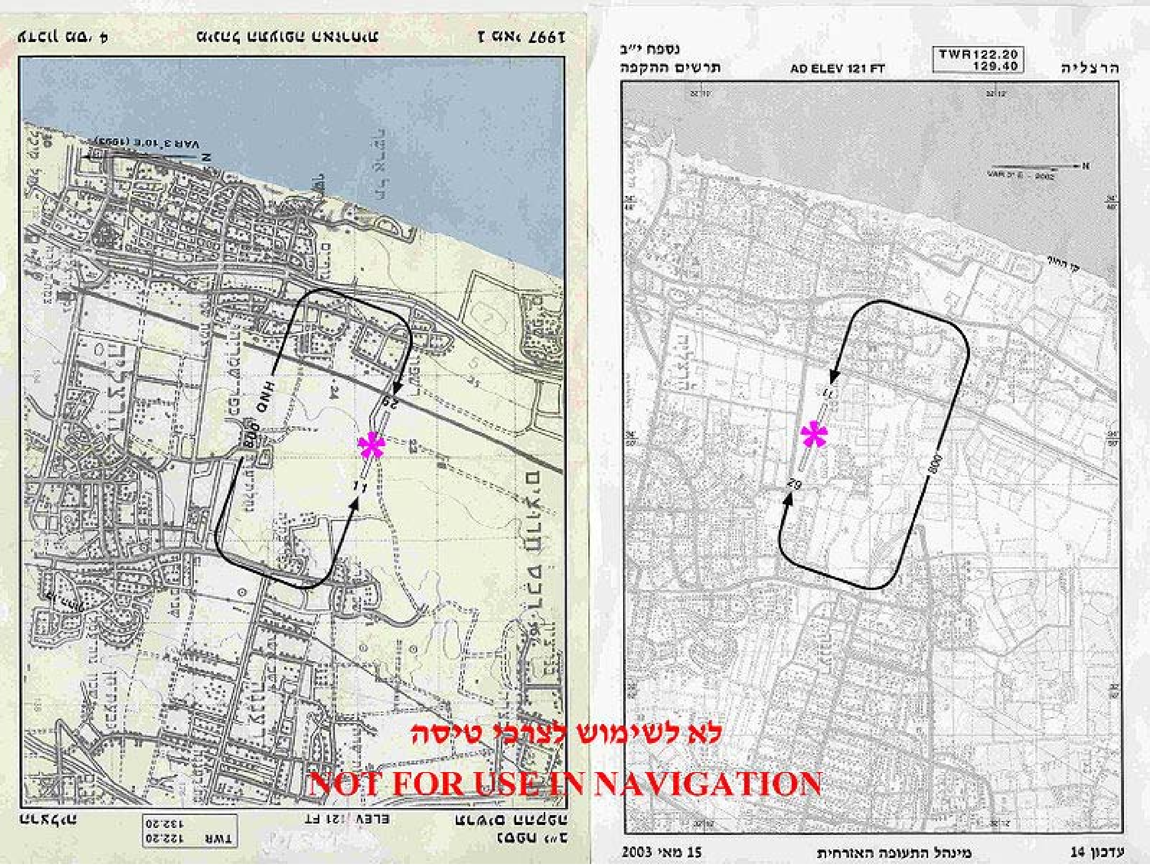
With the spread of radio technology, several experimental radio based navigation aids were developed from the late 1920s onwards. These were most successfully used in conjunction with instruments in the cockpit in the form of Instrument landing systems (ILS), first used by a scheduled flight to make a landing in a snowstorm at Pittsburgh in 1938. A form of ILS was adopted by the ICAO for international use in 1949.

Following the development of radar in World War II, it was deployed as a landing aid for civil aviation in the form of Ground-controlled approach (GCA) systems, joined in 1948 by distance measuring equipment (DME), and in the 1950s by airport surveillance radar as an aid to air traffic control. VHF omnidirectional range (VOR) stations became the predominate means of route navigation during the 1960s, superseding the low frequency radio ranges and the Non-directional beacon (NDB). The ground based VOR stations were often co-located with DME transmitters and then labeled as VOR-DME stations on navigation charts. VORTAC stations, which combined VOR and TACAN features (military TACtical Air Navigation) — the latter including both a DME distance feature and a separate TACAN azimuth feature, which provides military pilots data similar to the civilian VOR, were also used in that new system. With the proper receiving equipment in the aircraft, pilots could know their radials in degrees to/from the VOR station, as well as the slant range distance to/from, if the station was co-located with DME or TACAN.

All of the ground-based navigation aids are being supplemented by satellite-based aids like Global Positioning System (GPS), which make it possible for aircrews to know their position with great precision anywhere in the world. With the arrival of Wide Area Augmentation System (WAAS), GPS navigation has become accurate enough for vertical (altitude) as well as horizontal use, and is being used increasingly for instrument approaches as well as en-route navigation. However, since the GPS constellation is a single point of failure that can be switched off by the U.S. military in time of crisis, onboard Inertial Navigation System (INS) or ground-based navigation aids are still required for backup.

Air safety topics

Misinformation and lack of information



Herzliya Airport (Israel) Runway location and airfield traffic pattern chart (left) was erroneously printed as a result of "black layer" 180° misplacement. The corrected chart is on the right.

A pilot might fly the plane in an accident-prone manner when misinformed by a printed document (manual, map etc.), by reacting to a faulty instrument or indicator (either in cockpit or on ground) or by following inaccurate instructions or information from flight or ground control. Lack of information by the control tower, or delayed instructions, are major factors contributing to accidents.

Lightning

Boeing studies have shown that airliners are struck by lightning on average of twice per year. While the "flash and bang" is startling to the passengers and crew, aircraft are able to withstand normal lightning strikes.

The dangers of more powerful positive lightning were not understood until the destruction of a glider in 1999. It has since been suggested that positive lightning may have caused the crash of Pan Am Flight 214 in 1963. At that time aircraft were not designed to withstand such strikes, since their existence was unknown at the time standards were set. The 1985 standard in force at the time of the glider crash, Advisory Circular AC 20-53A, was replaced by Advisory Circular AC 20-53B in 2006, however it is unclear whether adequate protection against positive lighting was incorporated.

The effects of normal lightning on traditional metal-covered aircraft are well understood and serious damage from a lightning strike on an airplane is rare. However, as more and more aircraft, like the upcoming Boeing 787, whose whole exterior is made of non-conducting composite materials take to the skies, additional design effort and testing must be made before certification authorities will permit these aircraft in commercial service.

Ice and snow

Snowy and icy conditions are frequent contributors to airline accidents. The December 8, 2005 accident where Southwest Airlines Flight 1248 slid off the end of the runway in heavy snow conditions is just one of many examples. Just as on a road, ice and snow buildup can make braking and steering difficult or impossible.

The icing of wings is another problem and measures have been developed to combat it. Even a small amount of ice or coarse frost can greatly decrease the ability of a wing to develop lift. This could prevent an aircraft from taking off. If ice builds up during flight the result can be catastrophic as evidenced by the crash of American Eagle Flight 4184 (an ATR 72 aircraft) near Roselawn, Indiana on October 31, 1994, killing 68, or Air Florida Flight 90.

Airlines and airports ensure that aircraft are properly de-iced before takeoff whenever the weather threatens to create icing conditions. Modern airliners are designed to prevent ice buildup on wings, engines, and tails (empennage) by either routing heated air from jet engines through the leading edges of the wing, tail, and inlets, or on slower aircraft, by use of inflatable rubber "boots" that expand and break off any accumulated ice.

Finally, airline dispatch offices keep watch on weather along the routes of their flights, helping the pilots avoid the worst of inflight icing conditions. Pilots can also be equipped with an ice detector in order to leave icy areas they have flown into.

Engine failure

Although aircraft are now designed to fly even after the failure of one or more aircraft engines, the failure of the second engine on one side for example is obviously serious. Losing all engine power is even more serious, as illustrated by the 1970 Dominicana DC-9 air disaster, when fuel contamination caused the failure of both engines. To have an emergency landing site is then very important.

In the 1983 *Gimli Glider* incident, an Air Canada flight suffered fuel exhaustion during cruise flight, forcing the pilot to glide the plane to an emergency deadstick landing. The automatic deployment of the ram air turbine maintained the necessary hydraulic pressure to the flight controls, so that the pilot was able to land with only a minimal amount of damage to the plane, and minor (evacuation) injuries to a few passengers.

The ultimate form of engine failure, physical separation, occurred in 1979 when a complete engine detached from American Airlines Flight 191, causing damage to the aircraft and loss of control.

Metal fatigue

Metal fatigue has caused failure either of the engine or of the aircraft body.

Examples:

- the January 8, 1989 Kegworth air disaster
- De Havilland Comets accidents in 1953 and 1954
- Aloha Airlines Flight 243 in 1988

Now that the subject is better understood, rigorous inspection and nondestructive testing procedures are in place.

Delamination

Composite materials consist of layers of fibers embedded in a resin matrix. In some cases, especially when subjected to cyclic stress, the fibers may tear off the matrix, the layers of the material then separate from each other - a process called delamination, and form a mica-like structure which then falls apart. As the failure develops inside the material, nothing is shown on the surface; instrument methods (often ultrasound-based) have to be used to detect such a material failure.

Aircraft have developed delamination problems, but most were discovered before they caused a catastrophic failure. Delamination risk is as old as composite material. Even in the 1940s, several Yakovlev Yak-9s experienced delamination of plywood in their construction.

Stalling

Stalling an aircraft (increasing the angle of attack to a point at which the wings fail to produce enough lift), can be dangerous and can result in a crash unless the pilot reacts in the proper manner. Upon entering a stall, the pilot will need an adequate altitude buffer to regain control, reduce the angle of attack to a point where the boundary layer reattaches to the wing, and airspeed is brought up to where level flight can resume. Stalls are most dangerous at low altitudes, which occur during takeoff and landing.

Devices have been developed to warn the pilot when the plane's speed is coming close to the stall speed. These include stall warning horns (now standard on virtually all powered aircraft), stick shakers and voice warnings. Most stalls are a result of the pilot allowing the plane to go too slow for the particular weight and configuration at the time. However, because flow separation (stall) is purely a function of angle of attack, most aircraft can be pushed hard enough to cause a stall even at high speeds (those that can't simply lack the control authority to change the angle of attack enough at speed to induce a stall).

Notable crashes, caused by a full stall of the airfoils:

- British European Airways Flight 548, June 18, 1972
- United Airlines Flight 553, December 8, 1972
- Aeroflot Flight 7425, July 10, 1985
- Arrow Air Flight 1285, December 12, 1985
- Northwest Airlines Flight 255, August 16, 1987
- Delta Air Lines Flight 1141, August 31, 1988
- The Paul Wellstone King Air Charter crash, October 25, 2002
- Colgan Air Flight 3407, February 12, 2009
- Turkish Airlines Flight 1951, February 25, 2009

Fire

Safety regulations control aircraft materials and the requirements for automated fire safety systems. Usually these requirements take the form of required tests. The tests measure flammability and the toxicity of smoke. When the tests fail, they fail on a prototype in an engineering laboratory, rather than in an aircraft.

Fire on board the aircraft, and more especially the toxic smoke generated, have been the cause of accidents. An electrical fire on Air Canada Flight 797 in 1983 caused the deaths of 23 of the 46 passengers, resulting in the introduction of floor level lighting to assist people to evacuate a smoke-filled aircraft. Two years later a fire on the runway caused the loss of 55 lives, 48 from the effects of incapacitating and subsequently lethal toxic gas and smoke, in the 1985 British Airtours Flight 28M. That accident raised serious concerns relating to survivability, something that prior to 1985 had not been studied in such detail. The swift incursion of the fire into the fuselage and the layout of the aircraft impaired passengers' ability to evacuate, with areas such as the forward galley area becoming a bottle-neck for escaping passengers, with some dying very close to the exits. A large amount of research into evacuation and cabin and seating layouts was carried at Cranfield Institute to try to measure what makes a good evacuation route, which led to the seat layout by Overwing exits being changed by mandate and the examination of evacuation requirements relating to the design of galley areas. The use of smoke hoods or misting systems were also examined although both were rejected.

The cargo holds of most airliners are equipped with "fire bottles" (essentially remote-controlled fire extinguishers) to combat a fire that might occur in the baggage holds, below the passenger cabin. In May 1996 ValuJet Airlines Flight 592 crashed into the

Florida Everglades a few minutes after takeoff after a fire broke out in the forward cargo hold. All 110 aboard were killed.

At one time fire fighting foam paths were laid down before an emergency landing, but the practice was considered only marginally effective, and concerns about the depletion of fire fighting capability due to pre-foaming led the United States FAA to withdraw its recommendation in 1987.

One possible cause of fires in airplanes are wiring problems that involve intermittent faults, such as wires with breached insulation touching each other, having water dripping on them, or short circuits. These are difficult to detect once the plane is on the ground. However, there are methods, such as spread-spectrum time-domain reflectometry, that can feasibly test live wires on aircraft during flight.

Bird strike

Bird strike is an aviation term for a collision between a bird and an aircraft. It is a common threat to aircraft safety and has caused a number of fatal accidents. In 1988 an Ethiopian Airlines Boeing 737 sucked pigeons into both engines during take-off and then crashed in an attempt to return to the Bahir Dar airport; of the 104 people aboard, 35 died and 21 were injured. In another incident in 1995, a Dassault Falcon 20 crashed at a Paris airport during an emergency landing attempt after sucking lapwings into an engine, which caused an engine failure and a fire in the airplane fuselage; all 10 people on board were killed. Canada Geese were ingested into the engines of US Airways 1549 causing the engines to fail on the Airbus A320 that crash landed onto the Hudson River.

Modern jet engines have the capability of surviving an ingestion of a bird. Small fast planes, such as military jet fighters, are at higher risk than heavy multi-engine ones. This is due to the fact that the fan of a high-bypass turbofan engine, typical on transport aircraft, acts as a centrifugal separator to force ingested materials (birds, ice, etc.) to the outside of the fan's disc. As a result, such materials go through the relatively unobstructed bypass duct, rather than through the core of the engine, which contains the smaller and more delicate compressor blades. Military aircraft designed for high-speed flight typically have pure turbojet, or low-bypass turbofan engines, increasing the risk that ingested materials will get into the core of the engine to cause damage.

The highest risk of the bird strike is during the takeoff and landing, in low altitudes, which is in the vicinity of the airports. Some airports use active countermeasures, ranging from a person with a shotgun through recorded sounds of predators to employing falconers. Poisonous grass can be planted that is not palatable to birds, nor to insects that attract insectivorous birds. Passive countermeasures involve sensible land-use management, avoiding conditions attracting flocks of birds to the area (e.g. landfills). Another tactic found effective is to let the grass at the airfield grow taller (approximately 12 inches (30 centimetres)) as some species of birds won't land if they cannot see one another.

Bird strike can also break windshields and wound the pilot.

Ground damage

Aircraft are occasionally damaged by ground equipment at the airport. In the act of servicing the aircraft between flights a great deal of ground equipment must operate in close proximity to the fuselage and wings. Occasionally the aircraft gets bumped or worse.

Damage may be in the form of simple scratches in the paint or small dents in the skin. However, because aircraft structures (including the outer skin) play such a critical role in the safe operation of a flight, all damage is inspected, measured and possibly tested to ensure that any damage is within safe tolerances. A dent that may look no worse than common "parking lot damage" to an automobile can be serious enough to ground an airplane until a repair can be made.

An example of the seriousness of this problem was the December 26, 2005 depressurization incident on Alaska Airlines flight 536. During ground services a baggage handler hit the side of the aircraft with a tug towing a train of baggage carts. This damaged the metal skin of the aircraft. This damage was not reported and the plane departed. Climbing through 26,000 feet (7,900 metres) the damaged section of the skin gave way due to the growing difference in pressure between the inside of the aircraft and the outside air. The cabin depressurized with a bang, frightening all aboard and necessitating a rapid descent back to denser (breathable) air and an emergency landing. Post landing examination of the fuselage revealed a 12 in × 6 in (30 cm × 15 cm) hole between the middle and forward cargo doors on the right side of the airplane.

The three pieces of ground equipment that most frequently damage aircraft are the passenger boarding bridge, catering trucks, and cargo "beltloaders." However, any other equipment found on an airport ramp can damage an aircraft through careless use, high winds, mechanical failure, and so on.

The generic industry colloquial term for this damage is "ramp rash", or "hangar rash".

Volcanic ash

Plumes of volcanic ash near active volcanoes present a risk especially for night flights. The ash is hard and abrasive and can quickly cause significant wear on the propellers and turbocompressor blades, and scratch the cockpit windows, impairing visibility. It contaminates fuel and water systems, can jam gears, and can cause a flameout of the engines. Its particles have low melting point, so they melt in the combustion chamber and the ceramic mass then sticks on the turbine blades, fuel nozzles, and the combustors, which can lead to a total engine failure. It can get inside the cabin and contaminate everything there, and can damage the airplane electronics.

There are many instances of damage to jet aircraft from ash encounters. In one of them in 1982, British Airways Flight 9 flew through an ash cloud, lost all four engines, and descended from 36,000 ft (11,000 m) to only 12,000 ft (3,700 m) before the flight crew managed to restart the engines. A similar incident occurred on December 15, 1989 involving KLM Flight 867.

With the growing density of air traffic, encounters like this are becoming more common. In 1991 the aviation industry decided to set up Volcanic Ash Advisory Centers (VAACs), one for each of 9 regions of the world, acting as liaisons between meteorologists, volcanologists, and the aviation industry.

Prior to the European air travel disruption of April 2010, aircraft engine manufacturers had not defined specific particle levels above which engines were considered to be at risk. The general approach taken by airspace regulators was that if the ash concentration rose above zero, then the airspace was considered unsafe and was consequently closed.

The April 2010 eruptions of Eyjafjallajökull caused sufficient economic difficulties that aircraft manufacturers were forced to define specific limits on how much ash is considered acceptable for a jet engine to ingest without damage. In April, the CAA, in conjunction with engine manufacturers, set the safe upper limit of ash density to be 2 mg per cubic metre of air space.

From noon 18 May 2010, the CAA revised the safe limit upwards to 4 mg per cubic metre of air space.

In order to minimise the level of further disruption that this and other volcanic eruptions could cause, the CAA announced the creation of a new category of restricted airspace called a Time Limited Zone. Airspace categorised as TLZ is similar to airspace experiencing severe weather conditions in that the restrictions are expected to be of a short duration; however, the key difference with TLZ airspace is that airlines must produce certificates of compliance in order for their aircraft to enter these areas. Flybe was the first airline to conform to these regulations and their aircraft will be permitted to enter airspace in which the ash density is between 2 mg and 4 mg per cubic metre.

Any airspace in which the ash density exceeds 4 mg per cubic metre is categorised as a no fly zone.

Aviation risks of flight through downstream ash clouds

It is important to make a distinction between flight through (or in immediate vicinity of) the eruption plume and flight through so-called affected airspace. Volcanic ash in the immediate vicinity of the eruption plume is of an entirely different particle size range and density to that found in downwind dispersal clouds which contain only the finest grade of ash. The ash loading at which this process affects normal engine operation is not established beyond the awareness that relatively high ash densities must exist. Whether this silica-melt risk remains at the much lower ash densities characteristic of downstream ash clouds is currently unclear. This is therefore a serious safety hazard which invites preventive risk management strategies in line with other comparable aviation risks.

Human factors

NASA air safety experiment. The airplane is a Boeing 720 testing a form of jet fuel containing the additive FM-9, known as "Antimisting kerosene" (AMK), which formed a hard-to-ignite gel when agitated violently, as in a crash.

Human factors including pilot error are another potential danger, and currently the most common factor of aviation crashes. Much progress in applying human factors to improving aviation safety was made around the time of World War II by people such as Paul Fitts and Alphonse Chapanis. However, there has been progress in safety throughout the history of aviation, such as the development of the pilot's checklist in 1937. Pilot error and improper communication are often factors in the collision of aircraft. This can take place in the air (1978 Pacific Southwest Airlines Flight 182) (TCAS) or on the ground (1977 Tenerife disaster) (RAAS). The ability of the flight crew to maintain situational awareness is a critical human factor in air safety. Human factors training is available to general aviation pilots and called single pilot resource management training.

Failure of the pilots to properly monitor the flight instruments resulted in the crash of Eastern Air Lines Flight 40 in 1972 (CFIT), and error during take-off and landing can have catastrophic consequences, for example cause the crash of Prinair Flight 191 on landing, also in 1972.

Rarely, flight crew members are arrested or subject to disciplinary action for being intoxicated on the job. In 1990, three Northwest Airlines crew members were sentenced to jail for flying from Fargo, North Dakota to Minneapolis-Saint Paul International Airport while drunk. In 2001, Northwest fired a pilot who failed a breathalyzer test after flying from San Antonio, Texas to Minneapolis-Saint Paul. In July 2002, two America West Airlines pilots were arrested just before they were scheduled to fly from Miami, Florida to Phoenix, Arizona because they had been drinking alcohol. The pilots have been fired from America West and the FAA revoked their pilot's licenses. As of 2005 they await trial in a Florida court. The incident created a public relations problem and America West has become the object of many jokes about drunk pilots. At least one fatal airliner accident involving drunk pilots has occurred when Aero Flight 311 crashed killing all 25 on board in 1961, which underscores the role that poor human choices can play in air accidents.

Human factors incidents are not limited to errors by the pilots. The failure to close a cargo door properly on Turkish Airlines Flight 981 in 1974 resulted in the loss of the aircraft - however the design of the cargo door latch was also a major factor in the incident. In the case of Japan Airlines Flight 123, improper maintenance resulted in the loss of the vertical stabilizer.

Controlled flight into terrain

Controlled flight into terrain is a class of accident in which an undamaged aircraft is flown, under control, into terrain or man-made structures. CFIT accidents typically are a result of pilot error or of navigational system error. Some pilots, convinced that advanced electronic navigation systems such as GPS and inertial guidance systems (inertial navigation system or INS) coupled with flight management system computers , or over-reliance on them, are partially responsible for these accidents, have called CFIT accidents "computerized flight into terrain". Failure to protect Instrument Landing System critical areas can also cause controlled flight into terrain. One of the most notable CFIT accidents was in December 1995 in which American Airlines flight 965 tracked off course while approaching Calí, Colombia and hit a mountainside after the speedbrakes were left deployed despite an aural terrain warning in the cockpit and an attempt to gain ample altitude in the nighttime contidions. Crew awareness and monitoring of navigational systems can prevent or eliminate CFIT accidents. Crew Resource Management is a modern method now widely used to improve the human factors of air safety. The Aviation Safety Reporting System, or ASRS is another.

Other technical aids can be used to help pilots maintain situational awareness. A ground proximity warning system is an on-board system that will alert a pilot if the aircraft is about to fly into the ground. Also, air traffic controllers constantly monitor flights from the ground and at airports.

Terrorism

Terrorism can also be considered a human factor. Crews are normally trained to handle hijack situations. Prior to the September 11, 2001 attacks, hijackings involved hostage negotiations. After the September 11, 2001 attacks, stricter airport and airline security measures are in place to prevent terrorism using a Computer Assisted Passenger Prescreening System, Air Marshals, and precautionary policies. In addition, counter-terrorist organizations monitor potential terrorist activity.

Although most air crews are screened for psychological fitness, some may take suicidal actions. In the case of EgyptAir Flight 990, it appears that the first officer deliberately dived his aircraft into the Atlantic Ocean while the captain was away from his station, in 1999 off Nantucket, Massachusetts. Motivations are unclear, but recorded inputs from the black boxes showed no mechanical problem, no other aircraft in the area, and was corroborated by the cockpit voice recorder.

The use of certain electronic equipment is partially or entirely prohibited as it may interfere with aircraft operation, such as causing compass deviations. Use of personal electronic devices and calculators may be prohibited when an aircraft is below 10,000', taking off, or landing. The American Federal Communications Commission (FCC) prohibits the use of a cell phone on most flights, because in-flight usage creates problems with ground-based cells. There is also concern about possible interference with aircraft navigation systems, although that has never been proven to be a non-serious risk on airliners. A few flights now allow use of cell phones, where the aircraft have been specially wired and certified to meet both FAA and FCC regulations.

Attack by a hostile country

Aircraft, whether passenger planes or military aircraft, are sometimes attacked in both peacetime and war. Notable examples of this are:

- On February 21, 1973 Libyan Arab Airlines Flight 114 727-224 entered the then-Israeli-controlled airspace over the Sinai Peninsula, was intercepted by two Israeli F-4 Phantom IIs and shot down while trying to re-enter Egyptian airspace after failing to follow instructions issued by the Israeli pilots. Of the 113 people on board, there were 5 survivors, including the co-pilot.
- 1 September 1983 downing by the Soviet Union of Korean Air Lines Flight 007, carrying 269 people (including a sitting U.S. Congressman Larry McDonald),
- 3 July 1988 shoot-down by United States Navy of Iran Air Flight 655, carrying 290 people.
- 4 October 2001 shoot-down by Ukrainian Air Force of Russian flight 1812 (Tel-Aviv - Novosibirsk), carrying 78 people.

Airport design

Airport design and location can have a big impact on air safety, especially since some airports such as Chicago Midway International Airport were originally built for propeller planes and many airports are in congested areas where it is difficult to meet newer safety standards. For instance, the FAA issued rules in 1999 calling for a runway safety area, usually extending 500 feet (150 m) to each side and 1,000 feet (300 m) beyond the end of a runway. This is intended to cover ninety percent of the cases of an aircraft leaving the runway by providing a buffer space free of obstacles. Since this is a recent rule, many airports do not meet it. One method of substituting for the 1,000 feet (300 m) at the end of a runway for airports in congested areas is to install an Engineered materials arrestor system, or EMAS. These systems are usually made of a lightweight, crushable concrete that absorbs the energy of the aircraft to bring it to a rapid stop. They have stopped three aircraft (as of 2005) at JFK Airport.

Infection

On an airplane, people sit in a confined space for extended periods of time, which increases the risk of transmission of airborne infections. For this reason, airlines place restrictions on the travel of passengers with known airborne contagious diseases (e.g. tuberculosis). During the severe acute respiratory syndrome (SARS) epidemic of 2003, awareness of the possibility of acquisition of infection on a commercial aircraft reached its zenith when on one flight from Hong Kong to Beijing, 16 of 120 people on the flight developed proven SARS from a single index case.

There is very limited research done on contagious diseases on aircraft. The two most common respiratory pathogens to which air passengers are exposed are parainfluenza and influenza. In one study, the flight ban imposed following the attacks of September 11, 2001 was found to have restricted the global spread of seasonal influenza, resulting in a much milder influenza season that year, and the ability of influenza to spread on aircraft has been well documented. There is no data on the relative contributions of large droplets, small particles, close contact, surface contamination, and no data on the relative importance of any of these methods of transmission for specific diseases, and therefore very little information on how to control the risk of infection. There is no standardisation of air handling by aircraft, installation of HEPA filters or of hand washing by air crew, and no published information on the relative efficacy of any of these interventions in reducing the spread of infection.

Emergency airplane evacuations

According to a 2000 report by the National Transportation Safety Board, emergency airplane evacuations happen about once every 11 days in the U.S. While some situations are extremely dire, such as when the plane is on fire, in many cases the greatest challenge for passengers can be the use of the airplane slide. In a TIME article on the subject, Amanda Ripley reported that when a new supersized Airbus A380 underwent mandatory evacuation tests in 2006, 33 of the 873 evacuating volunteers got hurt. While the evacuation was generally considered a success, one volunteer suffered a broken leg, while the remaining 32 received slide burns. Such accidents are common. In her article, Ripley provides tips on how to make it down the airplane slide without injury.

