Aviation Risks

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Chapter- 1

Aircraft Hijacking

Aircraft hijacking (also known as **skyjacking** and **sky controlling**) is the unlawful seizure of an aircraft by an individual or a group. In most cases, the pilot is forced to fly according to the orders of the hijackers. Occasionally, however, the hijackers have flown the aircraft themselves. In at least one case, a plane was hijacked by the official pilot.

Unlike the typical hijackings of land vehicles or ships, skyjacking is not usually committed for robbery or theft. Most aircraft hijackers intend to use the passengers as hostages, either for monetary ransom or for some political or administrative concession by authorities. Motives vary from demanding the release of certain inmates (notably IC-814) to highlighting the grievances of a particular community (notably AF 8969). Hijackers also have used aircraft as a weapon to target particular locations (notably during the September 11, 2001 attacks).

Hijackings for hostages commonly produce an armed standoff during a period of negotiation between hijackers and authorities, followed by some form of settlement. Settlements do not always meet the hijackers' original demands. If the hijackers' demands are deemed too great and the perpetrators show no inclination to surrender, authorities sometimes employ armed special forces to attempt a rescue of the hostages (notably Operation Entebbe).

History

The first recorded aircraft hijack took place on February 21, 1931, in Arequipa, Peru. Byron Rickards, flying a Ford Tri-Motor, was approached on the ground by armed revolutionaries. He refused to fly them anywhere and after a 10-day standoff Rickards was informed that the revolution was successful and he could go in return for giving one group member a lift to Lima.

Note: In the Fort Worth Star-Telegram daily newspaper (morning edition) 19 September 1970, J. Howard "Doc" DeCelles states that he was actually the victim of the first skyjacking in December 1929. He was flying a postal route for the Mexican company Transportes Aeras Transcontinentales, ferrying mail from San Luis Potosí to Toreon and then on to Guadalajara. "Doc" was approached by Gen. Saturnino Cedillo, governor of the state of San Luis Potosí and one of the last remaining lieutenants of Pancho Villa. Cedillo was accompnied by several other men. He was told through an interpreter he had no choice in the matter. "Doc" stalled long enough to convey the information to his boss, who told him to cooperate. He had no maps, but was guided by the men as he flew above Mexican mountains. He landed on a rode as directed, and was held captive for several hours under armed guard. He eventually was released with a "Buenos" from Cedillo and his staff. DeCelles kept his flight log, according to the article, but he did not file a report with authorities. "Doc" went on to work for the FAA in Fort Worth after his flying career.

Between 1948 and 1957 there were 15 hijackings worldwide, an average of a little more than one per year. Between 1958 and 1967, this climbed to 48, or about five per year. The number grew to 38 in 1968 and 82 in 1969, the largest number in a single year in the history of civil aviation; in January 1969 alone, eight airliners were hijacked to Cuba. Between 1968 and 1977, the annual average jumped to 41.

In 1973, the Nixon Administration ordered the discontinuance by the CIA of the use of hijacking as a covert action weapon against the Castro regime. Cuban intelligence followed suit. That year, the two countries reached an agreement for the prosecution or return of the hijackers and the aircraft to each other's country. The Taiwanese intelligence also followed the CIA's example-vis-a-vis China.

These measures plus the improvement in Israel's relations with Egypt and Jordan, the renunciation of terrorism by the Palestine Liberation Organisation, the on-going peace talks between the PLO and Israel, the collapse of the communist states in East Europe, which reduced the scope for sanctuaries for terrorists, and the more cautious attitude of countries such as Libya and Syria after the U.S. declared them State-sponsors of international terrorism, the collapse of ideological terrorist groups such as the Red Army Faction and the tightening of civil aviation security measures by all countries have arrested and reversed the steep upward movement of hijackings.

However, the situation has not returned to the pre-1968 level and the number of successful hijackings continues to be high - an average of 18 per annum during the 10-year period between 1988 and 1997, as against the pre-1968 average of five.

On September 11, 2001, 19 al-Qaedan-affiliated Islamic extremists hijacked American Airlines Flight 11, United Airlines Flight 175, American Airlines Flight 77, and United Airlines Flight 93 and crashed them into the Twin Towers of the World Trade Center, the southwestern side of the Pentagon building, and Stonycreek Township near Shanksville, Pennsylvania in a terrorist attack.

Dealing with hijackings

Before the September 11, 2001 attacks, pilots and flight attendants were trained to adopt the "Common Strategy" tactic, which was approved by the FAA. It taught crew members to comply with the hijackers' demands, get the plane to land safely and then let the security forces handle the situation. Crew members advised passengers to sit quietly in order to increase their chances of survival. They were also trained not to make any 'heroic' moves that could endanger themselves or other people. The FAA realized that the longer a hijacking persisted, the more likely it would end peacefully with the hijackers reaching their goal.This led to an escalation of attacks. First a few planes were hijacked and blown up on the ground, then hijackers began killing a few passengers to make a "political statement" this escalation continued until reaching the logical conclusion on September 11, 2001.

September 11 presented a unique situation because it involved suicide hijackers who could fly an aircraft. The "Common Strategy" tactic was not designed to handle suicide hijackings. This resulted in the hijackers exploiting a weakness in the civil aviation security system. Since then the "Common Strategy" policy is no longer used.

Since the September 11th attacks, the situation for crew members, passengers and hijackers has changed. As in the case of United Airlines Flight 93, where an airliner crashed into a field during a fight between flight attendants, passengers and hijackers while likely heading to the White House or the United States Capitol, crew members and passengers now have to calculate the risks of passive cooperation, not only for themselves but also for those on the ground. Future hijackers most likely will encounter greater resistance from passengers and flight crews, making a successful hijacking more unlikely. An example of active passenger and crew member resistance occurred when passengers and flight attendants of American Airlines Flight 63 from Paris to Miami on December 22, 2001, helped prevent Richard Reid from igniting explosives hidden in his shoe. Flight attendants and pilots now receive extensive anti-hijacking and self-defense training designed to thwart a hijacking.

Informing air traffic control

To communicate to air traffic control that an aircraft is being hijacked, a pilot under duress should squawk 7500 or vocally, by radio communication, transmit "(Aircraft callsign); Transponder seven five zero zero." This should be done when possible and safe. An air traffic controller who suspects an aircraft may have been hijacked may ask the pilot to confirm "squawking assigned code." If the aircraft is *not* being hijacked, the pilot should *not* squawk 7500 and should inform the controller accordingly. A pilot under duress may also elect to respond that the aircraft is not being hijacked, but then neglect to change to a different squawk code. In this case the controller would make no further requests and immediately inform the appropriate authorities. A complete lack of a response would also be taken to indicate a possible hijacking. Of course, a loss of radio communications may also be the cause for a lack of response, in which case a pilot would usually squawk 7**6**00 anyway.

On 9/11, the hijacker-pilot of Flight 11, Mohamed Atta, mistakenly transmitted announcements to ATC, meaning to go through the Boeing 767. Also, Amy Sweeney and Betty Ong called the American Airlines office, telling the workers that Flight 11 was hijacked.

Prevention

Cockpit doors on most commercial airlines have been strengthened and are now bullet resistant. In the United Kingdom, United States, Canada, Australia and France, air marshals have also been added to some flights to deter and thwart hijackers. Airport security plays a major role in preventing hijackers. Screening passengers with metal detectors and luggage with x-ray machines prevents weapons from being taken on to an aircraft. Only in Israel is decompression used on all luggage to check for pressure sensor detonators. Along with the FAA, the FBI also monitors terror suspects. Any person who is a threat to civil aviation is banned from flying.

Shooting down aircraft

Several states have stated that they would shoot down hijacked commercial aircraft if it can be assumed that the hijackers intend to use the aircraft in a 9/11-style attack, despite killing innocent passengers on board. According to reports, U.S. fighter pilots have been trained to shoot down hijacked commercial airliners should it become necessary. Other countries such as India, Poland, and Russia have enacted laws or decrees that allow the shooting down of hijacked planes. Polish Constitutional Court however, in September 2008, decided that the regulations were unconstitutional and dismissed them.

India

In August 2005, India revealed its new anti-hijacking policy. The policy came into force after the cabinet committee on security (CCS) approved it. The main points of the policy are

- Any attempt to hijack will be considered an act of aggression against the country and will prompt a response fit for an aggressor.
- Hijackers, if captured, will be sentenced to death.
- Hijackers will be engaged in negotiations only to bring the incident to an end, to comfort passengers and to prevent loss of lives.
- The plane will be shot down if it is deemed to become a missile heading for strategic targets.
- The plane will be escorted by armed fighter aircraft(s) and will be forced to land.
- A grounded plane will not be allowed to take off under any circumstance.

The list of strategic targets is prepared by the Bureau of Civil Aviation in India. The decision to shoot down a plane is taken by CCS. However, due to the shortage of time, whoever – the prime minister, the defense minister or the home minister – can be reached first will take the call. In situations in which an aircraft becomes a threat while taking off

– which gives very little reaction time – a decision on shooting it down may be taken by an Indian Air Force officer not below the rank of Assistant Chief of Air Staff (Operations).

Germany

In January 2005 a federal law came into force in Germany – the *Luftsicherheitsgesetz* – that allowed "direct action by armed force" against a hijacked aircraft to prevent a 9/11-type attack. However, in February 2006 the Federal Constitutional Court of Germany struck down these provisions of the law, stating such preventive measures were unconstitutional and would essentially be state-sponsored murder, even if such an act would save many more lives on the ground. The main reasoning behind this decision was that the state would effectively be taking the lives of innocent hostages in order to avoid a terrorist attack. The Court also ruled that the Minister of Defense is constitutionally not entitled to act in terrorism matters, as this is the duty of the state and federal police forces.

The President of Germany, Horst Köhler, himself urged judicial review of the constitutionality of the Luftsicherheitsgesetz after he signed it into law in 2005.

International law issues

Tokyo Convention

The Convention on Offences and Certain Other Acts Committed on Board Aircraft ("Tokyo Convention") is a multilateral convention, done at Tokyo between 20 August and 14 September 1963, coming into force on 4 December 1963, and is applicable to offences against penal law and to any acts jeopardising the safety of persons or property on board civilian aircraft while in-flight and engaged in international air navigation.

The convention, for the first time in the history of international aviation law, recognises certain powers and immunities of the aircraft commander who on international flights may restrain any person(s) he has reasonable cause to believe is committing or is about to commit an offence liable to interfere with the safety of persons or property on board or who is jeopardising good order and discipline.

Hague Convention

Signed at The Hague on 16 December 1970, the Convention for the Suppression of Unlawful Seizure of Aircraft contains 14 articles relating to what constitutes hijacking as well as guidelines for what is expected of governments when dealing with hijackings. The convention does not apply to customs, law enforcement or military aircraft, thus its scope appears to exclusively encompass civilian aircraft. Importantly, the convention only comes into force if the aircraft takes off or lands in a place different than its country of registration. For aircraft with joint registration, one country is designated as the registration state for the purpose of the convention.

Chapter- 2

Aircraft Upset

Aircraft upset is a dangerous condition in aircraft operations which may result in the **loss of control** of the aircraft, and sometimes the total loss of the aircraft itself. **Loss of control** may be due to turbulent weather, pilot disorientation, or a system failure.

The U.S. NASA Aviation Safety Program defines **upset prevention** and **upset recovery** to prevent loss of control accidents due to aircraft upset after inadvertently entering an extreme or abnormal flight attitude.

A Boeing-compiled list determined that 2,051 lives were lost in 22 accidents in the years 1998–2007 due to **LOC** accidents. NTSB data for 1994–2003 count 32 accidents and more than 2,100 lives lost worldwide.

Overview

Prior to the fatal 1994 crash of USAir Flight 427, the U.S. NTSB "...had issued a series of safety recommendations over a 24-year period, asking the FAA to require air carriers to train pilots in recoveries from unusual flight attitudes. Throughout this period, the Safety Board was generally not satisfied with the FAA's responses to these recommendations; specifically, the Board disagreed with the FAA's responses that cited the inadequacy of flight simulators as a reason for not providing pilots with the requested training. However, after the USAir flight 427 accident and the October 31, 1994, ATR-72 accident involving Simmons Airlines flight 4184 near Roselawn, Indiana, the FAA issued guidance to air carriers, acknowledging the value of flight simulator training in unusual attitude recoveries and encouraging air carriers to voluntarily provide this training to their pilots."

Some carriers did implement their own voluntary training programs, following those accidents, and the NTSB regarded those programs as "excellent."

In October 1996, the NTSB issued a formal Safety Recommendation (A-96-120), which requested the FAA to require all airlines to provide simulator training for flight crews, which would enable them to recognize and recover from "unusual attitudes and upset

maneuvers, including upsets that occur while the aircraft is being controlled by automatic flight control systems, and unusual attitudes that result from flight control malfunctions and uncommanded flight control surface movements."

In 2004, the U.S. FAA issued its first *Airplane Upset Recovery Training Aid*. The second revision of that document was released in 2008 and is available at the FAA's website.

New FAA rules are expected to be finalized in 2010, requiring specific training for pilots to recover from aircraft upset incidents. New training programs may be known under the term *advanced maneuver - upset recovery training* (**AM-URT**).

In 2009, the Royal Aeronautical Society formed a new group of experts, who will form documentation to allow better simulations of aircraft upset conditions, and thus better training programs.

Detailed definition

An airplane upset is defined as an airplane in flight **unintentionally** exceeding the parameters normally experienced in line operations or training. In other words, the airplane is not doing what it was commanded to do and is approaching unsafe parameters. While specific values may vary among airplane models, the following **unintentional** conditions generally describe an airplane upset:

- Pitch attitude greater than 25 deg, nose up.
- Pitch attitude greater than 10 deg, nose down.
- Bank angle greater than 45 deg.
- Within the above parameters, but flying at airspeeds inappropriate for the conditions.

Recovery to a stable flight path should be initiated **as soon as a developing upset condition is recognized**. This preventive action may alleviate what might otherwise develop into a very serious event.

Jet upset

The phrase **jet upset** refers to past accidents (some crashed and some recovered, usually with significant damage to the structure), where a jet airliner was "upset" and went into a high dive. That phenomenon was almost unknown in the days of piston-driven propeller airliners, which is why those accidents were referenced as "jet" upsets: because it was a repeated phenomena that was unique to jet airliners, with swept-back wings, jet engines and movable horizontal stabilizers, none of which were found on the piston/propeller airliners. With the phasing out of piston-driven propeller airliners, that phrase has gradually given way to "loss of control," which includes, but is not limited to, the upset/high-dive type of accidents. The term *jet upset* was most heavily used in the 1960s and 1970s as the phenomenon was not well understood and was still being researched. Contemporary authors tend to group the phenomenon under *loss of control*.

There have been a variety of causes and contributing factors, in past jet upset accidents:

- **February, 1959:** A Pan Am B-707 upset and went into a high dive while cruising over the Atlantic at FL 350. Control was not recovered until reaching 6,000 ft. After landing safely at Gander, extensive structural damage was found, but there were only a few minor injuries. The Captain was in the cabin when the autopilot disconnected without adequate warning to the First Officer, who was distracted with a "howgozit" report form. It wasn't until the FO felt the stall buffet that he realized they were descending rapidly and about to turn upside down. He was unable to level the wings. Fortunately, the Captain was able to return to the cockpit strap into his seat while enduring significant G-forces. He took over the controls, leveled the wings and pulled out of the dive.

- **February, 1963:** A Northwest B-720B was hit with a powerful updraft (it suddenly began climbing at 9,000 ft. per minute) while climbing through 17,000 ft as it tried to fly between thunderstorms shortly after takeoff. The nose pitched up so high that the pilot reacted by using full nose-down trim on the horizontal stabilizer (HS), while simultaneously pushing the elevators to the full down position. Then, an equally powerful down draft hit the plane and it went straight down in a matter of seconds. The pilot, of course pulled back on the yoke, which moved the elevators to the full up position. But, that imposed such a high G-load on the plane, that the HS jackscrew stalled, so that the HS remained in the full trimmed down position. The plane came apart in the air, before hitting the ground.

- **July, 1963:** A United B-720, while climbing through FL 370, upset and dove until recovery at 14,000 ft. The plane encountered severe turbulence, downdrafts and updrafts, which caused the plane to stall. The plane was approaching the coffin corner of its flight envelope, when the turbulence was encountered. After that near disaster, the stall and mach buffet margins were widened on all jet aircraft, to preclude a plane getting into that situation again, where severe turbulence narrows the "coffin alley" margins so instantly that the pilots do not have time to avoid a high altitude stall.

- **November, 1963:** All 118 on board a Trans-Canada Airlines DC-8-54F were killed, when the plane crashed 5 minutes after takeoff near Montreal, leaving a crater in the ground. Impact speed was over 500 mph. They found the pitch trim compensator actuator was in the extended position and the horizontal stabilizer trim setting was at 1.65 to 2 degrees nosedown (both were improper positions, for that stage of flight). "The probable cause of this accident could not be determined with certainty. Certain possible causes which were put forward could not be ruled out: 1) Icing of the Pitot system; 2) Failure of the vertical gyro; 3) An unprogrammed and unnoticed extension of the Pitch Trim Compensator."

- **February, 1964:** An Eastern Airlines DC-8 crashed into Lake Pontchartrain about 5 minutes after taking off from the New Orleans Moisant Airport. All 58 on

board perished. The water was only 20 ft. deep, yet only 60% of the wreckage was recovered, because the breakup was so extensive. The FDR tape was too damaged to help the analysis. Instead, they used the maintenance records of that plane, and of other DC-8s, to conclude that the pilots had trimmed the stabilizer to the full nose-down position, to counter the excessive nose-up attitude that, in turn, was caused by a malfunctioning PTC that had extended too far. Once the upset occurred, it was not possible to trim the HS back to the nose-up position, because of the severe G-forces generated by their pulling back on the yoke after the upset.

- **February, 1985:** China Airlines Flight 006: The number 4 engine flamed out on a China Airlines 747SP, while cruising at FL 410 over the Pacific Ocean. The captain ordered an attempt to restart the engine, while remaining at FL410 and with the autopilot controlling the plane. The airspeed was declining (because the remaining 3 engines did not have enough power to remain at a safe airspeed at that altitude). When the captain finally disconnected the AP, he failed to use left rudder to counteract the asymmetrical thrust, and the plane rolled rapidly to the right and entered a high dive attitude. He was unable to recover from the dive until below 11,000 ft. when they emerged from the clouds. The plane exceeded the maximum operating airspeed (Vmo) twice, during the dive. After recovery, the plane landed safely at San Francisco. It suffered major structural damage and 2 occupants received serious injuries.