Runway safety

Several terms fall under the flight safety topic of **runway safety**, including **incursion, excursion,** and **confusion**.

Runway excursion is an incident involving only a single aircraft, where it makes an inappropriate exit from the runway. This can happen because of pilot error, poor weather, or a fault with the aircraft. **Overrun** is a type of excursion where the aircraft is unable to stop before the end of the runway. A recent example of such an event is Air France Flight 358 in 2005. Further examples can be found in the overruns category.

Runway event is another term for a **runway accident**.

Runway incursion involves a first aircraft, as well as a second aircraft, vehicle, or person. It is defined by the U.S. FAA as: "Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take off of aircraft."

Runway confusion involves a single aircraft, and is used to describe the error when the aircraft makes "the unintentional use of the wrong runway, or a taxiway, for landing or take-off". An example of a runway confusion incident is Comair Flight 191.

Runway excursion is the most frequent type of landing accident, slightly ahead of **runway incursion**. For runway accidents recorded between 1995 and 2007, 96% were of the 'excursion' type.

The U.S. FAA publishes a lengthy annual report on runway safety issues, available from the FAA website here. New systems designed to improve runway safety, such as Airport Movement Area Safety System (AMASS) and Runway Awareness and Advisory System (RAAS), are discussed in the report. AMASS prevented the serious near-collision in the 2007 San Francisco International Airport runway incursion.

Accidents and incidents

- List of airship accidents
- Lists of aviation accidents and incidents
- Aviation accidents and incidents
- Flight recorder, includes *flight data recorder* and *cockpit voice recorder*

Statistics

There are three main statistics which may be used to compare the safety of various forms of travel:

Deaths per billion journeys	Deaths per billion hours	Deaths per billion kilometres
Bus: 4.3	Bus: 11.1	**Air**: 0.05
Rail: 20	Rail: 30	Bus: 0.4
Van: 20	**Air**: 30.8	Rail: 0.6
Car: 40	Water: 50	Van: 1.2
Foot: 40	Van: 60	Water: 2.6
Water: 90	Car: 130	Car: 3.1
Air: 117	Foot: 220	Bicycle: 44.6
Bicycle: 170	Bicycle: 550	Foot: 54.2
Motorcycle: 1640	Motorcycle: 4840	Motorcycle: 108.9

It is worth noting that the air industry's insurers base their calculations on the *number of deaths per passenger-journey* statistic while the industry itself generally uses the *number of deaths per passenger-kilometre* statistic in press releases.

Investigators

- Australian Transport Safety Bureau
- Flugunfalluntersuchungsstelle im BMVIT (Austria)
- Transportation Safety Board of Canada
- Air Accidents Investigation Institute of the Czech Republic
- Danish Aircraft Accident Investigation Board
- Bureau d'Enquêtes et d'Analyses pour la sécurité de l'Aviation Civile (France)
- Bundesstelle für Flugunfalluntersuchung (Germany)
- Air Accident Investigation Unit (Ireland)
- Aircraft and Railway Accidents Investigation Commission (Japan)
- Civil Aviation Authority of New Zealand
- Transport Accident Investigation Commission (New Zealand)
- Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (Spain)
- Swedish Accident Investigation Board
- Büro für Flugunfalluntersuchung (Switzerland)
- Air Accidents Investigation Branch (UK)
- National Transportation Safety Board (USA)
- European Co-ordination Center for Aircraft Incident Reporting Systems (ECCAIRS)
- International Civil Aviation Organisation

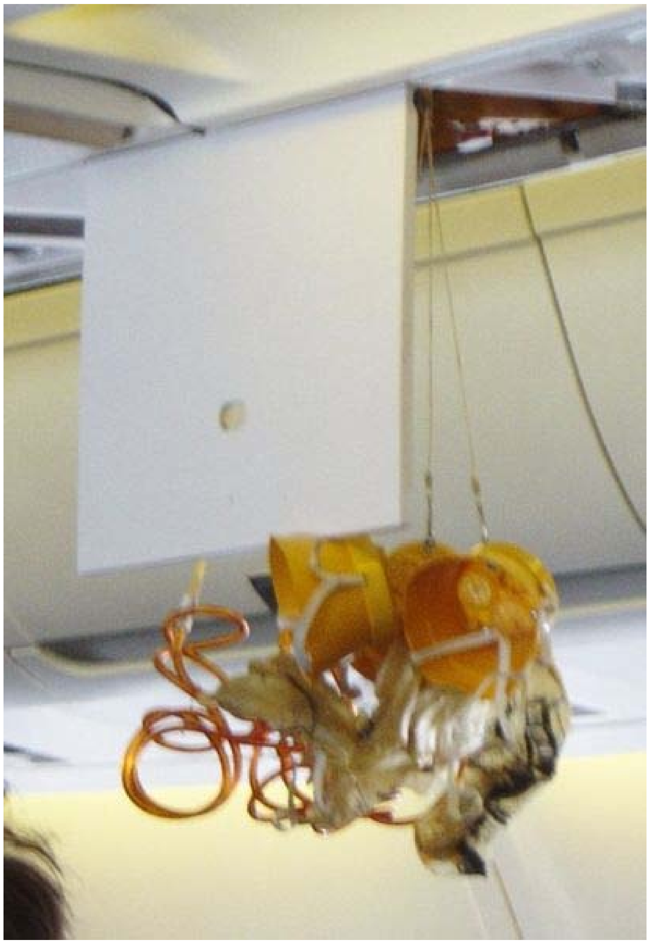
Safety Improvement Initiatives

The Safety Improvement Initiatives are aviation safety partnerships between regulators, manufacturers, operators and professional unions, research organisations, international organisations to further enhance safety. The major Safety initiatives worldwide are:

- **Commercial Aviation Safety Team (CAST)** in the US. The Commercial Aviation Safety Team (CAST) was founded in 1998 with a goal to reduce the commercial aviation fatality rate in the United States by 80 percent by 2007.
- **European Strategic Safety Initiative (ESSI)** . The European Strategic Safety Initiative (ESSI) is an aviation safety partnership between EASA, other regulators and the industry. The initiative objective is to further enhance safety for citizens in Europe and worldwide through safety analysis, implementation of cost effective action plans, and coordination with other safety initiatives worldwide.

Chapter 2

Emergency Oxygen System



Oxygen masks dropping

Aircraft emergency oxygen systems are emergency equipment fitted to commercial aircraft, intended for use when the cabin pressurisation system has failed and the level of oxygen in the cabin atmosphere drops below a safe level. It consists of a number of individual oxygen masks stored in compartments above passenger seats, and some form of central oxygen generator.

Use

Most commercial aircraft are pressurized at a maximum cabin altitude of 8,000 feet, where it is possible to breathe normally without an oxygen mask. If the cabin pressurization level reaches the equivalent of 14,000 feet or higher on the exterior, or a decompression occurs above that flying level and hypoxia is possible, compartments containing the oxygen masks will open automatically, either above or in front of the passenger and crew seats, and the oxygen masks will drop down in front of the passenger. Oxygen masks may also drop on extremely rough landings or during severe turbulence if the oxygen mask panel becomes loose. Rows of seats typically have an extra mask (i.e. 3 seats, 4 masks), in case someone has an infant in their lap, or someone in the aisle needs to grab one.

An oxygen mask consists of a yellow, soft, silicone facial cup with white elastic bands for securing the mask to the passenger's face. This band is adjustable by pulling two ends looped through the facial cup. The mask may also have a concentrator or re-breather bag that may or may not inflate depending on the cabin altitude, which has (in some instances) made passengers nervous the mask was not providing adequate oxygen, causing some to remove them, who thereby suffered hypoxia. All airlines now make a point in the safety video or demonstration to point out that the bag may not inflate. The bag is attached to a tube, connected to the oxygen source in the compartment, allowing for it to drop down and hang in front of the passengers. To operate on all aircraft except the L-1011, they must be pulled sharply toward the passenger who needs it to un-clip the flow pin and start the process of transporting the oxygen to the passenger. Passenger oxygen masks cannot deliver enough oxygen for sustained periods at high altitudes. This is why the flight crew needs to place the aircraft in a controlled emergency descent to a lower altitude where it is possible to breathe without emergency oxygen. While the masks are being used, passengers are not allowed to leave their seat for any reason until it is safe to breathe without the emergency oxygen. If there is a fire on board the aircraft, masks are not deployed, as the production of oxygen may further fuel the fire.

Aircraft safety cards and in-flight safety demonstrations shown at the beginning of each flight explain the location and use of oxygen masks.

Some aircraft, such as the SAAB Series Aircraft and the 1900D, have a mask system where either a mask is stored under the seat or is distributed by the cabin attendant. These masks are removed from packaging and plugged into the socket for oxygen supply.

Mechanism

There are two systems that are typically found on aircraft:

- A *gaseous manifold system*, which connects all oxygen masks to a central oxygen supply, usually in the cargo hold area. Pulling down on one oxygen mask starts the oxygen supply for that mask only. The entire system can usually be reset in the cockpit or in some other location in the aircraft.

- A *chemical oxygen generator system* connected to all masks in the compartment. Pulling down on one oxygen mask removes the firing pin of the generator igniniting a mixture of sodium chlorate and iron powder, opening the oxygen supply for all the masks in the compartment. Oxygen production cannot be shut off once a mask is pulled, and oxygen production typically lasts for 10-15 minutes. During the production of oxygen, the generator becomes extremely hot and should not be touched. A burning smell may be noted and cause alarm among passengers, but this smell is a normal part of the chemical reaction. This system can be found on the MD-80 aircraft, whose system is also unique in the fact that the masks are secured to the compartment door and do not hang in front of the passengers by the tube.

Usage history

Remarkably, for a widely-deployed piece of safety equipment, some research has suggested that no lives are known to have been saved by use of an emergency oxygen mask - nor any lives lost through the absence of one - whilst carrying oxygen generating apparatus, albeit as cargo, has caused at least one fatal accident. The fatal accident was ValuJet Flight 592, in 1996, where expired chemical oxygen generators were loaded as cargo on board the aircraft without being safely deactivated; in transit, it is believed these generators activated; the heat generated from the activated generators caused the boxes they were improperly stored in to catch fire.

In the three cases of in-flight explosive decompression studied, one took place at a sufficiently low altitude for atmospheric oxygen to be sufficient, whilst in the other two cases the systems failed in the accident and did not provide oxygen to the passengers. However, in several other cases, oxygen masks have kept passengers conscious and alert during a decompression and have protected passengers from injury.

The cockpits of aircraft generally contain a separate oxygen system for the flight crew, and effective use of these has no doubt saved many aircraft. Hypoxia, which can cause severe disorientation and unconsciousness, sets in quickly; if a flight crew does not realise the cabin has decompressed, or is too slow to respond, they can quickly lose control of the aircraft. For example, on Helios Airways Flight 522 in 2005, the cabin depressurized slowly during the ascent to cruising altitude, and whilst the passenger oxygen masks were released at 14,000 feet, the crew were disoriented and failed to realise the significance of this; they lost control within a few minutes, having not put on their own oxygen masks. In the 1999 South Dakota Learjet crash, the NTSB report concluded that only a few seconds delay in using their masks following decompression would be enough to incapacitate a flight crew.

In one case, in 2000, a Boeing 737-800 suffered a slow depressurization, coupled with the failure of the cabin altitude warning system. The depressurization was only discovered by the crew due to the automatic deployment of the passenger oxygen masks; this gave them time to respond appropriately.

Chapter 3

Deicing

An American Airlines MD-80 aircraft being de-iced at Syracuse Hancock International Airport.

Spray de-icing at Salt Lake City airport, 2010

De-icing is defined as removal of existing, snow ice, frost, etc., from a surface.

Anti-icing is understood to be the application of chemicals that not only de-ice, but remain on a surface and continue to delay the reformation of ice up to a certain period of time, or prevent adhesion of ice to make mechanical removal easier.

Methods

De-icing can be accomplished by mechanical methods (scraping, pushing); through the application of heat; by use of dry or liquid chemicals designed to lower the freezing point of water (various salts or brines, alcohols, glycols); or by a combination of these different techniques.

Anti-icing of aircraft is accomplished by applying a protective layer, using a viscous fluid called **anti-ice fluid**, over a surface to absorb the contaminate. All anti-ice fluids offer only limited protection, dependent upon frozen contaminant type and prevailing weather conditions. A fluid has failed when it no longer can absorb the contaminant and it essentially becomes a contaminant itself. Even water can be a contaminant in this sense, as it dilutes the anti-icing agent until it is no longer effective.

De-icing of roads has traditionally been done with salt, spread by snowplows or dump trucks designed to spread it, often mixed with sand and gravel, on slick roads. Sodium chloride (rock salt) is normally used, as it is inexpensive and readily available in large quantities. However, since salt water still freezes at -18°C or 0°F, it is of no help when the temperature falls below this point. It also has a strong tendency to cause corrosion, rusting the steel used in most vehicles and the rebar in concrete bridges. More recent snowmelters use other salts, such as calcium chloride and magnesium chloride, which not only depress the freezing point of water to a much lower temperature, but also produce an exothermic reaction. They are somewhat safer for concrete sidewalks, but excess should still be removed.

More recently, organic compounds have been developed that reduce the environmental issues connected with salts and have longer residual effects when spread on roadways, usually in conjunction with salt brines or solids. These compounds are generated as byproducts of agricultural operations such as sugar beet refining or the distillation process that produces ethanol. Additionally, mixing common rock salt with some of the organic compounds and magnesium chloride results in spreadable materials that are both effective to much colder temperatures (-30°F/-34°C) as well as at lower overall rates of spreading per unit area.

Infrared

Infrared is the transmission of energy by means of electromagnetic waves or rays. Infrared is invisible and travels in straight lines from the heat source to surfaces and objects without significantly heating the space (air) it passes through. When infrared waves strike an object, they release their energy as heat. This heat is either absorbed or reflected by the cooler surface. Infrared energy is continually exchanged between "hot" and "cold" surfaces until all surfaces have reached the same temperature (equilibrium). The colder the surfaces, the more effective the infrared transfer from the emitter. This heat transfer mechanism is substantially faster than conventional heat transfer modes used by conventional deicing (convection and conduction) due to the cooling effect of the air on the deicing fluid spray.

Environmental impact

Deicing salts such as sodium chloride or magnesium chloride leach into urban soils, where they accumulate and can eventually become toxic to the organisms in these soils.

Propylene glycol used to de-ice aircraft can contaminate drinking water supplies and harm aquatic life. Some airports are now capturing and treating de-icing runoff before allowing it to enter waterways.

Aircraft-related use

On the ground, when there are freezing conditions and precipitation, de-icing an aircraft is crucial. Frozen contaminants cause critical control surfaces to be rough and uneven disrupting smooth air flow and greatly degrading the ability of the wing to generate lift and increasing drag. This situation can cause a crash. If large pieces of ice separate when the aircraft is in motion, they can be ingested in engines or hit propellers and cause catastrophic failure. Frozen contaminants can jam control surfaces, preventing them from moving properly. Because of this potentially severe consequence, de-icing is performed at airports where temperatures are likely to be around 0°C.

In flight, droplets of supercooled water often exist in stratiform and cumulus clouds. They form into ice when they are struck by the wings of passing airplanes and abruptly crystallize. This disrupts airflow over the wing, reducing lift, so aircraft that are expected to fly in such conditions are equipped with a de-icing system.

De-icing techniques are also employed to ensure that engine inlets and various sensors on the outside of the aircraft are clear of ice or snow.

De-icing on the ground is usually done by spraying aircraft with a de-icing fluid based on propylene glycol, similar to ethylene glycol antifreeze used in some automobile engine coolants. Ethylene Glycol (EG) is still in use for aircraft de-icing in some parts of the world because it has a lower operational use temperature (LOUT) than PG, but Propylene Glycol (PG) is more common because it is classified as non-toxic, unlike Ethylene Glycol. Nevertheless, it still must be used with a containment system to capture the used liquid, so that it cannot seep into the ground and water courses. Even though classified as non-toxic, it has negative effects in nature, since it uses oxygen during breakdown, causing aquatic life to suffocate. In one case, a significant snow in Atlanta in early January 2002 caused an overflow of such a system, briefly contaminating the Flint River downstream of the Atlanta airport. Many airports recycle used de-icing fluid, separating water and solid contaminants, enabling reuse of the fluid in other applications.

Fluid types

There are several types of de-icing fluid, falling into two basic categories: 1. De-icing fluids -Heated glycol diluted with water for de-icing and snow/frost removal, also referred to as Newtonian fluids (owing to their viscous flow similar to water) and 2. Anti-icing fluid - unheated, undiluted propylene glycol based fluids that has been thickened (imagine half-set gelatin), also referred to as Non-Newtonian fluids (owing to their characteristic viscous flow), applied to retard the future development of ice or to prevent falling snow or sleet from accumulating. Anti-icing fluids provide holdover protection against the formation of ice while the aircraft is stationary on the ground but when subjected to shearing force such as the air flow over the fluid surface, an aircraft accelerating for take off - the fuids whole reology changes and it becomes significantly thinner, running off to leave a clean and smooth aerodynamic surface to the wing. In some cases both types of fluid are applied, first the heated glycol/water mixture to remove contaminants, followed by the unheated thickened fluid to keep ice from reforming before the aircraft takes off. This is called "a two-step procedure".

Methanol de-ice fluid has been employed for years to de-ice small wing and tail surfaces of small to medium-sized general aviation aircraft and are usually applied with a small hand-held sprayer. Methanol can only remove frost and light ground ice prior to flight.

Mono-ethylene, di-ethylene and propylene glycol are nonflammable petroleum products and similar products are most commonly found in automotive cooling systems. Gylcol has very good de-icing properties and the aviation grade is referred to as SAE/ISO/AEA Type I (AMS 1424 or ISO 11075). it is usually applied to contaminated surfaces diluted 50% with water at 95 degrees Fahrenheit using a cherry picker on a truck containing 1500 to 2000 US Gallons (5680 to 7570 L) for on-ramp or departure runway entry point application. Colour-dyed fluid is preferred as it can be confirmed easily by visual observation that an aircraft has received a de-ice. Run off Type I appears to turn slush a pink tinge hence the term pink snow. Otherwise, all Type I fluids are orange.

Inflight ice buildups are most frequent on the leading edges of the wings, tail and engines (including the propellers or fan blades). Lower speed aircraft frequently use pneumatic deicing boots on the leading edges of wings and tail for inflight de-icing. The rubber coverings are periodically inflated, causing ice to crack and flake off. Once the system is activated by the pilot, the inflation/deflation cycle is automatically controlled. In the past, it was thought such systems can be defeated if they are inflated prematurely; that the pilot must allow a fairly thick layer of ice to form before inflating the boots. Recent research shows “bridging” does not occur with modern boots.

Some aircraft may also use electrically heated resistive elements embedded in a rubber sheet cemented to the leading edges of wings and tail surfaces, propeller leading edges, and helicopter rotor blade leading edges. Such systems usually operate continuously. When ice is detected, they first function as de-icing systems, then as *anti-icing* systems for continued flight in icing conditions. Some aircraft use chemical de-icing systems which pump antifreeze such as alcohol or propylene glycol through small holes in the wing surfaces and at the roots of propeller blades, melting the ice, and making the surface inhospitable to ice formation. A fourth system, developed by NASA, detects ice on the surface by sensing a change in resonance frequency. Once an electronic control module has determined that ice has formed, a large current spike is pumped into the transducers to generate a sharp mechanical shock, cracking the ice layer and causing it to be peeled off by the slipstream.

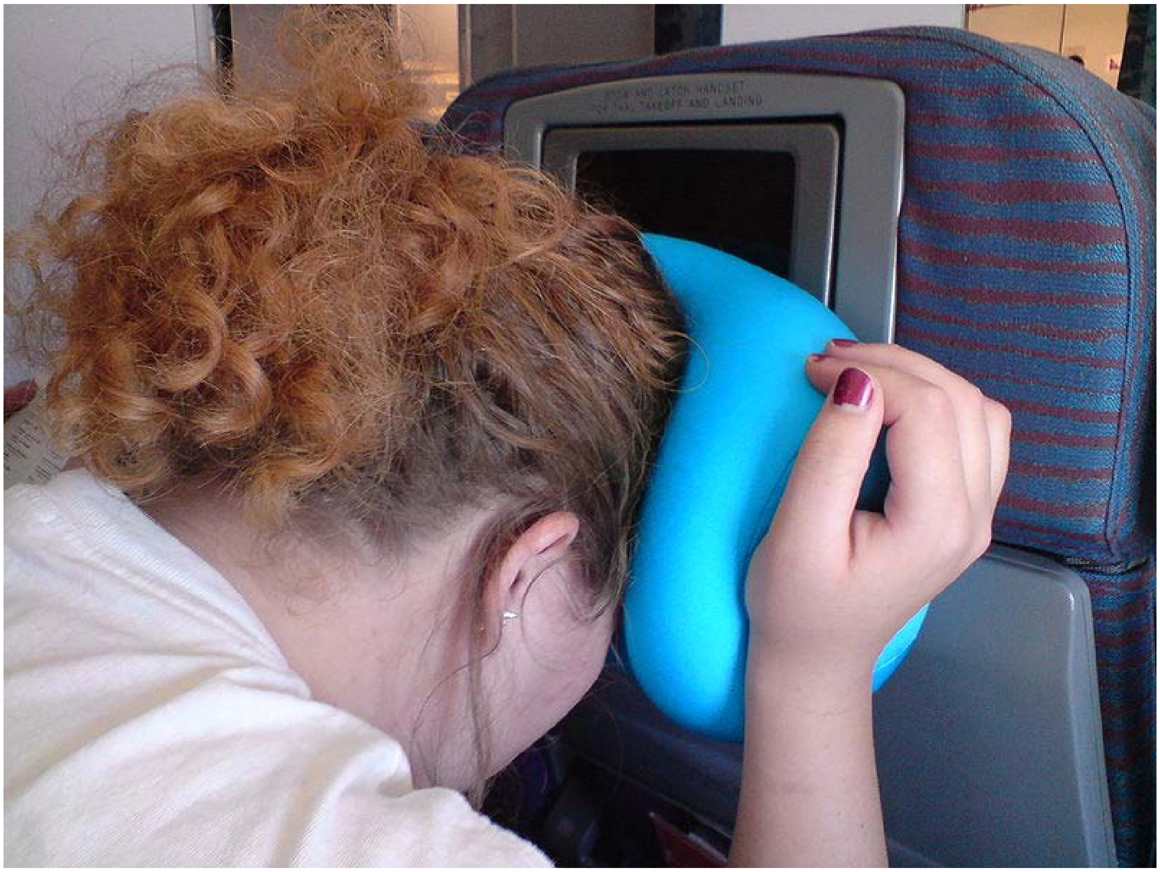
Many modern civil fixed-wing transport aircraft use anti-ice systems on the leading edge of wings, engine inlets and air data probes using warm air. This is bled from engines and is ducted into a cavity beneath the surface to be anti-iced. The warm air heats the surface up to a few degrees above zero, preventing ice from forming. The system may operate autonomously, switching on and off as the aircraft enters and leaves icing conditions.

Chapter 4

Brace Position

Bracing or **crash position** is an instruction that can be given to prepare for a crash, such as on an aircraft, the instruction to ***brace for impact*** is often given if the aircraft must make an emergency landing over land or water.

Types of brace position



A demonstration of the brace position

There are many different ways to adopt the brace position, with many countries adopting their own version based on research performed by their own aviation authority or that of other countries. There is commonality among all brace positions despite these variations. For a forward seated passenger wearing only a lap belt, common recommendations for the brace position include:

- Placing the head on, or as close as possible to, the surface it is most likely to strike. (For example, the bulkhead or seat in front.)
- Having the passenger lean over to some degree to avoid jackknifing or submarining.
- Placing the feet flat on the floor.

In the United Kingdom, following the Kegworth air disaster in 1989, the UK Civil Aviation Authority contracted an engineering consultancy, Hawtal Whiting Structures, to perform computer based analytical investigation to optimise the brace for impact position for forward facing passengers. This was supported by medical information from the University of Nottingham and testing at the Institute of Aviation Medicine.

The brace position as set out to airlines in the UK for passengers in forward facing seats is based on extensive analytical work arising from Kegworth. It is subtly different from that in the United States and some other countries. Passengers should place their feet and knees together with their feet firmly on the floor (either flat or on the balls of their feet) and tucked behind the knees to prevent shins and legs being broken against the base of the seat in front. They should bend as far forward as possible, resting their head against the seat in front if it is within reach and place their hands on the back of their head, with the hands one on top of another (rather than interlocked). Their elbows should then be brought in. This prevents both flailing of the arms in the crash sequence and protects the head from flying debris. The head should be as far below the top of the seats as possible to prevent injury from any collapsing overhead compartments.

The brace procedure for the forward facing seat in the United States is similar to that of the UK, but rather than placing the hands on the back of the head, passengers are advised to place them on the top of the seat in front, one hand holding the other wrist and resting the head in the space between the arms. If the seat in front is not within reach then passengers are advised to either grab their ankles or place their hands under their legs and grab the opposite forearm.

Most experts will say that maximum protection for a forward facing seat is when the passenger is able to pre-position their head on the surface they are likely to impact (e.g., seat back or bulkhead), as the risk of head trauma is significantly reduced during the crash. Reducing head trauma may also help the passenger stay conscious, which is also essential for rapid evacuation after the crash.

Flight attendant brace positions are somewhat different due to the design of aircraft jumpseats. So far, there has been little research into the best brace position for flight attendants, though airlines have adopted positions that are very similar to one another.

In rear facing seats, the attendant should be sitting with their back and head firmly against the back of the jumpseat, their knees and feet together and slightly in front of or behind the knee (depending on the individual airlines procedures) - commonly referred to as "toes to tail". In European carriers, the hands can be placed behind the head and hands one on top of the other and the elbows brought in to meet, taking care that the forearm does not cover the ear and restrict hearing. This position provides the flight attendant protection to the face from any flying debris (as it will impact their elbows) yet still provides them with the ability to view the cabin and not muffle their commands. In the United States, the Federal Aviation Administration (FAA) does not recommend placing the hands behind the neck as their research suggests such actions can cause unnecessary loading on the neck and spine during an impact. Instead, US flight attendants are typically taught to sit on their hands, palms facing the ceiling, underneath their upper legs. Other variations include clasping the hands on the knees or using one arm to "hug" the opposing arm.

For forward facing jumpseats, the position is exactly the same but with the feet behind the knees, with some airlines requiring flight attendants to tuck their chin in to their chest ("bow to the captain") to reduce the likelihood of whiplash injuries.

There is also a third brace position for flight attendants, and that is the "normal" brace position. This is adopted by the attendant for every take off and landing and provides them with protection from any sudden emergencies and allows them to adopt the full brace position quickly should they need to. The only difference between the normal brace and the full brace position is that the attendants will either fold their arms across their stomach or immobilize them by placing their hands under their thighs with the palms up. This position forms part of every flight attendant's "sixty second review" - a technique being adopted by airlines whereby the attendant will go over various factors in their head during the take-off and landing sequence. Things such as "how do I open my door?", "where is the next nearest exit?", "am I over land or water?" and "what commands will I shout" are just a few of the questions an attendant will ask themselves. The belief is that this mental review focuses the attendant on the safety-critical role they have during take-off and landing and will result in faster decision making and adaptation to the scenario.

Newer brace positions are being adopted by many U.S. airlines in which the flight attendants do not sit on their hands. Instead, they place their hands flat on top of their thighs. This new position is being adopted because in the event of a crash, sitting on hands can cause injury and/or crushing.

Infants

If carrying an infant on a lap, it is generally recommended that above positions should be adopted as best as possible, cradling the child with one arm and using this to also protect the child's head. In the UK, lap children are instructed to wear an infant safety belt which is a separate seat belt with a loop that connects to the parent's belt; however, in the United States such belts are not permitted by FAA regulations. The FAA believes that such baby belts significantly increases the risk of injury to the child. In the early era of commercial aviation, the recommended brace position for children was on the floor against a bulkhead; this has since been amended due to the position's lack of protection. The safest position for an infant is in an aviation certified child safety seat.

Myths

There have been myths surrounding the use of the brace procedure, namely that adopting the brace procedure is only useful for preserving dental integrity for identification after a crash. Another myth is that the position is designed to increase the chance of death to reduce insurance-paid medical cost. Instances where the brace procedure has been adopted have been shown to save lives. In one accident, passengers were asleep on an aircraft that was about to collide with trees. One passenger awoke and adopted the procedure, and he was the only survivor. All passengers aboard Scandinavian Airlines Flight 751, which crashed, survived: an outcome which it has been suggested was largely thanks to the passengers' universal adoption of the brace position.

During the "Miracle on the Hudson" flight on January 15, 2009, there were fewer than three minutes to land U.S. Airways Flight 1549 into the Hudson River and the only words the passengers heard from the pilot were "Brace for Impact". Flight attendants chanted, "Brace! Brace! Heads down! Stay down!" and all 155 people on board survived with no life-threatening injuries. Several books were written about this rare feat of successful water landing by a commercial aircraft, including a book titled *Brace for Impact* written by crash survivors that was released on the first anniversary of the crash.

Safety cards

Many government aviation administrations or regulatory bodies mandate the depiction of how to adopt the brace position on aircraft safety cards and in-flight safety demonstrations, such as a 1993 ruling by the United Kingdom Civil Aviation Authority (issued in a Notice to Air Operator Certificate Holders 1993) or, for example, in CAO 020.11 (section 14.1.3), issued by the Civil Aviation Safety Authority of Australia.

The depiction of how to adopt the brace position is not a basic standard set forth by the International Civil Aviation Organization. While many regulatory bodies have adopted this addition on their own (as noted above), the FAA has not required it on flights to, from, or within the United States.

Planned or unplanned crash landings

In an unexpected emergency on a passenger aircraft where an impact may be possible, cabin crew are trained to recognize such situations (e.g., flight attendants sense that the take-off is not going as usual) and shout commands to passengers, such as "Bend over! Stay down!", "Brace for impact! Heads down! Stay down!" or "Brace! Brace! Heads down! Grab your ankles!". In a developing emergency, the cabin crew can first give a briefing to passengers on how to properly adopt the brace position. Before the emergency landing, the flight deck usually gives a pre-arranged signal (such as the command, "Brace for impact." over the public announcement system or flashing the fasten seat-belt sign several times), whereupon the cabin crew will shout commands to passengers to adopt the brace position, such as "Brace, Brace! Stay down!" or "Get your heads down, stay down!", Which the cabin crew is required to chant repeatedly in a loud voice until the aircraft comes to a complete stop or they receive an "evacuate" command. Every airline has their own command when commanding passengers to take the brace position. European carriers usually prefer to give detailed instructions about brace position, emergency exits and jackets before taking off.

Kegworth

In the 1989 Boeing 737-400 Kegworth air disaster crash, the pilot was able to announce "Prepare for crash landing" 10 seconds before impact; the resulting injuries—from both those who did and did not adopt the brace position—would later be studied to provide further research on this topic. A CAA-funded engineering–medical joint research team was established, led by Nigel Rock of Hawtal Whiting (HW) Engineering Consultants and Prof Angus Wallace of the Nottingham University Hospital. The team was aided by Wng Cmdr David Anton of the Royal Airforce Institute of Aviation Medicine. The work used mathematical modelling derived from the automobile industry to analyse the human body under crash conditions.

Chapter 5

Flight Attendant

Flight attendants or **cabin crew** (also known as **stewards/stewardesses** or **air hosts/hostesses**) are members of an aircrew employed by airlines primarily to ensure the safety and comfort of passengers aboard commercial flights, on select business jet aircraft, and on some military aircraft.

History

The role of a flight attendant ultimately derives from that of similar positions on passenger ships or passenger trains, but it has more direct involvement with passengers because of the confined quarters and often longer travel times on aircraft. Additionally, the job of a flight attendant revolves around safety to a much greater extent than those of similar staff on other forms of transportation. Flight attendants on board a flight collectively form a *cabin crew,* as distinguished from pilots and engineers in the cockpit.

Heinrich Kubis was the world's (and Germany's) first flight attendant, in 1912.

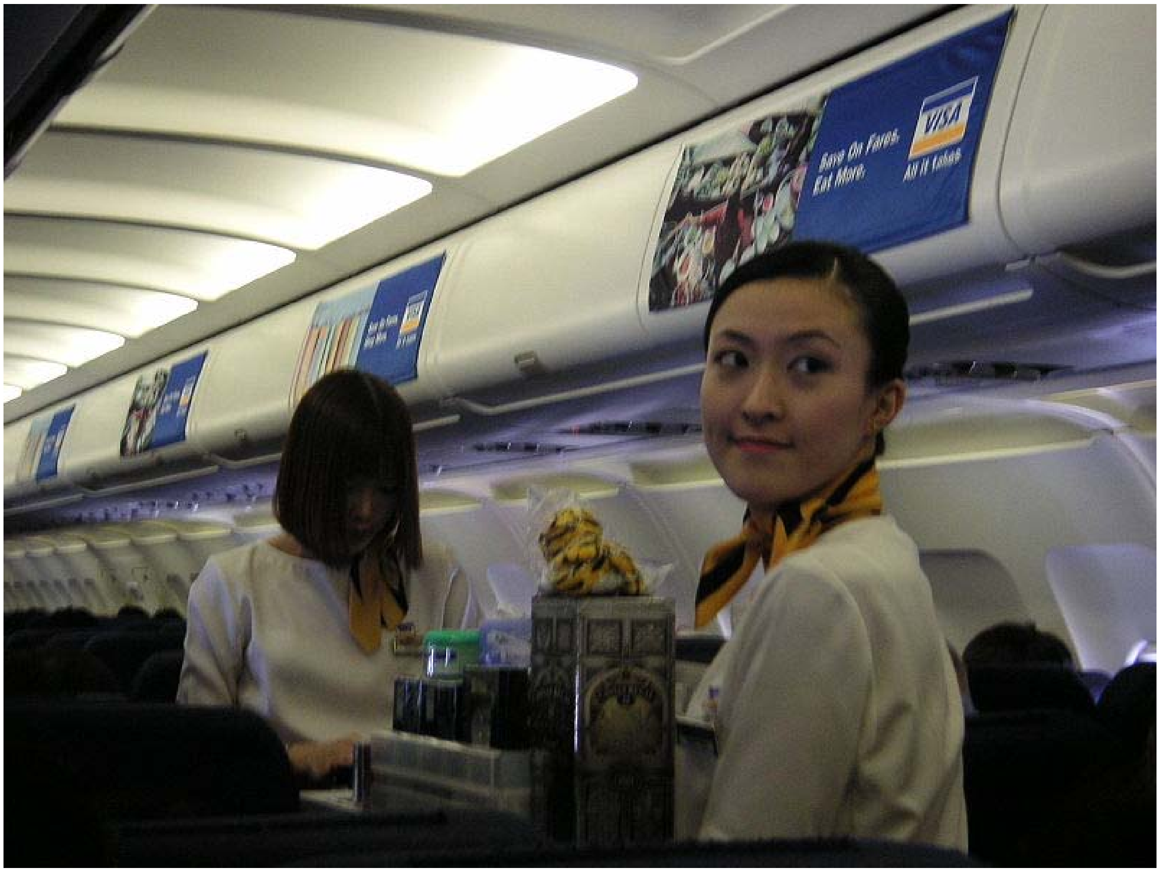
Origins of the word "steward" in transportation are reflected in the term "steward" as used in maritime transport terminology. The term purser and chief steward are often used interchangeably describing personnel with similar duties among seafaring occupations. This lingual derivation results from the international British maritime tradition dating back to the 14th century and the civilian United States Merchant Marine which US aviation is somewhat modeled. Due to international conventions and agreements, in which all ships' personnel who sail internationally are similarly documented by their respective countries, the U.S. Merchant Marine assigns such duties to the chief steward in the overall rank and command structure of which pursers are not positionally represented or rostered.

Imperial Airways of the United Kingdom had "cabin boys" or "stewards"; in the 1920s. In the USA, Stout Airways was the first to employ stewards in 1926, working on Ford Trimotor planes between Detroit and Grand Rapids, Michigan. Western Airlines (1928) and Pan American World Airways (Pan Am) (1929) were the first US carriers to employ stewards to serve food. Ten-passenger Fokker aircraft used in the Caribbean had stewards in the era of gambling trips to Havana, Cuba from Key West, Florida. Lead flight attendants would in many instances also perform the role of purser, steward, or chief steward in modern aviation terminology.

The first female flight attendant was a 25-year-old registered nurse named Ellen Church . Hired by United Airlines in 1930, she also first envisioned nurses on aircraft. Other airlines followed suit, hiring nurses to serve as flight attendants, then called "stewardesses," on most of their flights. The requirement to be a registered nurse was relaxed at the start of World War II, as many nurses enlisted into the armed forces.

In 1962, St Bona of Pisa, a 12th-century pilgrim, was canonised by Pope John XXIII as patron saint of air hostesses.

Overview



Flight attendants on Tiger Airways

The primary role of a flight attendant is to ensure passenger safety. In addition to this, flight attendants are often tasked with customer service duties such as serving meals and drinks, as a secondary responsibility.

The number of flight attendants follows from international safety regulations. For planes with up to 19 passenger seats, no flight attendant is needed. For larger planes one flight attendant per 50 passenger seats is needed.

The majority of flight attendants for most airlines are female, though a substantial number of males have entered the industry since the 1970s.

Responsibilities

A Lufthansa flight attendant performing a pre-flight safety demonstration

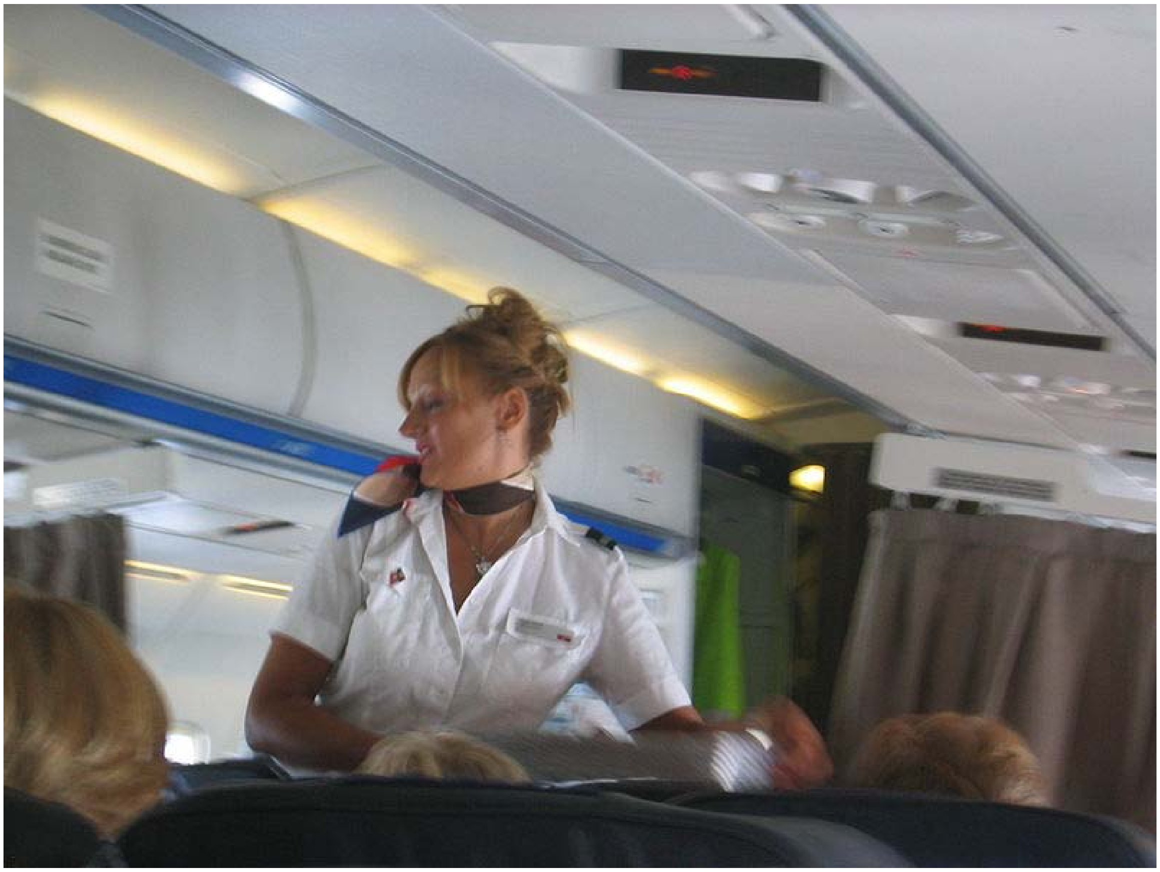
The majority of a flight attendant's duties are safety related. Prior to each flight, flight attendants attend a safety briefing with the pilots and lead flight attendant. During this briefing they go over safety and emergency checklists, the locations and amounts of emergency equipment and other features specific to that aircraft type. Boarding particulars are verified, such as special needs passengers, small children travelling as unaccompanied or VIPs. Weather conditions are discussed including anticipated turbulence. Prior to each flight a safety check is conducted to ensure all equipment such as lifevests, torches and firefighting equipment are on board, in the right quantity, and in proper condition. Any unserviceable or missing items must be reported and rectified prior to takeoff. They must monitor the cabin for any unusual smells or situations. They assist with the loading of carry-on baggage, checking for weight, size and dangerous goods. They then must do a safety demonstration or monitor passengers as they watch a safety video. They then must "secure the cabin" ensuring tray tables are stowed, seats are in their upright positions, armrests down and carry ons stowed correctly and seat belts fastened prior to takeoff. All the service between boarding and take-off is called *Pre Take off Service*.

Once up in the air, flight attendants will usually serve drinks and/or food to passengers. When not performing customer service duties, flight attendants must periodically conduct cabin checks and listen for any unusual noises or situations. Checks must also be done on the lavatory to ensure the smoke detector hasn't been deactivated and to restock supplies as needed. Regular cockpit checks must be done to ensure the pilot's health and safety. They must also respond to call lights dealing with special requests. During turbulence, flight attendants must ensure the cabin is secure. Prior to landing all loose items, trays and rubbish must be collected and secured along with service and galley equipment. All hot liquids must be disposed of. A final cabin check must then be completed prior to landing. It is vital that flight attendants remain aware as the majority of emergencies occur during takeoff and landing. Upon landing, flight attendants must remain stationed at exits and monitor the airplane and cabin as passengers disembark the plane. They also assist any special needs passengers and small children off the airplane and escort children, while following the proper paperwork and ID process to escort them to the designated person picking them up.

Flight attendants are highly trained to deal with a wide variety of emergencies,and are trained in First Aid. More frequent situations may include a bleeding nose, illness, small injuries, intoxicated passengers, aggressive and anxiety stricken passengers. Emergency training includes rejected takeoffs, emergency landings, cardiac and in-flight medical situations, smoke in the cabin, fires, depressurization, on-board births and deaths, dangerous goods and spills in the cabin, emergency evacuations, hijackings, water landings, and sea, jungle, arctic, and desert survival skills.

Flight attendant in an Embraer ERJ 145 LR of PBair, Thailand

Swiss stewardess serving orange juice



Stewardess in a Swiss flight from London to Zurich

Chief Purser

The Chief Purser (CP), Inflight Service Manager (ISM), Cabin Service Manager (CSM). The title associating with this crew member differs from airline to airline. These crew are mainly found on larger aircraft types and are in charge of the running of the cabin. They report when the cabin is secure for takeoff and landing, deliver on-board announcements, and any broken or missing emergency equipment items to the pilots after the preflight check. They generally operate the doors during routine flights as well as hold the manifest and account for all money and required paperwork and reports for each flight. 2-4 Senior Crew Members may also be on board the larger aircraft types. Chief Pursers are flight attendants that have been promoted through the ranks- Flight attendant → Senior crew member → Purser → Chief Purser. To reach this position the crew member must have had a mandatory amount of service years within the airline or airlines prior to changing airline. Further training is mandatory, and Chief Pursers typically earn a higher salary than flight attendants because of the added responsibility.

Purser

The purser will, on board larger aircraft with multiple flight attendants, assist the Chief Purser and have similar roles and responsibilities. 2-4 Senior Crew Members may also be on board the larger aircraft types. Pursers are flight attendants or a related job, typically with an airline for several years prior to application for, and further training to become a purser, and normally earn a higher salary than flight attendants because of the added responsibility.

Qualifications

Training

Malaysia Airlines regional cabin staff

Flight attendants are normally trained in the hub or headquarters city of an airline over a period that may run from six weeks to six months, depending on the country and airline. The main focus of training is safety. One of the most elaborate training facilities was Breech Academy which Trans World Airlines (TWA) opened in 1969 in Overland Park, Kansas. Other airlines were to also send their attendants to the school. However, during the fare wars the school's viability declined and it closed around 1988.

Safety training includes, but is not limited to: emergency passenger evacuation management, use of evacuation slides/life rafts, in-flight firefighting, survival in the jungle, sea, desert, ice, first aid, CPR, defibrillation, ditching/emergency landing procedures, decompression emergencies, Crew Resource Management and security.

In the United States the Federal Aviation Administration requires flight attendants on aircraft with 20 or more seats to hold a *Certificate of Demonstrated Proficiency*. This is not considered to be the equivalent of an airman certificate (licence), although it is issued on the same card stock. It shows that a level of required training has been met. It is not limited to the airline at which the attendant is employed (although some initial documents showed where the holder was working), and is the attendant's personal property. It does have two ratings, called Group I and II. Either or both of these may be earned depending upon the type of aircraft (propeller or turbofan) on which the holder has trained.

There are also training schools that are not affiliated with any particular airline, where students generally not only undergo generic, though otherwise practically identical training to flight attendants employed by an airline, as well as having modules in the curriculum to help students gain employment with an airline. These schools often use actual airline equipment in their lessons, though some are equipped with full simulator cabins capable of replicating a number of emergency situations.

Aviation Australia, based in Brisbane, Queensland is a notable example, as its facilities are comprehensive to the point that multiple airlines use the school for either the training or retrain and re-certification their staff.

Language

Multilingual flight attendants are often in demand to accommodate international travellers. The languages most in demand, other than English, are French, Spanish, Mandarin, Cantonese, Japanese, Arabic, German, Portuguese, and Italian. In the United States, airlines with international routes pay an additional stipend for language skills on top of flight pay, and some airlines hire specifically for certain languages when launching international destinations.

Height and weight

Most airlines have height requirements for safety reasons, making sure that all flight attendants can reach overhead safety equipment. Typically, the acceptable height for this is 160 to 185 cm (5 ft 3 in to 6 ft 1 in) tall. Some airlines, such as EVA Air, have height requirements for purely aesthetic purposes. Regional carriers using small aircraft with low ceilings can have height restrictions.

Flight attendants are also subject to weight requirements as well. Weight must usually be in proportion to height; persons outside the normal range may not be qualified to act as flight attendants.

Uniforms and presentation

Garuda Indonesia flight attendants uniform featuring kebaya and *parang gondosuli* batik

The first stewardess uniforms were designed to be durable, practical, and inspire confidence in passengers. The first stewardesses for United Airlines wore green berets, green capes and nurse's shoes. Other airlines, such as Eastern Air Lines, actually dressed stewardesses in nurses' uniforms.

Perhaps reflecting the military aviation background of many commercial aviation pioneers, many early uniforms had a strongly military appearance; hats, jackets, and skirts showed simple straight lines and military details like epaulettes and brass buttons. Many uniforms had a summer and winter version, differentiated by colours and fabrics appropriate to the season: navy blue for winter, for example, khaki for summer. But as the role of women in the air grew, and airline companies began to realise the publicity value of their stewardesses, more feminine lines and colours began to appear in the late 1930s and early 1940s. Some airlines began to commission designs from high-end department stores and still others called in noted designers or even milliners to create distinctive and attractive apparel.

Flight attendants are generally expected to show a high level of personal grooming such as appropriate use of cosmetics and thorough personal hygiene.

Flight attendants must not have any tattoos visible when a uniform is worn. These requirements are designed to give the airlines a positive representation.

In advertising

Singapore Girls, female flight attendants of Singapore Airlines

In the 1960s and 1970s, many airlines began advertising the attractiveness and friendliness of their stewardesses. National Airlines began a "Fly Me"; campaign using attractive stewardesses with taglines such as "I'm Lorraine. Fly me to Orlando." (A low budget 1973 film about three flight attendants, *Fly Me*, starring Lenore Kasdorf, was based on the ad campaign.) Braniff International Airways, presented a campaign known as the "Air Strip" with similarly attractive young stewardesses changing uniforms mid-flight. A policy of at least one airline required that only unmarried women could be flight attendants. Flight attendant Roz Hanby became a minor celebrity when she became the face of British Airways in their "Fly the Flag" advertising campaign over a 7 year period in the 1980s. Singapore Airlines is currently one of the few airlines still choosing to use the image of their stewardesses, known as Singapore Girls, in their advertising material. However, this is starting to be phased out, in favour of advertising which emphasises the modernity of their fleet.

Unions

Flight attendant unions were formed, beginning at United Airlines in the 1940s, to negotiate improvements in pay, benefits and working conditions. Those unions would later challenge what they perceived as sexist stereotypes and unfair work practices such as age limits, size limits, limitations on marriage, and prohibition of pregnancy. Many of these limitations have been lifted by judicial mandates. The largest flight attendants union is the Association of Flight Attendants, representing over 42,000 flight attendants at 21 airlines within the US.

In the UK, cabin crew can be represented by either Cabin Crew '89, or the much larger and more powerful Transport and General Workers' Union.

In Australia, flight attendants are represented by the Flight Attendants' Association of Australia (FAAA). There are two divisions: one for international crews (long-haul) and one for domestic crews (short-haul).

In New Zealand, Flight Attendants can be represented by either the Flight Attendants and Related Services Association (FARSA) or by the Engineering, Printing and Manufacturing Union (EPMU).

Discrimination

Originally female flight attendants were required to be single upon hiring, and were fired if they got married, exceeded weight regulations, or reached age 32 or 35 depending on the airline . In the 1970s the group Stewardesses for Women's Rights protested sexist advertising and company discrimination, and brought many cases to court. The age restriction was elminated in 1970 . The no-marriage rule was eliminated throughout the US airline industry by the 1980s. The last such broad categorical discrimination, the weight restrictions, were eliminated in the 1990s through litigation and negotiations. By the end of the 1970s, the term *stewardess* had generally been replaced by the gender-neutral alternative *flight attendant.* More recently the term *cabin crew* or *cabin staff* has begun to replace 'flight attendants' in some parts of the world, because of the term's recognition of their role as members of the crew.

Roles in emergencies

Actions of flight attendants in emergencies have long been credited in saving lives; in the United States, the National Transportation Safety Board (NTSB) and other aviation authorities view flight attendants as essential for safety, and are thus required on Part 121 aircraft operations. Studies, some done in light of British Airtours Flight 28M, have concluded that assertive cabin crew are essential for the rapid evacuation of aeroplanes. Notable examples of cabin crew actions include:

September 11, 2001

The role of flight attendants received heightened prominence after the September 11 attacks when flight attendants (such as Sandra W. Bradshaw and CeeCee Lyles of United Airlines Flight 93, Robert Fangman of United Airlines Flight 175, Renee May of American Airlines Flight 77 and Betty Ong and Madeline Amy Sweeney of American Airlines Flight 11) actively attempted to protect passengers from assault, and also provided vital information to air traffic controllers on the hijackings.

In the wake of these attacks many flight attendants at major airlines were laid off because of decreased passenger loads.

All US based airlines sent their flight attendants back to training. This revolutionised training and focused more on physical protection in the events of emergencies. Flight attendants are now trained to be offensive during attacks, rather than obeying commands.

Other emergencies

- Naila Nazir, Pakistani air hostess (employee of Pakistan International Airlines) who received 1985's Flight Safety Foundation (FSF) Heroism Award for her brave handling of tense and dangerous situation during 13 days of flight PK-326 hijacking ordeal.
- British Airtours Flight 28M, the two forward flight attendants, Arthur Bradbury and Joanna Toff, repeatedly crawled into the smoked filled and burning cabin to drag a number of passengers to safety, and were subsequently awarded the Queen's Gallantry Medal. The two rear flight attendants, Sharon Ford and Jacqui Ubanski, who opened the rear doors but were overwhelmed by fire and smoke were awarded the same medal posthumously.
- Scandinavian Airlines Flight 751, when cabin crew recognised an emergency landing was imminent and commanded the passengers to "bend down...hold your knees" to adopt the brace position.
- Atlantic Southeast Airlines Flight 529, whose sole flight attendant, Robin Fech, provided emergency briefings, brace and evacuation commands to the passengers when the Embraer EMB 120 Brasilia aircraft sustained serious damage to one of

its engines and crash landed. The NTSB accident report commended "the exemplary manner in which the flight attendant briefed the passengers and handled the emergency".

- BOAC Flight 712, where a flight attendant, Barbara Jane Harrison died saving passengers from an on-board fire and was posthumously awarded the George Cross.
- British Airways Flight 5390, in which a flight attendant was able to prevent a pilot from being lost through a cockpit window that had failed.
- Southern Airways Flight 242, on which the cabin crew provided safety briefings to their passengers, and on their own initiative, warned passengers of the impending crash by commanding passengers to adopt the brace position. At least one flight attendant is known to have assisted in rescuing trapped passengers.
- Air Florida Flight 90, in which the lone surviving flight attendant passed the only lifevest she could find to another passenger. She is recognised in the NTSB report for this "unselfish act."
- TWA flight attendant Uli Derickson who protected passengers during the TWA Flight 847 hijacking by assisting with negotiation efforts.
- TWA Flight 843, when a TWA Lockheed L-1011 aircraft crashed after an aborted takeoff in 1992. The aircraft was destroyed by fire. Nine flight attendants, along with five off-duty flight attendants, evacuated all 292 persons on board without loss of life. The NTSB in their after accident reported noted, "The performance of the flight attendants during the emergency was exceptional and probably contributed to the success of the emergency evacuation."
- On British Airways Flight 2069, cabin crew stopped the plane from being crashed by a mentally ill passenger.
- Crew on American Airlines Flight 63 prevented shoe bomber Richard Colvin Reid from blowing up the plane.
- Flight attendants on Qantas Flight 1737 prevented their plane from being hijacked by a passenger with mental health issues. Two of them were taken to hospital with stab wounds.
- Aloha Airlines Flight 243 suffered a decompression which tore an 18-foot (5.5 m) section of fuselage away from the plane. Despite her injuries, flight attendant Michelle Honda crawled up and down the aisle reassuring passengers.
- Senior Purser Neerja Bhanot saved the lives of passengers and crew when Pan Am Flight 73 was hijacked. She was killed while protecting children from the terrorists. After her death she received the Special Courage Award from the United States Department of Justice.
- Flight Attendants on Air Canada Flight 797 (Sergio Benetti, Judi Davidson, Laura Kayama) used procedures which were not specifically taught in training such as moving passengers to the front of the aircraft to move them away from the fire and smoke, and passing out towels for passengers to cover their nose and mouths with while the cabin was filling with smoke.
- Flight Attendants on US Airways Flight 1549 successfully evacuated all passengers from the aircraft within 90 seconds despite the fact that the rear was rapidly filling with water.