Related accidents

- 1974-03-03 Turkish Airlines Flight 981 (cargo door failure, caused severing of essential flight control cables).
- 1979-04-04 TWA Flight 841 (1979) (Improper manipulation of flaps/slats by pilots; the plane high dived from 39,000 ft. to 5,000 ft, in 63 seconds. Landed safely.)
- 1985-08-12 Japan Airlines Flight 123 (Improper repair caused bulkhead explosion, which severed all hydraulic flight control lines)
- 1989-07-19 United Airlines Flight 232 (Catastrophic engine failure caused loss of all 3 hydraulic flight control lines)
- 1994-06-30 1994 A330 test flight crash (Control was lost after the pilot shut down one engine, close to the ground, during a certification test flight)
- 1994-09-08 USAir Flight 427 (Control lost when the rudder PCU malfunctioned, causing the rudder to move in the opposite direction, commanded by the pilot)
- 1994-10-31 American Eagle Flight 4184 While in a holding pattern, extensive ice accumulation produced a sudden reversal of the aileron controls, causing the plane to upset and dive into the ground.
- 1994-12-11 Philippine Airlines Flight 434
- 2001-11-12 American Airlines Flight 587
- 2003-11-22 DHL Baghdad incident
- 2005-03-06 Air Transat Flight 961
- 2007-01-01 Adam Air Flight 574
- 2009-02-12 Colgan Air Flight 3407

Chapter- 3

Atmospheric Icing and Compressor Stall

Atmospheric icing

The effect of atmospheric icing on a tree.

Atmospheric icing occurs when water droplets in the atmosphere freeze on objects they contact. This is very dangerous on aircraft, as the built-up ice changes the aerodynamics of the flight surfaces, which can increase the risk of a subsequent stalling of the airfoil.

Not all water freezes at 0°C or 32°F. Liquid water below this temperature is called supercooled, and such supercooled droplets cause the icing problems on aircraft. Below -20°C, icing is rare because clouds at these temperatures usually consist of ice particles rather than supercooled water droplets. Below -42°C, supercooled water cannot exist, therefore icing is impossible.

Icing also occurs on towers, wind turbines, boats, oil rigs, trees and other objects exposed to low temperatures and water droplets.

Related aircraft incidents

- Northwest Airlines Flight 6231 1 December 1974
- Arrow Air Flight 1285 12 December 1985
- Air Florida Flight 90 13 January 1982
- Air Ontario Flight 1363 10 Mar 1989
- United Express Flight 2415 26 December 1989
- USAir Flight 405 22 March 1992
- American Eagle Flight 4184 31 October 1994
- Comair Flight 3272 9 January 1997
- Comair Flight 5054 19 March 2001
- Continental Connection Flight 3407 12 February 2009
- Qantas Airbus A380 2010

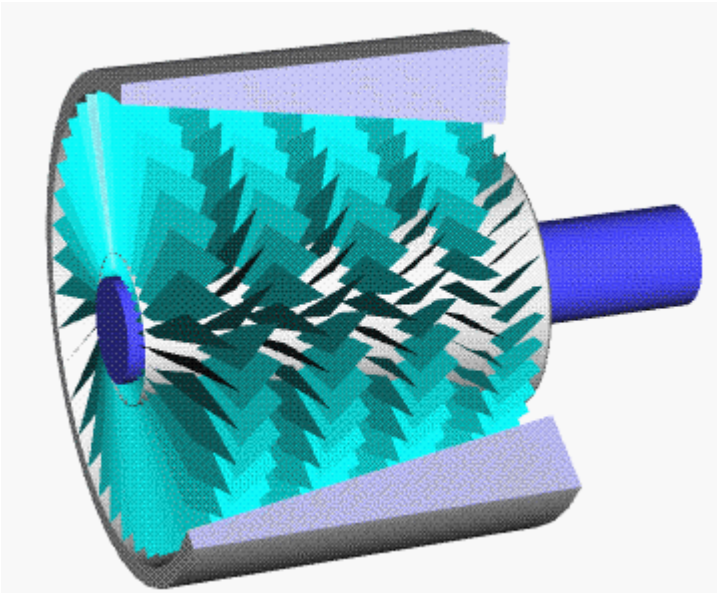
Compressor stall

A **compressor stall** is a situation of abnormal airflow resulting from a stall of the aerofoils within the compressor of a jet engine. Stall is found in dynamic compressors, particularly axial compressors, as used in jet engines and turbochargers for reciprocating engines.

Compressor stalls result in a loss of compressor performance, which can vary in severity from a momentary engine power drop (occurring so quickly it is barely registered on engine instruments) to a complete loss of compression (compressor surge) necessitating a reduction in the fuel flow to the engine.

Modern compressors are carefully designed and controlled to avoid or limit stall within an engine's operating range. Stall was a common problem on early jet engines with simple aerodynamics and manual or mechanical fuel control units, but has been virtually eliminated by better design and the use of hydromechanical and electronic control systems such as Full Authority Digital Engine Controls.

Types



An axial compressor showing both the stator and rotor blades.

There are two types of compressor stall:

Rotational stall

Rotational stall is a local disruption of airflow within the compressor which continues to provide compressed air but with reduced effectiveness. Rotational stall arises when a small proportion of aerofoils experience aerofoil stall disrupting the local airflow without destabilising the compressor. The stalled aerofoils create pockets of relatively stagnant air (referred to as *stall cells*) which, rather than moving in the flow direction, rotate around the circumference of the compressor. The stall cells rotate with the rotor blades but at 50%-70% of their speed, affecting subsequent aerofoils around the rotor as each encounters the stall cell. Stable local stalls can also occur which are axi-symmetric, covering the complete circumference of the compressor disc but only a portion of its radius, with the remainder of the face of the compressor continuing to pass normal flow.

A rotational stall may be momentary, resulting from an external disturbance, or may be steady as the compressor finds a working equilibrium between stalled and unstalled areas. Local stalls substantially reduce the efficiency of the compressor and increase the structural loads on the aerofoils encountering stall cells in the region affected. In many cases however, the compressor aerofoils are critically loaded without capacity to absorb the disturbance to normal airflow such that the original stall cells affect neighbouring regions and the stalled region rapidly grows to become a complete compressor stall.

Axi-symmetric stall or compressor surge

Axi-symmetric stall, more commonly known as **compressor surge**; or **pressure surge**, is a complete breakdown in compression resulting in a reversal of flow and the violent expulsion of previously compressed air out through the engine intake, due to the compressor's inability to continue working against the already-compressed air behind it. The compressor either experiences conditions which exceed the limit of its pressure rise capabilities or is highly loaded such that it does not have the capacity to absorb a momentary disturbance, creating a rotational stall which can propagate in less than a second to include the entire compressor.

The compressor will recover to normal flow once the engine pressure ratio reduces to a level at which the compressor is capable of sustaining stable airflow. If, however, the conditions that induced the stall remain, the return of stable airflow will reproduce the conditions at the time of surge and the process will repeat. Such a "locked-in" or self-reproducing stall is particularly dangerous, with very high levels of vibration causing accelerated engine wear and possible damage, even the total destruction of the engine.

Causes

Compressor stalls are **aerodynamic stalls** in which the aerofoils in the compressor are loaded above their lifting capability. This can arise for a number of reasons which result in either a drop in the expected compressor performance or the compressor is loaded in conditions beyond its design.

Factors affecting compressor performance

- Damaged compressor components caused by ingestion of foreign objects. One of the most common causes of compressor stalls in commercial aviation aircraft is a bird strike. On take-off, while maneuvering on the ground, or while on approach to landing, planes often operate in proximity to birds. It is not uncommon for birds to be sucked into engine intakes, and the disruption to the airflow and damage to the blades often causes compressor stall. Other pieces of FOD on a runway, such as pieces of tire rubber, litter, or a metal piece dropped from another plane Therefore, runways must be clear of all material capable to be sucked into compressors.

- Worn or contaminated compressor components such as eroded rotor blades, seals or bleed valves. Even dust and dirt in the compressor can reduce its efficiency and lead to a stall if the contamination is severe enough.

Factors increasing compressor loads

- Aircraft operation outside of design envelope. E.g., extreme flight manoeuvre resulting in airflow separations within the engine intake. Flight within icing conditions where ice can build up within the intake or compressor. Engine thrust

requirements too high for the operating altitude. (limited with modern fly-by-wire controls)
- Engine operation outside specified design parameters. E.g., abrupt increases in engine thrust (*slam acceleration*) causing a mismatch between engine components. (Occurrence reduced through the use of modern electronic control units.)
- Turbulent or hot airflow to the engine intake. E.g., use of reverse thrust at low forward speed, resulting in re-ingestion of hot turbulent air, or for military aircraft, ingestion of hot exhaust gases from fired missile.
- Worn or contaminated engine components. E.g., poorly performing control unit or turbine within an engine may result in a mismatch increasing the likelihood of stall.
- On the Starfighter Lockheed F-104A gunsmoke of the guns mounted disrupted compressor intake. On this type a variable nose cone design in both compressor inlets was applied to tackle the problem.

Effects

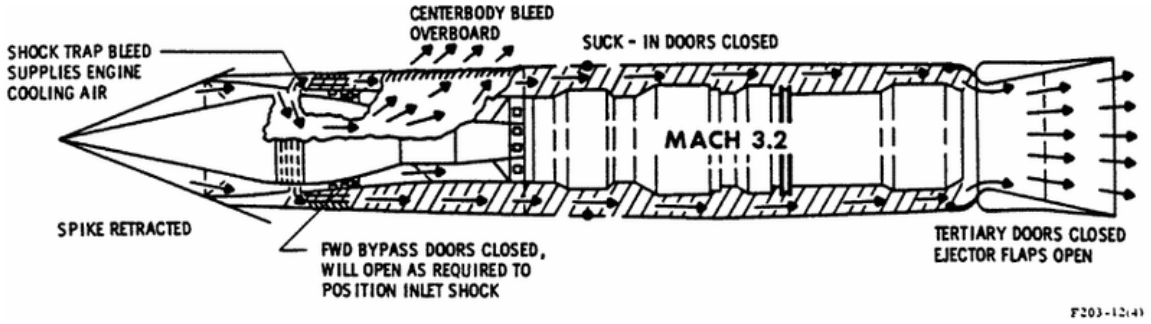
Compressor axially-symmetric stalls, or compressor surges, are immediately identifiable because they produce one or more extremely loud bangs from the engine. Reports of jets of flame emanating from the engine are common during this type of compressor stall. These stalls may be accompanied by an increased exhaust gas temperature, an increase in rotor speed due to the large reduction in work done by the stalled compressor and—in the case of multi-engine aircraft -- yawing in the direction of the affected engine due to the loss of thrust. Severe stresses occur within the engine and aircraft particularly from the intense aerodynamic buffeting within the compressor.

Response and recovery

The appropriate response to compressor stalls varies according the engine type and situation, but usually consists of immediately and steadily decreasing thrust on the affected engine. While modern engines with advanced control units can avoid many causes of stall, jet aircraft pilots must continue to take this into account when dropping airspeed or increasing throttle.

Notable stall occurrences

Aircraft development



Airflow through the Pratt & Whitney J58 turbojet as installed in the Lockheed SR-71 Blackbird

Pratt & Whitney J58 engines

The Lockheed SR-71 Blackbird, a supersonic reconnaissance aircraft developed in the United States, employed Pratt & Whitney J58 turbojet engines that were known for their tendency to "hard unstart", that is, to produce spectacular compressor stalls, often violent enough to throw the pilot's head against the canopy of the aircraft.

These were due to shock waves that moved out of their proper location within the jet's air intakes during supersonic flight. The stall of one engine produced a dramatic loss of thrust from one side, triggering a violent yaw movement, and required quick action by the crew to avoid compromise of the mission or airframe. Unstarts were the bane of SR-71 pilots until computer controls on the engines later in the SR-71 program significantly reduced their incidence and simplified recovery.

Rolls-Royce Avon engine

The Rolls-Royce Avon turbojet engine was affected by repeated compressor surges early in its development which proved difficult to eliminate from the design. Such was the perceived importance and urgency of the engine that Rolls-Royce licensed the compressor design of the Sapphire engine from Armstrong Siddeley to speed development.

The engine, as redesigned, went on to power landmark aircraft such as the English Electric Canberra bomber, and the de Havilland Comet and Sud Aviation Caravelle airliners.

Olympus 593

During Concorde's development, compressor stall was recognised as a potential problem. Because Concorde needed very high performance to fly across the Atlantic, the engines

had to be run very close to the surge line. In one case during the test programme, a compressor stall caused a back-fire which blew out the inlet ramp from an engine nacelle entirely, although in most cases the engine itself was physically capable of surviving surge. The problem was solved by the development of the digital air-intake control system which calculated the appropriate compressor spool speed to operate the engine within the surge margin and fed this data to the engine controls. Thus surge was never a problem in routine flight.

Aircraft crashes

U.S. Navy F-14 crash

A compressor stall contributed to the 1994 death of Lt. Kara Hultgreen, the first female carrier-based United States Navy fighter pilot. Her aircraft, a Grumman F-14 Tomcat, experienced a compressor stall and failure of its left engine, a Pratt and Whitney TF30 turbofan, due to disturbed airflow caused by Hultgreen's attempt to recover from an incorrect final approach position by executing a sideslip; compressor stalls from excessive yaw angle were a known deficiency of this type of engine.

Southern Airways Flight 242

The 1977 loss of Southern Airways Flight 242, a Douglas DC-9-31, while penetrating a thunderstorm cell over Georgia was attributed to compressor stalls brought on by ingestion of large quantities of water and hail which blocked bleed air removal from both of its Pratt & Whitney JT8D-9 turbofan engines. The stalls were so severe as to cause the destruction of the engines, leaving the flight crew with no choice but to make an emergency landing on a public road; 62 passengers and another 8 people on the ground were killed.

Trans World Airlines Flight 159

On November 6, 1967, TWA Flight 159, a Boeing 707 on its takeoff roll from the then-named Greater Cincinnati Airport, passed Delta Air Lines Flight 379, a Douglas DC-9 stuck in the dirt a few feet off the runway's edge. The first officer on the TWA aircraft heard a loud bang, now known to have been a compressor stall induced by ingestion of exhaust from Delta 379 as it was passed. Believing a collision had occurred, the copilot aborted the takeoff. Because of its speed, the aircraft overran the runway, injuring 11 of the 29 passengers, one of whom died four days later as a result of the injuries.

US Airways Flight 1549

US Airways Flight 1549, an Airbus A320, floating in the Hudson River after bird strikes caused compressor stalls and complete failure of both engines.

On January 15, 2009, US Airways Flight 1549, an Airbus A320 ditched in the Hudson River about five minutes after take-off. The apparent cause was compressor stall in both engines after flying through a flock of birds about 90 seconds after take-off. This same aircraft may have suffered a compressor stall on the right engine two days earlier. After an incident in which an Airbus A321-200 experienced compressor stalls on both engines during initial climb out on December 15, 2008, an EASA Emergency Airworthiness Directive 2008-228 requested operators of CFM56-5B engines (operated on the plane that crashed into Hudson River) to monitor exhaust gas temperatures (EGT) for deterioration and make sure that at least one engine shows less than 80 °C deterioration in its EGTs. The FAA have issued the same requirements as Airworthiness Directive AD 2009-01-01 with immediate effect.

Chapter- 4

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- 5

Control Reversal and Controlled Flight into Terrain

Control reversal

Control reversal is an adverse effect on the controllability of aircraft. To the pilot it appears that the flight controls have reversed themselves; in order to roll to the left, for instance, they have to push the control stick to the right, opposite of the normal direction.

Causes

There are several causes for this problem: pilot error, effects of high-speed flight, incorrectly connected controls, and various coupling forces on the aircraft.

Pilot error

Pilot error is the most common cause of control reversal. In unusual attitudes it is not uncommon for the pilot to become disoriented and start feeding in incorrect control movements in order to regain level flight. This is particularly common when using helmet mounted display systems, which introduce graphics that remain steady in the pilot's view, notably when using a particular form of attitude display known as an *inside-out* display.

Incorrectly connected controls

Incorrectly connected controls are another common cause of this problem. It is a recurring problem after maintenance on aircraft, notably homebuilt designs that are being flown for the first time after some minor work. However it is not entirely uncommon on commercial aircraft, and has been the cause of several accidents including the death of Avro designer Roy Chadwick.

Wing twist

Another version of the problem occurs when the amount of airflow over the wing becomes great enough that the force generated by the ailerons is enough to twist the wing itself, due to insufficient torsional stiffness of the wing structure. For instance when the aileron is deflected upwards in order to make that wing move down, the wing twists in the opposite direction. The net result is that the airflow is directed down instead of up and the wing moves upward, opposite of what was expected. This form of control reversal is often lumped in with a number of "high speed" effects as compressibility.

Examples

Wright Brothers glider

The Wright Brothers suffered a form of control reversal, normally referred to as adverse yaw. In their 1902 glider they continued to encounter a problem where the glider would roll in one direction but yaw in the reverse direction, then spin into the ground. They eventually cured the problem by adding a movable rudder system, now found on all aircraft.

The root cause of the problem was dynamic. Warping the wing did what was expected in terms of lift, thereby rolling the plane, but also had an effect on drag. The result was that the upward-moving wing was dragged backwards, yawing the glider. If this yaw was violent enough, the additional speed on the lower wing as it was driven forward would make it generate more lift, and reverse the direction of the roll.

Supermarine Spitfire

Due to the unusually high speeds at which the Supermarine Spitfire could dive, this problem of aileron reversal became apparent when it was wished to increase the lateral maneuverability (rate of roll) by increasing the aileron area. The aircraft had a wing designed originally for an aileron reversal airspeed of 580 mph, and any attempt to increase the aileron area would have resulted in the wing twisting when the larger ailerons were applied at high speed, the aircraft then rolling in the opposite direction to that intended by the pilot. The problem of increasing the rate of roll was temporarily alleviated with the introduction of "clipped" wing tips (to reduce the aerodynamic load on the tip area, allowing larger ailerons to be used) until a new, stiffer wing could be incorporated. This new wing was introduced in the Mark XXI and had a theoretical aileron reversal speed of 825 mph (1,328 km/h).

Boeing B-47

The Boeing B-47 was speed limited at low altitudes because the large, flexible wings would cancel out the effect of the control surfaces under some circumstances.

Gossamer Condor

Control reversal also affected the Gossamer Condor, the Kremer Prize-winning human-powered airplane. When a wing-warping mechanism was tried as a solution to a long-running turning problem, the effect was to turn the airplane in the opposite direction to that expected by conventional airplane knowledge. When the Condor was rigged "conventionally", the inside wing slowed down so much that it settled to the ground. By employing "backwards" wired wing-warping, the inside wingtip angle of attack was increased so that the added drag slowed that wing while the added lift allowed the airfoil to stay aloft at a slower speed. The tilted canard could then complete the turn.

Controlled flight into terrain

A piece of the remains of Air New Zealand Flight 901, which crashed in 1979. All 257 people on the plane were killed.

Controlled flight into terrain (**CFIT**) describes an accident in which an airworthy aircraft, under pilot control, is unintentionally flown into the ground, a mountain, water, or an obstacle. The term was coined by engineers at Boeing in the late 1970s. The pilots are generally unaware of the danger until it is too late.

According to Boeing, CFIT "is a leading cause of airplane accidents involving the loss of life. There have been over 9,000 deaths due to this since the beginning of the commercial jet age."

Causes

While there are many reasons why a plane might crash into terrain, including bad weather and navigation equipment problems, it is claimed that pilot error is the single biggest factor leading to a CFIT incident."

Even highly experienced professionals may commit CFIT due to fatigue, loss of situational awareness, or disorientation. CFIT is considered a form of spatial disorientation, where the pilot(s) do not correctly perceive their position and orientation with respect to the plane of the Earth's surface.

The incidents often involve a collision with significantly raised terrain such as hills or mountains, and may occur in conditions of clouds or otherwise reduced visibility. CFIT often occurs during aircraft descent to landing, near an airport. CFIT may be associated with subtle equipment malfunctions. If the malfunction occurs in a piece of navigational equipment and it is not detected by the crew, it may mislead the crew into improperly guiding the aircraft despite other information received from all properly functioning equipment, or despite clear sky visibility that should have allowed the crew to easily notice ground proximity (compare tunnel vision).

Solutions

Traditionally adequate procedures and crew coordination and communication (CRM) as well as control or surveillance by air traffic services may reduce the likelihood of CFIT. In order to prevent the occurrence of CFIT accidents, manufacturers and safety regulators developed terrain awareness and warning systems (TAWS). The first generation of these TAWS systems is known as a ground proximity warning system (GPWS), which uses a radar altimeter to assist in calculating terrain closure rates. This system has now been further improved with the addition of a GPS terrain database and is known as an enhanced ground proximity warning system (EGPWS). This and the older system have mandatory pilot procedures and actions following any caution or warning event. Smaller aircraft often use a GPS database of terrain to provide terrain warning. The GPS database contains a database of nearby terrain and will present terrain that is near the aircraft in red or yellow depending on its distance from the aircraft.

Statistics show that aircraft fitted with a second-generation EGPWS have not suffered a CFIT accident if TAWS or EGPWS are properly handled (there are at least three CFIT accidents of planes with EGPWS/TAWS: Garuda Indonesia Flight 200, 2010 Polish Air Force Tu-154 crash, Mirosławiec air accident). As of 2007, 5% of the world's commercial airlines still lack a TAWS, leading to a prediction of two CFIT accidents in 2009.

Notable accidents

Many notable accidents have been ascribed to CFIT.

Flight	Date	Comments
TWA Flight 3	January 16, 1942	Hollywood movie star Carole Lombard was one of the victims.
Star Dust airliner	August 2, 1947	Due to a misjudgment of position, the flight crew appear to have believed that the aircraft was approaching the airport of Santiago, when in fact it was still above Tupungato mountain in the Andes. The plane vanished shortly after its last transmission estimating the time of its arrival at Santiago. Its wreckage was discovered fifty years later.
Superga air disaster	May 4, 1949	The entire Torino A.C. football team was killed in a collision with the hill of Superga, near Turin.
Pan Am Flight 151	June 21, 1951	
British Commonwealth Pacific Airlines Flight 304	October 29, 1953	American pianist William Kapell was one of the victims.
Trans-Canada Air Lines Flight 810	December 9, 1956	
Northeast Airlines Flight 823	February 1, 1957	
1958 Bristol Britannia 312 crash	December 24, 1958	
American Airlines Flight 320	February 3, 1959	
The Day the Music Died	February 3, 1959	Musicians Buddy Holly, Ritchie Valens, and J. P. "The Big Bopper" Richardson killed, along with the pilot.
TAA Fokker Friendship disaster	June 10, 1960	
Alitalia Flight 771	July 7, 1962	
United Airlines Flight 389	August 16, 1965	
American	November	

Airlines Flight 383	8, 1965	
Iberia Airlines Flight 062	November 4, 1967	British film and television actress June Thorburn was one of the victims.
TWA Flight 128	November 20, 1967	
South African Airways Flight 228	April 20, 1968	Incorrect flap retraction sequence after take-off.
Southern Airways Flight 932	November 14, 1970	Crashed near Huntington, West Virginia, killing all 75 on board, including 37 members of the Marshall University Thundering Herd football team. The crash was the subject of the 2006 feature film, *We Are Marshall*.
Uruguayan Air Force Flight 571	October 13, 1972	Known less formally as the Andes flight disaster, October 13, 1972 to December 23, 1972, during which stranded snow-bound survivors resorted to cannibalism.  Survivors amongst the wreckage of Uruguayan Air Force Flight 571 The incident became the subject of feature films and best-selling books.
Braathens SAFE Flight 239	December 23, 1972	
Eastern Air Lines Flight 401	December 29, 1972	The cockpit crew became fixated on a faulty landing gear light and had failed to realize that the autopilot had been switched off. The distracted crew did not recognize the plane's slow descent and the otherwise completely airworthy aircraft struck swampy ground in the Everglades, killing 101 out of 176 passengers and crew. This accident became the subject of books and made-for-television movies.
Delta Air Lines Flight 723	July 31, 1973	

TWA Flight 514	Dec 1, 1974	
Air New Zealand Flight 901	November 28, 1979	Crashed into Mount Erebus, Antarctica on November 28, 1979. There is still disagreement over the exact causes of the crash, but it is commonly accepted that a changing of preprogrammed coordinates, the pilots' loss of situational awareness and whiteout conditions at the time were contributory factors leading to the crash. All 257 people on the plane were killed.
Dan-Air Flight 1008	April 25, 1980	Crashed into high terrain in Tenerife after turning the wrong way in a holding pattern. All 146 people aboard were killed.
Mt. San Pietro disaster	December 1, 1981	Inex-Adria Aviopromet Flight 1308, flying from Ljubljana, Slovenia, to Ajaccio, Corsica, crashed into mountains shortly before it was scheduled to land. All 180 people on board were killed.
Avianca Flight 011	November 27, 1983	
Eastern Air Lines Flight 980	January 1, 1985	Struck Mount Illimani in Bolivia at an altitude of 19,600 feet. The flight took off from Silvio Pettirossi International Airport in Asunción, Paraguay, and intended to reach El Alto International Airport in La Paz, Bolivia. All 19 passengers and 10 crew were killed on impact.
1986		
Mozambican Tupolev Tu-134 crash	October 19, 1986	Mozambican president Samora Machel and 33 others were killed.
Avianca Flight 410	March 17, 1988	
Indian Airlines Flight 113	October 19, 1988	The aircraft hit an electric mast in Ahmedabad, India, five miles (eight km) out on approach in poor visibility. All six crew members and 124 of 129 passengers were killed.
Independent Air Flight 1851	February 8, 1989	
Surinam Airways Flight PY764	June 7, 1989	
Indian Airlines Flight 605	February 14, 1990	Crashed short of the runway during final approach to Bangalore, killing 92 on board.
Air Inter Flight 148	January 20, 1992	Crashed into Mt. Ste. Odile in the Vosges Mountains whilst on approach into Strasbourg Entzheim Airport.
Thai Airways International Flight 311	July 31, 1992	Crashed on approach to Kathmandu. All 111 people on board were killed, 59 days before the PIA Flight 268 accident at Kathmandu,

Pakistan International Airlines Flight 268	September 28, 1992	 Wreckage Of PIA Flight 268. Crashed on approach to Kathmandu. The approach to Kathmandu is difficult, as the airport is located in an oval-shaped valley surrounded by mountains. Flight 268 was approximately 900 feet below the designated approach path and crashed into a steep cloud-covered hillside. All 167 people on the plane were killed.
SAM Colombia Flight 505	May 19, 1993	Crashed near Mt. Panamo Frontino, killing the 132 oboard the Boeing 727
Asiana Airlines Flight 733	July 26, 1993	While approaching in bad weather, a Boeing 737-500 crashed into a mountain near Mokpo, South Korea. 68 of 106 on board were killed.
Ansett New Zealand Flight 703	June 5, 1995	
American Airlines Flight 1572	November 12, 1995	
American Airlines Flight 965	December 20, 1995	Crashed into a mountain near Cali, Colombia. The crew failed to recognize a series of navigational errors they had made, and forgot that they had deployed the air brakes. All eight crew members and 152 of the 156 passengers were killed.
1996 Croatia USAF CT-43 crash	April 3, 1996	A modified Boeing 737 crashed into a mountain in Croatia. One of the victims was United States Secretary of Commerce Ron Brown.
Vnukovo Flight 2801	August 29, 1996	
Korean Air Flight 801	August 6, 1997	
Garuda Indonesia Flight 152	September 26, 1997	An Airbus A300, registered PK-GAI, crashed in Pancur Batu, Pematang Siantar, North Sumatera. Became the

		worst air disaster in Indonesian aviation history.
1996 New Hampshire Learjet crash	December 24, 1996	Found November 13, 1999
Crossair Flight 3597	November 24, 2001	Flight from Berlin to Zurich that crashed during its landing approach, killing 24 people.
Air China Flight 129	April 15, 2002	
Kam Air Flight 904	February 3, 2005	
2006 Slovak Air Force Antonov An-24 crash	January 19, 2006	
Armavia Flight 967	May 3, 2006	
Steve Fossett	Sep 3, 2007	
Atlasjet Flight 4203	November 30, 2007	
Santa Bárbara Airlines Flight 518	February 21, 2008	
Polish Air Force Tu-154 Flight	April 10, 2010	President Lech Kaczynski on board
Airblue Flight 202	July 28, 2010	Crashed into the Margalla Hills near Islamabad, Pakistan

Chapter- 6

Flameout and Helmet fire

Flameout

A **flameout** refers to the failure of a jet engine caused by the extinction of the flame in the combustion chamber. It can be caused by a number of factors, including fuel exhaustion; compressor stall; insufficient oxygen supply; foreign object damage (such as birds, hail or even volcanic ash); severe inclement weather; and mechanical failure.

Description

Flameouts occur most frequently when the engine is at an intermediate or low power setting (such as during the cruise and descent phases of flight). Most of the time, they are recovered from uneventfully. To recover from a flameout, the pilot should ensure the engine's fuel supply has been restored and then simply perform an engine restart as detailed in the aircraft's Flight Operations Manual.

Early jet engines, such as Junkers Jumo 004 used in early German jets, including the Messerschmitt Me 262, were at relatively high risk of flameout. Fast acceleration or inappropriate throttle settings could impoverish the fuel/air mixture causing a flameout. If this happened at low altitude, it would often lead to the total loss of the aircraft. However, modern jets are engineered to a higher degree of technical quality and are controlled by systems (FADEC) that constantly fine-tune their performance; as such flameouts are not such a risk as they were in the early days of jet-powered aviation.

Windmill restart

A way to try and restart an engine that has experienced a flameout is by using a procedure called a windmill restart; this is a maneuver that uses the kinetic energy of the aircraft to attempt to restart the engine. The procedure is designed to force air into the

engine housing to spin the rotors and create enough pneumatic pressure for ignition. Typically in jet aircraft, to achieve the needed compression, airspeed of at least 300 knots is required, at which point the engine may be able to restart. However, due to the significant loss of altitude required for the procedure, it is generally deemed a last resort.

Notable incidents of flameout

- On 6th August 1945 the top USAAF fighter ace Richard Bong lost his life in a flight accident as his Lockheed P-80 Shooting Star fighter suffered a flame out and dived to ground.

- In June 1972, Jean Boulet piloted an Aérospatiale Lama helicopter to an absolute altitude record of 12,442 meters (40,814 ft) . At the extreme altitude the engine flamed out. The helicopter landed safely after the longest ever autorotation in history.

- In a huge hailstorm in 1977, Southern Airways 242, a DC-9, lost both engines due to the hail. The plane landed on a highway and crashed into a gas station, killing 72.

- In 1982, British Airways Flight 9 suffered flameouts in all four of its engines after flying through a cloud of pyroclastic material thrown up by the eruption of Mount Galunggung. The pilots were eventually able to restart three of the engines and make a safe landing.

- On 21 November 2002, during a routine test flight the Eurofighter DA6, a Spanish development prototype, crashed following an irrecoverable ‘double engine flame-out’ in flight; both crew members escaped unharmed.

- In 2004, Pinnacle Airlines Flight 3701 suffered flameouts in both of its engines. The aircraft crashed near Jefferson City, Missouri after being unable to restart the engines. The pilot and co-pilot were both killed.

- In September 2007, while engaged in separation tests of the GBU-39 Small Diameter Bomb, an F-22 Raptor suffered a brief dual-engine flameout while performing a negative-g, 360 degree roll with eight SDBs loaded in the weapons bay. The flameout occurred because the aircraft entered the maneuver with an incorrect trim setting. The engines were restarted almost immediately, allowing the pilot to remain in control of the aircraft and land at Edwards AFB, California, without further incident.

Helmet fire

"Helmet fire" is an expression for a mental state characterized by unnaturally high stress and task-saturation and loss of situational awareness. The term originates in the military pilot community: military pilots are trained in high-performance aircraft and wear helmets to protect their cranium and muffle out engine and wind noise. A fire aboard any aircraft is considered a serious emergency, and the term **helmet fire** is used jokingly to say that the pilot is undergoing so much stress that his brain is on fire or smoke is coming out of his ears.

Pilots most frequently get task-saturated when flying instrument approaches, especially in actual instrument meteorological conditions. A complex procedure must be flown while making radio calls, changing the speed and configuration of the airplane, and maintaining assigned altitudes, all while flying by reference to instruments. When the sum of these tasks exceeds the pilot's capability to deal with them effectively, he becomes task saturated and unable to perform any one of the tasks proficiently. The pilot may lose situational awareness, become confused, disoriented, may stammer on the radio, may forget how to fly the approach or what his last clearance was, and this can rapidly develop into an unsafe situation, in many cases leading to missed approach, airspace violation, mid-air collision, controlled flight into terrain or any of a number of disasters.

While seasoned pilots occasionally (though rarely) experience helmet fires, they are very commonly seen among student pilots, especially military student pilots who are learning to fly IFR for the first time. Fortunately, the experienced instructor in the aircraft with the student applies Crew Resource Management to keep unsafe situations from developing. However, the episode can frequently be embarrassing for the student.

Experienced pilots rarely experience task saturation due to the ability to perform more simultaneous tasks and also due to better task prioritization. When task saturation becomes imminent, lower priority tasks should be deferred to a time when saturation is less likely to occur. A well-known mantra in dealing with any unexpected situation in an airplane is to *aviate, navigate then communicate*, in other words; *fly the airplane first*. This is a reminder that, under all circumstances, maintaining control of the aircraft supersedes all other tasks. Such deferral is no substitute for raw ability to perform multiple tasks, but provides an important lifeline in unexpected circumstances.

Chapter- 7

Microburst

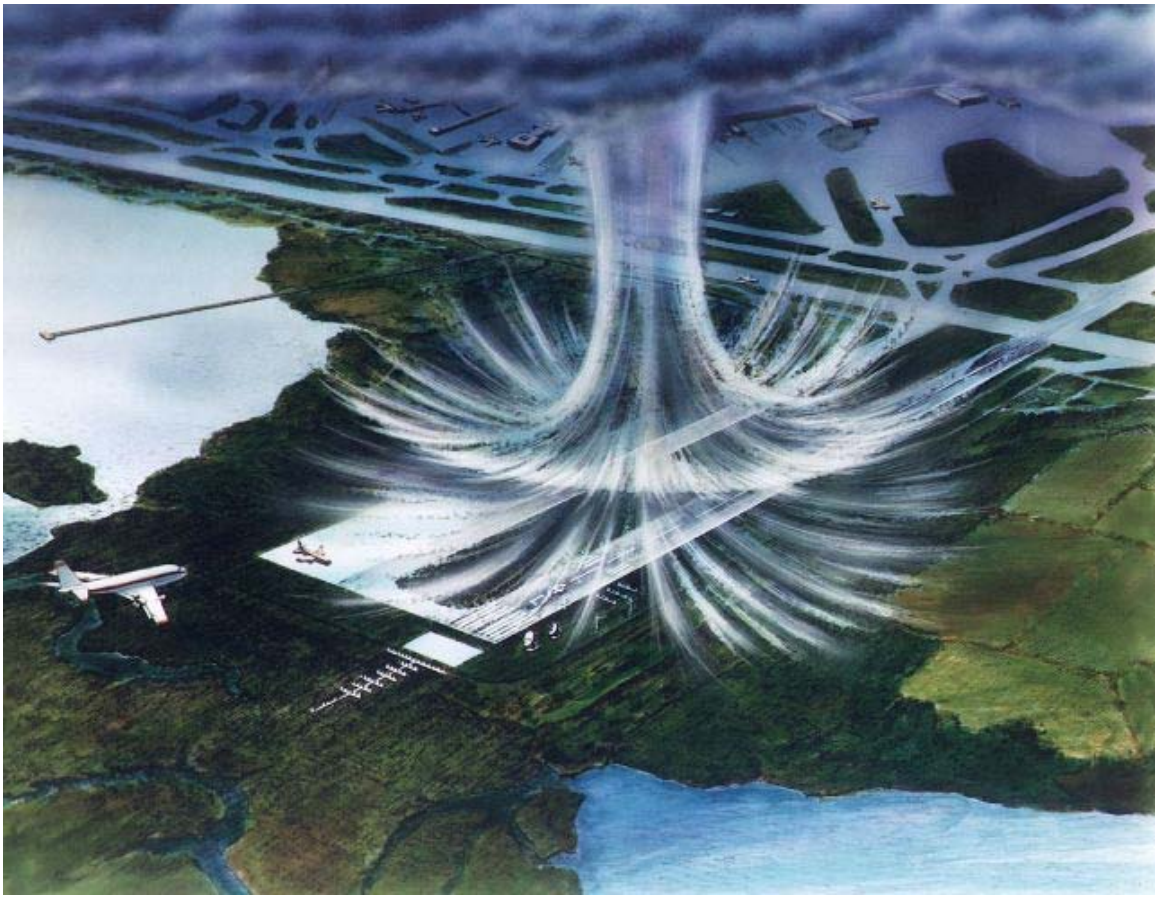


Illustration of a microburst. Note the downward motion of the air until it hits ground level. It then spreads outward in all directions. The wind regime in a microburst is opposite to that of a tornado.