- Nine cabin crew members aboard Air France Flight 358 successfully evacuated the aircraft within 90 seconds after the A340-300 overran a runway at Toronto Pearson International Airport. The NTSB stated that the actions of the cabin crew contributed to the 100% survival rate.

Chapter 6

Lasers and Aviation Safety

Under certain conditions, laser light or other bright lights (spotlights, searchlights) directed at aircraft can be a hazard. The most likely scenario is when a bright visible laser light causes distraction or temporary flash blindness to a pilot, during a critical phase of flight such as landing or takeoff. It is far less likely, though still possible, that a visible or invisible beam could cause permanent harm to a pilot's eyes. Although laser weapons are under development by the military, these are so specialized, expensive and controlled that it is essentially impossible for non-military lasers to cause structural damage to an aircraft.

Aviation hazards from bright light can be minimized or eliminated in two primary ways. First, users on the ground can exercise caution, to prevent or minimize any laser or other bright light being directed in airspace and especially towards aircraft. Second, pilots should have awareness of laser/aviation hazards and knowledge of basic recovery procedures in case of laser or bright light exposure.

Pointing a laser at an aircraft can be hazardous to pilots and has resulted in arrests, trials and jail sentences. It also results in calls to license or ban laser pointers. Some jurisdictions such as New South Wales have restricted laser pointers as a result of multiple incidents.

Lasers and bright lights

Although here we, concentrates on lasers, other bright directional lights such as searchlights and spotlights can have the same dazzling/distracting/flashblinding effects. Searchlight/spotlight operators should take the same basic precautions as laser users. Similarly, pilots and safety officials should keep in mind that a reported "laser" incident may be caused by a non-laser bright light.

Lasers in airspace

There are many valid reasons that lasers are aimed into airspace. Lasers are used in industry and research, such as in atmospheric remote sensing, and as "guide stars" in adaptive optics astronomy. Lasers and searchlights are used in entertainment; for example, in outdoor shows such as the nightly IllumiNations show at Walt Disney World's EPCOT Center. Laser pointers are used by the general public; sometimes they will be accidentally or deliberately aimed at or near aircraft. (Of course, no unauthorized person should deliberately aim any type of laser at or near an aircraft.)

Lasers are even used, or proposed for use, with aircraft. Pilots straying into unauthorized airspace over Washington, D.C. can be warned to turn back by shining eye-safe low-power red and green lasers at them. At least one system has been tested that would use lasers on final approach to help line up the pilot on the proper glideslope. NASA has tested a Helicopter Airborne Laser Positioning System. The FAA has tested laser-projected lines on airport runways, to increase visibility of "hold short" markings.

Because of these varied uses, it is not practical to ban lasers from airspace. This would unduly restrict legitimate uses, it would not prevent accidental illumination incidents, and it would not stop someone who deliberately, out of malice or ignorance, targeted aircraft. For this reason, practical laser/aviation safety is based on informed users and informed pilots.

Primary hazards of lasers and bright lights

FAA flight simulator showing veiling **glare** where it is hard to see through the light to the background scene. Light level 5.0 µW/cm²; for example, a legal 5 mW laser pointer at 1,200 feet (365 m).

(Note: The photos at right flash because most incidents are of flashes and not of steady illumination. In accidental illuminations there may be just one or a few flashes. Even in deliberate illuminations, it is hard to hand-hold a laser on a moving target, so there will be a series of longer flashes. With helicopters at close range, it is possible to have a more-or-less continuous light.)

There are some subjects which laser/aviation safety experts agree pose no real hazard. These include passenger exposure to laser light, pilot distraction during cruising or other non-critical phases of flight, and laser damage to the aircraft.

The main concerns of safety experts are almost exclusively focused on laser and bright light effects on pilots, especially when they are in a critical phase of flight: takeoff, approach, landing, and emergency maneuvers.

There are four primary areas of concern. The first three are "visual effects" that temporarily distract or block pilots' vision. (For lasers, these effects are only of concern when the laser emits visible light.)

- **Distraction and startle.** An unexpected laser or bright light could distract the pilot during a a nighttime landing or takeoff. A pilot might not know what was happening at first. They may be worried that a brighter light or other threat would be coming.

- **Glare and disruption.** As the light brightness increases, it starts to interfere with vision. Veiling glare would make it difficult to see out the windscreen. Night vision starts to deteriorate.

- **Temporary flash blindness.** This works exactly like a bright camera flash: there is no injury, but night vision is temporarily knocked out. There may be afterimages—again, exactly like a bright camera flash leaving temporary spots.

The three visual effects above are the primary concern for aviation experts. This is because they could happen with lower-powered lasers that are commonly available. The fourth concern, eye damage, is much less likely. It would take specialized equipment not readily available to the general public.

- **Eye damage.** Though it is unlikely, high power visible or invisible (infrared, ultraviolet) laser light could cause permanent eye injury. The injury could be relatively minor, such as spots only detectable by medical exam or on the periphery of vision. At higher power levels, the spots may be in the central vision, in the same area where the original light was viewed. Most unlikely of all is injury causing a complete and permanent loss of vision. To do this requires very specialized equipment and a desire to deliberately target aircraft.

It is extremely unlikely that any of the four elements above would cause loss of the aircraft, especially if the pilots react properly and work as a team.

Analyzing the hazard

The exact hazard in a specific situation depends on a number of factors.

Laser/bright light factors

- **The power of the laser or bright light.** The more light emitted, the brighter and more hazardous it will be.
- **The beam divergence.** A low-divergence "tight" beam will be a hazard at greater distances than one which spreads out rapidly.
- **Visibility (wavelength) of the beam.** An infrared or ultraviolet laser beam does not present any visual effect risk to pilots, as they cannot see it. However, at high

powers it can present an eye damage risk. In some cases, this hazard may be greater since a pilot would not know they were being illuminated.

- **Color of the beam** (for visible wavelengths). In general, the eyes of pilots in an illuminated nighttime cockpit are most sensitive to greenish-yellow light (of wavelength around 500–600 nanometers, peaking at 555 nm). A blue or red laser will appear much dimmer—and thus less distracting—than a green or yellow laser of equal power (wattage). To give a specific example, a 10-watt continuous-wave YAG laser at 532 nanometers (green), can appear brighter to the eye than an 18-watt continuous-wave argon-ion laser that outputs 10 watts of 514 nm (green-blue) light plus 8 watts of 488 nm (blue) light.
- **Pulsed/continuous nature of the beam.** Some laser beams emit their energy in pulses. A pulsed laser presents a greater eye damage risk than a continuous laser of equal (average) power. This is because the power is packed into shorter but more intense pulses.

Operational factors

- **Beam movement.** If the beam is moving around such as in a laser show, it covers a greater area of the sky and thus has a greater chance to illuminate an aircraft. However, if it did scan across a cockpit, in general the exposure duration would be shorter. (A more precise analysis would look at the relative motion of the beam and aircraft.)
- **Location of the beam relative to airports.** The beam must avoid airspace around airports and busy air routes. The FAA has established safety zones around airports, which are described in the "Regulation" section below. It is possible to use beams within the zones, if the beam power is below the FAA limit for the zone.
- **Projector and laser stability.** To avoid accidents, the laser projector must be secured with relation to termination points and beam blocks. If a projector slips, or safety software fails, the beam could enter unsafe areas of airspace.

Situational factors

- **Day vs. night.** Almost all concern is over nighttime illumination. The three visual effects listed above (distraction, glare and flash blindness) are minimized during the day since the eye is not dark adapted, and since visible lasers are not often used outdoors in daytime.
- **Motion and speed of the aircraft.** A slow aircraft is at greater risk than a fast one (relative to travel across the viewer's line of sight). Helicopters are at greatest risk because they can hover, presenting a relatively stationary target.
- **Distance to the aircraft.** A low-flying aircraft is at greater risk. Again, helicopters are vulnerable due to their close ground proximity.
- **Direction relative to the aircraft and cockpit.** A beam aimed directly at an incoming aircraft gives the greatest risk to pilots. One aimed across the aircraft's travel gives less risk, partially because the light enters through the side windows, and partially because it is harder to keep the beam aimed exactly at the cockpit

area. A beam aimed straight up gives the least risk, although it is still possible for the beam to illuminate the cockpit during a banking turn.

Pilot/aircrew factors

- **Flight phase.** The risk is greatest when the exposure comes during a time of high workload: takeoffs, critical or emergency maneuvers, and landings.
- **Pilot awareness and response.** Ideally, pilots will be aware of laser and bright light hazards, and will know how to recover in case of an incident. Conversely, a pilot can make the situation worse if he or she overreacts, stares at the light to try to locate its source, or takes immediate unnecessary evasive maneuvers.

The U.S. FAA has studied some of these factors. They conducted research using pilots in flight simulators to determine the effects of laser exposure on pilot performance; results were released in August 2003 and June 2004.

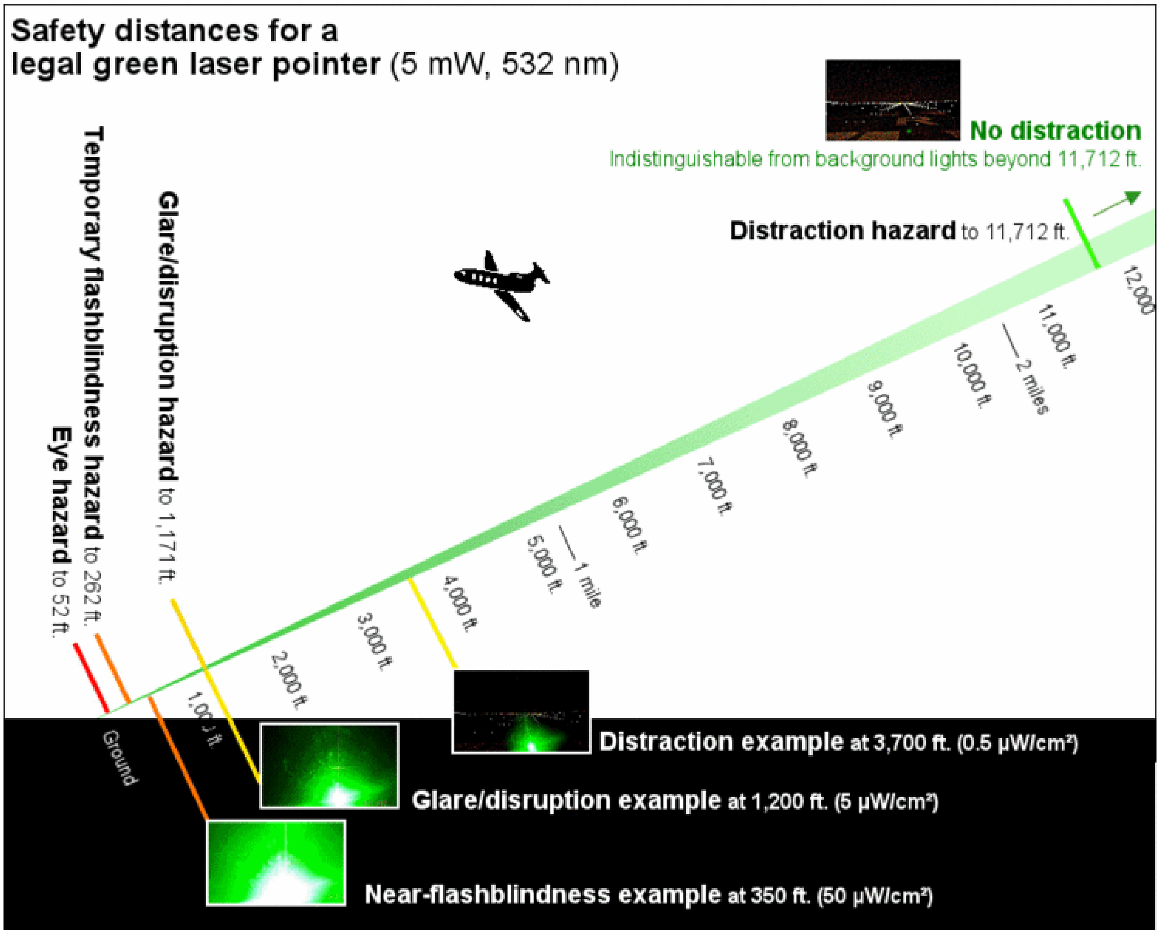
Accidental vs. deliberate exposure

Laser users must take appropriate precautions to avoid accidents. (Some steps are outlined below in the section "Reducing the hazard".) In most cases, an accidental exposure is likely to be one or a few brief flashes, as the aircraft moves through a stationary beam, or as a hand-held beam sweeps over the cockpit.

There have been cases of deliberate intent, where someone through ignorance or malice deliberately aimed a laser at an aircraft. Note that no one should ever deliberately aim a laser at an aircraft. It can result in pilot distraction, and may well result in searches by authorities to find the source. There have been a number of cases reported where laser pointer users were arrested and tried; a few have even gone to jail. Such incidents also can lead to calls to license or ban laser pointers.

Whether an accidental or deliberate exposure, any pilot seeing a flash should avoid looking in the direction of the light, since it may be quickly followed by additional flashes.

Example laser safety calculations



Graphic illustrating how laser pointer hazards are most serious when the laser is close to the aircraft

The graphic at right shows many important laser/aviation safety concepts. For example, it shows that the areas of most concern—eye damage, flash blindness and glare—occur relatively close to the aircraft. The distraction risk covers the longest hazard distance, but fortunately also presents the least concern. The photos in the graphic also give an idea of what the visual effect looks like to the pilot, at various distances.

Note that while the distances given are exact ("52 feet", "262 feet"), the laser's brightness is in fact falling off slowly. It is not as if at 51 feet the laser is an eye hazard and at 53 feet it is eye safe. Effects diminish continuously with increasing distance.

Also, the weaker effects are part of any stronger effect. Even if a laser does not cause eye damage at 25 feet, it can still cause flash blindness, glare and a distraction.

For any given laser, the relative distances shown here may change. For example, an invisible (infrared) laser can be an eye hazard for hundreds of feet, but presents no flash blindness, glare or distraction hazard. Because of this, each laser must be analyzed individually.

To give another example, here are calculations of a more powerful laser—the type that might be used in an outdoor laser show. A 6-watt green (532 nm) laser with a 1.1 milliradian beam divergence is an eye hazard to about 1,600 feet (488 meters), can cause flash blindness to about 8,200 feet (1.5 mi/2.5 km), causes veiling glare to about 36,800 feet (7 mi/11.2 km), and is a distraction to about 368,000 feet (70 mi/112 km).

Reducing the hazard

There are a number of ways that laser users, regulators and pilots reduce the potential hazard from outdoor laser use. These measures include:

Police enforcement

Police have begun using helicopters to patrol and seek out people using lasers to disrupt aviation.

User hazard reduction measures

- Using the lowest power necessary for the task.
- Increasing the beam divergence. The beam spreads out faster, so at any given distance, the amount of light entering the eye or a cockpit windscreen will be less (e.g., lower irradiance).
- Keeping beams away from areas with many aircraft, such as airports and flight paths.
- Terminating beams on buildings, dense trees, etc. to prevent laser light from entering protected airspace. This is a common protection measure for outdoor laser shows, if there are structures available for termination.
- Using spotters to watch for aircraft. This is commonly done for laser shows which tend to be short-duration (around an hour) and infrequent (nightly shows are rare).
- Using automated detection systems such as radar or sky cameras. These are used for long-duration (all night) and frequent (nightly) applications, such as laser guide stars used at astronomical observatories.
- Developing and following policies for outdoor laser operations, such as the ANSI standard "Safe Use of Lasers Outdoors" or NASA's "Use Policy for Outdoor Lasers".

Regulatory hazard reduction measures

- Restricting the sale or use of laser devices. This is done in some jurisdictions. For example, in April 2008 New South Wales, Australia banned laser pointer possession, except by special permit, in an effort to reduce the number of laser illuminations of aircraft. In October 1997 in the United Kingdom, administrative steps were taken to restrict the sale of laser pointers > 1 milliwatt output, for similar reasons (although the purchase, importation and use of such pointers in the UK remains lawful). In the U.S., the Congressional Research Service notes that a ban could "pose significant challenges because these devices are widely available at low cost and are used in a variety of applications such as laser pointers, laser levels and laser gun sights."

- Requiring review or approval of outdoor laser uses. This is discussed in the Regulation and control section below.
- Amending existing laws, or enacting new ones, to try to discourage irresponsible laser use. One U.S. federal effort in this direction is the "Securing Airplane Cockpits Against Lasers Act of 2005", discussed in the History section below.

Pilot/aircrew hazard reduction measures

- Fixed laser installations (e.g. laser guide stars from observatories) may be marked on aeronautical charts so pilots are aware of potential beams along their flight path. Temporary uses (laser shows) may be described in pre-flight information. For example, in the U.S., laser uses submitted to the FAA are often listed in NOTAMs for pilots.
- Education and training. The SAE G-10T Laser Hazards Subcommittee is working on Aerospace Recommended Practice document 5598, "Laser Visual Interference - Pilot Operational Procedures." This will provide information for pilots on recognizing and recovering from a laser or bright light incident. Articles in aviation publications also have provided helpful information, such as "Laser Illuminations: The Last Line of Defense - The Pilot!".

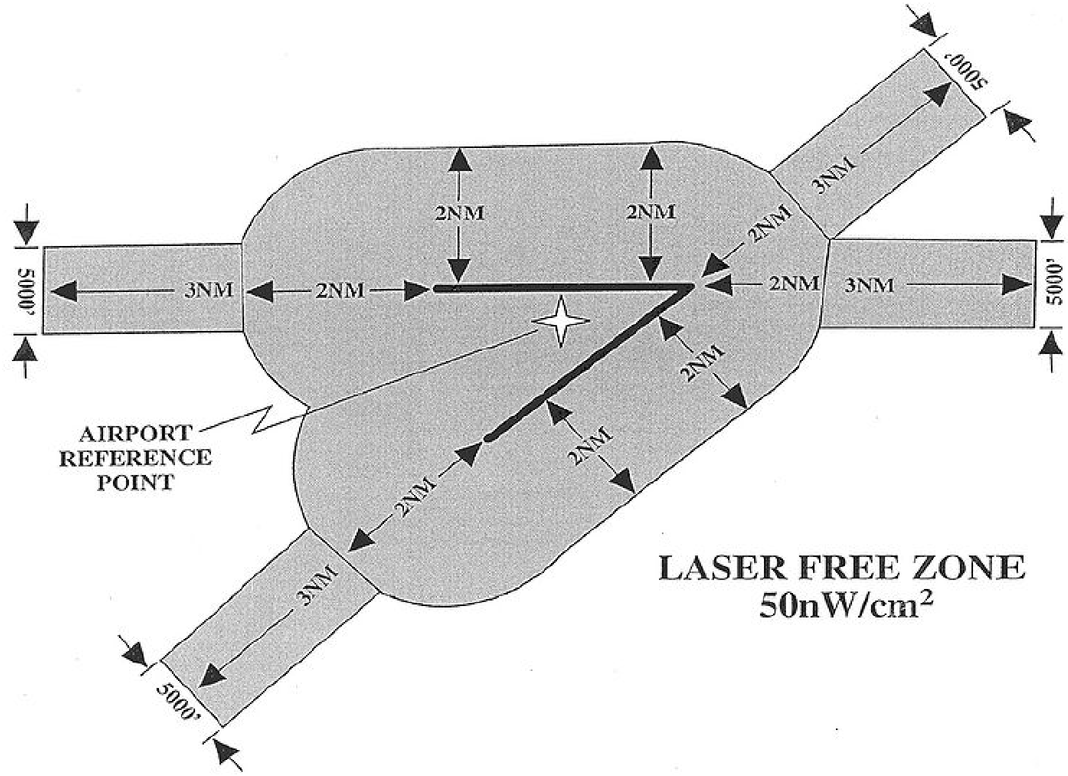
Active hazard reduction (proposed measures)

Some measures have been proposed to protect aircrews including goggles and windscreen filters. These may work in theory (especially against known wavelengths) and may be useful in some situations such as military operations. However, these measures may not be suitable, practical or recommended for widespread civil air operations.

- **Laser safety goggles.** Laboratory-type laser safety goggles are not well suited for pilot operation. "The 20% transmission ratio of laboratory laser eyewear would probably have disastrous effects on a cockpit crew who must read instruments while flying at night.... The optical quality of such systems also becomes a factor because slight amounts of distortion or haze which may be of no concern in the laboratory may be a major concern to pilots flying at low altitudes and high speed." Also, there may be a variety of laser wavelengths/colors that may need to be defended against. If all wavelengths are protected, the goggles essentially are opaque. There are also issues with the discomfort of wearing goggles routinely, given that laser incidents are relatively rare.
- **Active "smart" goggles** which can detect laser light and then activate a blocking/dimming process based on the power and wavelength. It is not known if

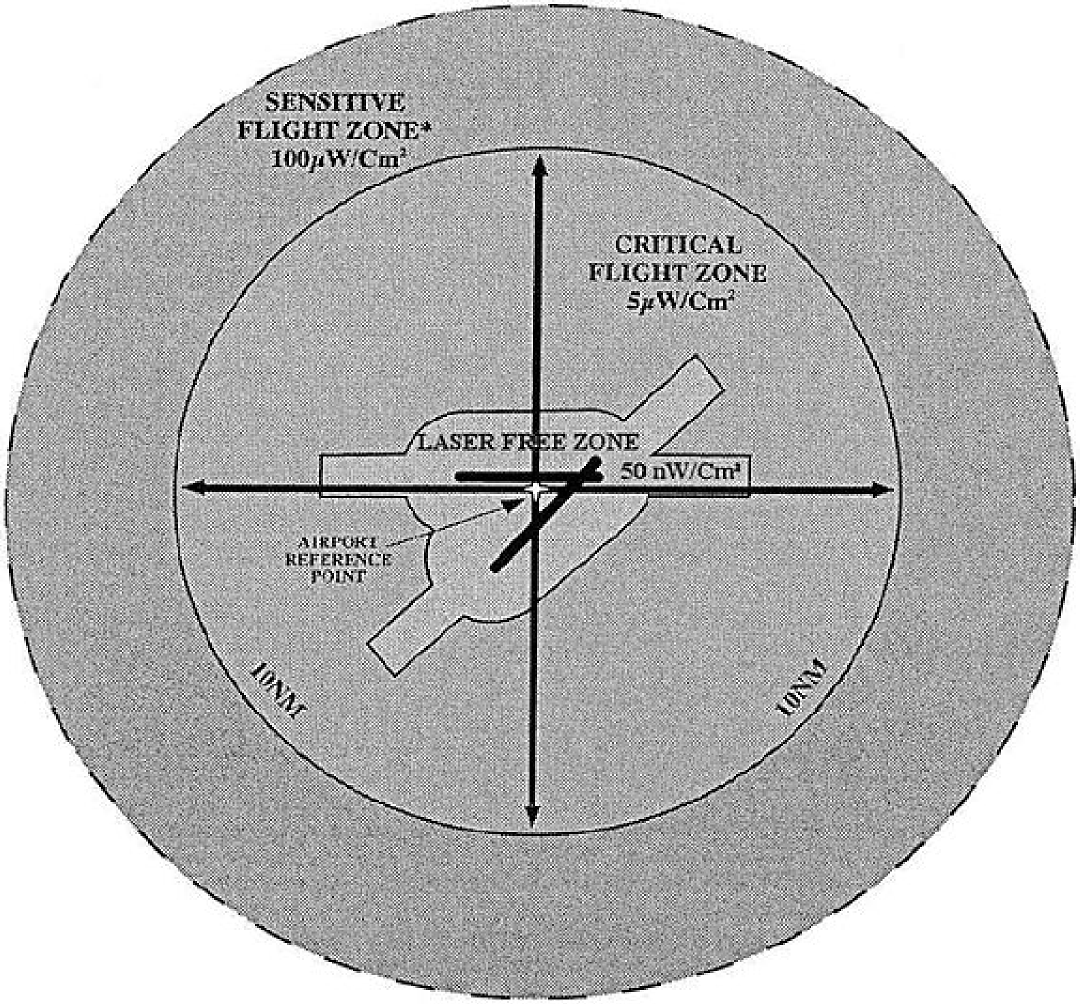
these are in production or use; if so, it is likely that these are used only in military applications.
- **Glare shields** that can be pulled down over a windscreen to reduce all incoming light.
- **Laser event detectors/recorders** that can sense a laser illumination and record information about the wavelength and power. This does not provide protection but does give information about an illumination which may be useful for later analysis or legal action.

Regulation and control



The U.S. FAA Laser Free Zone extends horizontally 2 NM (3,700 m) from the centerline of all runways (two dark lines in this diagram) with additional 3 NM (5,560 m) extensions at each end of a runway. Vertically, the LFZ extends to 2,000 feet (610 m) above ground level.

AIRSPACE FLIGHT ZONES



The U.S. FAA Critical Flight Zone extends horizontally 10 NM (18.5 km) around the airport, and extends vertically to 10,000 feet (3,050 m) above ground level. The optional Sensitive Flight Zone is designated around special airspace needing bright-light protection.

In the United States, laser airspace guidelines can be found in Federal Aviation Administration Order JO 7400.2 (Revision "G" as of April 2008), Procedures for Handling Airspace Matters, Part 6, Chapter 29, "Outdoor Laser Operations". Bright light airspace guidelines are in Chapter 30, "High Intensity Light Operations".

In the United Kingdom, CAP 736 is the "Guide for the Operation of Lasers, Searchlights and Fireworks in United Kingdom Airspace."

For all laser users, the ANSI Z136.6 document gives guidance for the safe use of outdoor lasers. While this document is copyrighted by ANSI and is relatively costly, a flavor of its recommendations can be seen in NASA's Use Policy for Outdoor Lasers.

Airspace zones

The U.S. FAA has established airspace zones. These protect the area around airports and other sensitive airspace from the hazards of safe-but-too-bright visible laser light exposure:

- The **Laser Free Zone** extends immediately around and above runways, as depicted at right. Light irradiance within the zone must be less than 50 nanowatts per square centimeter (0.05 microwatts per square centimeter). This was set at "a level that would not cause any visual disruption."
- The **Critical Flight Zone** covers 10 nautical miles (NM) around the airport; the light limit is 5 microwatts per square centimeter ($\mu W/cm^2$). This "was determined to be the level at which significant glare problems can occur."
- The optional **Sensitive Flight Zone** is designated by the FAA, military or other aviation authorities where light intensity must be less than 100 $\mu W/cm^2$. This might be done for example around a busy flight path or where military operations are taking place. This "was identified as the level of exposure at which significant flash blindness and afterimages could interfere with a pilot's visual performance."
- The **Normal Flight Zone** covers all other airspace. The light intensity must be less than 2.5 milliwatts per square centimeter (2500 $\mu W/cm^2$). This is about half of the Class 3R power level, and is not considered hazardous for a brief exposure.