Tree damage from a downburst

A **microburst** is a very localized column of sinking air, producing damaging divergent and straight-line winds at the surface that are similar to, but distinguishable from, tornadoes, which generally have convergent damage. There are two types of microbursts: wet microbursts and dry microbursts. They go through three stages in their life cycle: the downburst, outburst, and cushion stages. The scale and suddenness of a microburst makes it a great danger to aircraft due to the low-level wind shear caused by its gust front, with several fatal crashes having been attributed to the phenomenon over the past several decades.

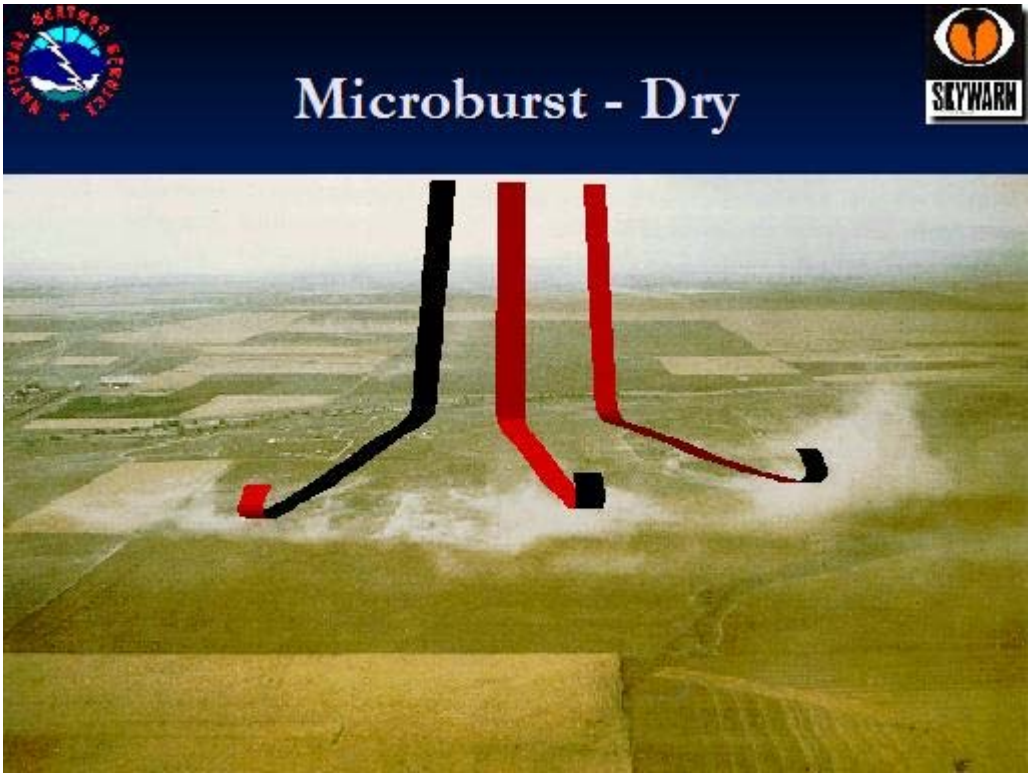
A microburst often has high winds that can knock over fully grown trees. They usually last for a couple of seconds.

History of term

The term was defined by senior weather expert Tetsuya Theodore Fujita as affecting an area 4 km (2.5 mi) in diameter or less, distinguishing them as a type of **downburst** and apart from common wind shear which can encompass greater areas. Fujita also coined the term **macroburst** for downbursts larger than 4 km (2.5 mi), a scale of size known as the mesoscale.

A distinction can be made between a **wet microburst** which consists of precipitation and a **dry microburst** which consists of virga. They generally are formed by precipitation-cooled air rushing to the surface, but they perhaps also could be powered from the high speed winds of the jet stream deflected to the surface in a thunderstorm.

Microbursts are recognized as capable of generating wind speeds higher than 75 m/s (168 mph; 270 km/h).

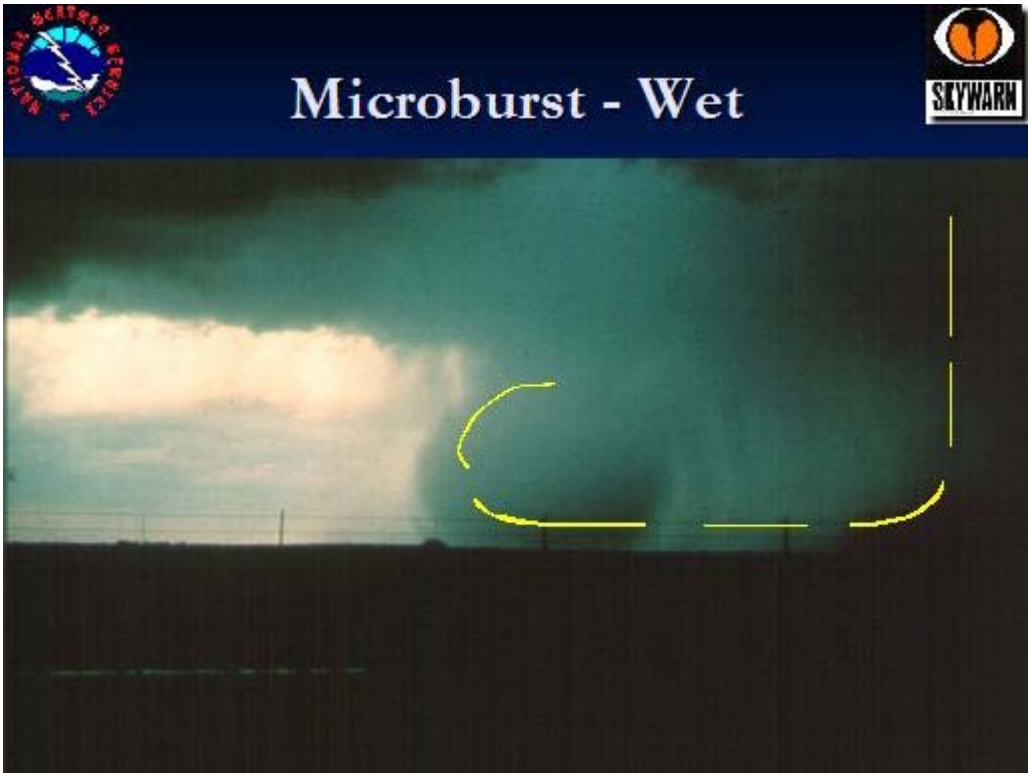


Dry microburst schematic from NWS

Dry microbursts

When rain falls below cloud base or is mixed with dry air, it begins to evaporate and this evaporation process cools the air. The cool air descends and accelerates as it approaches the ground. When the cool air approaches the ground, it spreads out in all directions and this divergence of the wind is the signature of the microburst. High winds spread out in this type of pattern showing little or no curvature are known as straight-line winds.

Dry **microbursts**, produced by high based thunderstorms that generate little surface rainfall, occur in environments characterized by a thermodynamic profile exhibiting an inverted-V at thermal and moisture profile, as viewed on a Skew-T log-P thermodynamic diagram. Wakimoto (1985) developed a conceptual model (over the High Plains of the United States) of a dry microburst environment that comprised three important variables: mid-level moisture, a deep and dry adiabatic lapse rate in the sub-cloud layer, and low surface relative humidity.



Wet microburst schematic from NWS

Wet microbursts

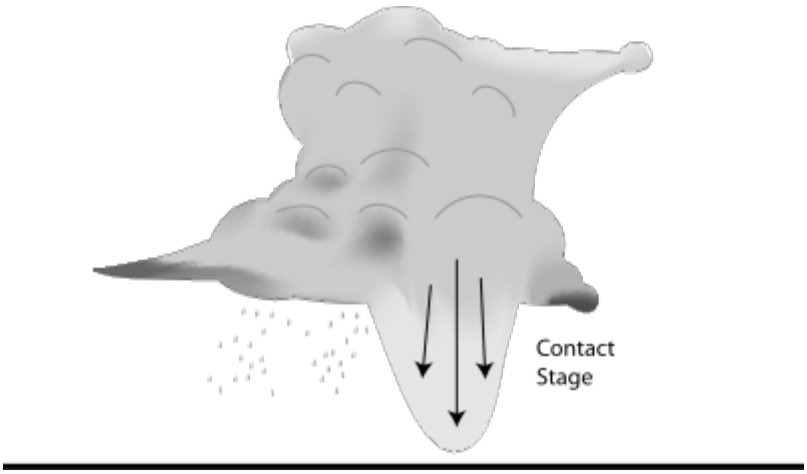
Wet microbursts are downbursts accompanied by significant precipitation at the surface which are warmer than their environment (Wakimoto, 1998). These downbursts rely more on the drag of precipitation for downward acceleration of parcels than negative buoyancy which tend to drive "dry" microbursts. As a result, higher mixing ratios are necessary for these downbursts to form (hence the name "wet" microbursts). Melting of ice, particularly hail, appears to play an important role in downburst formation (Wakimoto and Bringi, 1988), especially in the lowest one kilometer above ground level (Proctor, 1989). These factors, among others, make forecasting wet microbursts a difficult task.

Characteristic	Dry Microburst	Wet Microburst
Location of Highest Probability within the United States	Midwest/West	Southeast
Precipitation	Little or none	Moderate or heavy
Cloud Bases	As high as 500 mb	Usually below 850 mb
Features below Cloud Base	Virga	Shafts of strong precipitation reaching the ground
Primary Catalyst	Evaporative cooling	Downward transport of higher

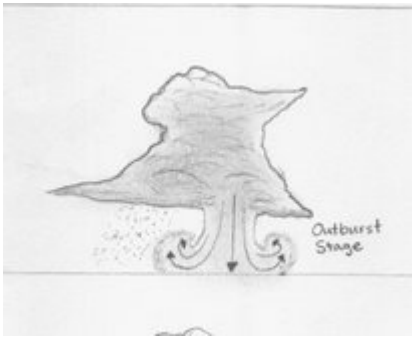
		momentum
Environment below Cloud Base	Deep dry layer/low relative humidity/dry adiabatic lapse rate	Shallow dry layer/high relative humidity/moist adiabatic lapse rate
Surface Outflow Pattern	Omni-directional	Gusts of the direction of the mid-level wind

Development stages of microbursts

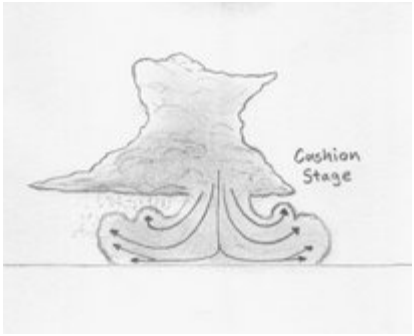
The evolution of downbursts is broken down into three stages: the contact stage, the outburst stage and the cushion stage.



A downburst initially develops as the downdraft begins its descent from cloud base. The downdraft accelerates and within minutes, reaches the ground (contact stage). It is during the contact stage that the highest winds are observed.

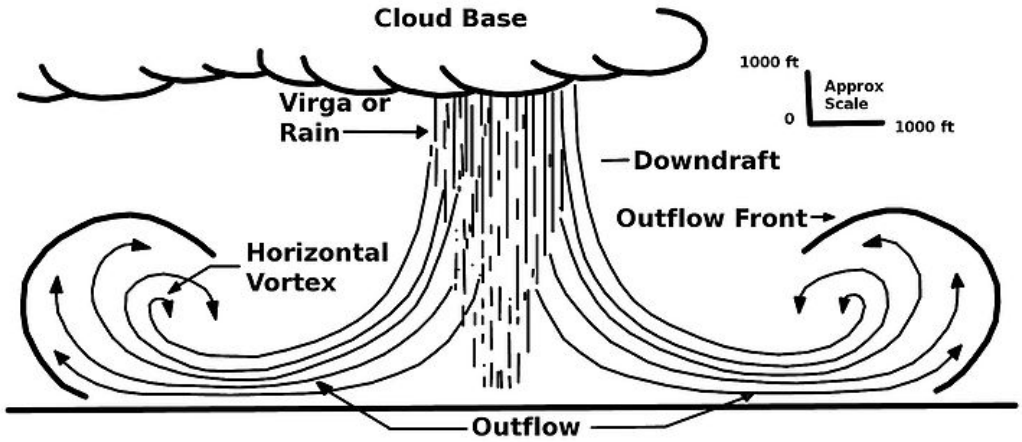


During the outburst stage, the wind "curls" as the cold air of the downburst moves away from the point of impact with the ground.



During the cushion stage, winds about the curl continue to accelerate, while the winds at the surface slow due to friction.

Physical processes of dry and wet microbursts



Simple explanation

In the case of a wet microburst, the atmosphere is warm and humid in the lower levels and dry aloft. As a result, when thunderstorms develop, heavy rain is produced but some of the rain evaporates in the drier air aloft. As a result the air aloft is cooled thereby causing it to sink and spread out rapidly as it hits the ground. The result can be both strong damaging winds and heavy rainfall occurring in the same area. Wet downbursts can be identified visually by such features as a shelf cloud, while on radar they sometimes produce bow echoes. In the case of a dry microburst, the atmosphere is warm but dry in the lower levels and moist aloft. Thus when showers and thunderstorms develop, most of the rain evaporates before reaching the ground.

Basic physical processes using simplified buoyancy equations

Start by using the vertical momentum equation

$$\frac{dw}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

By decomposing the variables into a basic state and a perturbation, defining the basic states, and using the Ideal Gas Law ($p = \rho R T_v$), then the equation can be written in the form

$$B \equiv -\frac{\rho'}{\bar{\rho}} g = g\frac{T_v' - \bar{T}_v}{\bar{T}_v}$$

where B is used to denote buoyancy. Note that the virtual temperature correction usually is rather small and to a good approximation, it can be ignored when computing buoyancy. Finally, the effects of precipitation loading on the vertical motion are parameterized by including a term that decreases buoyancy as the liquid water mixing ratio (ℓ) increases, leading to the final form of the parcel's momentum equation:

$$\frac{dw'}{dt} = \frac{1}{\bar{\rho}}\frac{\partial p'}{\partial z} + B - g\ell$$

The first term is the effect of perturbation pressure gradients on vertical motion. In some storms this term has a large effect on updrafts (Rotunno and Klemp, 1982) but there is not much reason to believe it has much of an impact on downdrafts (at least to a first approximation) and therefore will be ignored.

The second term is the effect of buoyancy on vertical motion. Cleary, in the case of microbursts, one expects to find that B is negative meaning the parcel is cooler than its environment. This cooling typically takes place as a result of phase changes (evaporation, melting, and sublimation). Precipitation particles that are small, but are in great quantity, promote a maximum contribution to cooling and, hence, to creation of negative buoyancy. The major contribution to this process is from evaporation.

The last term is the effect of water loading. Whereas evaporation is promoted by large numbers of small droplets, it only takes a few large drops to contribute substantially to the downward acceleration of air parcels. This term is associated with storms having high precipitation rates. Comparing the effects of water loading to those associated with buoyance, if a parcel has a liguid water mixing ration of 1.0 gkg^{-1}, this is roughly equivalent to about 0.3 K of negative buoyancy; the latter is a large (but not extreme) value. Therefore, in general terms, negative buoyancy is typically the major contributor to downdrafts.

Negative vertical motion associated only with buoyancy

Using pure "parcel theory" results in a prediction of the maximum downdraft of

$$-w_{\max} = \sqrt{2 \times \mathrm{NAPE}}$$

where NAPE is the Negative Available Potential Energy,

$$\mathrm{NAPE} = -\int_{\mathrm{SFC}}^{\mathrm{LFS}} B\, dz$$

and where LFS denotes the Level of Free Sink for a descending parcel and SFC denotes the surface. This means that the maximum downward motion is associated with the integrated negative buoyancy. Even a relatively modest negative buoyancy can result in a substantial downdraft if it is maintained over a relatively large depth. A downward speed of 25 m/s results from the relatively modest NAPE value of 312.5 m^2s^{-2}. To a first approximation, the maximum gust is roughly equal to the maximum downdraft speed.

A photograph of the surface curl soon after a microburst impacted the surface

Danger to aircraft

The scale and suddenness of a microburst makes it a great danger to aircraft, particularly those at low altitude which are taking off and landing. The following are some fatal crashes and/or aircraft incidents that have been attributed to microbursts in the vicinity of airports:

- A MALÉV Ilyushin Il-18 (HA-MOC), Copenhagen Airport – 28 August 1971.
- Eastern Air Lines Flight 66, John F. Kennedy International Airport – June 24, 1975
- Pan Am Flight 759, New Orleans International Airport – July 9, 1982
- Delta Air Lines Flight 191, Dallas-Fort Worth International Airport – August 2, 1985
- Martinair Flight 495, Faro Airport – December 21, 1992
- USAir Flight 1016, Charlotte/Douglas International Airport – July 2, 1994
- Goodyear Blimp (Stars and Stripes), Coral Springs, Florida – June 16, 2005

A microburst often causes aircraft to crash when they are attempting to land (the above mentioned Pan Am flight is a notable exception). The microburst is an extremely powerful gust of air that, once hitting the ground, spreads in all directions. As the aircraft is coming in to land, the pilots try to slow the plane to an appropriate speed. When the microburst hits, the pilots will see a large spike in their airspeed, caused by the force of the headwind created by the microburst. A pilot inexperienced with microbursts would try to decrease the speed. The plane would then travel through the microburst, and fly into the tailwind, causing a sudden decrease in the amount of air flowing across the wings. The decrease in airflow over the wings of the aircraft causes a drop in the amount of lift produced. This decrease in lift combined with a strong downward flow of air can cause the thrust required to remain at altitude to exceed what is available.

Danger to buildings

- On September 22, 2010 in the Hegewisch neighborhood of Chicago, a wet microburst hit, causing severe localized damage and localized power outages, including fallen-tree impacts into at least four homes. No fatalities were reported.

- On September 16, 2010, just after 5:30 pm, a wet macroburst [a more extensive downburst than a microburst] with winds of 125mph hit parts of Central Queens in New York City, causing extensive damage to trees, buildings and vehicles in an area 8 miles long and 5 miles wide. Approximately 3,000 trees were knocked down by some reports. There was one fatality when a tree fell onto a car on the Grand Central Parkway.

- On June 24, 2010, shortly after 4:30 PM, a Wet Microburst hit the city of Charlottesville, Virginia. Field reports and damage assessments show that Charlottesville experienced numerous down bursts during the storm, with wind estimates at over 75 miles per hour. In a matter of minutes, trees and downed

power lines littered the roadways. A number of houses were hit by trees. Immediately after the storm, up to 60,000 Dominion Power customers in Charlottesville and surrounding Albemarle County were without power.

- On June 11, 2010, around 3 am, a wet microburst hit a neighborhood in southwestern Sioux Falls, SD. It caused major damage to four homes, all of which were occupied. No injuries were reported. Roofs were blown off of garages and walls were flattened by the estimated 100 mph winds. Cost of repairs could be $500,000 or more.

- On May 2, 2009, the lightweight steel and mesh building in Irving, Texas used for practice by the Dallas Cowboys football team was flattened by a microburst, according to the National Weather Service.

- On March 12, 2006, a microburst hit Lawrence, Kansas. 60 percent of the University of Kansas campus buildings sustained some form of damage from the storm. Preliminary estimates put the cost of repairs at between $6 million and $7 million.

Strong microburst winds flip a several-ton shipping container up the side of a hill, Vaughan Ontario, Canada

Chapter- 8

Mid-Air Collision

Computer-generated image of United Airlines Flight 718 and TWA Flight 2 colliding.

A **mid-air collision** is an aviation accident in which two or more aircraft come into contact during flight. Owing to the relatively high velocities involved and any subsequent impact on the ground or sea, very severe damage or the total destruction of at least one of the aircraft involved usually results. The chance of surviving a major mid-air collision is virtually nil in the absence of ejector seats and parachutes, as indicated below, although occasionally this rule may be violated (as on 1965 Carmel mid-air collision).

The potential for a mid-air collision is increased by miscommunication, error in navigation, and deviations from flight plans. Albeit a rare occurrence due to the vastness of open space available, collisions can and have happened near or at airports, due to the large volume of aircraft and closer spacing compared to general flight.

First recorded mid air collision

Contemporary artist's impression of the first mid air collision, 1910

The first recorded collision between air-planes occurred at the 'Milano Circuito Aereo Internazionale' meeting held between 24 September and 3 October 1910 in the city of Milan, Italy. On 3 October Rene Thomas of France in an Antionette monoplane collided with Captain Bertram Dickson of the British army in a Farman biplane by ramming him in the rear. Both pilots survived but Dickson was so badly injured he never flew again.

Recent efforts to prevent military collisions in the United States

There are many types and causes of mid-air collisions. On some occasions, military aircraft conducting training flights inadvertently collide with civilian aircraft. Before 1958, civilian air traffic controllers guiding civilian flights and military controllers guiding military aircraft were both unaware of the other's aircraft.

The 1958 collision between United Airlines Flight 736 and a fighter jet, as well as another U.S. military/civilian crash one month later involving Capital Airlines Flight 300, hastened the signing of the Federal Aviation Act of 1958 into law. The act created the Federal Aviation Agency (later renamed the Federal Aviation Administration), and provided unified control of airspace for both civil and military flights.

In 2005, as part of an effort to reduce such military/civilian mid-air collisions in U.S. airspace, the Air National Guard Flight Safety Division, led by Lt Col Edward Vaughan, used the Disruptive Solutions Process to create the See and Avoid web portal. In late 2006, the U.S. Defense Safety Oversight Council (DSOC) recognized and funded the site as its official civil/military midair collision prevention website, with participation by all the services.

In 2008, this site is expected to expand to include international airspace where U.S. military aircraft operate.

List of notable civilian mid-air collisions

Date		Fatalities	Survivors	Flights involved	Phase of flight	Site
1922	Apr 7	7	0	First mid-air collision of airliners	Cruise	Picardie, France,
1938	Aug 24	45		Two Japanese aircraft	?	Ōmori, Tokyo, Japan
1942	Oct 23	12	2	American Airlines Flight 28 / US Army B-34 flight	Ascent/descent	Chino Canyon, California, U.S.
1945	Jul 12	2	24	Eastern Airlines Flight 45 / U.S. Army Air Force A-26 Invader	Descent	Florence, South Carolina, U.S.
1948	April 5	15	0	British European Airways Vickers VC.1 Viking / Soviet Air Force Flight	Approach	RAF Gatow, Berlin, Germany.
1948	Jul 4	39	0	Scandinavian	Descent	Northwood, London

				Airlines System DC-6 / RAF Avro York Flight		UK.
1949	Nov 1	55	1	Eastern Air Lines 537 / Lockheed P-38 test flight	Approach	Washington, D.C., U.S.
1951	Apr 25	43	0	Cubana de Aviación 493 / US Navy flight	Cruise/climb	Key West, Florida, U.S.
1952	Jun 28	2	60	American Airlines Flight 910 / private Temco Swift	Approach	Dallas, Texas, USA
1954	Apr 8	37	0	Trans Canada Air Lines Canadair North Star / Royal Canadian Air Force flight	Climb	Moose Jaw, Canada.
1955	Jan 12	15	0	TWA flight / Private flight	Climb	Boone County, Kentucky, U.S.
1956	Jun 30	128	0	UA Flight 718 / TWA Flight 2	Cruise	Grand Canyon, Arizona, U.S.
1958	Apr 21	49	0	United Airlines Flight 736 / USAF F-100 Super Sabre	Cruise	Las Vegas, Nevada, U.S.
1958	May 20	13	1	Capital Airlines Flight 300 / Air National Guard flight	Descent	Brunswick, Maryland, U.S.
1958	May 20	31	1	British European	Descent	Near Anzio, Italy

				Airways Flight 142 / Italian Air Force F-86 Sabre flight		
1960	Dec 16	134	0	UA Flight 826 / TWA Flight 266	Descent	New York City, New York, U.S.
1963	Feb 1	87		Middle East Airlines Flight 265 / Turkish Air Force flight	Descent	Ankara, Turkey
1965	Dec 4	4	158	TWA Flight 42 / Eastern Airlines Flight 853	Descent	Carmel, New York, U.S.
1967	Mar 9	26	0	TWA Flight 553 / Private flight	Descent	Urbana, Ohio, U.S.
1967	Jul 19	82	0	Piedmont Airlines Flight 22 / Lanseair Inc. flight	Climb/descent	Hendersonville, North Carolina, U.S.
1969	Jun 23	120	0	Aeroflot Flight 831 / Soviet Air Force An-12	Cruise	Kaluga Oblast, Russia
1969	Sep 9	82	0	Allegheny Airlines Flight 853 / Private flight	Descent	Fairland, Indiana, U.S.
1971	Jul 30	162	1	ANA Flight 58 / JASDF flight	Cruise	near Shizukuishi, Japan
1972	Jun 29	13	0	Air Wisconsin Flight 671 / North Central	Descent	Appleton, Wisconsin, U.S

				Airlines Flight 290		
1973	Mar 5	68	107	Spantax Flight 400 / Iberia Flight 504	Cruise	Nantes, France
1975	Jan 9	14	0	Golden West Airlines Flight 261 / Private flight	Climb	near Whittier, California, USA
1976	Jun 6	50	1	Hughes Airwest Flight 706 / US Marines flight	Climb	San Gabriel Mountains, California
1976	Sep 9	64	0	Aeroflot Flight 31 / Aeroflot Flight 7957	Cruise	near Anapa, Ruissa
1976	Sep 10	176	0	BA Flight 476 / Inex-Adria Flight 550	Cruise	near Zagreb, Croatia
1978	Sep 25	144	0	PSA Flight 182 / Private flight	Descent	San Diego, California, U.S.
1979	Aug 11	178	0	Aeroflot 65816 / Aeroflot 65735	Cruise	Dniprodzerzhynsk, Ukraine
1981	Apr 11	14	0	Air US Flight 716 / Private flight	Climb	Near Fort Collins-Loveland Municipal Airport, U.S
1981	Jun 18	25	0	Grand Canyon Airlines Flight 6 / Private helicopter flight	Low level	Grand Canyon, U.S
1981	Aug 24	37	1	Aeroflot Flight 811 / military aircraft	Cruise	Zavitinsk, Russia
1984	Aug 24	17	0	Wing West	Descent/climb	San Luis Obispo,

				Airlines Flight 628 / Private flight		California, U.S.
1985	Oct 1	5	0	Private Cessna 441 / private Cessna 152	Descent	Dallas, Texas, USA
1986	Aug 31	82	0	Aeroméxico Flight 498 / Private flight	Descent/climb	Cerritos, California, U.S.
1992	Dec 22	159	0	Libyan Arab Airlines Flight 1103 / Libyan Air Force MiG-23 Flight	Approach	Tripoli, Libya
1993	Feb 8	133	0	Iran Air Tours Tupolev 154 flight / Iranian Air Force Sukhoi Su-17 flight	Climb/descent	Tehran, Iran
1993	Nov 26	4	0	NZ Police Eagle / NZ Police traffic patrol	Low level	Auckland, New Zealand
1996	Nov 12	349	0	Saudi Airlines Flight 763 / Kazakhstan Airlines Flight 1907	Climb/descent	Charkhi Dadri, India
1998	Jul 30	15	0	Proteus Air Flight 706 / Private flight	Low level	Quiberon Bay, France
2002	Jul 1	71	0	Bashkirian Airlines Flight 2937 / DHL Flight 611	Cruise	Überlingen, Germany

2005	Jan 18	1	2	Private Air Tractor AT-502B / US Air Force T-37 flight	Cruise	near Hollister, Oklahoma, USA
2006	Sep 29	154	7	Gol Transportes Aéreos Flight 1907 / ExcelAire flight	Cruise	Amazon Rainforest, Brazil
2007	Jul 27	4	0	KNXV-TV news helicopter / KTVK news helicopter	Low level	Phoenix, Arizona
2009	Feb 10	0	0	Kosmos-2251 / Iridium 33	Orbit	Outer space
2009	Aug 8	9	0	Piper PA-32 / Eurocopter AS350 Tour Helicopter	Low level	Hudson River, New York.
2010	Feb 6	3	3	Piper Pawnee / Cirrus SR20	Low level	Boulder, Colorado

List of notable military mid-air collisions

XB-70 *62-0207* following the mid-air collision on 8 June 1966.

Date		Fatalities	Survivors	Aircraft involved	Site
1940	Sep 29	0	4	Two RAAF Avro Ansons	Brocklesby, New South Wales, Australia
1952	Apr 4	15	0	USAF C-47 Skytrain / USAF C-124 Globemaster II	Mobile, Alabama, USA
1953	May 15	3	4	Two USAF C-119 Flying Boxcars / USAF F-84 Thunderjet	near Weinheim, Germany
1953	Jan 15	26	0	RAF Vickers Valetta / RAF Avro Lancaster	Mediterranean Sea near Sicily
1955	Aug 11	66	0	Two USAF C-119 Flying Boxcars	near Stuttgart, Germany
1958	Feb 5	0	4	USAF B-47 Stratojet / USAF	Tybee Island,

				F-86 Sabre	Georgia
1958	Mar 27	18	0	USAF C-119 Flying Boxcar / USAF C-124 Globemaster II	Bridgeport, Texas, USA
1966	Jan 17	7	4	USAF B-52G Stratofortress / USAF KC-135 Stratotanker	Mediterranean Sea near Palomares, Almería
1966	Jun 8	2	1	XB-70 Valkyrie prototype / F-104 Starfighter	near Barstow, California, USA
1983	May 1	0	3	McDonnell Douglas F-15 Eagle / A-4 Skyhawk of the Israeli Air Force	Negev, Israel
1985	Jul 5	1		Two A-4F Skyhawk aircraft of the Blue Angels	Niagara Falls, USA
1988	Aug 28	75		Three Aermacchi MB-339PAN aircraft of the Frecce Tricolori	Ramstein Air Base, Germany
1989	Sep 3	1	1	Two Canadair CT-114 Tutor Snowbirds during the Canadian International Air Show	Toronto, Ontario, Canada
1994	Mar 23	24	7	F-16 Fighting Falcon / C-130 Hercules	Pope Air Force Base, North Carolina, USA
1996	June 12	18	10	Two UH-60 Black Hawk Helicopters of the Australian SAS	Townsville, Australia
1997	Feb 4	73	0	1997 Israeli helicopter disaster, 2 IAF Sikorsky CH-53	She'ar Yashuv, Israel
1997	Sep 13	33		Luftwaffe Tu-154 / USAF C-141	Namibia, Africa
2002	Nov 6	1		Two MiG-29 aircraft of the Slovak Air Force	near Spišská Nová Ves, Slovakia
2009	Feb 11	4		Two Grob Tutors of the	Porthcawl, Wales

			R.A.F.	
2009	Oct 30	9	USCG C-130 / USMC Cobra Helicopter of the U.S. Military	Coast of So. Cal, U.S.A

Chapter- 9

Pilot Error

Pilot error (sometimes called **cockpit error**) is a term used to describe the cause of an accident involving an airworthy aircraft where the pilot is considered to be principally or partially responsible. Pilot error can be defined as a mistake, oversight, lapse in judgement, or failure to exercise due diligence by an aircraft operator during the performance of his/her duties.

Usually in an accident deemed due to "pilot error", the pilot in command (Captain) made the error unintentionally. However, an intentional disregard for a standard operating procedure (or warning) is still considered pilot error, even if the pilot's actions justified criminal charges.

An aircraft operator (airline or aircraft owner) is generally not held accountable for an incident that is principally due to a mechanical failure of the aircraft unless the mechanical failure occurred as a result of pilot error.

The pilot may be declared to be in error even during adverse weather conditions if the investigating body deems that the pilot did not exercise due diligence. The responsibility for the accident in such a case would depend upon whether the pilot could reasonably know of the danger and whether he or she took reasonable steps to avoid the weather problem. Flying into a hurricane (for other than legitimate research purposes) would be considered pilot error; flying into a microburst would not be considered pilot error if it was not detectable by the pilot, or in the time before this hazard was understood. Some weather phenomena (such as clear-air turbulence or mountain waves) are difficult to avoid, especially if the aircraft involved is the first aircraft to encounter the phenomenon in a certain area at a certain time.

One of the most famous incidents of an aircraft disaster attributed to pilot error was the crash of Eastern Air Lines Flight 401 near Miami, Florida on December 29, 1972. The pilot, co-pilot, and Flight Engineer had become fixated on a faulty landing gear light and had failed to realize that the autopilot buttons had been bumped by one of the crew altering the settings from level flight to a slow descent. The distracted flight crew did not

notice the plane losing height and the aircraft eventually struck the ground in the Everglades, killing 101 out of 176 passengers and crew.

The subsequent National Transportation Safety Board (NTSB) report on the incident blamed the flight crew for failing to monitor the aircraft's instruments properly. Details of the incident are now frequently used as a case study in training exercises by aircrews and air traffic controllers.

Placing pilot error as a cause of an aviation accident is often controversial. For example, the NTSB ruled that the crash of American Airlines Flight 587 was due to the failure of the rudder which was caused by "unnecessary and excessive rudder pedal inputs" on the part of the co-pilot who was operating the aircraft at the time. Attorneys for the co-pilot, who was killed in the crash, argue that American Airlines' pilots had never been properly trained concerning extreme rudder inputs. The attorneys also claimed that the rudder failure was actually caused by a flaw in the design of the Airbus A300 aircraft and that the co-pilot's rudder inputs should not have caused the catastrophic rudder failure that led to the accident that killed 265 people.

During 2004 in the United States, pilot error was listed as the primary cause of 78.6% of fatal general aviation accidents, and as the primary cause of 75.5% of general aviation accidents overall. For scheduled air transport, pilot error typically accounts for just over half of worldwide accidents with a known cause.

Notable examples

- 28 July 1945 - a United States Army Air Forces B-25 bomber bound for Newark Airport crashed into the 79th floor of the Empire State Building after the pilot became lost in a heavy fog bank situated over Manhattan. All three crewmen were killed as well as eleven office workers in the building.

- 2 August 1947 - *Star Dust*, a British South American Airways Avro Lancastrian, crashed in the Tupungato glacier field high in the Andes about 60 miles (100 km) from its destination of Santiago, Chile; killing all eleven occupants. The aircraft was instantly buried from the resulting avalanche and heavy snowfall; it then became encased in glacier ice. The wreckage was not discovered until 2000. Details of the crash are somewhat unclear, but modern investigators believe a navigation error on the part of the flight crew was the principal cause of the accident.

- 24 December 1958 - BOAC Bristol Britannia 312, registration G-AOVD, crashed as a result of a controlled flight into terrain, (CFIT), near Winkton, England while on a test flight. The crash was caused by a combination of bad weather and a failure on the part of both pilots to read the altimeter correctly. The First Officer and 2 other people survived.

- 28 February 1966 - American astronauts Elliott See and Charles Bassett were killed when their T-38 Talon crashed into a building at Lambert-St. Louis International Airport during bad weather.

- 27 March 1977 - the Tenerife disaster; a senior KLM pilot failed to hear, understand or follow tower instructions, causing two Boeing 747s to collide on the runway at Tenerife; 583 people were killed in the worst-ever air disaster.

- 28 December 1978 - United Airlines Flight 173; a flight simulator instructor Captain allowed his Douglas DC-8 to run out of fuel while investigating a landing gear problem. United Airlines subsequently changed their policy to disallow "simulator instructor time" in calculating a pilot's "total flight time". It was thought that a contributory factor to the accident is that an instructor can control the amount of fuel in simulator training so that it never runs out.

- 13 January 1982 - Air Florida Flight 90, a Boeing 737-200 with 79 passengers and crew, crashed into the 14th Street Bridge and careened into the Potomac River shortly after taking off from Washington National Airport. Seventy-five passengers and crew, and four motorists on the bridge were killed. The NTSB report blamed the flight crew for not properly employing the plane's de-icing system.