For non-visible lasers (infrared and ultraviolet), the irradiance at the aircraft must be eye-safe—below the Maximum Permissible Exposure level for that wavelength. For pulsed visible lasers, the irradiance at the aircraft must be both eye-safe and must be at or below any applicable FAA laser zone.

In the UK, restrictions are in place in a zone that includes a circle 3 NM (5.5 km) in radius around an aerodrome (airport) plus extensions off each end of each runway. The runway zones are rectangles 20 NM (37 km) in total length and 1000 meters (3280 feet) wide, centered about each runway.

Reporting

In the U.S., those persons operating outdoor lasers are requested to file reports with the FAA at least 30 days in advance, detailing their laser power(s). They must reference their operation location with respect to local airports and describe the laser power emitted within the Sensitive, Critical and Laser Free zones. Note that it is possible to use lasers whose output exceeds the limits of these zones, if other control measures are in place. For example, spotters could be used to watch for aircraft, and turn off the laser if a potential conflict is sighted. (This raises separate issues about the number, training and effectiveness of the spotters; the FAA must be satisfied that these issues are answered for the particular operation.)

FAA Advisory Circular 70-1 "Outdoor Laser Operations" contains two forms plus instructions. One form is a "Notice of Proposed Laser Operations", the other is a "Laser Configuration Worksheet" which is filled out for each laser or each different laser configuration. The FAA will review the report, and will either send a letter of objection or will send a letter of non-objection. The language is important; the FAA does not "approve" or "disapprove" as this implies a higher level of regulatory authority which the FAA does not have.

If the laser use is for a show or display in the U.S., there is a more stringent regulatory process. In the U.S., any use of lasers in a show or display requires pre-approval from the FDA Center for Devices and Radiological Health. This is required both for the laser equipment, and separately for the show itself (site, audience configuration, beam effects, etc.). As part of the CDRH's show approval ("variance") process, the CDRH will require a letter of non-objection from the FAA. Without this, the laser show cannot legally proceed.

In the U.S., laser activity in a given area is communicated to pilots before their flight via a NOTAM. Pilots exposed to a laser or bright light during flight should follow Advisory Circular 70-2 "Reporting of Laser Illumination of Aircraft".

UK laser operators report outdoor laser, searchlight or firework operations at least 28 days in advance, using the Notification Form found in annex A of the CAP 736 document.

Regulatory and standards development

A key group inside the U.S. working on laser/aviation safety is the SAE G-10T, Laser Safety Hazards Subcommittee. It consists of laser safety experts and researchers, pilots and other interested parties representing military, commercial and private aviation, and laser users. Their recommendations have formed the basis of the FAA laser and bright light regulations and forms, as well as standards adopted in other countries and by the ICAO.

The ANSI Z136.6 standard is the "American National Standard for Safe Use of Lasers Outdoors." The Z136.6 committee has worked closely with SAE G-10T and others, to develop recommended safety procedures for outdoor laser use.

History

Until the early 1990s, laser and bright light aviation incidents were sporadic. In the U.S., NASA's Aviation Safety Reporting System showed only one or two incidents per year. The SAE G-10T subcommittee began meeting around 1993 as the number of incidents grew. Almost all of the incidents were known or suspected to be due to outdoor laser displays. Almost all of the concern was over potential eye damage; at the time visual effects were felt to be a minor consequence.

In late 1995, a number of illumination incidents occurred in Las Vegas due to new outdoor laser displays. Although the displays had been approved by the FDA as eye-safe for their airport proximity, no one had realized that the glare/distraction hazard would adversely affect pilots. In December 1995 the FDA issued an emergency order shutting down the Las Vegas shows.

Within the SAE G-10T subcommittee, there was some consideration about cutting back or banning laser shows. However, it became apparent that there were a large number of non-entertainment laser users as well. The focus shifted to control of known laser users, whether shows or industry/research. New policies and procedures were developed, such as the FAA 7200 Chapter 29, and Advisory Circular 70-1. Although incidents continued to occur (from January 1996 to July 1999, the FAA's Western-Pacific Region identified more than 150 incidents in which low-flying aircraft were illuminated by lasers), the situation seemed under control.

Then in late 2004 and early 2005, came a significant increase in reported incidents linked to laser pointers. The wave of incidents may have been triggered in part by "copycats" who read press accounts of laser pointer incidents. In one case, David Banach of New Jersey was charged under federal Patriot Act anti-terrorism laws, after he allegedly shone a laser pointer at aircraft.

Responding to the incidents, the Congressional Research Service issued a study on the laser "threat to aviation safety and security." Because there was no federal law specifically banning deliberate laser illumination of aircraft, Congressman Ric Keller introduced H.R. 1400, the "Securing Airplane Cockpits Against Lasers Act of 2005." The bill was passed by the U.S. House and Senate, but did not go to conference and thus did not become law. In 2007, Keller re-introduced the bill as H.R. 1615. Although passed by the House in May 2007, it was not acted on by the Senate before the end of the 110th Congress and never became law.

On March 28, 2008, a "coordinated attack" took place using four green laser pointers aimed at six aircraft landing at the Sydney (New South Wales) Australia airport. As a result of this attack plus others, a law was proposed in mid-April 2008 in NSW to ban possession of handheld lasers, even "harmless classroom pointers". The Australian state of Victoria has reportedly had a similar ban since 1998, but press reports state that it is easy to buy lasers without a permit.

On February 22, 2009, a dozen planes were targeted with green laser beams at Seattle-Tacoma International Airport. An FAA spokeswoman said there were 148 laser attacks on aircraft in the U.S. from January 1, 2009 to February 23, 2009.

Chapter 7

Fatigue Avoidance Scheduling Tool

Fatigue is a major human factors issue in aviation safety. The **Fatigue Avoidance Scheduling Tool** (FAST) was developed by the United States Air Force in 2000–2001 to address the problem of aircrew fatigue in aircrew flight scheduling. FAST is a Windows program that allows scientists, planners and schedulers to quantify the effects of various work-rest schedules on human performance. It allows work and sleep data entry in graphic, symbolic (grid) and text formats. The graphic input-output display shows cognitive performance effectiveness (y axis) as a function of time (x axis). An upper, green area on the graph ends at the time for normal sleep, 90% effectiveness. The goal of the planner or scheduler is to keep performance effectiveness at or above 90% by manipulating the timing and lengths of work and rest periods. A work schedule is entered as red bands on the time line. Sleep periods are entered as blue bands across the time line, below the red bands.

The calculated performance effectiveness represents composite human performance on a number of cognitive tasks, scaled from zero to 100%. The oscillating line in the graph represents expected group average performance on these tasks as determined by time of day, biological rhythms, time spent awake, and amount of sleep, and various confidence limits around the average may be displayed. The graphic display may be cut and pasted into reports and briefing slides. Cognitive effectiveness estimates for work periods of any length may also be cut and pasted in tabular format.

History

FAST was developed under Phase 1 and 2 Small Business Innovation Research (SBIR) contract awards from the US Air Force Research Laboratory (AFRL), Human Effectiveness Directorate, to NTI, Inc., (Dr. Douglas R. Eddy, Principal Investigator) with Science Applications International Corporation as a subcontractor (Dr. Steven R. Hursh, Modeler). Fatigue predictions in FAST are derived from the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) simulation invented by Dr. Hursh, currently the President of the Institutes for Behavior Resources and Adjunct Professor of Behavioral Biology, Johns Hopkins University School of Medicine.

The SAFTE simulation integrates quantitative information about (1) circadian rhythms in metabolic rate; (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness; and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness. The SAFTE model has been under development by Dr. Hursh for more than a decade. In the general architecture of the SAFTE model, a circadian process influences both cognitive effectiveness and sleep regulation. Sleep regulation is dependent upon hours of sleep, hours of wakefulness, current sleep debt, the circadian process and sleep fragmentation (awakenings during a sleep period). Cognitive effectiveness is dependent upon the current balance of the sleep regulation process, the circadian process, and sleep inertia.

The SAFTE simulation has received a broad scientific review and the DoD considers it a complete, accurate, and operationally practical model to aid operator scheduling. The SAFTE simulation's software implementation and applicabilities have since been validated in both aviation (Eddy and Hursh, 2008; need ref) and railroad work environments.

During the Phase 2 effort, the model was refined with findings from AF research and other studies providing a blood alcohol index, lapse index, sleep timing algorithm, and interface features (performance variation percentiles, mission timeline, grid input, and fatigue factors dashboard, to name a few). FAST provided the military physiologist the first computerized tool that used a homeostatic model for optimizing aviator performance under conditions of limited sleep while minimizing the need for pharmacological aids. Missions could be planned that provided sufficient rest to maintain effective performance and, when normal, nocturnal sleep was impossible, arrange interventions such as naps or pharmacological treatments to maintain performance. The tool was intended to improve flight safety, optimize mission success during sustained operations, and minimize the need for pharmacological aids.

During the Phase 2 and Phase 3 efforts, the FAST team had the opportunity to train different groups of AF personnel on the use of FAST to solve fatigue problems they were having with sustained operations, overseas deployment, and night training operations. The training was accomplished with numerous groups in part through several of the USAF School of Aerospace Medicine’s educational functions (2002–2007) and in part through the AFRL Aviation Fatigue Countermeasures Workshop taught approximately tri-annually by Drs. John A. Caldwell, J. Lynn Caldwell, and James C. Miller. Students over the years included flight surgeons, aerospace physiologists and aerospace physiology technicians on annual training; aerospace physiologists and aerospace physiology technicians during initial training; flight surgeons participating in USAFSAM’s Residency in Aerospace Medicine (RAM) and Advanced Aerospace medicine for International Medical officers (AAMIMO) programs; and aviation safety officers from The U.S. Air Force, Navy, Marines, and Army, and from the Canadian Forces. Many of these new users recommended that the FAST product be transformed in several ways to make it more useful to operational units.

FAST was used successfully by the development team, Air Force researchers, and several AF operational units to solve fatigue problems throughout AF operations. Scientists in the Warfighter Fatigue Countermeasures Branch (WFC, now AFRL/RHPF) and operators used FAST to identify and avoid fatigue in more than 2,000 hours of B-2 bomber operations from Whiteman AFB and night operations at Shaw AFB, to optimize shift work schedules for security forces at Brooks AFB, to assess the impact of sleep loss and night operations in accident investigation, and many other consults. During the period 2000–2007, Dr. Miller used FAST to assist USAF mishap investigation boards in at least nine investigations of aviation mishaps. Additionally, FAST was used to prepare guidance for various operational units in the United States and Canada. These FAST users had no problems entering data, trying different schedules, making modifications to existing schedules, or interpreting results. However, all of these applications involved experts or personnel that they had trained. Attempts to apply FAST to daily flying scheduling operations were unsuccessful because the user interface was designed originally for scientists, not for operators.

The Federal Railroad Administration sponsored a major evaluation of the SAFTE biomathematical fatigue model (or simulation) to determine if it could predict increased risk of railroad accidents based on work schedule information (Hursh, Raslear et al., 2006). The project examined 30-day work histories of locomotive crews prior to 400 human factors accidents and 1000 nonhuman factors accidents. SAFTE estimated crew effectiveness (the inverse of fatigue) based entirely on work schedule information and opportunities to obtain sleep. Over 1 million 30-min work intervals were evaluated based on data from five US freight railroads. A reliable linear relationship existed between crew effectiveness and the risk of human factors accidents ($r = -0.93$), but not for non-human factors accidents. The risk of human factors accidents was elevated at effectiveness scores below 90 and increased progressively with reduced effectiveness. At an effectiveness score ≤ 50, human factors accidents were 65 percent more likely than chance. Below an effectiveness score of 70, accident cause codes indicated the kinds of operator errors consistent with fatigue, confirming that the relationship between accident risk and effectiveness was meaningful. Further analysis indicated that SAFTE/FAST also predicted an increase in accident severity; human factors accidents that occurred when average effectiveness was calculated to be less than 77 were 2½ times more costly than similar accidents that occurred when effectiveness was greater than 90.

In 2005, AFRL awarded a 3-year, Phase 3 SBIR contract to NTI to develop and demonstrate a browser-based, predictive and quantitative fatigue-management software tool for mission planning, crew performance assessment, and status reporting, based upon FAST. A “24/7 Operational Effectiveness Toolset” was developed as an Internet-based tool accessible through a browser, providing support for the scheduling of regular, cyclic work and rest (regularly rotating shiftwork), for irregular work-rest schedules, for the effects of pharmaceutical countermeasures, and for the formal Operational Risk Management (ORM) of fatigue effects. Specific user groups selected for interface design included mission (flight) schedulers, pilots, mishap investigators, and shift work schedulers. Usability tests of the interfaces were conducted to determine if they met the needs of expert users and the tool was easy to learn for novices. The final reports for this project were being reviewed at AFRL in November 2008.

Present status

FAST is available at cost to U.S. DoD components. FAST and other implementations of the underlying SAFTE are now commercial products marketed through Fatigue Science. These tools are being implemented as part of Fatigue Risk Management Systems in aviation and other transportation industries.

U.S. Navy

In the U.S. Navy, Aviation Safety Officer (ASO) students and prospective commanders of naval aviation squadrons have been introduced to FAST in the School of Aviation Safety (SAS) courses since October 2004. Navy and Army student Flight Surgeons get a 2-hour computer lab introduction to FAST. CAPT (Dr.) Nick Davenport was the person who added FAST to those curricula. As a result of a FAST evaluation meeting that was held at the Naval Safety Center (NSC) on 26 April 2006, the NSC mandated that all Flight Surgeons use FAST in analyzing the 72-hour and 14-day histories in aviation mishap investigations. FAST has often assisted in identifying fatigue effects that would have been missed otherwise, and occasionally has helped rule out fatigue in cases where it was suspected.

FlyAwake

In early 2007, the 201 Airlift Squadron of the District of Columbia Air National Guard (ANG), successfully integrated its own version of the SAFTE model into its daily scheduling operations. This integration required the full-time attention of two pilot schedulers, but yielded valuable risk mitigation data that could be used by planners and leaders to predict and adjust critical times of fatigue in the flight schedule. In August 2007, the Air National Guard Aviation Safety Division, under the direction of Lt Col Edward Vaughan, funded a project to provide a user interface for daily use by pilot schedulers and integration with automated flight scheduling software. This user-responsive interface, known as FlyAwake (FlyAwake.org), was conceived and managed by Captain Lynn Lee. The project cited empirical data collected in combat and non-combat aviation operations, and challenged existing crew rest policies as adequate in preventing degraded human performance.

Ongoing efforts

Presently (November 2008), the NSC has a heightened interest in fatigue and is relying on FAST as a tool to illustrate the principles of sleep deprivation, and the effects of circadian rhythm disruption and fatigue on performance, as well as in mishap investigation and mission planning. The NSC is also participating in field research by the ANG and The Walter Reed Army Institute of Research (WRAIR) on Naval Air Reserve aircrews in operational missions to help develop and validate FlyAwake. Additionally, Drs. Hursh and Miller train Flight Surgeons and Aerospace Physiologists at the USAF School of Aerospace Medicine on fatigue effects, countermeasures, and use of the FAST software to evaluate fatigue in AF operations. The FAA is using SAFTE/FAST to evaluate all proposed Ultra-Long Range (ULR) city pairs by US carriers. Effectiveness at critical phases of flight is one factor used to decide if the planned schedule, rest provisions, and crew complement are adequate to ensure safe operations. The Army is sponsoring work by MTS, IBR, and Archinoetics to develop an aggregate unit level fatigue assessment tool based on the SAFTE/FAST system. This project is expected to be completed by mid-2010.

Chapter 8

Inerting System

An **inerting system** increases the safety of a fuel tank, ball mill, or other sealed or closed-in tank that contains highly flammable material. Inert in scientific terminology means ‘not readily reactive with other elements; forming no chemical compounds or something that is not chemically reactive.’ An inert fuel tank is non-combustible. The inerted space may be on land, or aboard ship, or airborne.

A fire requires three elements: heat (ignition source), fuel and oxygen (or air) to initiate and sustain. A fire can be prevented by removing any one of the three elements. If presence of an ignition source can not be prevented in a fuel tank then a fuel tank can be made inert by (1) reducing the oxygen content of the ullage (space above the fuel that contains air and fuel vapors) below the threshold required for combustion, or (2) by reducing the air-fuel ratio of the ullage below the minimum threshold (Lower Flammability Limit) required for combustion, or (3) increasing the fuel air ratio above the maximum threshold (Upper Flammability Limit) that can support combustion.

At present, fuel tanks are rendered inert by adulterating the ullage with an inert gas such as nitrogen, nitrogen enriched air, steam or carbon dioxide. This reduces the oxygen content of the ullage below combustion threshold. Without sufficient oxygen in the tank, the fuel vapors in the ullage cannot ignite, and an explosion does not occur. Alternate methods based on reducing the ullage fuel air ratio below Lower flammable limit (LFL) or increasing the fuel air ratio above the Upper flammable limit (UFL) have also been proposed.

Inerting gas systems in aircraft

Fuel tanks for combat aircraft have long been inerted, as well as self-sealing, but those for transports, both military and civil, have not, due to considerations of cost and weight.

Cleve Kimmel first pitched an inerting system to passenger airlines in the early 1960s. His proposed system for passenger aircraft would have used nitrogen. However, the Federal Aviation Administration refused to consider Kimmel's system after the airlines complained it was impractical. Indeed, early versions of Kimmel's system weighed 2,000 pounds—which would have probably made an aircraft too heavy to fly with passengers on it. However, the FAA did almost no research into making fuel tanks inert for 40 years, even in the face of several catastrophic fuel tank explosions. Instead, the FAA focused on keeping ignition sources out of the fuel tanks.

The FAA did not even consider lightweight inerting systems for commercial jets until the 1996 crash of TWA Flight 800. The crash was blamed on an explosion in the center wing fuel tank of the Boeing 747 used in the flight. This tank is normally used only on very long flights, and little fuel was present in the tank at the time of the explosion. A small amount of fuel in a tank is more critical than a large amount, since heat entering the fuel tank with residual fuel causes the fuel to increase in temperature faster and evaporate. This causes the ullage fuel air ratio to increase rapidly and the ullage fuel air ratio to exceed the lower flammability limit. Large quantity of fuel (high mass loading) in the fuel tank retains the heat energy and slows down the fuel evaporation rate. Explosion of Thai Airways International Boeing 737 in 2001 and Philippine Airlines 737 in 1990 also occurred in a tank that had residual fuel. All the above three explosions occurred on a warm day, in the Center Wing tank (CWT) that is within the contours of the fuselage. These fuel tanks are located in the vicinity of external equipment that heats the fuel tanks. The National Transportation Safety Board's (NTSB) final report on the crash of TWA 747 concluded “The fuel air vapor in the ullage of the TWA flight 800 CWT was flammable at the time of the accident.” NTSB identified “Elimination of Explosive Mixture in Fuel tanks in Transport Category Aircraft” as Number 1 item on its Most Wanted List in 1997.

After the Flight 800 crash, a 2001 report by an FAA committee stated that U.S. airlines would have to spend US$35 billion to retrofit their existing aircraft fleets with inerting systems that might prevent future such explosions. However, another FAA group developed a nitrogen enriched air (NEA) based inerting system prototype that operated on compressed air supplied by the aircraft’s propulsive engines. Also, the FAA determined that the fuel tank could be rendered inert by reducing the ullage oxygen concentration to 12% rather than previously accepted threshold of 9-10%. Boeing commenced testing a derivative system of their own, performing successful test flights in 2003 with several 747 aircraft. The new, simplified inerting system was originally suggested to the FAA through public comment. It uses a hollow fiber membrane material that separates supplied air into nitrogen-enriched air (NEA) and oxygen enriched air (OEA). This technology is extensively used for generating oxygen-enriched air for medical purposes. It uses a membrane that preferentially allows the nitrogen molecule (molecular weight 28) to pass through it and not the oxygen molecule (molecular weight 32).

Unlike the inerting systems on military aircraft, this inerting system would run continuously to reduce fuel vapor flammability whenever the aircraft's engines are running; and its goal is to reduce oxygen content within the fuel tank to 12%, lower than normal atmospheric oxygen content of 21%, but higher than that of inerted military aircraft fuel tanks, which is a target of 9% oxygen. This is accomplished by ventilating fuel vapor laden ullage gas out of the tank and into the atmosphere.

Current FAA Rules on inerting in aircraft

After what it said was seven years of investigation, the FAA proposed a rule in November 2005, in response to an NTSB recommendation, which would require airlines to "reduce the flammability levels of fuel tank vapors on the ground and in the air". This was a shift from the previous 40 years of policy in which the FAA focused only on reducing possible sources of ignition of fuel tank vapors.

The FAA issued the final rule on July 21, 2008. The rule amends regulations applicable to the design of new airplanes (14CFR§25.981), and introduces new regulations for continued safety (14CFR§26.31-39), Operating Requirements for Domestic Operations (14CFR§121.117) and Operating Requirements for Foreign Air Carriers (14CFR§129.117). The regulations apply to airplanes certificated after January 1, 1958 of passenger capacity of 30 or more or payload capacity of greater than 7500 pounds. The regulations are performance based and do not require the implementation of a particular method.

The proposed rule would affect all future fixed-wing aircraft designs (passenger capacity greater than 30) , and require a retrofit of more than 3,200 Airbus and Boeing aircraft with center wing fuel tanks, over nine years. The FAA had initially planned to also order installation on cargo aircraft, but this was removed from the order by the Bush administration. Additionally, regional jets and smaller commuter planes would not be subject to the rule, because the FAA does not consider them at high risk for a fuel-tank explosion. The FAA estimated the cost of the program at US$808 million over the next 49 years, including US$313 million to retrofit the existing fleet. It compared this cost to an estimated US$1.2 billion "cost to society" from a large airliner exploding in mid-air. The proposed rule comes at a time when nearly half of the U.S. airlines' capacity is on carriers that are in bankruptcy.

The order affects aircraft whose air conditioning units have a possibility of heating up the center wing fuel tank. Some Airbus A320 and Boeing 747 aircraft are slated for "early action". Regarding new aircraft designs, the Airbus A380 does not have a center wing fuel tank and is therefore exempt, and the Boeing 787 has a fuel tank safety system that already complies with the proposed rule. The FAA has stated that there have been four fuel tank explosions in the previous 16 years—two on the ground, and two in the air—and that based on this statistic and on the FAA's estimate that one such explosion would happen every 60 million hours of flight time, about 9 such explosions will probably occur in the next 50 years. The inerting systems will probably prevent 8 of those 9 probable explosions, the FAA said. Before the inerting system rule was proposed, Boeing stated that it would install its own inerting system on airliners it manufactures beginning in 2005. Airbus had argued that its planes' electrical wiring made the inerting system an unnecessary expense.

As of December 2, 2009, the FAA has a pending rule to increase the standards of on board interting systems again. New technologies are being developed by others to provide fuel tank inerting:

(1) The OBIGGS system, tested in 2004 by the FAA and NASA, with an opinion written by the FAA in 2005 . This system is currently in use by many military aircraft types, including the C-17. This system provides the level of safety that the proposed increase in standards by the proposed FAA rules has been written around. Critics of this system cite the high maintenance cost reported by the military.

(2) Three independent research and development firms have proposed new technologies in response to Research & Development grants by the FAA and SBA. The focus of these grants is to develop a system that is superior to OBIGGS that can replace classic inerting methods. None of these approaches has been validated in the general scientific community, nor have these efforts produced commercially available products. All the firms have issued press releases or given non-peer reviewed talks.

Other methods of inerting fuel tanks

Two other methods in current use to inert fuel tanks are a foam suppressant system and a ullage system. The FAA has decided that the added weight of both alternatives make them impractical for implementation in the aviation field . Some US Military aircraft still use Nitrogen based foam inerting systems, and some companies will ship containers of fuel with an ullage system across train routes.

Chapter 9

Flight Test

Flight test is a branch of aeronautical engineering that develops and gathers data during flight of an aircraft and then analyzes the data to evaluate the flight characteristics of the aircraft and validate its design, including safety aspects. The flight test phase accomplishes two major tasks: 1) finding and fixing any aircraft design problems and then 2) verifying and documenting the aircraft capabilities for government certification or customer acceptance. The flight test phase can range from the test of a single new system for an existing aircraft to the complete development and certification of a new aircraft. Therefore the duration of a flight test program can vary from a few weeks to several years.

Civil Aircraft Flight Test

There are typically two categories of flight test programs – commercial and military. Commercial flight testing is conducted to certify that the aircraft meets all applicable safety and performance requirements of the government certifying agency. In the US, this is the Federal Aviation Administration (FAA); in Canada, Transport Canada (TC); in the United Kingdom (UK), the Civil Aviation Authority; and in the European Union, the European Aviation Safety Agency (EASA). Since commercial aircraft development is normally funded by the aircraft manufacturer and/or private investors, the certifying agency does not have a stake in the commercial success of the aircraft. These civil agencies are concerned with the aircraft's safety and that the pilot's flight manual accurately reports the aircraft's performance. The market will determine the aircraft's suitability to operators. Normally, the civil certification agency does not get involved in flight testing until the manufacturer has found and fixed any development issues and is ready to seek certification.

Military aircraft Flight Test

Military programs differ from commercial in that the government contracts with the aircraft manufacturer to design and build an aircraft to meet specific mission capabilities. These performance requirements are documented to the manufacturer in the Aircraft Specification and the details of the flight test program (among many other program requirements) are spelled out in the Statement of Work. In this case, the government is the customer and has a direct stake in the aircraft's ability to perform the mission. Since the government is funding the program, it is more involved in the aircraft design and testing from early-on. Often military test pilots and engineers are integrated as part of the manufacturer's flight test team, even before first flight. The final phase of the military aircraft flight test is the Operational Test (OT). OT is conducted by a government-only test team with the dictate to certify that the aircraft is suitable and effective to carry out the intended mission. Flight testing of military aircraft is often conducted at military flight test facilities. The US Navy tests aircraft at Naval Air Station Patuxent River, MD (a.k.a. "Pax River") and the US Air Force at Edwards Air Force Base, CA. The U.S. Air Force Test Pilot School and the U.S. Naval Test Pilot School are the programs designed to teach military test personnel. In the UK most military flight testing is conducted by three organizations, the RAF, BAE Systems and QinetiQ. For minor upgrades the testing may be conducted by one of these three organisations in isolation, but major programs are normally conducted by a joint trials team (JTT), with all three organisations working together under the umbrella of an Integrated Project Team (IPT) airospace

Flight Test Processes

Flight Testing is highly expensive and potentially very risky. Unforeseen problems can lead to damage to aircraft and loss of life, both of aircrew and people on the ground. For these reasons modern flight testing is probably one of the most safety conscious professions today. Flight trials can be divided into 3 sections, planning, execution and analysis and reporting.

Preparation

For both commercial and military aircraft, flight test preparation begins well before the aircraft is ready to fly. Initially what needs to be tested must be defined, from which the Flight Test Engineers prepare the test plan, which is essentially certain manoeuvres to be flown (or systems to be exercised). A full certification/qualification flight test program for a new aircraft will require testing for many aircraft systems and in-flight regimes; each is typically documented in a separate test plan. During the actual flight testing, similar maneuvers from all test plans are combined and the data collected on the same flights, where practical. This allows the required data to be acquired in the minimum number of flight hours.

Once the flight test data requirements are established, the aircraft is instrumented to record that data for analysis. Typical instrumentation parameters recorded during a flight test are: temperatures, pressures, structural loads, vibration/accelerations, noise levels (interior and exterior), aircraft performance parameters (airspeed, altitude, etc.), aircraft controls positions (stick/yoke position, rudder pedal position, throttle position, etc.), engine performance parameters, and atmospheric conditions. During selected phases of flight test, especially during early development of a new aircraft, many parameters are transmitted to the ground during the flight and monitored by the Flight Test Engineer and test support engineers. This provides for safety monitoring and allows real-time analysis of the data being acquired.

Execution

When the aircraft is completely assembled and instrumented, it typically conducts many hours of ground testing before its first/maiden flight. This ground testing will verify basic aircraft systems operations, measure engine performance, evaluate dynamic systems stability, and provide a first look at structural loads. Flight controls will also be checked out. Once all required ground tests are completed, the aircraft is ready for the first flight. First/maiden flight is a major milestone in any aircraft development program and is undertaken with the utmost caution.

There are several aspects to a flight test program: handling qualities, performance, aero-elastic/flutter stability, avionics/systems capabilities, weapons delivery, and structural loads. Handling qualities evaluates the aircraft's controllability and response to pilot inputs throughout the range of flight. Performance testing evaluates aircraft in relation to its projected abilities, such as speed, range, power available, drag, airflow characteristics, and so forth. Aero-elastic stability evaluates the dynamic response of the aircraft controls and structure to aerodynamic (i.e. air-induced) loads. Structural tests measure the stresses on the airframe, dynamic components, and controls to verify structural integrity in all flight regimes. Avionics/systems testing verifies all electronic systems (navigation, communications, radars, sensors, etc.) perform as designed. Weapons delivery looks at the pilot’s ability to acquire the target using on-board systems and accurately deliver the ordnance on target. Weapons delivery testing also evaluates the separation of the ordnance as it leaves the aircraft to ensure there are no safety issues. Other military unique tests are: air-to-air refueling, radar/infrared signature measurement, and aircraft carrier operations. Emergency situations are evaluated as a normal part of all flight test program. Examples are: engine failure during various phases of flight (takeoff, cruise, landing), systems failures, and controls degradation. The overall operations envelope (allowable gross weights, centers-of-gravity, altitude, max/min airspeeds, maneuvers, etc.) is established and verified during flight testing. Aircraft are always demonstrated to be safe beyond the limits allowed for normal operations in the Flight Manual.

Because the primary goal of a flight test program is to gather accurate engineering data, often on a design that is not fully proven, piloting a flight test aircraft requires a high degree of training and skill, so such programs are typically flown by a specially trained test pilot, and the data is gathered by a flight test engineer, and often visually displayed to the test pilot and/or flight test engineer using flight test instrumentation.

Analysis and Reporting

It includes the analysis of a flight for certification.It analyze the internal and outer part of the flight by checking its all minute parts. Reporting includes the analyzed data result.

Flight Test Team

The make-up of the Flight Test Team will vary with the organization and complexity of the flight test program, however, there are some key players who are generally part of all flight test organizations. The leader of a flight test team is usually a flight test engineer (FTE) or possibly an experimental test pilot. Other FTEs or pilots could also be involved. Other team members would be the Flight Test Instrumentation Engineer, Instrumentation System Technicians, the aircraft maintenance department (mechanics, electricals, avionics technicians, etc.), Quality/Product Assurance Inspectors, the ground-based computing/data center personnel, plus logistics and administrative support. Engineers from various other disciplines would support the testing of their particular systems and analyze the data acquired for their specialty area.

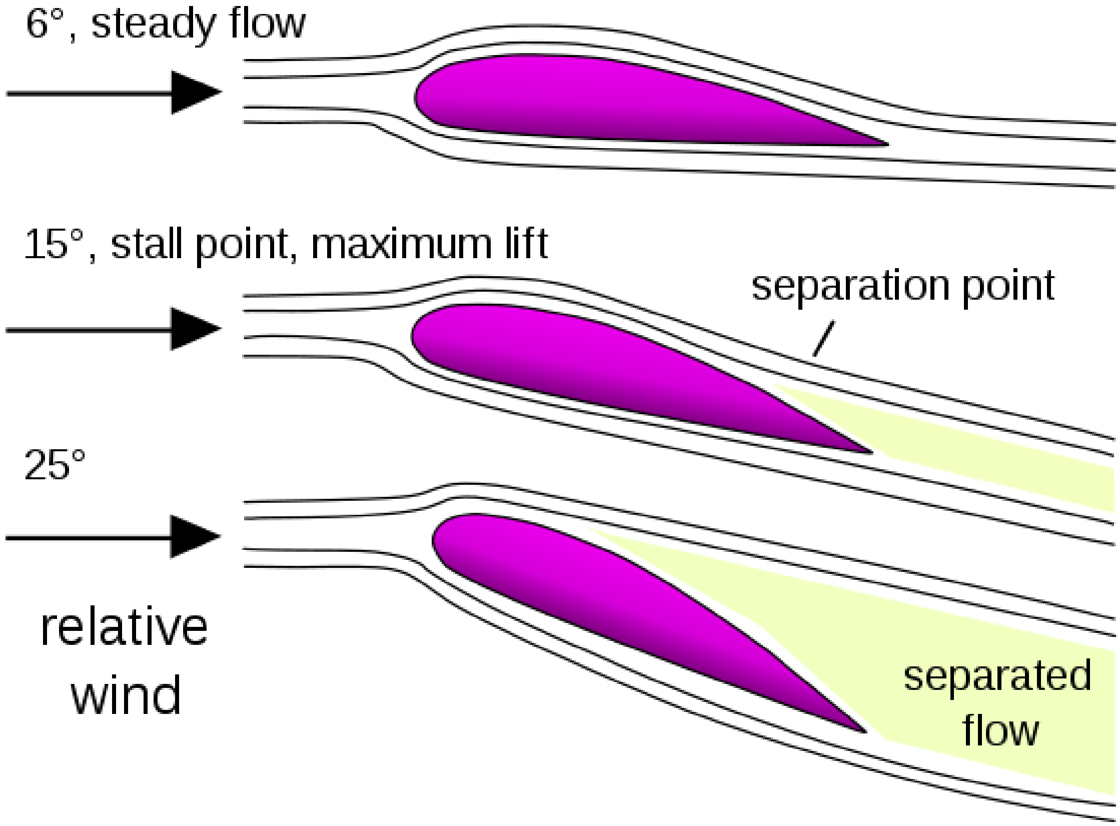
Since many aircraft development programs are sponsored by government military services, military or government-employed civilian pilots and engineers are often integrated into the flight test team. The government representatives provide program oversight and review and approve data. Government test pilots may also participate in the actual test flights, possibly even on the first/maiden flight.

Chapter 10

Stall (Flight)

In fluid dynamics, a **stall** is a reduction in the lift coefficient generated by an airfoil as angle of attack increases. This occurs when the critical angle of attack of the airfoil is exceeded. The critical angle of attack is typically about 15 degrees, but it may vary significantly depending on the airfoil and Reynolds number. In recent years there has been an increasing use of vectored thrust in manned and unmanned aircraft to surpass the stall limit, thereby giving rise to post-stall technology.

Formal definition



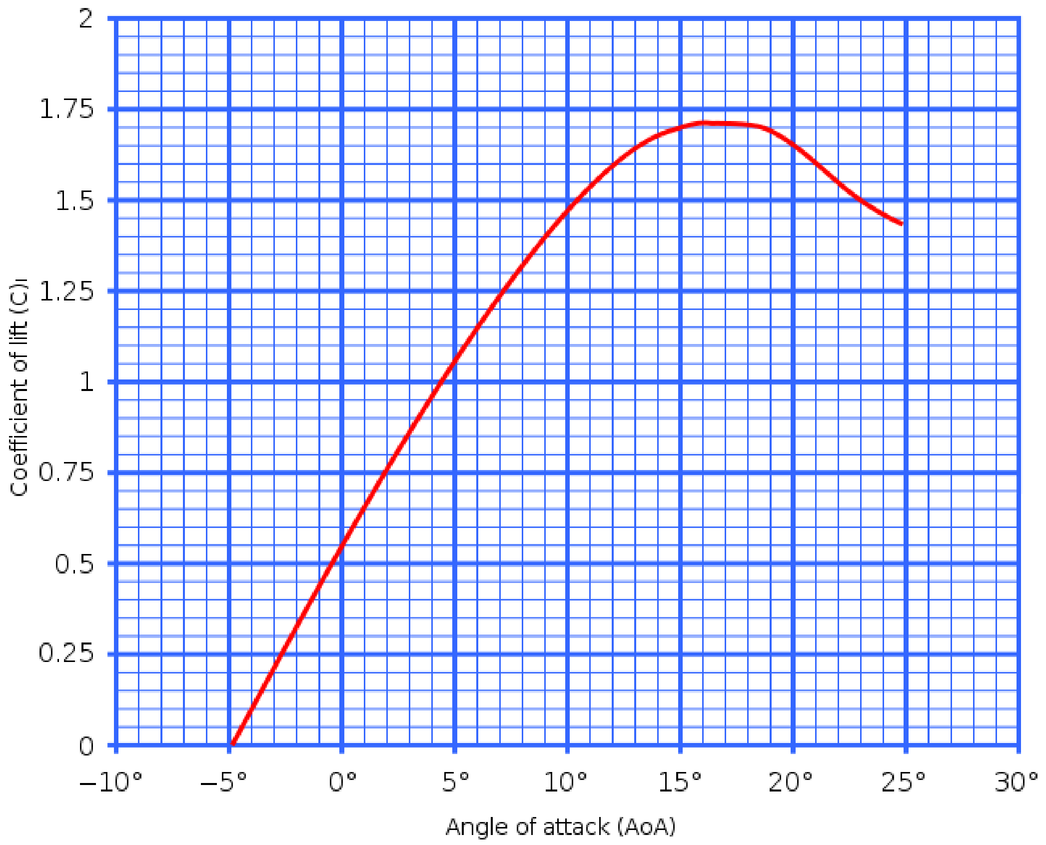
A **stall** is a condition in aerodynamics and aviation where the angle of attack increases beyond a certain point such that the lift begins to decrease. The angle at which this occurs is called the *critical angle of attack*. This critical angle is dependent upon the profile of the wing, its planform, its aspect ratio, and other factors, but is typically in the range of 8 to 20 degrees relative to the incoming wind for most subsonic airfoils. The critical angle of attack is the angle of attack on the lift coefficient versus angle-of-attack curve at which the maximum lift coefficient occurs.

Flow separation *begins* to occur at small angles of attack while *attached* flow over the wing is still dominant. As angle of attack increases, the separated regions on the top of the wing increase in size and hinder the wing's ability to create lift. At the critical angle of attack, separated flow is so dominant that further increases in angle of attack produce *less* lift and vastly more drag.

A fixed-wing aircraft during a stall may experience buffeting or a change in attitude. Most aircraft are designed to have a gradual stall with characteristics that will warn the pilot and give the pilot time to react. For example an aircraft that does not buffet before the stall may have an audible alarm or a stick shaker installed to simulate the feel of a buffet by vibrating the stick fore and aft. The "buffet margin" is, for a given set of conditions, the amount of ‘g’, which can be imposed for a given level of buffet. The critical angle of attack in steady straight and level flight can only be attained at low airspeed. Attempts to increase the angle of attack at higher airspeeds can cause a high speed stall or may merely cause the aircraft to climb.

Any yaw of the aircraft as it enters the stall regime can result in autorotation, which is also sometimes referred to as a 'spin'. Because air no longer flows smoothly over the wings during a stall, aileron control of roll becomes less effective, whilst simultaneously the tendency for the ailerons to generate adverse yaw increases. This increases the lift from the advancing wing and accentuates the probability of the aircraft to enter into a spin.

Depending on the aircraft's design, a stall can expose extremely adverse properties of balance and control; particularly in a prototype.



An example of the relationship between angle of attack and lift on a cambered airfoil. The exact relationship is usually measured in a wind tunnel and depends on the airfoil section. The relationship for an aircraft wing depends on the planform & its aspect ratio. Aircraft cannot operate steadily at angles of attack greater than their stall angle.

Graph

The graph shows that the greatest amount of lift is produced as the critical angle of attack is reached (which in early 20th century aviation was called the "burble point"). This angle is 17.5 degrees in this case but changes from airfoil to airfoil. In particular, for aerodynamically thick airfoils (thickness to chord ratios of around 10%) the critical angle is increased compared with a thin airfoil of the same camber. Symmetric airfoils have lower critical angles (but also work efficiently in inverted flight). The graph shows that as the angle of attack exceeds the critical angle, the lift produced by the airfoil decreases.

The information in a graph of this kind is gathered using a model of the airfoil in a wind tunnel. Because aircraft models are normally used, rather than full-size machines, special care is needed to make sure data is taken in the same Reynolds number regime (or scale speed) as in free flight. The separation of flow from the upper wing surface at high angles of attack is quite different at low Reynolds number from that at the high Reynolds numbers of real aircraft. High pressure wind tunnels are one solution to this problem.

Steady operation of an aircraft at an angle of attack above the critical angle is not generally possible because, after exceeding the critical angle, the loss of lift from the wing causes the nose of the aircraft to fall, reducing the angle of attack again. This nose drop, independent of control inputs, indicates the pilot has actually stalled the aircraft.

This graph shows the stall angle, yet in practice most pilot operating handbooks (POH) or generic flight manuals describe stalling in terms of airspeed. This is because all aircraft are equipped with an airspeed indicator, but fewer aircraft have an angle of attack indicator. An aircraft's stalling speeds is published by the manufacturer (and is required for certification by flight testing) for a range of weights and flap positions, but the stalling angle of attack is not published.

As speed reduces, angle of attack has to increase to keep lift constant until the critical angle is reached. The airspeed at which this angle is reached is the (1g, unaccelerated) stalling speed of the aircraft in that particular configuration. Deploying flaps/slats decreases the stall speed to allow the aircraft to take off and land at a lower speed.

Aerodynamic description of a stall

Stalling an airplane

An airplane can be made to stall in any pitch attitude or bank angle or at any airspeed but is commonly practiced by reducing the speed to the unaccelerated stall speed, at a safe altitude. Unaccelerated (1g) stall speed varies on different aeroplanes and is represented by colour codes on the air speed indicator. As the plane flies at this speed the angle of attack must be increased to prevent any loss of altitude or gain in airspeed (which corresponds to the stall angle described above). The pilot will notice the flight controls have become less responsive and may also notice some buffeting, a result of the turbulent air separated from the wing hitting the tail of the airplane.

In most light aircraft, as the stall is reached the aircraft will start to descend (because the wing is no longer producing enough lift to support the aeroplane's weight) and the nose will pitch down. Recovery from this stalled state usually involves the pilot decreasing the angle of attack and increasing the air speed, until smooth air flow over the wing is resumed. Normal flight can be resumed once recovery from the stall is complete. The maneuver is normally quite safe and if correctly handled leads to only a small loss in altitude (50'-100'). It is taught and practised in order for pilots to recognize, avoid, and recover from stalling the airplane. A pilot is required to demonstrate competency in controlling an aircraft during and after a stall for certification, and it is a routine maneuver for pilots when getting to know the handling of a new aircraft type. The only dangerous aspect of a stall is a lack of altitude for recovery.

A special form of asymmetric stall in which the aircraft also rotates about its yaw axis is called a spin. A spin can occur if an aircraft is stalled and there is an asymmetric yawing moment applied to it. This yawing moment can be aerodynamic (sideslip angle, rudder, adverse yaw from the ailerons), thrust related (p-factor, one engine inoperative on a multi-engine non-centreline thrust aircraft), or from less likely sources such as severe turbulence. The net effect is that one wing is more deeply stalled than the other and the aircraft descends rapidly while rotating and some aircraft cannot recover from this condition without correct pilot control inputs (which must stop yaw) and loading. A new solution to the problem of difficult (or impossible) stall-spin recovery is provided by the ballistic parachute recovery system.

The most common stall-spin scenarios occur on takeoff (departure stall) and during landing (base to final turn) because of insufficient airspeed during these manoeuvres. Stalls also occur during a go-around manoeuvre if the pilot does not properly respond to the out-of-trim situation resulting from the transition from low power setting to high power setting at low speed. Stall speed is increased when the upper wing surfaces are contaminated with ice or frost creating a rougher surface.

Stalls do not derive from airspeed and can occur at any speed -but only if the wings have too high an angle of attack. Attempting to increase the angle of attack at 1g by moving the control column back normally causes the aircraft to rise. However aircraft often experience higher g, for example when turning steeply or pulling out of a dive. In these cases, the wings are already operating at a higher angle of attack to create the necessary force (derived from lift) to accelerate in the desired direction. Increasing the g loading still further, by pulling back on the controls, can cause the stalling angle to be exceeded - even though the aircraft is flying at a high speed. These "high speed stalls" produce the same buffeting characteristics as 1g stalls and can also initiate a spin if there is also any yawing.

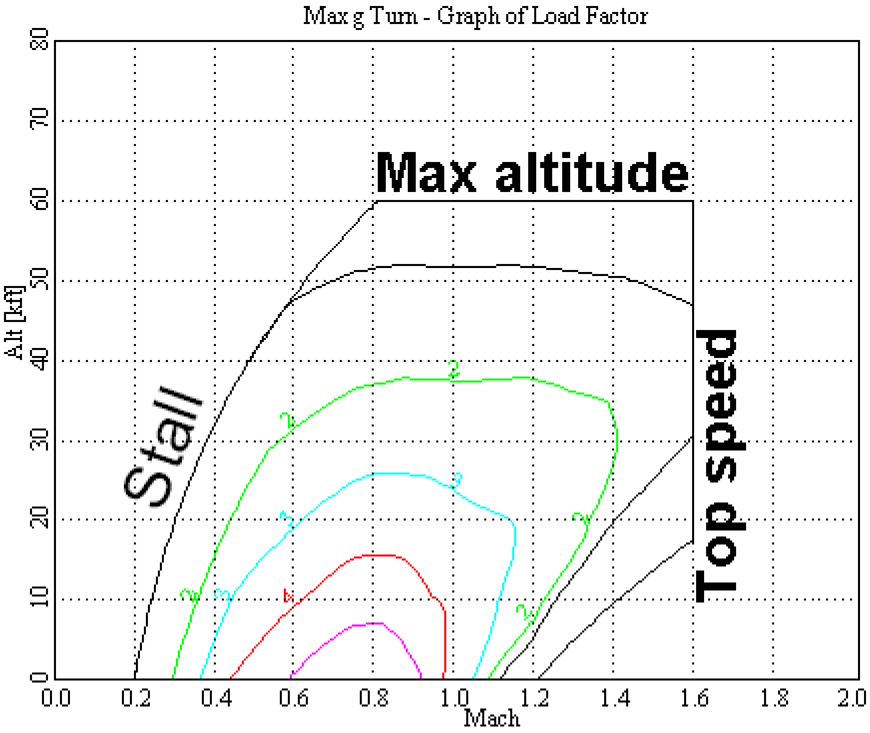
Symptoms of an approaching stall

One symptom of an approaching stall is slow and sloppy controls. As the speed of the aeroplane decreases approaching the stall, there is less air moving over the wing and therefore less air will be deflected by the control surfaces (ailerons, elevator and rudder) at this slower speed. Some buffeting may also be felt from the turbulent flow above the wings as the stall is reached. The stall warning will sound, if fitted, in most aircraft 5 to 10 knots above the stall speed.

Stalling characteristics

Different aircraft types have different stalling characteristics. A benign stall is one where the nose drops gently and the wings remain level throughout. Slightly more demanding is a stall where one wing stalls slightly before the other, causing that wing to drop sharply, with the possibility of entering a spin. A dangerous stall is one where the nose rises, pushing the wing deeper into the stalled state and potentially leading to an unrecoverable *deep stall*. This can occur in some T-tailed aircraft where the turbulent airflow from the stalled wing can blanket the control surfaces at the tail.

“Stall speed”



Flight envelope of a fast airplane. Left edge is the stall speed curve.

The airspeed indicator is often used to indirectly predict stall conditions.

Stalls depend only on angle of attack, not airspeed. Because a correlation with airspeed exists, however, a "stall speed" is usually used in practice. It is the speed below which the airplane cannot create enough lift to sustain its weight in 1g flight. In steady, level flight (1g), the faster an airplane goes, the less angle of attack it needs to hold the airplane up (*i.e.,* to produce lift equal to weight). As the airplane slows down, it needs to increase angle of attack to create the same lift (equal to weight). As the speed slows further, at some point the angle of attack will be equal to the critical (stall) angle of attack. This speed is called the "stall speed". The angle of attack cannot be increased to get more lift at this point and so slowing below the stall speed will result in a descent. And so, airspeed is often used as an indirect indicator of approaching stall conditions. The stall speed will vary depending on the airplane's weight, altitude and configuration (flap setting, etc.).

There are multiple V speeds which are used to indicate when a stall will occur:

- V_S: the computed stalling speed with flaps retracted at design speed. Often has the same value as V_{S1}.
- V_{S0}: the stalling speed or the minimum steady flight speed in landing configuration (full flaps, landing gear down, spoiler retracted).
- V_{S1}: the stalling speed or the minimum steady flight speed in a specific configuration (usually a "clean" configuration with flaps, landing gear and spoilers all retracted).
- V_{SR}: reference stall speed.
- V_{SR0}: reference stall speed in the landing configuration.
- V_{SR1}: reference stall speed in a specific configuration.
- V_{SW}: speed at which onset of natural or artificial stall warning occurs.

On an airspeed indicator, the bottom of the white arc indicates V_{S0} at maximum weight, while the bottom of the green arc indicates V_{S1} at maximum weight. While an aircraft's V_S speed is computed by design, its V_{S0} and V_{S1} speeds must be demonstrated empirically by flight testing.

Accelerated and turning flight stall

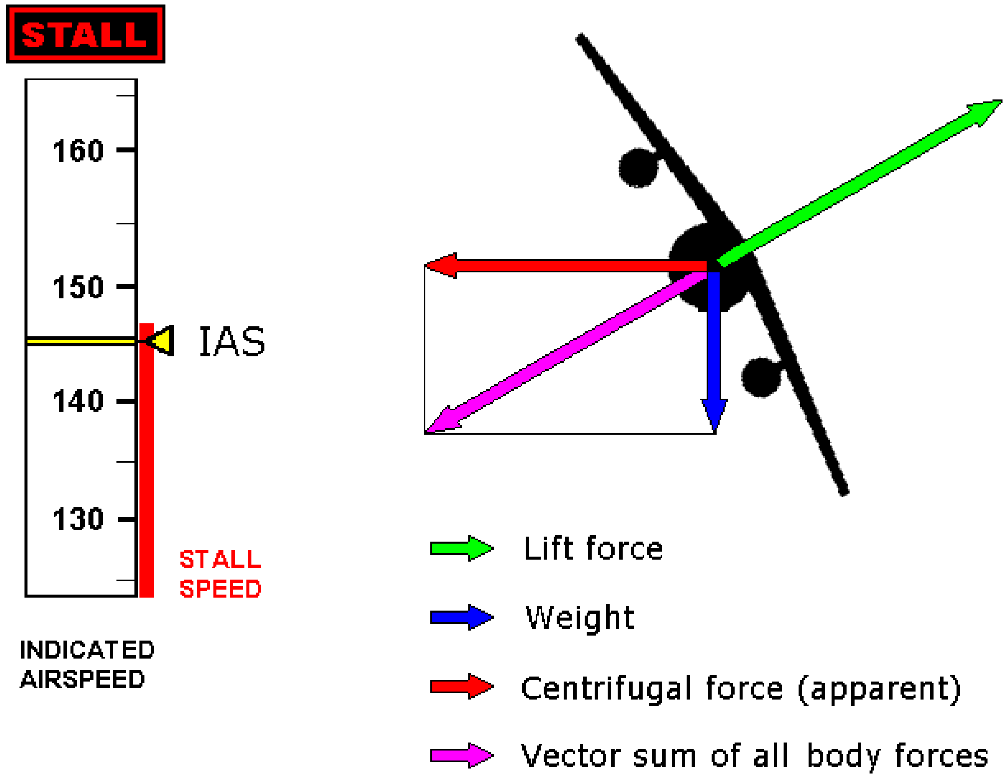


Illustration of a turning flight stall, occurring during a co-ordinated turn with progressively-increasing angle of bank.

An **accelerated stall** is a stall that occurs while the aircraft is experiencing a load factor higher than 1 (1g), for example while turning or pulling up from a dive. In these conditions, the aircraft stalls at higher speeds than the normal stall speed (which always refers to straight and level flight).

Considering for example a banked turn, the lift required is equal to the weight of the aircraft plus extra lift to provide the centripetal force necessary to perform the turn, that is:

$$L = nW$$

where:

L = lift
n = load factor (greater than 1 in a turn)
W = weight of the aircraft

To achieve the extra lift, the lift coefficient, and so the angle of attack, will have to be higher than it would be in straight and level flight at the same speed. Therefore, given that the stall always occurs at the same critical angle of attack, by increasing the load factor (e.g. by tightening the turn) such critical angle - and the stall - will be reached with the airspeed remaining well above the normal stall speed, that is:

$$V_{st} = V_s \sqrt{n}$$

where:

V_{st} = stall speed
V_s = stall speed of the aircraft in straight, level flight
n = load factor

The table that follows gives some examples of the relation between the angle of bank and the square root of the load factor. It derives from the trigonometric relation (secant) between L and W.

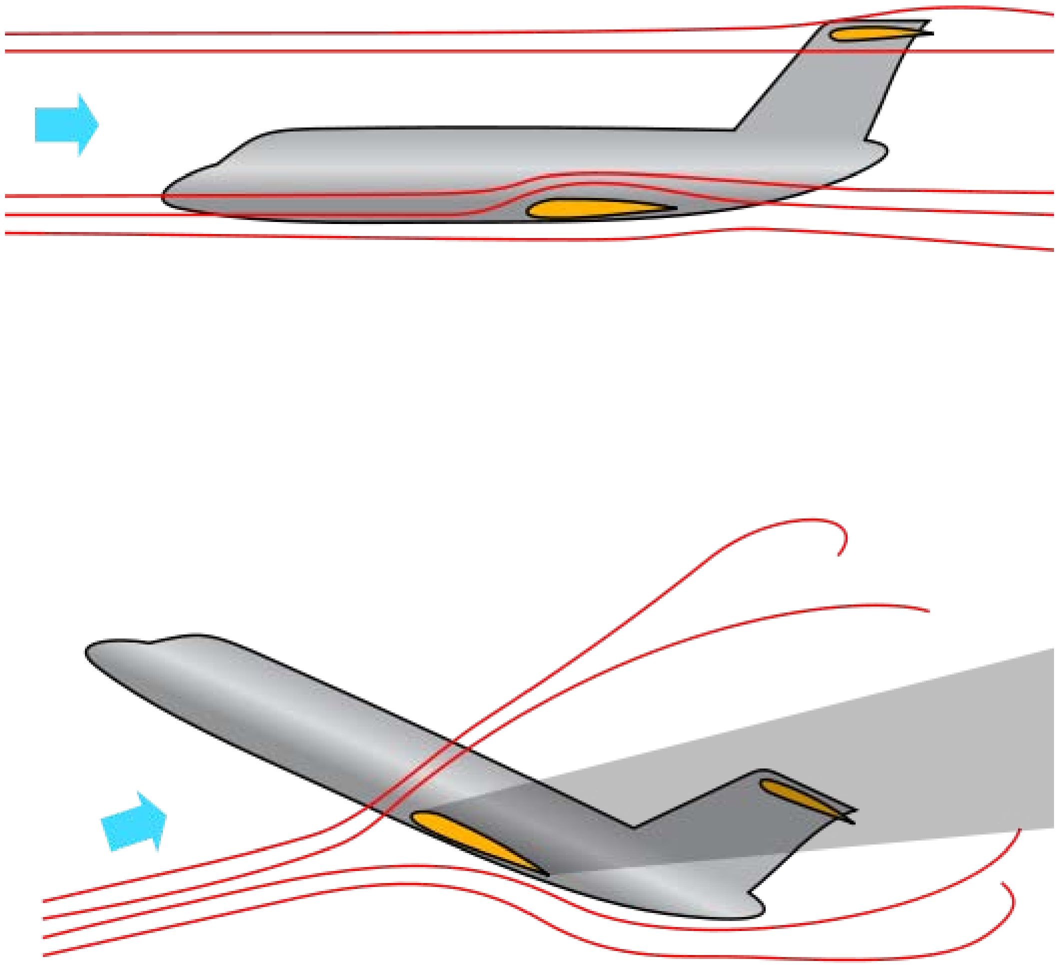
bank angle	$\sqrt{n}$
30°	1.07
45°	1.19
60°	1.41

For example, in a turn with bank angle of 45°, V_{st} is 19% higher than V_s.