- 19 February 1985 - above the Pacific Ocean the crew of China Airlines Flight 006 lost control of their Boeing 747SP after the No. 4 engine flamed out. The aircraft fell 10,000 feet in twenty seconds and lost a total of 30,000 feet in two-and-a-half minutes before control was regained. There were no fatalities but the aircraft was badly damaged.

- 28 August 1988 - the Ramstein airshow disaster; a member of an Italian aerobatic team misjudged a manoeuvre, causing a mid-air collision. Three pilots and 67 spectators on the ground were killed.

- 31 August 1988 - Delta Air Lines Flight 1141 crashed on takeoff after the crew forgot to deploy the flaps for increased lift. Of the 108 crew and passengers on board, fourteen were killed.

- 8 January 1989 - in the Kegworth air disaster, a fan blade broke off in the left engine of a new Boeing 737-400, but the pilots mistakenly shut down the right engine. The left engine eventually failed completely and the crew could not restart the right engine before the aircraft crashed. Instrumentation on the 737-400 was different from earlier models, but no flight simulator for the new model was available in Britain.

- 3 September 1989 - The crew of Varig Flight 254 made a series of mistakes so that their Boeing 737 ran out of fuel hundreds of miles off-course above the Amazon jungle. Thirteen died in the ensuing crash-landing.

- 21 October 1989 - Tan-Sahsa Flight 414 crashed into a hill near Toncontin International Airport in Tegucigalpa, Honduras, because of a bad landing procedure by the pilot. 127 people died in the accident.

- 23 March 1994 - Aeroflot Flight 593 crashed on its way to Hong Kong. The captain, Yaroslav Kudrinsky, invited his two children into the cockpit, and permitted them to sit at the controls, against airline regulations. His fifteen-year-old son, Eldar Kudrinsky, accidentally disconnected the autopilot, causing the plane to bank to the right before diving. The co-pilot brought up the plane too far, causing it to stall and start a flat spin. The pilots recovered the plane but it crashed into a forest, killing all 75 people on board.

- 12 October 1997 - singer John Denver was killed when his newly-bought Rutan Long-EZ home-built aircraft crashed into the Pacific Ocean off Pacific Grove, California. The NTSB indicated that Denver lost control of the aircraft while attempting to manipulate the fuel selector handle, which had been placed in a hard-to-reach position by the aircraft's builder. The NTSB cited his unfamiliarity with the aircraft's design as a cause of the crash.

- 16 July 1999 - John F. Kennedy, Jr., the son of U.S. President John F. Kennedy, was killed along with his wife and sister-in-law when the Piper Saratoga light aircraft he was piloting crashed into the Atlantic Ocean off the coast of Martha's Vineyard, Massachusetts. The NTSB released an official statement that the crash was caused by "the pilot's failure to maintain control of the airplane during a descent over water at night, which was a result of spatial disorientation". Kennedy did not hold a certification for IFR flight, but did continue to fly after weather conditions obscured visual landmarks.

- 31 August 1999 - 65 people died after Lineas Aéreas Privadas Argentinas (LAPA) flight 3142 crashed after an attempted take-off with the flaps retracted.

- 12 July 2000 - Hapag-Lloyd Flight 3378 crash-landed a few hundred metres short of the runway at Vienna International Airport after the aircraft ran out of fuel. There was no loss of life.

- 12 November 2001 - American Airlines Flight 587 encountered heavy turbulence and the co-pilot over applied the rudder pedal, turning the Airbus A300 side to side. Due to the excessive stress, the rudder failed. The A300 spun and hit a residential area, crushing 5 houses and killing 265. Contributing factors included wake turbulence and pilot training.

- 15 April 2002 - Air China Flight 129, a Boeing 767-200, crashed near Pusan, South Korea killing 128 of the 166 people aboard. The co-pilot had been flying too low.

- 25 October 2002 - eight people, including US Senator Paul Wellstone, were killed in a crash near Eveleth, Minnesota. The NTSB concluded that "the flight crew did not monitor and maintain minimum speed."

- 26 February 2004 - a Beech 200 carrying Macedonian President Boris Trajkovski crashed, killing Trajkovski and eight other passengers. The crash investigation ruled that the accident was caused by "procedural mistakes by the crew" during the landing approach.

- 3 January 2004. Flash Airlines Flight 604 dived into the Red Sea shortly after take off. All 148 people were killed. The captain had encountered vertigo, his control column was slanted to the right, and the captain did not notice. The 737 banked until it was unable to stay in the air. It is Egypt's worst air disaster.

- 14 August 2005 - the pilots of Helios Airways Flight 522 lost consciousness, most likely due to hypoxia caused by failure to switch the cabin pressurization to "Auto" during the pre-flight preparations. The Boeing 737-300 crashed, killing all on board.

- 3 May 2006 - Armavia Flight 967 performed a CFIT, killing all on board, after the pilot lost spatial awareness during a simultaneous turn and climb.

- August 27, 2006 - Comair Flight 191 operating a Bombardier CRJ-100ER aircraft, crashed while taking off from Lexington's Blue Grass Airport. 49 of the 50 on board, including all 47 passengers, were killed.

- 1 January 2007 - Adam Air Flight 574; The crew's preoccupation with a malfunction of the inertial reference system diverted their attention from the flight instruments and allowed the increasing descent and bank angle to go unnoticed. Appearing to have become spatially disoriented, the pilots did not detect and appropriately arrest the descent soon enough to prevent loss of control. This caused the aircraft to impact the water at high speed and a steep angle and disintegrate, killing all 102 people on board.

- 7 March 2007 - Garuda Indonesia Flight 200; poor Crew Resource Management and the failure to extend the flaps led the aircraft to run off the end of the runway after landing. Twenty-two of the 140 occupants were killed. Note: The Captain's intentional non-compliance with EGPWS warnings is not an error, so technically this is not a "pilot error" accident.

- 12 May 2010 - Afriqiyah Airways Flight 771 undershot the runway on approach to Tripoli, killing 103 of the 104 occupants on the plane.

- 28 July 2010 - Airblue Flight 202 crashed into the Margalla Hills due to the pilot keep going the wrong way, killing all 152 occupants aboard.

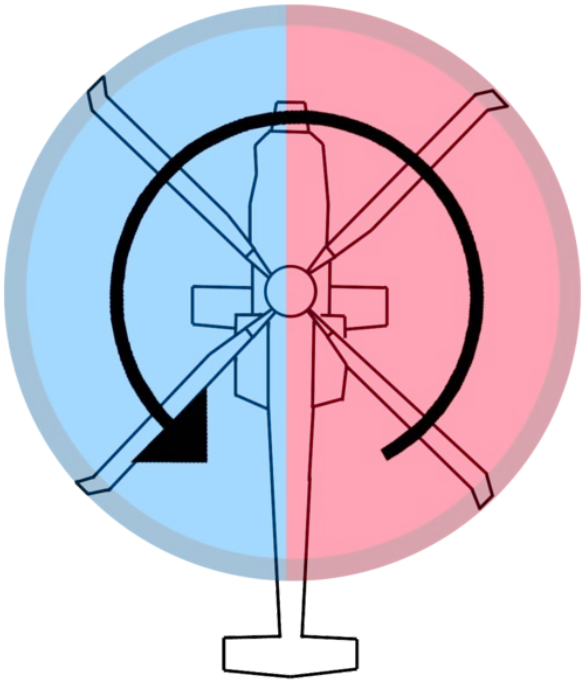
Chapter- 10

Retreating Blade Stall and Spin (Flight)

Retreating blade stall

Retreating blade stall is a hazardous flight condition in helicopters and other rotary wing aircraft, where the rotor blade rotating away from the direction of flight stalls. The stall is due to low relative airspeed and/or excessive angle of attack (or AOA). Retreating blade stall is the primary limiting factor of a helicopter's airspeed, and the reason even the fastest helicopters can only fly slightly faster than 200 knots.

Advancing vs. retreating blades



retreating blade side advancing blade side

A rotor blade that is moving in the same direction as the aircraft is called the *advancing blade* and the blade moving in the opposite direction is called the *retreating blade.*

Balancing lift across the rotor disc is important to a helicopter's stability. The amount of lift generated by an airfoil is proportional to its airspeed. In a zero airspeed hover the rotor blades, regardless of their position in rotation, have equal airspeeds and therefore equal lift. In forward flight the advancing blade has a higher airspeed than the retreating blade, creating unequal lift across the rotor disc.

A fuller treatment is provided in dissymmetry of lift.

Compensation

Most helicopter designs compensate for this by incorporating a certain degree of "flap" of the rotor blades through articulation of the rotor head and/or individual rotor blades, depending on the type of rotor system. When flapping, a rotor blade will travel upward during its advance, creating a lesser Angle of Attack (AOA) and therefors lesser lift. When the blade retreats, the blade travels downward to flap down, increasing the AOA and therefore generating greater lift. Semi-rigid and Fully articulated rotors are two common designs which compensate for the effects of dissymmetry of lift through mechanical means in the rotor head. Semi-rigid rotor systems flap both blades in equal and opposite motion as the rotor head teeters on a teetering hinge. Fully-articulated rotor systems accomplish flapping motion primarily with independent mechanical movement about a flapping hinge and/or span-wise flexing of the rotor blades. In the case of the less common Rigid rotor system, the only method used for articulating flap is to allow the rotor blades to independently have a certain degree of span-wise flex and not at their attachment point to the rotor head.

The pilot may compensate the induced roll with left or right cyclic control input (as determined by the rotation of the rotor) up to a degree. However, the rapid rate of change of blade flex and angle of attack causes uncontrolled longitudinal twist and severe vibration in later stages, resulting in total loss of cyclic control if left unchecked.

Assuming no rotor damage, recovery from the condition is possible by using the procedure described below under Flight performance during a retreating blade stall.

Failure

These compensations can only do so much. Increasing angle of attack to compensate for reduced blade airspeed has the effect of maintaining lift only until the point where critical angle of attack is reached, after this point lift sharply decreases. This situation is called retreating blade stall.

All airfoils have a critical angle of attack (also called a stall angle of attack) which is the angle of attack that produces most lift. Above this angle flow over the airfoil becomes detached and lift decreases, this is commonly called a stall.

When a fixed-wing aircraft exceeds its critical angle of attack the entire aircraft loses lift and enters a condition called a stall. The usual results of a fixed-wing stall are a sharp drop in aircraft altitude and a dive. Stalls in fixed-wing aircraft are often a recoverable event.

In a retreating-blade stall, however, only the retreating half of the helicopter's rotor disc experiences a stall. The advancing blade continues to generate lift, but the retreating blade enters a stall condition, usually resulting in an uncommanded increase in pitch of the nose and a roll in the direction of the retreating side of the rotor disc. In counter-clockwise rotating rotor systems (as in most American-made types) this is the left side. In clockwise rotating systems it is a roll to the right.

Flight performance during a retreating blade stall

As the aircraft approaches the airspeed at which it will encounter retreating blade stall, the aircraft will shudder and the nose will begin to pitch up. The resultant upward pitching of the aircraft's nose will begin to correct the situation as it results in slowing the aircraft. However, if uncorrected, and if the aircraft continues to accelerate, the aircraft may roll in the direction of the retreating blade.

Recovery involves decreasing the angle of attack and allowing the retreating blade to recover from its stalled condition. This is done by lowering the collective pitch.

The stall will not happen due to speed, but a higher pitch on the retreating side. If you are at speed and immediately reduce collective you have potentially put the blade back in a non-stalled state, but you will now begin to slow down, descend and level out.

Causes of retreating blade stall

Retreating blade stall is more likely to occur when the following conditions exist either alone or in combination:

- High gross weight
- High airspeed
- Low rotor RPM
- High density altitude
- Steep or abrupt turns
- Turbulent ambient air

Retreating blade stall starts at the tip region and develops inboard (one of the exam questions in Helicopter Principles of Flights).

Spin (flight)

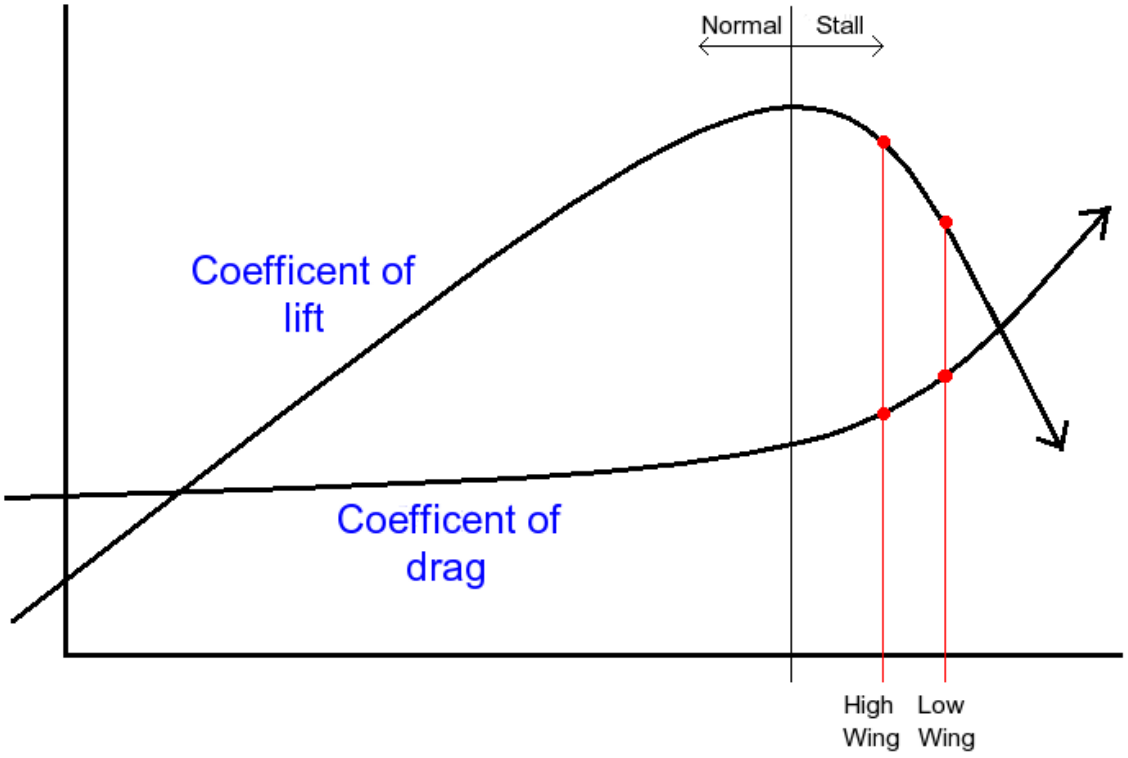
Spinning plane during an aerobatic display

In aviation, a **spin** is an aggravated stall resulting in autorotation about the spin axis wherein the aircraft follows a corkscrew path. Spins can be entered unintentionally or intentionally, from any flight attitude and from practically any airspeed—all that is required is sufficient yaw rate while an aircraft is stalled. In either case, however, a specific and often counterintuitive set of actions may be needed for an effective recovery to be made. If the aircraft exceeds published limitations regarding spins, or is loaded improperly, or if the pilot uses incorrect technique to recover, the spin can lead to a crash.

In a spin, one or both wings are in a stalled condition, if both are stalled one wing will be in a deeper stall condition than the other. This causes the aircraft to autorotate (yaw) towards the deeper-stalled wing due to its higher drag. Spins are also characterized by high angle of attack, low airspeed, and high rate of descent.

Spins differ from spiral dives which are characterized by low angle of attack and high airspeed. A spiral dive is not a type of spin because neither wing is stalled. In a spiral dive the airplane will respond conventionally to the pilot's inputs to the flight controls.

How a spin occurs



Aerodynamic spin diagram

Certificated, light, single-engine airplanes must meet specific criteria regarding stall and spin behavior. Many types of airplane will only spin if the pilot simultaneously yaws and stalls the airplane (intentionally or unintentionally). Under these circumstances, one wing tends to stall more deeply than the other. The wing that stalls first will drop, increasing its angle of attack and deepening the stall. Both wings must be stalled for a spin to occur. The other wing will rise, decreasing its angle of attack, and the aircraft will yaw towards the more deeply-stalled wing. The difference in lift between the two wings causes the aircraft to roll, and the difference in drag causes the aircraft to yaw.

One common scenario that can lead to an unintentional spin is an uncoordinated turn towards the runway during the landing sequence. A pilot who is overshooting the turn to

final approach may be tempted to apply rudder to increase the rate of turn. The result is twofold: the nose of the airplane drops below the horizon and the bank angle increases. Reacting to these unintended changes, the pilot may then begin to pull the elevator control aft (thus increasing the angle of attack) while applying opposite aileron to decrease bank angle. Taken to its extreme, this can result in an uncoordinated turn with sufficient angle of attack to cause the aircraft to stall. This is called a *cross-control stall*, and is very dangerous if it happens at low altitude where the pilot has little time to recover. In order to avoid this scenario, pilots are taught the importance of always making coordinated turns.

Spins can also be entered intentionally for training, flight testing, or aerobatics.

Phases

In aircraft that are capable of recovering from a spin, the spin has four phases. For all or some types of spin some airplanes are not recoverable. At low height recovery may also be impossible. In both cases, only the first three phases occur.

- Entry – The pilot stalls the plane while in uncoordinated flight.
- Incipient – With one wing more stalled than the other, the rotation starts.
- Developed – The aircraft's rotation rate, airspeed, and vertical speed are stabilized. At least one wing of the aircraft is stalled.
- Recovery – After appropriate control inputs, the angle of attack of both wings decreases below the critical angle of attack, rotation slows. The nose attitude of the aircraft steepens, airspeed increases, autorotation stops, the aircraft is no longer stalled. The controls respond conventionally and the airplane can be returned to normal flight.

Modes

The US National Aeronautics and Space Administration (NASA) has defined four different modes of spinning. These four modes are defined by the angle of attack of the airflow on the wing.

NASA Spin Mode Classification

Spin mode	Angle-of-attack range, degrees
Flat	65 to 90
Moderately flat	45 to 65
Moderately steep	30 to 45
Steep	20 to 30

During the 1970s NASA used its spin tunnel at the Langley Research Center to investigate the spinning characteristics of single-engine general aviation airplane designs. A 1/11-scale model was used with nine different tail designs.

Some tail designs that caused inappropriate spin characteristics had two stable spin modes – one steep or moderately steep; and another that was either moderately flat or flat. Recovery from the flatter of the two modes was usually less reliable or impossible. The further aft that the center of gravity was located the flatter the spin and the less reliable the recovery. For all tests the center of gravity of the model was at either 14.5% of Mean Aerodynamic Chord (MAC) or 25.5% of MAC.