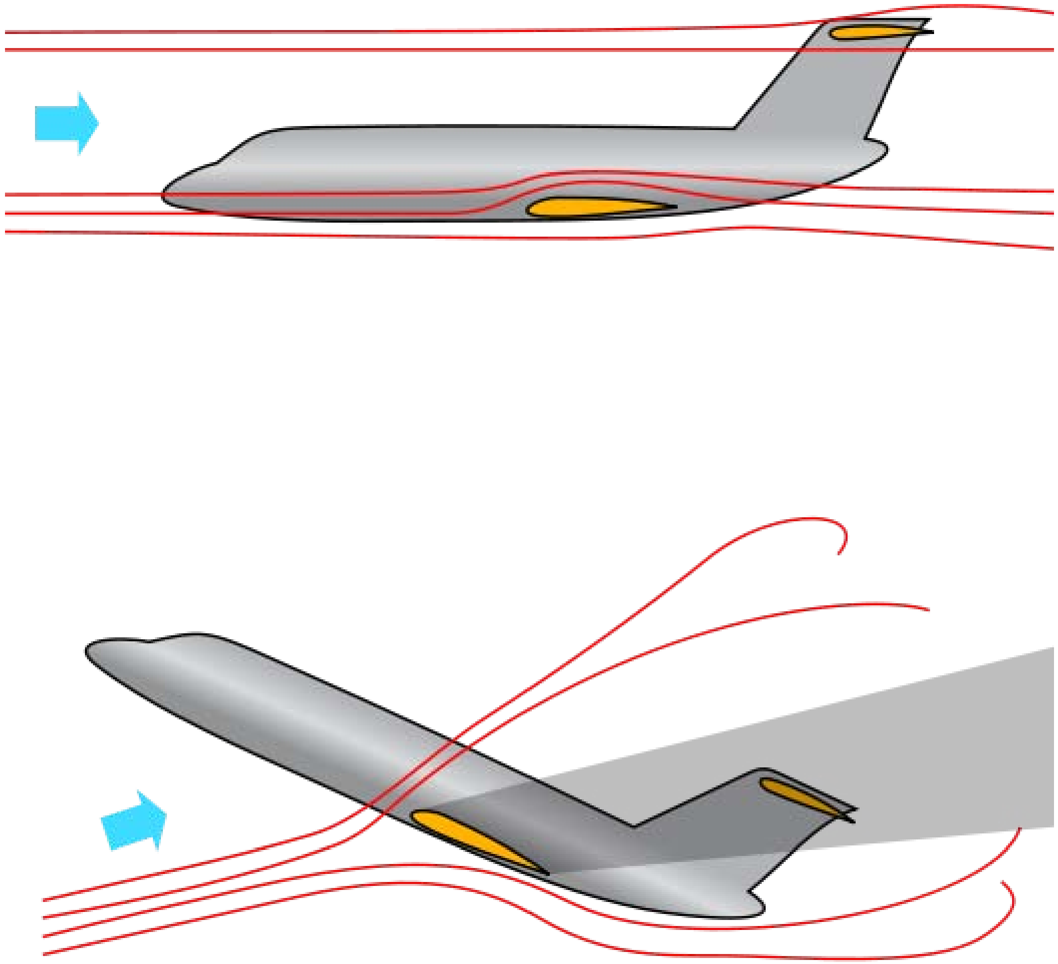
It should be noted that, according to Federal Aviation Administration (FAA) terminology, the above example illustrates a so-called **turning flight stall**, while the term *accelerated* is used to indicate an *accelerated turning stall* only, that is a turning flight stall where the airspeed decreases at a given rate.

A notable example of air accident involving a low-altitude turning flight stall is the 1994 Fairchild Air Force Base B-52 crash.

Deep stall



Normal flight Deep stall condition – T-tail in "shadow" of wing



The deep stall affects aircraft with a T-tail configuration.

A *deep stall* (or *super-stall*) is a dangerous type of stall that affects certain aircraft designs, notably those with a T-tail configuration. In these designs, the turbulent wake of a stalled main wing "blankets" the horizontal stabilizer, rendering the elevators ineffective and preventing the aircraft from recovering from the stall.

Although effects similar to deep stall had long been known to occur on many aircraft designs, the name first came into widespread use after a deep stall led to the crash of the prototype BAC 1-11 G-ASHG on October 22, 1963, killing its crew. This led to changes to the aircraft, including the installation of a stick shaker to clearly warn the pilot of the problem before it occurred. Stick shakers are now a part of all commercial airliners. By sheer coincidence, also on October 22, 1963, a Tu-134 was lost in a flight test due to the same cause. Nevertheless, the problem continues to cause accidents; on June 3, 1966 a Hawker Siddeley Trident (G-ARPY) was lost to deep stall; deep stall is suspected to be cause of another Trident (G-ARPI) crash on June 18, 1972; on April 3, 1980 a prototype of the Canadair Challenger business jet entered deep stall during testing, killing one of the test pilots who was unable to leave the plane in time and on July 26, 1993 a Canadair CRJ-100 was lost in flight test due to a deep stall.

In the early 1980s, a Schweizer SGS 1-36 sailplane was modified for NASA's controlled deep-stall flight program.

A different type of stall affecting the F-16 fighter is also known as a deep stall because of its similar difficulty in recovery, but for a different reason. The aircraft is designed to be inherently unstable, which when kept under control by its "fly-by-wire" system allows for higher maneuverability. However, this design, coupled with the intent of the control computer to keep the fighter level, prevents the aircraft from pitching nose-down in a stall, which would allow the pilot to recover given sufficient altitude. This is known as a deep stall because the elevators are rendered useless by the flight computer even though, unlike a T-tail, air does contact the elevators, and even with the computer disabled it is difficult to recover from (the pilot must "rock" the aircraft with elevator input until it pitches nose-down, which can take several seconds).

Stall warning and safety devices

Aeroplanes can be equipped with devices to prevent or postpone a stall or to make it less (or in some cases more) severe, or to make recovery easier.

- An **aerodynamic twist** can be introduced to the wing with the leading edge near the wing tip twisted downward. This is called **washout** and causes the wing root to stall before the wing tip. This makes the stall gentle and progressive. Since the stall is delayed at the wing tips, where the ailerons are, roll control is maintained when the stall begins.
- A **stall strip** is a small sharp-edged device which, when attached to the leading edge of a wing, encourages the stall to start there in preference to any other location on the wing. If attached close to the wing root it makes the stall gentle and progressive; if attached near the wing tip it encourages the aircraft to drop a wing when stalling.
- A **stall fence** is a flat plate in the direction of the chord to stop separated flow progressing out along the wing
- **Vortex generators**, tiny strips of metal or plastic placed on top of the wing near the leading edge that protrude past the boundary layer into the free stream. As the name implies, they energize the boundary layer by mixing free stream airflow with boundary layer flow thereby creating vortices, this increases the inertia of the boundary layer. By increasing the inertia of the boundary layer airflow separation and the resulting stall may be delayed.
- An **anti-stall strake** is a leading edge extension which generates a vortex on the wing upper surface to postpone the stall.
- A **stick pusher** is a mechanical device which prevents the pilot from stalling an aeroplane. It pushes the elevator control forwards as the stall is approached, causing a reduction in the angle of attack. Generically, a stick pusher is known as a *stall identification device* or *stall identification system*.
- A **stick shaker** is a mechanical device which shakes the pilot's controls to warn of the onset of stall.

- A **stall warning** is an electronic or mechanical device which sounds an audible warning as the stall speed is approached. The majority of aircraft contain some form of this device that warns the pilot of an impending stall. The simplest such device is a *stall warning horn*, which consists of either a pressure sensor or a movable metal tab that actuates a switch, and produces an audible warning in response.
- An **Angle-Of-Attack (AOA) Indicator** or A.K.A Lift Reserve Indicator is a pressure differential instrument that integrates airspeed and angle of attack into one instantaneous, continuous readout. An AOA indicator provides a visual display of the amount of available lift throughout its slow speed envelope regardless of the many variables which act upon an aircraft. This indicator is immediately responsive to changes in speed, angle of attack and wind conditions and automatically compensates for aircraft weight, altitude, and temperature.
- An **angle of attack limiter** or an "alpha" limiter is a flight computer that automatically prevents pilot input from causing the plane to rise over the stall angle. Some alpha limiters can be disabled by the pilot.

Stall warning systems often involve inputs from a broad range of sensors and systems to include a dedicated angle of attack sensor.

Blockage, damage, or inoperation of stall and angle of attack (AOA) probes can lead to the stall warning becoming unreliable and cause the stick pusher, overspeed warning, autopilot and yaw damper to malfunction.

If a forward canard is used for pitch control, rather than an aft tail, the canard is designed to meet the airflow at a slightly greater angle of attack than the wing. Therefore, when the aircraft pitch increases abnormally, the canard will usually stall first, causing the nose to drop and so preventing the wing from reaching its critical AOA. Thus the risk of main wing stalling is greatly reduced. Unfortunately if the main wing stalls, recovery becomes difficult as the canard is more deeply stalled and angle of attack increases rapidly.

If an aft tail is used, the wing is designed to stall before the tail. In this case, the wing can be flown at higher lift coefficient (closer to stall) to produce more overall lift.

Most military combat aircraft have an angle of attack indicator among the pilot's instruments which lets the pilot know precisely how close to the stall point the aircraft is. Modern airliner instrumentation may also measure angle of attack although this information may not be directly displayed on the pilot's display, instead driving a stall warning indicator or giving performance information to the flight computer (for fly by wire systems).

Flight beyond the stall

As a wing stalls aileron effectiveness is reduced, making the plane hard to control and increasing the risk of a spin starting. Post stall, steady flight beyond the stalling angle (where the coefficient of lift is largest), requires engine thrust to replace lift as well as alternate controls to replace the loss of effectiveness of the ailerons. For high powered aircraft, the loss of lift (and increase in drag) beyond the stall angle is less of a problem than maintaining control. Control can be provided by vectored thrust as well as a rolling stabilator (or taileron) and the enhanced manoeuvering capability by flights at very high angles of attack can provide a tactical advantage for military fighters such as the F-22 Raptor. Short term stalls at 90–120° are sometimes performed at airshows. The highest angle of attack in sustained flight so far demonstrated was 70 degrees in the X-31 at the Dryden Flight Research Center.

Spoilers

Except for flight training, airplane testing and aerobatics, a stall is usually an undesirable event. Spoilers (sometimes called lift dumpers), however, are devices that are intentionally deployed to create a carefully controlled flow separation over part of an aircraft's wing to reduce the lift it generates, increase the drag, and allow the aircraft to descend more rapidly without gaining speed. Spoilers are also deployed asymmetrically (one wing only) to enhance roll control. Spoilers can also be used on aborted take-offs and after main wheel contact on landing to increase the aircraft's weight on its wheels for better braking action.

Unlike powered airplanes, which can control descent by increasing or decreasing thrust, gliders have to increase drag to increase the rate of descent. In high performance gliders spoiler deployment is extensively used to control the approach to landing.

Spoilers can also be thought of as "lift reducers" because they reduce the lift of the wing in which the spoiler resides. For example, an uncommanded roll to the left could be reversed by raising the right wing spoiler (or only a few of the spoilers present in large airliner wings). This has the advantage of avoiding the need to increase lift in the wing that is dropping (which may bring that wing closer to stalling).

Chapter 11

Bird Strike

F-16 canopy after a bird strike

A **bird strike** (sometimes **birdstrike**, **avian ingestion** (only if in an engine), **bird hit**, or **BASH** - **B**ird **A**ircraft **S**trike **H**azard) is a collision between an airborne animal (usually a bird or bat) and a man-made vehicle, especially aircraft. The term is also used for bird deaths resulting from collisions with man made structures such as power lines, towers and wind turbines. A bug strike is an impairment of an aircraft or aviator by an airborne insect.

Bird strikes are a significant threat to flight safety, and have caused a number of accidents with human casualties. Major accidents involving civil aircraft are quite low and it has been estimated that there is only about 1 accident resulting in human death in one billion (10^9) flying hours. The majority of bird strikes (65%) cause little damage to the aircraft; however, the collision is usually fatal to the bird.

Most accidents occur when the bird hits the windscreen or flies into the engines. These cause annual damages that have been estimated at $400 million within the United States of America alone and up to $1.2 billion to commercial aircraft worldwide.

Event description

View of fan blades of JT8D Jet engine after a bird strike.

Bird strikes happen most often during takeoff or landing, or during low altitude flight. However, bird strikes have also been reported at high altitudes, some as high as 6,000 m (19,685 ft) to 9,000 m (29,528 ft) above the ground. Bar-headed geese have been seen flying as high as 10,175 m (33,383 ft) above sea level. An aircraft over the Côte d'Ivoire collided with a Rüppell's Vulture at the astonishing altitude of 11,300 m (37,073 ft), the current record avian height. The majority of bird collisions occur near or on airports (90%, according to the ICAO) during takeoff, landing and associated phases. According to the FAA wildlife hazard management manual for 2005, less than 8% of strikes occur above 900 m (2,953 ft) and 61% occur at less than 30 m (100 ft).

A hawk stuck in the nosecone of a C-130

The point of impact is usually any forward-facing edge of the vehicle such as a wing leading edge, nose cone, jet engine cowling or engine inlet.

Jet engine ingestion is extremely serious due to the rotation speed of the engine fan and engine design. As the bird strikes a fan blade, that blade can be displaced into another blade and so forth, causing a cascading failure. Jet engines are particularly vulnerable during the takeoff phase when the engine is turning at a very high speed and the plane is at a low altitude where birds are more commonly found.

The force of the impact on an aircraft depends on the weight of the animal and the speed difference and direction at the impact. The energy of the impact increases with the square of the speed difference. Hence a low-speed impact of a small bird on a car windshield causes relatively little damage. High speed impacts, as with jet aircraft, can cause considerable damage and even catastrophic failure to the vehicle. The energy of a 5 kg (11 lb) bird moving at a relative velocity of 275 km/h (171 mph) approximately equals the energy of a 100 kg (220 lb) weight dropped from a height of 15 metres (49 ft).

However, according to the FAA only 15% of strikes (ICAO 11%) actually result in damage to the aircraft.

Inside of a jet engine after a bird strike

Bird strikes can damage vehicle components, or injure passengers. Flocks of birds are especially dangerous, and can lead to multiple strikes, and damage. Depending on the damage, aircraft at low altitudes or during take off and landing often cannot recover in time, and thus crash.

Remains of the bird, termed *snarge*, are sent to identification centers where forensic techniques may be used to identify the species involved. These samples need to be taken carefully by trained personnel to ensure proper analysis and reduce the risks of zoonoses.

The Israeli Air Force has a larger than usual birdstrike risk as Israel is on a major spring and autumn long-distance bird migration route.

Sacramento International Airport has had more bird strikes (1,300 collisions between birds and jets between 1990 and 2007, causing an estimated $1.6 million in damage) than any other California airport. Sacramento International Airport has the most bird strikes of any airport in the west and sixth among airports in the US, according to the FAA, as it is located along the Pacific Flyway, a major bird migration path.

Species

The animals most frequently involved in bird strikes are large birds with big populations, particularly geese and gulls in the United States. In parts of the US, Canada Geese and migratory Snow Geese populations have risen significantly while feral Canada Geese and Greylag Geese have increased in parts of Europe increasing the risk of these large birds to aircraft. In other parts of the world, large birds of prey such as *Gyps* vultures and *Milvus* kites are often involved. In the US reported strikes are divided between waterfowl (32%), gulls (28%), and raptors (17%) (Data from the BSC USA). The Smithsonian Institution's Feather Identification Laboratory has identified turkey vultures as the most damaging birds, followed by Canada geese and white pelicans, all very large birds. In terms of frequency, the laboratory most commonly finds Mourning Doves and Horned Larks involved in the strike.

The largest numbers of strikes happen during the spring and fall migrations. Bird strikes above 500 feet altitude are about 7 times more common at night than during the day during the bird migration season.

Large land-bound animals, such as deer, can also be a problem to aircraft during take off and landing, and over 650 civil aircraft collisions with deer were reported in the U.S. between 1990 and 2004.

Deer entangled in a landing gear

An animal hazard reported from London Stansted Airport in England is rabbits: they get run over by ground vehicles and planes, and they pass large amounts of droppings, which attract mice, which attract owls, which become another birdstrike hazard.

Countermeasures

There are three approaches to reduce the effect of bird strikes. The vehicles can be designed to be more *bird resistant*, the birds can be moved out of the way of the vehicle, or the vehicle can be moved out of the way of the birds.

Vehicle design

A ICE 3 high speed train after hitting a bird

Most large commercial jet engines include design features that ensure they can shut-down after "ingesting" a bird weighing up to 1.8 kg (4 lb). The engine does not have to survive the ingestion, just be safely shut down. This is a 'stand alone' requirement, *i.e.*, the engine, not the aircraft, must pass the test. Multiple strikes (from hitting a bird flock) on twin engine jet aircraft are very serious events because they can disable multiple aircraft systems, requiring emergency action to land the aircraft, as in the January 15, 2009, forced ditching of US Airways Flight 1549.

Modern jet aircraft structures must be able to withstand one 1.8 kg (4 lb) collision; the empennage (tail) must withstand one 3.6 kg (8 lb) bird collision. Cockpit windows on jet aircraft must be able to withstand one 1.8 kg (4 lb) bird collision without yielding or spalling.

At first, bird strike testing by manufacturers involved firing a bird carcass from a gas cannon and sabot system into the tested unit. The carcass was soon replaced with suitable density blocks, often gelatin, to ease testing. Currently testing is mainly conducted with computer simulation, although final testing usually involves some physical experiments.

Aircraft Forward Lighting can play an important role in enhancing the detectability of birds to aircraft. Vision is the primary sensory pathway serving the animal in detection of approaching objects (e.g., trees, buildings, other birds, and predators) and adjustment of flight path relative to an object's approach. In a very basic sense, once a threat is identified, the animal can utilize its high aerodynamic capabilities to avoid collision. Recent experimental findings suggest that birds will use similar strategies in response to aircraft approach

Bird management

A bird control vehicle belonging to Copenhagen Airport Kastrup, equipped with various tools.

To reduce birdstrikes on takeoff and landing, airports engage in bird management and control. There is no single solution that works for all situations. Birds have been noted for their adaptability and control methods may not remain effective for long. Management techniques include changes to habitat around the airport to reduce its attractiveness to birds. Vegetation which produces seeds, grasses which are favored by geese, manmade food, a favorite of gulls, all should be removed from the airport area. Trees and tall structures which serve as roosts at night for flocking birds or perches should be removed or modified to discourage bird use.

A UH-60 Black Hawk after a collision with a Common Crane, and resulting failure of the windshield.

Other approaches try to scare away the birds using frightening devices, for example sounds, lights, pyrotechnics, radio-controlled airplanes, decoy animals/corpses, lasers, dogs etc. Firearms are also occasionally employed. A successful approach has been the utilization of dogs, particularly Border collies, to scare away birds and wildlife. Another alternative is bird capture and relocation. Falcons are sometimes used to harass the bird population, as for example on John F. Kennedy International Airport. At Manchester Airport in England the usual type of falcon used for this is a peregrine falcon/lanner falcon hybrid, as its flight range covers the airport. An airport in New Zealand uses electrified mats to reduce the number of worms that attracted large numbers of sea gulls.

Flight path

A UH-60 after collision with a crane, and subsequent failure of the windshield as seen from the inside.

Pilots have very little training in wildlife avoidance nor is training required by any regulatory agency. However, they should not takeoff or land in the presence of wildlife, avoid migratory routes, wildlife reserves, estuaries and other sites where birds may congregate. When operating in the presence of bird flocks, pilots should seek to climb above 3,000 feet as rapidly as possible as most birdstrikes occur below 3,000 feet. Additionally pilots should slow their aircraft when confronted with birds. The energy that must be dissipated in the collision is approximately the relative kinetic energy (E_k) of the bird, defined by the equation $E_k = \frac{1}{2}mv^2$ where m is the mass and v is the relative velocity (the sum of the velocities of the bird and the plane). Therefore the speed of the aircraft is much more important than the size of the bird when it comes to reducing energy transfer in a collision. The same can be said for jet engines: the slower the rotation of the engine, the less energy which will be imparted onto the engine at collision.

The body density of the bird is also a parameter that influences the amount of damage caused.

The US Military Aviation Hazard Advisory System uses a Bird Avoidance Model based on data from the Smithsonian Institution, historical patterns of bird strikes and radar tracking of bird activity. This model has been extremely successful. Prior to flight USAF pilots check for bird activity on their proposed low level route or bombing range. If bird activity is forecast to be high, the route is changed to one of lower threat. In the first year this BAM model was required as a preflight tool, the USAF Air Combat Command experienced a 70% drop in birdstrikes to its mission aircraft.

TNO, a Dutch R&D Institute, has developed the successful ROBIN (Radar Observation of Bird Intensity) for the Royal Netherlands Airforce. ROBIN is a near real-time monitoring system for flight movements of birds. ROBIN identifies flocks of birds within the signals of large radar systems. This information is used to give Air Force pilots warning during landing and take-off. Years of observation of bird migration with ROBIN have also provided a better insight into bird migration behaviour, which has had an influence on averting collisions with birds, and therefore on flight safety. Since the implementation of the ROBIN system at the Royal Netherlands Airforce the number of collisions between birds and aircraft in the vicinity of military airbases has decreased by more than 50%.

There are no civil aviation counterparts to the above military strategies. Some experimentation with small portable radar units has taken place at some airports. However, no standard has been adopted for radar warning nor has any governmental policy regarding warnings been implemented.

Incidents

The Federal Aviation Administration estimates the problem costs US aviation 600 million dollars annually and has resulted in over 200 worldwide deaths since 1988. In the United Kingdom, the Central Science Laboratory estimates that, worldwide, the cost of birdstrikes to airlines is around US$1.2 billion annually. This cost includes direct repair cost and lost revenue opportunities while the damaged aircraft is out of service. Estimating that 80% of bird strikes are unreported, there were 4,300 bird strikes listed by the United States Air Force and 5,900 by US civil aircraft in 2003.

The first reported bird strike was by Orville Wright in 1905, and according to the Wright Brothers' diaries *Orville ... flew 4,751 meters in 4 minutes 45 seconds, four complete circles. Twice passed over fence into Beard's cornfield. Chased flock of birds for two rounds and killed one which fell on top of the upper surface and after a time fell off when swinging a sharp curve.*

French pilot Eugene Gilbert in 1911 encountered an angry mother eagle over the Pyrenees Mountains enroute from Paris to Madrid during the great aviation race held that year between those two cities. The bird feared for the safety of her young which were perched high in a nest in the mountains and as Gilbert flew past she thought he was a predator. Gilbert flying a Bleriot XI open cockpit was able to ward off the large bird by firing pistol shots at her but not killing her.

The first recorded bird strike fatality was reported in 1912 when aero-pioneer Cal Rodgers collided with a gull which became jammed in his aircraft control cables. He crashed at Long Beach, California, was pinned under the wreckage and drowned.

The greatest loss of life directly linked to a bird strike was on October 4, 1960, when Eastern Air Lines Flight 375, a Lockheed L-188 Electra flying from Boston, flew through a flock of common starlings during take off, damaging all four engines. The plane crashed shortly after take-off into Boston harbor, with 62 fatalities out of 72 passengers. Subsequently, minimum bird ingestion standards for jet engines were developed by the FAA.

On September 22, 1995, a U.S. Air Force E-3 Sentry AWACS aircraft (Callsign Yukla 27, serial number 77-0354), crashed shortly after take off from Elmendorf AFB, AK. The plane lost power to both port side engines after these engines ingested several Canada Geese during takeoff. The aircraft went down in a heavily wooded area about two miles northeast of the runway, killing all 24 crew members on board.

The Space Shuttle Discovery also hit a bird (a vulture) during the take-off of STS-114 on July 26, 2005, although the collision occurred early during take off and at low speeds, with no obvious damage to the shuttle.

NASA also lost an astronaut, Theodore Freeman, to a bird strike. He was killed when a goose shattered the plexiglass cockpit of his T-38 Talon, resulting in shards being ingested by the engines, leading to a fatal crash.

Aircraft continue to be lost on a routine basis to birdstrikes. In the fall of 2006, the USAF lost a twin engine T-38 trainer to a bird strike (ducks) and in October 2007, the US Navy lost a T-45 jet trainer in a collision with a bird.

In the summer of 2007, Delta Air Lines suffered an incident in Rome, Italy, as one of its Boeing 767 aircraft, on takeoff, ingested yellow legged gulls into both engines. Although the aircraft returned to Rome safely, both engines were damaged and had to be changed. United Air Lines suffered a twin engine bird ingestion by a Boeing 767 on departure from Chicago's O'Hare Field in the spring of 2007. One engine caught fire and bird remains were found in the other engine.

Virgin America Flight 837 performed an emergency landing at San Francisco International Airport on September 3, 2007 due to a bird strike. The plane involved was "Air Colbert", named for host of *The Colbert Report* Stephen Colbert.

On April 29, 2007, a Thomsonfly Boeing 757 from Manchester Airport, UK to Lanzarote Airport, Spain suffered a bird strike when at least one bird, supposedly a heron, was ingested by the starboard engine. The plane landed safely back at Manchester Airport a while later. The incident was captured by 2 plane spotters on opposite sides of the airport, as well as the emergency calls picked up by a plane spotter's radio. The videos were later published.

On November 10, 2008, Ryanair Flight 4102 from Frankfurt to Rome made an emergency landing at Ciampino Airport after multiple bird strikes put both engines out of commission. After touchdown, the left main landing gear collapsed, and the aircraft briefly veered off the runway before the crew regained control. Passengers and crew were evacuated through the starboard emergency exits. Three passengers and two crew members were injured, none seriously.

On January 4, 2009, a bird strike is suspected in the crash of a PHI S-76 helicopter in Louisiana. While the final report has not been published, early reports point to a bird impacting the windscreen and retarding the throttles, leading to the death of 7 of the 8 persons on board.

On January 15, 2009, US Airways Flight 1549 from LaGuardia Airport to Charlotte/Douglas International Airport ditched into the Hudson River after experiencing a loss of both turbines. It is suspected that the engine failure was caused by running into a flock of geese at an altitude of about 975 m (3,200 feet), shortly after takeoff. All 150 passengers and 5 crew members were safely evacuated after a successful water landing. On May 28, 2010, the NTSB published its final report into the accident.

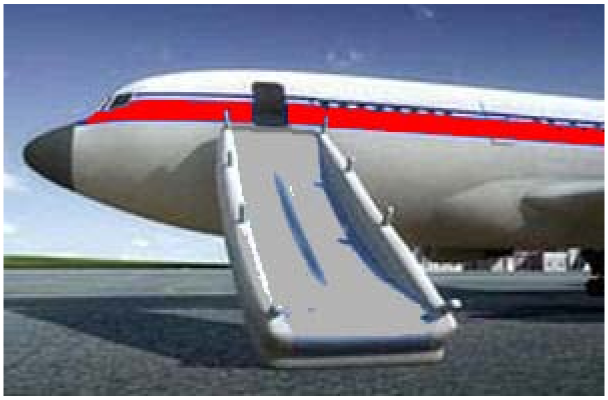
On September 18, 2009, American Eagle Airlines Flight 5183 from Dallas Texas to Lawton Oklahoma, collided with over 100 pigeons during takeoff on runway 31L. The takeoff was aborted and the aircraft sustained minor damage. 34 whole birds were recovered, hundreds of body parts were also recovered. The aircraft returned safely to the gate with no injuries.

Bug strike

Flying insect strikes, like bird strikes, have been encountered by pilots since aircraft were invented. In 1911 future Air Force general Henry "Hap" Arnold as a young aviator flying a mile high and not wearing goggles nearly lost control of his Wright Model B after a bug flew in his eye causing distraction. Large numbers of bugs such as a locust swarm can infiltrate an aircraft engine and bring down a plane.

Chapter 12

Evacuation Slide



Inflated evacuation slide on a Hawker Siddeley Trident.

An **evacuation slide** is an inflatable slide used to evacuate an aircraft quickly. An escape slide is required on all commercial (passenger carrying) aircraft where the door sill height is such that, in the event of an evacuation, passengers would be unable to "step down" from the door uninjured (Federal Aviation Administration requires slides on all aircraft doors where the floor is 6 feet (1.8 m) or more above the ground).

Escape slides are packed and held within the door structure inside the *slide bustle*, a protruding part of the inside of an aircraft door that varies in size depending on both the size of the aircraft and the size of the door.

Many, but not all slides are also designed to double as life rafts in case of a water landing.

Window exits

Deflated evacuation slide on an Airbus A320.

Some aircraft have escape slides on the main doors of the plane, but do not have slides over the wings due to the fact that, when the flaps are fully lowered, the wings are low enough to the ground that passengers can evacuate safely. Some of these aircraft are the Embraer 190, Boeing 707, 717, 727 and 737. However, other aircraft require the use of overwing slides for the window exits to ensure passengers are able to reach the ground quickly and safely. These include Boeing 767, Boeing 757, Airbus A320-series aircraft. Typically, overwing evacuation slides are not designed for use in ditching situations as they cannot be detached and will not operate, as the system is disabled by the aspirators on the slide taking in water.

Window exits usually come in two configurations:

- An *unhinged hatch type exit*, where the hatch is unlocked from the inside and pulled into the cabin, whereupon it can be disposed. Some carriers recommend placing the hatch onto the adjacent seats, while others may recommend dropping it in the next seat row, or rotating the exit and throwing it outside the aircraft as far forward as possible. A manual inflation handle for the evacuation slide, if equipped, can be found in the window frame. Most aircraft overwing exits are of this type.
- A *hinged "self disposing" exit hatch*, that opens automatically outward using a spring when the exit handle is pulled. This exit design was designed in response to research generated after the Manchester air disaster in 1985 which indicated that unhinged hatch type exits were difficult to open by untrained passengers. This design is currently found only on Boeing 737 NG aircraft.

Window exits are usually equipped with "ditching" or "life" lines. These may be attached to the inside frame of the window exit, or located in a nearby storage locker. One end has a buckle to connect to attachments on the aircraft's wings.

History

The first aircraft evacuation slide was developed and produced by Air Cruisers, founded by James F. Boyle, inventor of the WWII life vest, the "Mae West". Prior to inflateables, some passenger aircraft utilized canvas type slides which required the crew to undertake an extensive rigging procedure. Canvas type slides are still found on some Russian aircraft. James F Boyle is credited with the invention of the inflatable aircraft slide while with Air Cruisers. The patent for the "Inflatable Escape Chute Assembly" was submitted by Boyle in 1954 and the designs was patented in 1956 under patent number 2,765,131. Today Air Cruisers provides slides for over 65% of the aircraft slide market.

Types

A packed evacuation slide

Evacuation slide in the box at the bottom of the door

There are two types of aircraft evacuation slides: slides and slide/rafts. A slide is for use only on land as a means of escape, although it has sufficient buoyancy to allow passengers to hold on to a lanyard running the length of it and use it as a buoyancy aid. A slide/raft is an evacuation slide that can be used both as a means of escape in a land evacuation and also as a life raft in a landing on water. Slide/rafts usually feature an erectable canopy, outer compartments to hold passengers and survival packs containing items such as leak stoppers, paddles and flares.

Slides can also be single or dual lane, depending on the width of the exit, a dual lane slide being capable of evacuating a greater number of people quickly in an evacuation.

Slides and slide/rafts can be detached from the girt bar, usually by a two or three step procedures. This may, for example, involve lifting up the flap on the girt bar, and pulling the detach handle. These procedures are usually placarded red on the slide, "For Ditching Use Only". Once the slide is separated, the slide remains attached to the aircraft by a mooring line. This line will break if the airframe submerges, or can be disconnected with a pre-supplied knife or disconnect handle.

A ramp slide is an evacuation slide that has a small platform between the exit and the slide itself, and is used mainly where the proximity of the exit to an engine requires the slide to be angled away from the engine to prevent damage. Airbus A310, Airbus 340-600, Airbus A380 and Boeing 747 aircraft have ramp slide attachments for their overwing evacuation slides. The overwing exits on the Airbus A320 series, Boeing 757-variant and Boeing 767-variant aircraft also utilize ramp slide attachments.

Another unique type of evacuation slide is found on certain DC-9, MD-80 and Boeing 717 aircraft. This type of slide is located in the aircraft's tailcone. This slide deploys after the tailcone is jettisoned by flight attendants, allowing for evacuation through the rear of the airframe. The procedure to use this exit may involve removing a plug-type pressure bulkhead, or a swing type door that leads directly to a walkway. At the end of the walkway is the slide pack and a manual tailcone jettison handle for use if the tailcone has not already been automatically jettisoned by opening the walkway entrance.

Certain evacuation slides do not use a slide bustle on the door as a container. Instead, the slide is "fuselage mounted" and is attached to a container located underneath or below the exit close to the aircraft exterior. This design of slide is found in the Airbus A321 aircraft at the emergency doors, and typically at all overwing evacuation slides other than the Boeing 747-400 series aircraft.

One of the newest development in evacuation slide technology can be found on the Airbus A380, which was developed by Goodrich Aircraft Interior Products. Certain slides on board the aircraft have the Tribrid Inflation System, which is connected to a sensing system within the door. If the door is opened in emergency mode at an abnormal attitude (e.g. nose up position due to the loss of landing gear), the slide will inflate normally but will also inflate several feet of additional slide to ensure the slide reaches the ground. This compares differently to the Boeing 747 as doors found on that aircraft have no such system; should the slide not reach the ground, the doors must be blocked to prevent passenger injury.

Operation

Prior to departure (usually before engine startup) all the aircraft doors are placed into the armed (or automatic) mode by the cabin crew. Methods of arming vary from aircraft to aircraft, but ultimately what is involved is the girt bar (a metal bar attached to the door end of the slide) being physically attached to brackets either in or adjacent to the door sill. On older aircraft, such as the Boeing 737, this is done physically by the cabin crew and on most other aircraft it involves pushing a lever on the door itself which arms the door internally.

If a rapid evacuation is required and the doors are opened while "armed", the opening of the door pulls the slide pack out of the bustle (because the girt bar is physically attached to the aircraft floor). Due to the weight of both the door and the slide, great effort is involved in pushing the door open sufficiently to free the slide from the bustle, thus on larger aircraft a "power assist" function kicks in to aid the opening, either electrically or from compressed gas. Once the slide is completely free it will fall under gravity and after travelling a certain distance a pin will be pulled from a squib containing compressed gas and the slide will inflate. Should this system fail, the slide can be manually inflated by the cabin crew by pulling a manual inflation handle at the top of the slide. Should this also fail, standard operating procedures require the cabin crew to send passengers away from the door and to one that has a functioning escape slide.

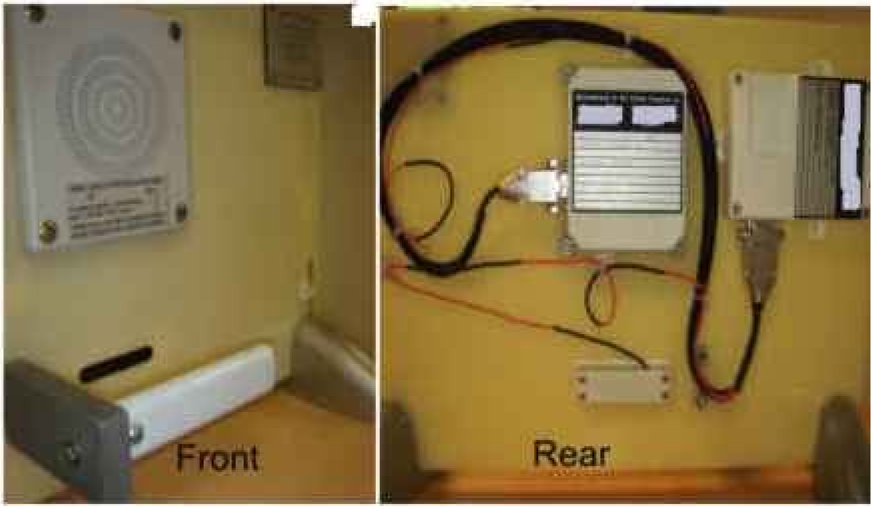
Some Russian-built aircraft like the Tupolev Tu-154 have a very complicated process to activate and deploy the slides. The slides are stored in cabinets usually beside the emergency exit inside the aircraft. There are usually about the same width and height as a seat. To activate the slide, one must pull the front cover to a 90 degree angle, then pull the slide out so it is lying flat on the floor or door sill, open the emergency exit and kick or push it out. Gravity will then pull the slide to the ground and it will inflate.

Aircraft safety cards and in-flight safety demonstrations show the passengers where the nearest emergency exits are and how to use the evacuation slides. Additionally, Flight Attendants receive extensive safety training that covers the use of evacuation slides.

Usage

In an article in TIME, Amanda Ripley and Dan Johnson, an aviation safety expert, compiled some tips on how to avoid injury and escape from a plane on an inflatable slide. Here are their suggestions. Number one: Have a Plan. Know where the exits are when you sit down on a plane. Two: Have a back-up plan. Passengers often have trouble opening the exit hatches and slides sometimes malfunction. Three: Get out fast. Don't even think about grabbing your overhead luggage. Four: Jump! Johnson says if everyone would jump the evacuation could go 50% faster. And faster is better. Five: to avoid burns, keep your heels up and your arms crossed over your chest. Women should avoid wearing pantyhose and spiked heels when they fly. The hose can melt onto the skin in the heat of a plane fire and the heels can pop the emergency slide. Six: When you reach the bottom, get out of the way. Pile-ups at the bottom of the slide can be brutal and slow down the exit for everyone.

Inadvertent deployment



A stand-alone device installed on the back of the door.

Inadvertent slide deployment occurs when the operator of the aircraft door attempts to open the door when it is in the armed position. This costs the industry millions in lost revenue every year, estimated at $20 million in North America by cabin crew alone.

A device can be used to prevent this problem. It works by sounding an audible alert (voice) when the door operator, whether trained or not, is about to open the door in the armed position. It works as an independent system, requiring no action other than arming the door as per normal standard operating procedures. When the door is placed in the armed position, the device is armed. It can be installed as a stand alone unit or integrated into the aircraft systems and powered from aircraft power.

Inflation systems

Both slides and slide/rafts use a non-explosive, inert gas inflation systems. The FAA requires evacuation of the entire aircraft in 90 seconds using 50% of the available evacuation exits. To meet this, all evacuation units need to deploy in less than 10 seconds. For large, wide body aircraft such as A300's and B747's a successful deployment is complete in about 5–7 seconds, depending on conditions (such as cold and winds).

The inflation system usually consists of a pressurized cylinder, a regulating valve, two high pressure hoses and two Aspirators. The cylinder can be from 100 to about 1000 cubic inches, filled to about 3000 psi with either gaseous Nitrogen, or a mixture of gaseous CO_2 and Nitrogen. Once made of steel, most cylinders now are made of aluminum or alloy cores wrapped with fiberglass, or other lightweight, fuel saving materials. The CO_2 is used to slow down the rate at which the valve expends the gases.

The valve is used to mechanically meter out the gas at a rate of roughly 3 - 600 psi and 4 CFM. Typically there are two high pressure hoses attached to the valve, which are connected at the other end to 'Aspirators'. These are usually cylindrical, hollow aluminum tubes with sliding cylindrical or internal 'flapper' doors that open when high pressure gas is applied, and close when the gas stream subsides and the internal slide back pressure reaches about 2.5 - 3.0 psi. They work on the 'Venturi' principle, and draw outside air into the evacuation unit at a rate of about 500:1. A 750 in^3 (0.43 ft^3) cylinder can fill a slide with about 850 cu ft (24 m^3). of air to a pressure of about 3 psi in about 4 – 6 seconds.

In order for the slide to deploy correctly, it is packed in a manner that has the aspirators directly under the outer cover. The entire, self contained 'slide pack' is approximately 3 ft (0.91 m). wide, 2.5 ft (0.76 m). wide and about 12" high, depending on aircraft type. In the center, forward part of the pack, a multi-layered piece of heavy urethane or neoprene/nylon fabric, called the 'girt', is left hanging out to a length of about 2 ft (0.61 m). When installed in the aircraft, a 'girt bar' is put through the center, outside end of the girt and attached to the interior floor, just inside and in front of the exit door. On the face of the girt are instructions in large red lettering, and a handle with the word 'PULL' on it.

This is rarely used however, because the lanyard attached to the handle runs through the girt to the valve, which is several inches too short when the girt is extended fully. When the slide is in the 'armed' position and the door is opened, the slide pack falls free of the door bustle (a semi-rigid outer container) and the weight and momentum of the slide pulls the lanyard from the valve, initiating the flow of gas. At about the same time, a metal pin that holds the center of the Valise closed is also pulled, releasing a 'daisy chain' and the two halves of the cover. When the cover is released and the inflation system activated, the two aspirators come shooting out of the pack, gulping vast quantities of air and restrained only by the fabric tubes to which they are securely fastened.

In order to compensate for any wind, new evacuation slides contain internal baffles, which cause the ends nearest the aircraft to inflate first, which are constructed to come out like four elbows and press against the fuselage of the aircraft, to the forward and aft sides of the exit door. There are also 'half-tie' restraints which keep the inflating slide from drooping or blowing under the aircraft. These restraints are constructed so that when the slide becomes fairly rigid, around 1.5 - 2.0 psi, they detach very quickly (there are usually two), and since the header tubes are already against the fuselage, the slide 'pops' almost horizontally out from the door, then drops relatively gently to the ground. Tests in 25-knot (46 km/h) cross winds have shown these deployment systems to be very effective.

Independent of the inflation system, all slides are equipped with at least one pressure relief device per inflation chamber. This protects the chamber from catastrophic failure due to over pressurizing. (Typically, modern slides are made of at least 2 inflation chambers, and should be able evacuate an aircraft even when one chamber loses all pressure.)

All new evacuation slides are tested on a mock-up of an aircraft exit door and filmed prior to being certified as 'airworthy' and delivered to a customer. Also, new units are usually constructed of urethane materials and impregnated or coated with an aluminized coating in order that the slide will survive for a short while even if fire is nearby. Older slides are yellow and made of neoprene/nylon fabric.

Exempted aircraft

Airplanes such as the Embraer 145 family, Fokker 50 family and the Bombardier CRJ family do not have escape slides because all exits are a safe distance from the ground (less than 6'.). On the primary entrance door, 1L, some of these aircraft have stairs that are either connected to the door or drop down.

There are a lot of aircraft that do not have evacuation slides fitted to them. These tend to be the smaller regional type aircraft. For example the Dash 8 series aircraft, Fokker F27 & F50, Jetstream, Shorts 330 and 360.

Chapter 13

Emergency Landing

JetBlue Airways Flight 292 making an emergency landing at LAX

An **emergency landing** is a landing made by an aircraft in response to a crisis which either interferes with the operation of the aircraft or involves sudden medical emergencies necessitating diversion to the nearest airport.

Types of emergency landings

There are several different types of emergency landings for powered aircraft: planned landing or unplanned landing

- *Forced landing*, the aircraft is forced to make a landing due to technical problems, medical problems or weather conditions. Landing as soon as possible is a priority, no matter where. A forced landing may be necessary even if the aircraft is still flyable. This can arise to either facilitate emergency medical or police assistance or get the aircraft on the ground before a major system failure occurs which would force a crash landing or ditch situation.
- *Precautionary landing*, may result from a planned landing at a location about which information is limited, from unanticipated changes during the flight, or from abnormal or even emergency situations. The sooner a pilot locates and inspects a potential landing site, the less the chance of additional limitations being imposed by worsening aircraft conditions, deteriorating weather, or other factors.
- *Crash landing*, is caused by the failure of or damage to vital systems such as engines, hydraulics, or landing gear, and so a landing must be attempted where a runway is needed but none is available. The pilot is essentially trying to get the aircraft on the ground in a way which minimizes the possibility of injury or death to the people aboard.
- *Ditching*, is the same as a crash landing, only on water. After the disabled aircraft makes contact with the surface of the water, the aircraft will eventually sink if it is not designed to float, although the craft may well float for hours depending on damage.

Procedures

If there is no engine power available during a forced landing, a fixed-wing aircraft glides, while a rotary winged aircraft (helicopter) autorotates to the ground by trading altitude for airspeed to maintain control. Pilots often practice "simulated forced landings", in which an engine failure is simulated and the pilot has to get the aircraft on the ground safely, by selecting a landing area and then gliding the aircraft at its best gliding speed.

If there is a suitable landing spot within the aircraft's gliding or autorotation distance, an unplanned landing will often result in no injuries or significant damage to the aircraft, since powered aircraft generally use little or no power when they are landing. Light aircraft can often land safely on fields, roads, or gravel river banks (or on the water, if they are float-equipped); but medium and heavy aircraft generally require long, prepared runway surfaces because of their heavier weight and higher landing speeds. Glider pilots routinely land away from their base and so most cross-country pilots are in current practice.

UAV forced landing research

Since 2003, research has been conducted on enabling UAVs to perform a forced landing autonomously.

Notable examples of emergency landings

Large airliners have multiple engines and redundant systems, so forced landings are extremely rare for them, but some notable ones have occurred. The most famous example is the Gimli Glider, an Air Canada Boeing 767 that ran out of fuel and glided to a safe landing in Gimli, Manitoba, Canada on July 23, 1983. On June 1982, British Airways Flight 9, a Boeing 747 en route from Kuala Lumpur to Perth lost power in all four engines, three of which subsequently recovered, eventually diverting to Jakarta. On April 28, 1988, Aloha Airlines Flight 243 experienced an explosive decompression mid-flight, forcing an emergency landing at the Kahului Airport with only one casualty, flight attendant Clarabell "C.B." Lansing. More recently, Air Transat Flight 236 ran out of fuel over the Atlantic Ocean on August 24, 2001 and made a successful forced landing in the Azores.

A less successful crash landing involved Southern Airways Flight 242 on April 4, 1977. The DC-9 lost both of its engines due to hail and heavy rain in a thunderstorm and, unable to glide to an airport, made a forced landing on a highway near New Hope, Georgia, United States. The plane made a hard landing and was still carrying a large amount of fuel, so it burst into flames, killing the majority of the passengers and several people on the ground.

Airliners frequently make emergency landings, and almost all of them are uneventful. However because of their inherent uncertain nature, they can quickly become crash landings or worse. Some notable instances include Swissair Flight 111, which crashed near Halifax, Nova Scotia, Canada on September 2, 1998 while dumping fuel in preparation for a precautionary landing due to fire; United Airlines Flight 232, which broke up while landing at Sioux City, Iowa, U.S.A. on July 19, 1989; and Air Canada Flight 797, which burned after landing at Cincinnati/Northern Kentucky International Airport on June 2, 1983 after a fire started in the cabin.

Emergency water landings

US Airways Flight 1549 after ditching in the Hudson River

Several passenger and cargo aircraft and helicopter ditchings have been documented. These intentional emergency water landings are the result of an in-flight fuel depletion or mechanical malfunction and not an accidental overshoot of a runway or an uncontrolled crash into a body of water. The following figures show survival rates for passengers and crew:

- US Airways Flight 1549, Airbus A320, New York City to Charlotte/Douglas International Airport, 15 January 2009, made a controlled safe water ditch into the Hudson River after losing thrust in both engines due to birdstrike at about 3000 feet altitude three minutes into the flight after a normal takeoff from LaGuardia Airport; 155 passengers and crew made an orderly evacuation as a NYC fireboat towed the floating aircraft with passengers standing on the wing. The survival rate was 100%.

- On 6 August 2005, Tuninter Flight 1153 (an ATR 72) ditched off the Sicilian coast after running out of fuel. Of 39 aboard, 23 survived with injuries including serious burns. The plane's wreck was found in three pieces. The survival rate was 59%.

- On December 4, 2004, Miami Air Lease' N41626, a Convair CV-340 cargo airplane with two pilots on board experienced an engine failure enroute between Opa-locka, Florida and Nassau, Bahamas. Unable to feather the propeller, the airplane rapidly lost altitude and the pilots ditched into Maule Lake, North Miami Beach, Florida. Both occupants were rescued. The survival rate was 100%.

- On 16 January 2002, Garuda Indonesia Flight 421 (a Boeing 737) successfully ditched into the Bengawan Solo River near Yogyakarta, Java Island after experiencing a twin engine flameout during heavy precipitation and hail. The pilots tried to restart the engines several times before making the decision to ditch the aircraft. Photographs taken shortly after evacuation show that the plane came to rest in knee-deep water. Of the 60 occupants, one flight attendant was killed. The survival rate was 98%.

- On 23 November 1996, Ethiopian Airlines Flight 961 (a Boeing 767-260ER), ditched in the Indian Ocean near Comoros after being hijacked and running out of fuel, killing 125 of the 175 passengers and crew on board. Unable to operate flaps, it impacted at high speed, dragging its left wingtip before tumbling and breaking into three pieces. The panicking hijackers were fighting the pilots for the control of the plane at the time of the impact, which caused the plane to roll just before hitting the water, and the subsequent wingtip hitting the water and breakup are a result of this struggle in the cockpit. Some passengers were killed on impact or trapped in the cabin when they inflated their life vests before exiting. Most of the survivors were found hanging onto a section of the fuselage that remained floating. The survival rate was 29%.

- On October 16, 1982, Colombian Air Force C 130 Hercules cargo aircraft ditched in Atlantic Ocean 330 kilometers east of Cape May, New Jersey after running out of fuel. Probably due to the buoyancy of the empty fuel tanks, the hull floated for 56 hours. 8 of the 13 occupants were rescued. The survival rate was 62%.

- On 2 May 1970, ALM Flight 980 (a McDonnell Douglas DC-9-33CF), ditched in mile-deep water after running out of fuel during multiple attempts to land at Princess Juliana International Airport on the island of Saint Maarten in the Netherlands Antilles under low-visibility weather. Insufficient warning to the cabin resulted in several passengers and crew still either standing or with unfastened seat belts as the aircraft struck the water. Of 63 occupants, 40 survivors were recovered by U.S. military helicopters. The survival rate was 63%.

- On 21 August 1963, an Aeroflot Tupolev Tu-124 ditched into the Neva River in Leningrad after running out of fuel. The aircraft floated and was towed to shore by a tugboat which it had nearly hit as it came down on the water. The tug rushed to the floating aircraft and pulled it with its passengers near to the shore where the passengers disembarked onto the tug; all 52 on board escaped without injuries. The survival rate was 100%.

- On 23 September 1962, Flying Tiger Line Flight 923, a Lockheed 1049H-82 Super Constellation passenger aircraft with a crew of 8 and 68 U.S. military (paratrooper) passengers ditched in the North Atlantic about 500 miles west of Shannon, Ireland after losing three engines on a flight from Gander, Newfoundland to Frankfurt, Germany. 45 of the passengers and 3 crew were rescued, with 23 passengers and 5 crew members being lost in the storm-swept seas. All occupants successfully evacuated the airplane. Those who were lost succumbed in the rough seas. The survival rate for landing and evacuation was 100%. The final survival rate of the accident was 63%.

- On 16 July 1962, a New York Airways Boeing Vertol 107 helicopter made an emergency landing in New York's East River after power failure. All 22 passengers were safely evacuated. The survival rate was 100%.

- In October 1956, Pan Am Flight 6 (a Boeing 377) ditched northeast of Hawaii, after losing two of its four engines. The aircraft was able to circle around USCGC *Pontchartrain* until daybreak, when it ditched; all 31 on board survived. The survival rate was 100%.

- In April 1956, Northwest Orient Airlines Flight 2 (also a Boeing 377) ditched into Puget Sound after what was later decided to be caused by failure of the crew to close the cowl flaps on the plane's engines. All aboard escaped the aircraft after a textbook landing, but four passengers and one flight attendant succumbed either to drowning or to hypothermia before being rescued. The survival rate was 87%.

- On 26 March 1955, Pan Am Flight 845/26 ditched 35 miles from the Oregon coast after an engine tore loose. Despite the tail section breaking off during the impact the aircraft floated for twenty minutes before sinking. Survivors were rescued after a further 90 minutes in the water. The survival rate was 83%.

- On 19 June 1954, Swissair Convair CV-240 HB-IRW ditched into the English Channel because of fuel starvation, which was attributed to pilot error. All three crew and five passengers survived the ditching and could escape the plane. However, three of the passengers could not swim and eventually drowned, because there were no life jackets on board, which was not prescribed at the time. The survival rate was 63%.

- On 3 August 1953, Air France Flight 152, a Lockheed L-749A Constellation ditched 6 miles from Fetiye Point, Turkey, 1,5 miles offshore into the Mediterranean Sea on a flight between Rome, Italy and Beirut, Lebanon. The propeller had failed due to blade fracture. Due to violent vibrations, engine number three broke away and control of engine number four was lost. The crew of eight and all but four of the 34 passengers were rescued. The survival rate was 91%.

- On 16 April 1952, the de Havilland Australia DHA-3 Drover VH-DHA operated by the Australian Department of Civil Aviation with 3 occupants was ditched in the Bismarck Sea between Wewak and Manus Island. The port propeller failed, a propeller blade penetrated the fuselage and the single pilot was rendered unconscious; the ditching was performed by a passenger. The survival rate was 100%.

- On 11 April 1952, Pan Am Flight 526A ditched 11,3 NW of Puerto Rico due to engine failure after take off. Many survived the initial ditching but panicking passengers refused to leave the sinking wreck and drowned. 52 passengers were killed, 17 passengers and crew members were rescued by the USCG. After this accident it was recommended to implement pre-flight safety demonstrations for over-water flights. The survival rate was 25%.

605 of 871 occupants of the above listed ditchings survived. A lot of passengers weren't killed by the impact but drowned because of hypothermia or panic. The average survival rate of the accidents listed above is 69%.