Single-engine airplane types certified in the normal category must be demonstrated to recover from a spin of at least one turn, while single-engine aircraft certified in the utility category must demonstrate a six turn spin that cannot be unrecoverable at any time during the spin due to pilot action or aerodynamic characteristic. NASA recommends various tail configurations and other strategies to eliminate the flatter of the two spin modes and make recovery from the steeper mode more reliable.

History

In aviation's early days, spins were poorly understood and often fatal. Proper recovery procedures were unknown, and a pilot's instinct to pull back on the stick served only to make a spin worse. Because of this, the spin earned a reputation as an unpredictable danger that might snatch an aviator's life at any time, and against which there was no defense.

The spin was initially explored by individual pilots performing ad-hoc experiments (often accidentally) and by aerodynamicists. In August 1912, Lieutenant Wilfred Parke RN became the first aviator to recover from an accidental spin when his Avro biplane entered a spin at 700 feet AGL in the traffic pattern at Larkhill. Parke attempted to recover from the spin by increasing engine speed, pulling back on the stick, and turning into the spin, with no effect. The aircraft descended 450 feet, and horrified observers braced themselves for a fatal crash.

Parke was disabled by centrifugal forces but was still considering a means of escape. In an effort to neutralize the forces pinning him against the right side of the cockpit, he applied full right rudder, and the aircraft leveled out fifty feet above the ground. With the aircraft now under control, Parke climbed, made another approach, and landed safely.

In spite of the discovery of "Parke's technique," pilots were not taught spin-recovery procedures until the beginning of World War I.

The first documented case of an intentional spin and recovery is that of Harry Hawker. In the summer of 1914, Hawker recovered from an intentional spin over Brooklands, England, by centralizing the controls.

In 1917, Frederick Lindemann conducted a series of experiments that led to the first understanding of the aerodynamics of the spin.

Entry and recovery

Some aircraft cannot be recovered from a spin using only their own flight control surfaces and must not be allowed to enter a spin under any circumstances. If an aircraft has not been certified for spin recovery, it should be assumed that spins are not recoverable and are unsafe in that aircraft. Important safety equipment, such as stall/spin recovery parachutes, which generally are **not installed** on production aircraft, are used during testing and certification of aircraft for spins and spin recovery.

Spin-entry procedures vary with the type and model of aircraft being flown but there are general procedures applicable to most aircraft. These include reducing power to idle and simultaneously raising the nose in order to induce an upright stall. Then, as the aircraft approaches stall, apply full rudder in the desired spin direction while holding full back-elevator pressure for an upright spin. Sometimes a roll input is applied in the direction opposite of the rudder (i.e., a cross-control).

If the aircraft manufacturer provides a specific procedure for spin recovery, that procedure must be used. Otherwise, to recover from an upright spin, the following generic procedure may be used: Power is first reduced to idle and the ailerons are neutralized. Then, full opposite rudder (that is, against the yaw) is added and held to counteract the spin rotation, and the elevator control is moved briskly forward to reduce the angle of attack below the critical angle. Depending on the airplane and the type of spin, the elevator action could be a minimal input before rotation ceases, or in other cases the elevator control may have to be moved to its full forward position to effect recovery from the upright spin. Once the rotation has stopped, the rudder must be neutralized and the airplane returned to level flight. This procedure is sometimes called PARE, for *P*ower idle, *A*ilerons neutral, *R*udder opposite the spin and held, and *E*levator through neutral. The mnemonic "PARE" simply reinforces the tried-and-true NASA standard spin recovery actions—the very same actions first prescribed by NACA in 1936, verified by NASA during an intensive, decade-long spin test program overlapping the 1970s and '80's, and repeatedly recommended by the FAA and implemented by the majority of test pilots during certification spin-testing of light airplanes.

Inverted spinning and erect or upright spinning are dynamically very similar and require essentially the same recovery process but use opposite elevator control. It must be noted that in an upright spin both roll and yaw are in the same direction but that an inverted spin is composed of opposing roll and yaw. It is crucial that the yaw be countered to effect recovery. The visual field in a typical spin (as opposed to a flat spin) is heavily dominated by the perception of roll over yaw, which can lead to an incorrect and dangerous conclusion that a given inverted spin is actually an erect spin in the reverse yaw direction (leading to a recovery attempt in which pro-spin rudder is mistakenly applied and then further exacerbated by holding the incorrect elevator input).

In some aircraft that spin readily upright and inverted—such as Pitts- and Christen Eagle-type high-performance aerobatic aircraft—an alternative spin-recovery technique may effect recovery as well, namely: Power off, Hands off the stick/yoke, Rudder full

opposite to the spin (or more simply "push the rudder pedal that is hardest to push") and held (aka the Mueller/Beggs technique). An advantage of the Mueller/Beggs technique is that no knowledge of whether the spin is erect or inverted is required during what can be a very stressful and disorienting time. Even though this method does work in a specific subset of spin-approved airplanes, the NASA Standard/PARE procedure can also be effective provided that care must be taken to ensure the spin does not simply cross from positive to negative (or vice versa) and that a too-rapid application of elevator control is avoided as it may cause aerodynamic blanketing of the rudder rendering the control ineffective and simply accelerate the spin. The converse, however, may not be true at all—many cases exist where Beggs/Mueller fails to recover the airplane from the spin, but NASA Standard/PARE will terminate the spin. Before spinning any aircraft the flight manual should be consulted to establish if the particular type has any specific spin recovery techniques that differ from standard practice.

Although entry techniques are similar, modern military fighter aircraft often tend to require yet another variation on spin recovery techniques. While power is still typically reduced to idle thrust and pitch control neutralized, opposite rudder is almost never used. Adverse yaw created by the rolling surfaces (ailerons, differential horizontal tails, etc.) of such aircraft is often more effective in arresting the spin rotation than the rudder(s), which usually become blanked by the wing and fuselage due to the geometric arrangement of fighters. Hence, the preferred recover technique has a pilot applying full roll control in the direction of the rotation (*i.e.,* a right-hand spin requires a right stick input), generally remembered as "stick into the spin." Likewise, this control application is reversed for inverted spins.

Center of gravity

The characteristics of an airplane with respect to spinning are significantly influenced by the position of the center of gravity. In general terms, the further forward the center of gravity the less readily the airplane will spin, and the more readily it will recover from a spin. Conversely, the further aft the center of gravity the more readily the airplane will spin, and the less readily it will recover from a spin. In any airplane the forward and aft limits on center of gravity are carefully defined. In some airplanes that are approved for intentional spinning the aft limit at which spins may be attempted is not as far aft as the aft limit for general flying. Intentional spinning should not be attempted casually, and the most important pre-flight precaution is to determine that the airplane's center of gravity will be within the range approved for intentional spinning.

Unrecoverable spins

The DH 108 – the torpedo-shaped objects on the wing tips are containers for anti-spin parachutes.

If the center of gravity of the airplane is behind the aft limit approved for spinning, any spin may prove to be unrecoverable except by using some special spin-recovery device such as a spin-recovery parachute specially installed in the tail of the airplane; or by jettisoning specially installed ballast at the tail of the airplane.

In the past, some airplanes displayed an unrecoverable spin in which the nose was higher, relative to the horizon, than in conventional spins. This is sometimes called a **flat spin**, although whether a flat spin is indeed unrecoverable depends on aircraft type and loading. The plane spins on its belly around the normal axis. The empennage will feel very light and loose. Depending on the aircraft, changing the rudder and aileron inputs or engine power settings may have little effect. There is a small number of accounts where pilots recovered from flat spins by loosening their restraint harnesses and leaning forward in an attempt to alter the position of the center of gravity.

Some World War II airplanes were notoriously prone to flat spins when loaded erroneously, such as the Bell P-39 Airacobra. The P-39 was a unique design with the engine behind the pilot's seat and a large cannon in the front. Without ammunition or a counterbalance load in the nose compartment, the P-39's center of gravity was too far aft to recover from a spin. Soviet pilots did numerous tests of the P-39 and were able to demonstrate its dangerous spinning characteristics. Bell then issued a recommendation to bail out if the airplane entered a spin. North American P-51 Mustangs with auxiliary fuel tanks not originally designed for the P-51 suffered from the same problem. Similarly, the Vought F4U Corsair was reputed to have appalling stall and spin recovery characteristics, even in the "clean" (no stores) configuration.

Modern fighter aircraft are not immune to the phenomena of unrecoverable spin characteristics. Although highly resistant to entering into a spin, once caught in one the Grumman F-14 Tomcat can exhibit a fast, flat spin from which it is nearly impossible to recover. Another example of a nonrecoverable flat spin occurred in 1963, with Chuck Yeager at the controls of the NF-104A rocket-jet hybrid: during his fourth attempt at

setting an altitude record, Yeager lost control and entered a flat spin, then ejected and survived.

An airplane spin tends to flatten as it progresses because then its mass is distributed furthest from its center of rotation, as rotating objects tend to rotate about their axis of maximum rotational inertia. Aircraft have their maximum rotational inertia when spinning on their normal axis, i.e. flatly.

In purpose-built aerobatic aircraft, spins may be intentionally flattened through the application of power and aileron within a normal spin. Rotation rates experienced are dramatic and can exceed 400 degrees per second in an attitude that may even have the nose above the horizon. Such maneuvers must be performed with the center of gravity in the normal range and with appropriate training, and consideration should be given to the extreme gyroscopic forces generated by the propellor and exerted on the crankshaft.

Aircraft design

For safety, all certificated, single-engine fixed-wing aircraft, including certificated gliders, must meet specified criteria regarding stall and spin behavior. Complying designs typically have a wing with greater angle of attack at the wing root than at the wing tip, so that the wing root stalls first, reducing the severity of the wing drop at the stall and possibly also allowing the ailerons to remain somewhat effective until the stall migrates outward toward the wing tip. One method of tailoring such stall behavior is known as washout. Some designers of recreational aircraft seek to develop an aircraft that is characteristically incapable of spinning, even in an uncoordinated stall.

Some airplanes have been designed with fixed leading edge slots. Where the slots are located ahead of the ailerons they provide strong resistance to stalling and may even leave the airplane incapable of spinning.

The flight control systems of some gliders and recreational aircraft are designed so that when the pilot moves the elevator control close to its fully aft position, as in slow speed flight and flight at high angle of attack, the trailing edges of both ailerons are automatically raised slightly so that the angle of attack is reduced at the outboard regions of both wings. This necessitates an increase in angle of attack at the inboard (center) regions of the wing, and promotes stalling of the inboard regions well before the wing tips.

A US certification standard for civil airplanes up to 12,500 lb maximum takeoff weight is Part 23 of the Federal Aviation Regulations, applicable to airplanes in the normal, utility and acrobatic categories. Part 23, §23.221 requires that single-engine airplanes must demonstrate recovery from either a one-turn spin if intentional spins will be prohibited or six-turn spins if intentional spins will be approved. Even large, passenger-carrying single-engine airplanes like the Cessna Caravan must be subjected to one-turn spins by a test pilot and repeatedly demonstrated to recover within no more than one additional turn. With a small number of airplane types the FAA has made a finding of equivalent level of

safety (ELOS) so that demonstration of a one-turn spin is not necessary. For example, this has been done with the Cessna Corvalis and the Cirrus SR20/22. Successful demonstration of the one-turn spin does not allow an airplane type to be approved for intentional spinning. If an airplane is to be approved for intentional spinning it must be repeatedly subjected to a spin of six turns and then demonstrated to recover within one and a half additional turns. Spin testing is a potentially hazardous exercise and the test aircraft must be equipped with some spin-recovery device such as a tail parachute or jettisonable ballast, or some method of rapidly moving the center of gravity forward.

Agricultural airplanes are typically certificated in the normal category at a moderate weight. For single-engine airplanes this requires successful demonstration of the one-turn spin. However, with the agriculture hopper full these airplanes are not intended to be spun and recovery is unlikely. For this reason, at weights above the maximum for the normal category, these airplanes are not subjected to spin testing and, as a consequence, can only be type certificated in the restricted category.

Spin kit

To make some sailplanes spin easily for training purposes or demonstrations a spin kit is available from the manufacturer.

Many training aircraft may appear to be resistant to entering a spin even though some are intentionally designed and certified for spins. A well-known example of this is the Piper Tomahawk, which is certified for spins, though the Piper Tomahawk's spin characteristics remain controversial. Aircraft that are not certified for spins may be difficult or impossible to recover once the spin exceeds the one-turn certification standard.

Although it has been removed from most flight test syllabuses, there are some countries that still require flight training on spin recovery. In the U.S. spin training is required only for flight instructor candidates. A spin occurs only after a stall, so the FAA emphasizes training pilots in stall recognition, prevention, and recovery as a means to reduce accidents due to unintentional stalls and/or spins.

A spin is often intimidating to the uninitiated, however many pilots trained in spin entry and recovery find that safely spinning is an interesting experience. In a spin, the occupants of the airplane will only feel reduced gravity during the entry phase and then will experience normal gravity, except that the extreme nose-down attitude will press the occupants forward against their restraint harnesses. The rapid rotation, combined with the nose-down attitude, can also be disorienting.

The recovery procedure from a spin requires using rudder to stop the rotation, then elevator to reduce angle of attack to stop the stall, then pulling out of the dive without exceeding the maximum permitted airspeed (VNE) or maximum G loading. The maximum G loading for a light airplane in the normal category is usually 3.8 G. For a light airplane in the acrobatic category it is usually at least 6 G.

Chapter- 11

Sensory Illusions in Aviation

Because human senses are adapted for use on the ground, navigating by sensory input alone during flight can be dangerous: sensory input does not always accurately reflect the movement of the aircraft, causing **sensory illusions**. These illusions can be extremely dangerous for pilots.

Vestibular system

Fluid in the inner ear reacts only to rate of change, not a sustained change. For example, if a pilot initiates a banking left turn, the inner ear will detect the roll into the turn, but if the turn is held constant, the inner ear will compensate and rather quickly, although inaccurately, report to the brain that it has returned to level flight.

As a result, when the pilot finally levels the wings, that new change will cause the inner ear to produce signals that produce the perception of banking to the right. This is the crux of the problem experienced by pilots flying without instruments in low-visibility weather. Even the best pilots will quickly become disoriented if they attempt to fly without instruments when there are no external visual references, because vision provides the predominant and coordinating sense that humans rely upon for stability. Perhaps the most treacherous thing under such conditions is that the signals the inner ear produces are incorrect though they may feel right.

These sensory illusions occur because flight is an unnatural environment; our senses are not capable of providing reliable signals that we can interpret and relate to our position in three dimensions without visual reference.

Vestibular/somatogyral illusions

Illusions involving the semicircular and somatogyral canals of the vestibular system of the ear occur primarily under conditions of unreliable or unavailable external visual

references and result in false sensations of rotation. These include the leans, the graveyard spin and spiral, and the coriolis illusion.

The leans

This is the most common illusion during flight, and is caused by a sudden return to level flight following a gradual and prolonged turn that went unnoticed by the pilot. The reason a pilot can be unaware of such a gradual turn is that human exposure to a rotational acceleration of 2 degrees per second squared or lower is below the detection threshold of the semicircular canals. Leveling the wings after such a turn may cause an illusion that the aircraft is banking in the opposite direction. In response to such an illusion, a pilot may lean in the direction of the original turn in a corrective attempt to regain the perception of a correct vertical posture.

Graveyard spin

The graveyard spin is an illusion that can occur to a pilot who enters a spin. For example, a pilot who enters a spin to the left will initially have a sensation of spinning in the same direction. However, if the left spin continues the pilot will have the sensation that the spin is progressively decreasing. At this point, if the pilot applies right rudder to stop the left spin, the pilot will suddenly sense a spin in the opposite direction (to the right).

If the pilot believes that the airplane is spinning to the right, the response will be to apply left rudder to counteract the sensation of a right spin. However, by applying left rudder the pilot will unknowingly re-enter the original left spin. If the pilot cross-checks the turn indicator, he would see the turn needle indicating a left turn while he senses a right turn. This creates a sensory conflict between what the pilot sees on the instruments and what the pilot feels. If the pilot believes the body sensations instead of trusting the instruments, the left spin will continue. If enough altitude is lost before this illusion is recognized and corrective action is not taken, impact with terrain is inevitable.

Graveyard spiral

The graveyard spiral is more common than the graveyard spin, and it is associated with a return to level flight following a prolonged bank turn. For example, a pilot who enters a banking turn to the left will initially have a sensation of a turn in the same direction. If the left turn continues (for more than about 20 seconds), the pilot will experience the sensation that the airplane is no longer turning to the left. At this point, if the pilot attempts to level the wings this action will produce a sensation that the airplane is turning and banking in the opposite direction (to the right). If the pilot believes the illusion of a right turn (which can be very compelling), he will re-enter the original left turn in an attempt to counteract the sensation of a right turn.

Unfortunately, while this is happening, the airplane is still turning to the left and losing altitude. Pulling the control yoke/stick and applying power while turning would not be a good idea because it would only make the left turn tighter. If the pilot fails to recognize

the illusion and does not level the wings, the airplane will continue turning left and losing altitude until it hits the ground.

Coriolis illusion

This involves the simultaneous stimulation of two semicircular canals and is associated with a sudden tilting (forward or backwards) of the pilot's head while the aircraft is turning. This can occur when tilting the head down (to look at an approach chart or to write on the knee pad), or up (to look at an overhead instrument or switch) or sideways. This can produce an overpowering sensation that the aircraft is rolling, pitching, and yawing all at the same time, which can be compared with the sensation of rolling down a hillside. This illusion can make the pilot quickly become disoriented and lose control of the aircraft.

Vestibular/somatogravic illusions

Somatogravic illusions are caused by linear accelerations. These illusions involving the utricle and the saccule of the vestibular system are most likely under conditions with unreliable or unavailable external visual references.

Inversion illusion

An abrupt change from climb to straight-and-level flight can stimulate the otolith organs enough to create the illusion of tumbling backwards, or inversion illusion. The disoriented pilot may push the aircraft abruptly into a nose-low attitude, possibly intensifying this illusion.

Head-up illusion

The head-up illusion involves a sudden forward linear acceleration during level flight where the pilot perceives the illusion that the nose of the aircraft is pitching up. The pilot's response to this illusion would be to push the yoke or the stick forward to pitch the nose of the aircraft down. A night take-off from a well-lit airport into a totally dark sky (black hole) or a catapult take-off from an aircraft carrier can also lead to this illusion, and could result in a crash.

Head-down illusion

The head-down illusion involves a sudden linear deceleration (air braking, lowering flaps, decreasing engine power) during level flight where the pilot perceives the illusion that the nose of the aircraft is pitching down. The pilot's response to this illusion would be to pitch the nose of the aircraft up. If this illusion occurs during a low-speed final approach, the pilot could stall the aircraft.

Visual illusions

Visual illusions are familiar to most of us. As children, we learned that railroad tracks — contrary to what our eyes might tell us — don't come to a point at the horizon. Even under conditions of good visibility, one can experience visual illusions.

Linear perspective illusions

This illusion may make a pilot change (increase or decrease) the slope of his final approach. They are caused by runways with different widths, upsloping or downsloping runways, and upsloping or downsloping final approach terrain. Pilots learn to recognize a normal final approach by developing and recalling a mental image of the expected relationship between the length and the width of an average runway.

Upsloping terrain or narrow or long runway

A final approach over an upsloping terrain with a flat runway, or to an unusually narrow or long runway may produce the visual illusion of being too high on final approach. The pilot may then pitch the aircraft's nose down to decrease the altitude, potentially resulting in dropping short of the runway at high speed.

Downsloping terrain or wide runway

A final approach over a downsloping terrain with a flat runway, or to an unusually wide runway may produce the visual illusion of being too low on final approach. The pilot may then pitch the aircraft's nose up to increase the altitude, which can result in a low-altitude stall or a missed approach.

Other visual illusions

Black-hole approach illusion

A black-hole approach illusion can happen during a final approach at night (no stars or moonlight) over water or unlit terrain to a lighted runway beyond which the horizon is not visible. If the pilot has no peripheral visual cues to be oriented relative to the earth, there may be the illusion of being upright and the runway itself to be tilted and sloping.

A particularly hazardous black-hole illusion involves approaching a runway under conditions with no lights before the runway and with city lights or rising terrain beyond the runway. These conditions may produce the visual illusion of being too high on final approach, resulting in pitching the aircraft nose down to decrease the perceived approach angle.

Autokinetic illusion

The autokinetic illusion gives the pilot the impression that a stationary object is moving in front of the airplane's path; it is caused by staring at a fixed single point of light (ground light or a star) in a totally dark and featureless background. This illusion can cause a misperception that such a light is on a collision course with the aircraft.

False visual reference illusions

False visual reference illusions may cause the pilot to orient the aircraft in relation to a false horizon; these illusions can be caused by flying over a banked cloud, night flying over featureless terrain with ground lights that are indistinguishable from a dark sky with stars, or night flying over a featureless terrain with a clearly defined pattern of ground lights and a dark, starless sky.

Vection illusion

This is when the brain perceives peripheral motion, without sufficient other cues, as applying to itself. Consider the example of being in a car in lanes of traffic, when cars in the adjacent lane start creeping slowly forward. This can produce the perception of actually moving backwards, particularly if the wheels of the other cars are not visible. A similar illusion can happen while taxiing an aircraft.

Chapter- 12

Traffic Collision Avoidance System

TCAS and IVSI Indicator

TCAS and EHSI Display

A **traffic collision avoidance system** or **traffic alert and collision avoidance system** (both abbreviated as **TCAS**) is an aircraft collision avoidance system designed to reduce the incidence of mid-air collisions between aircraft. It monitors the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision (MAC). It is a type of airborne collision avoidance system mandated by the International Civil Aviation Organization to be fitted to all aircraft with a maximum take-off mass (MTOM) of over 5700 kg (12,586 lbs) or authorized to carry more than 19 passengers.

Official definition from PANS-ATM (Nov 2007): ACAS / TCAS is an aircraft system based on secondary surveillance radar (SSR) transponder signals which operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft that are equipped with SSR transponders.

In modern glass cockpit aircraft, the TCAS display may be integrated in the Navigation Display (ND) or Electronic Horizontal Situation Indicator (EHSI); in older glass cockpit aircraft and those with mechanical instrumentation, such an integrated TCAS display may replace the mechanical Vertical Speed Indicator (which indicates the rate with which the aircraft is descending or climbing).

Impetus for a collision prevention system

Research into collision avoidance systems has been ongoing since at least the 1950s. ICAO and aviation authorities such as the Federal Aviation Administration were spurred

into action after several major mid-air collisions involving great loss of life. Some of these mid-air accidents include:

- Grand Canyon midair collision in 1956;
- The New York air disaster in 1960;
- The Asheville midair collision in 1967;
- The Zagreb mid-air collision in 1976;
- PSA Flight 182, a Boeing 727 which collided with a Cessna 172 in 1978;
- The Ukraine Aeroflot mid-air collision, between two Tupolev Tu-134 in 1979;
- Aeroméxico Flight 498, a 1986 collision similar to PSA Flight 182, which finally spurred the US Congress and other regulatory bodies into action and led to mandatory collision avoidance equipment.
- Chakri Dadri midair collision over a town near New Delhi, India in 1996;

The implementation of TCAS added a safety barrier to help prevent mid-air collisions. However, further study, refinements, training and regulatory measures were still required, because the limitations and misuse of the system still resulted in other incidents and fatal accidents, which include:

- The Japan Airlines near-miss incident in 2001;
- The Überlingen mid-air collision, between a Boeing 757 and a Tupolev Tu-154 in 2002, where the Tupolev pilots declined to follow their TCAS resolution advisory (RA), instead following the directions of the air traffic controller, while the Boeing pilots followed their TCAS RA. having no ATC instruction. By the time the crews of the two planes actually saw each other, it was too late and the planes collided, killing 71;
- The Gol Flight 1907 collision with an Embraer Legacy 600 in 2006;

TCAS basics

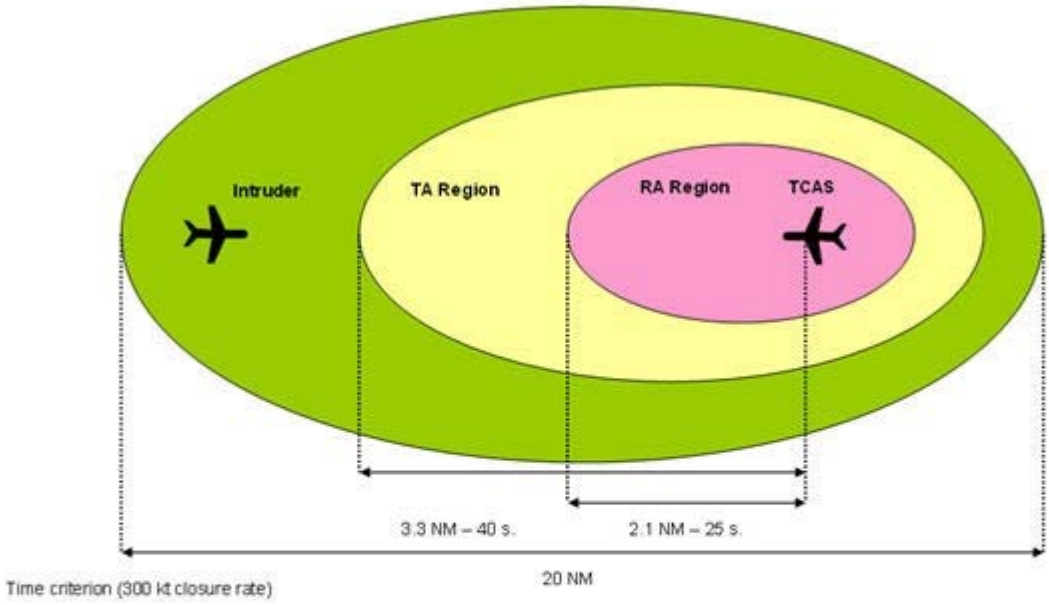
System description

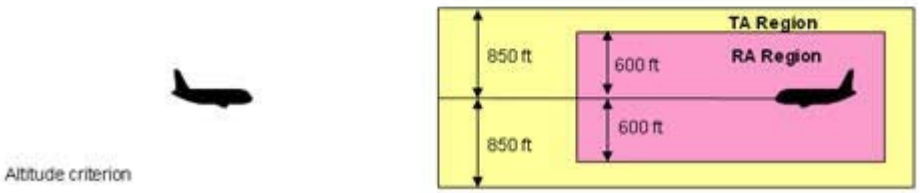
TCAS involves communication between all aircraft equipped with an appropriate transponder (provided the transponder is enabled and set up properly). Each TCAS-equipped aircraft interrogates all other aircraft in a determined range about their position (via the 1,030 MHz radio frequency), and all other craft reply to other interrogations (via 1,090 MHz). This interrogation-and-response cycle may occur several times per second.

The TCAS system builds a three dimensional map of aircraft in the airspace, incorporating their range (garnered from the interrogation and response round trip time), altitude (as reported by the interrogated aircraft), and bearing (by the directional antenna from the response). Then, by extrapolating current range and altitude difference to anticipated future values, it determines if a potential collision threat exists.

TCAS and its variants are only able to interact with aircraft that have a correctly operating mode C or mode S transponder. A unique 24-bit identifier is assigned to each aircraft that has a mode S transponder.

The next step beyond identifying potential collisions is automatically negotiating a mutual avoidance maneuver (currently, maneuvers are restricted to changes in altitude and modification of climb/sink rates) between the two (or more) conflicting aircraft. These avoidance maneuvers are communicated to the flight crew by a cockpit display and by synthesized voice instructions.





Example of ACAS Protection Volume between 5000 and 10000 feet

System components

A TCAS installation consists of the following components:

TCAS computer unit

Performs airspace surveillance, intruder tracking, its own aircraft altitude tracking, threat detection, RA maneuver determination and selection, and generation of advisories. The TCAS Processor uses pressure altitude, radar altitude, and discrete aircraft status inputs from its own aircraft to control the

collision avoidance logic parameters that determine the protection volume around the TCAS aircraft.

Antennas
: The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an omnidirectional or a directional antenna mounted on the bottom of the aircraft. Most installations use the optional directional antenna on the bottom of the aircraft. In addition to the two TCAS antennas, two antennas are also required for the Mode S transponder. One antenna is mounted on the top of the aircraft while the other is mounted on the bottom. These antennas enable the Mode S transponder to receive interrogations at 1030 MHz and reply to the received interrogations at 1090 MHz.

Cockpit presentation
: The TCAS interface with the pilots is provided by two displays: the traffic display and the RA display. These two displays can be implemented in a number of ways, including displays that incorporate both displays into a single, physical unit. Regardless of the implementation, the information displayed is identical. The standards for both the traffic display and the RA display are defined in DO-185A.

TCAS operation

The following section describes the TCAS operation based on TCAS II, since this is the version that has been adopted as an international standard (ACAS II) by ICAO and aviation authorities worldwide.

TCAS operation modes

TCAS II can be currently operated in the following modes:

Stand-by
: Power is applied to the TCAS Processor and the mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.

Transponder
: The mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in stand-by.

Traffic advisories only
: The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue traffic advisories (TA), and the resolution advisories (RA) will be inhibited.

Automatic (traffic/resolution advisories)
: The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue traffic advisories (TA) and resolution advisories (RA), when appropriate.

TCAS works in a coordinated manner, so when an RA is issued to conflicting aircraft, a required action (i.e., *Climb. Climb.*) has to be immediately performed by one of the aircraft, while the other one receives a similar RA in the opposite direction (i.e., *Descend. Descend.*).

TCAS alerts

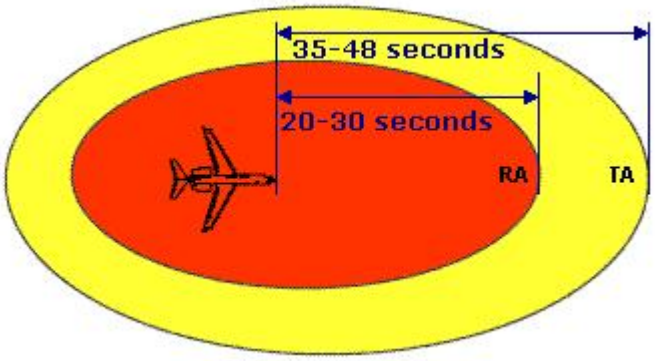
TCAS II issues the following types of aural annunciations:

- Traffic advisory (TA)
- Resolution advisory (RA)
- Clear of conflict

When a TA is issued, pilots are instructed to initiate a visual search for the traffic causing the TA. If the traffic is visually acquired, pilots are instructed to maintain visual separation from the traffic. The pilot training programs also indicate that no horizontal manoeuvers are to be made based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times manoeuver contrary to ATC instructions or disregard ATC instructions. The following points receive emphasis during pilot training:

- Do not manoeuver in a direction opposite to that indicated by the RA because this may result in a collision.
- Inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response.
- Be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized.
- If possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA.
- When the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.



Types of traffic and resolution advisories

Type	Text	Meaning	Required action
TA	*Traffic; traffic.*	Intruder near both horizontally and vertically.	Attempt visual contact, and be prepared to maneuver if an RA occurs.
RA	*Climb; climb.*	Intruder will pass below	Begin climbing at 1500 - 2000 ft/min
RA	*Descend. Descend.*	Intruder will pass above.	Begin descending at 1500 - 2000 ft/min
RA	*Increase climb.*	Intruder will pass just below	Climb at 2500 - 3000 ft/min.
RA	*Increase descent.*	Intruder will pass just above.	Descend at 2500 - 3000 ft/min.
RA	*Reduce climb.*	Intruder is probably well above.	Climb at a slower rate.
RA	*Reduce descent.*	Intruder is probably well below.	Descend at a slower rate.
RA	*Climb; climb now.*	Intruder that was passing above, will now pass below.	Change from a descent to a climb.
RA	*Descend; descend now.*	Intruder that was passing below, will now pass above.	Change from a climb to a descent.
RA	*Maintain vertical speed; maintain.*	Intruder will be avoided if vertical rate is maintained.	Maintain current vertical rate.
RA	*Adjust vertical speed; adjust.*	Intruder considerably away, or weakening of initial RA.	Begin to level off.
RA	*Monitor vertical speed.*	Intruder ahead in level flight, above or below.	Remain in level flight.
RA	*Crossing.*	Passing through the intruder's level. Usually added to any other RA.	Proceed according to the associated RA.
CC	*Clear of conflict.*	Intruder is no longer a threat.	Return promptly to previous ATC clearance.

Pilot/aircrew interaction during a TCAS event

TCAS event interaction

Aircrew	Controller
Traffic advisory (TA)	
Shall not manoeuver their aircraft in response to traffic advisories (TAs) only	Remains responsible for ATC separation
Should prepare for appropriate action if an RA occurs; but as far as practicable, pilots should not request traffic information	If requested by the aircrew, shall give traffic information
Resolution advisory (RA)	
Shall respond immediately and manoeuver as indicated, unless doing so would jeopardize the safety of the airplane	Shall not attempt to modify the flight path of an aircraft responding to an RA
Shall follow the RA even if there is a conflict between the RA and an Air Traffic Control (ATC) instruction to manoeuver	Shall not issue any clearance or instruction to the aircraft involved until the pilot reports returning to the terms of the assigned ATC clearance or instruction
Shall never manoeuver in the opposite sense to an RA, nor maintain a vertical rate in the opposite sense to an RA	Shall acknowledge the report by using the phrase *"ROGER"*
When deviating from an air traffic control instruction or clearance in response to any RA, shall: • As soon as permitted by flight crew workload, notify the appropriate ATC unit of the deviation. • Immediately inform ATC when they are unable to comply with a clearance or instruction that conflicts with an RA.	If requested by the aircrew, shall give traffic information
Shall promptly comply with any subsequent RAs issued by TCAS	Ceases to be responsible for providing separation between that aircraft and any other aircraft affected as a direct consequence of the manoeuver induced by the RA
Shall limit the alterations of the flight path to the minimum extent necessary to comply with the resolution advisories	

Clear of conflict

Shall promptly return to the terms of the ATC instruction or clearance when the conflict is resolved	Shall resume responsibility for providing separation for all the affected aircraft when he acknowledges: • A report from the pilot that the aircraft is resuming the assigned ATC clearance or instruction and issues an alternative clearance or instruction which is acknowledged by the pilot • A report from the pilot that the aircraft has resumed the assigned ATC clearance or instruction
Shall notify ATC after initiating a return to or resuming the current clearance	

Safety aspects of TCAS

Safety studies on TCAS estimate that the system improves safety in the airspace by a factor of between 3 and 5.

However, it is well understood that part of the remaining risk is that TCAS may induce midair collisions: "In particular, it is dependent on the accuracy of the threat aircraft's reported altitude and on the expectation that the threat aircraft will not make an abrupt maneuver that defeats the TCAS Resolution Advisory (RA). The safety study also shows that TCAS II will induce some critical near midair collisions...".

One potential problem with TCAS II is the possibility that a recommended avoidance maneuver might direct the flight crew to descend toward terrain below a safe altitude. Recent requirements for incorporation of ground proximity mitigate this risk. Ground proximity warning alerts have priority in the cockpit over TCAS alerts.

Some pilots have been unsure how to act when their aircraft was requested to climb whilst flying at their maximum altitude. The accepted procedure is to follow the climb RA as best as possible, temporarily trading speed for height. The climb RA should quickly finish. In the event of a stall warning, the stall warning would take priority.

Both cases have been already addressed by Version 7.0 of TCAS II and are currently handled by a corrective RA together with a visual indication of a green arc in the IVSI display to indicate the safe range for the climb or descent rate. However, it has been found that in some cases these indications could led to a dangerous situation for the involved aircraft. For example, if a TCAS event occurs when two aircraft are descending one over the other for landing, the aircraft at the lower altitude will first receive a *"Descend, descend"* RA, and when reaching an extreme low altitude, this will change to a *"Adjust Vertical Speed, Adjust"* RA, together with a green arc indication directing the

pilot to level off the aircraft. This could place the aircraft dangerously into the path of the intruder above, who is descending to land. A change proposal has been issued to correct this problem.

Relationship to automatic dependent surveillance-broadcast (ADS-B)

Automatic dependent surveillance-broadcast (ADS-B) messages are transmitted from aircraft equipped with suitable transponders, containing information such as identity, location, and velocity. The signals are broadcast on the 1090 MHz radio frequency. ADS-B messages are also carried on a Universal Access Transceiver (UAT) in the 978 MHz band.

TCAS equipment which is capable of processing ADS-B messages may use this information to enhance the performance of TCAS, using techniques known as "hybrid surveillance". As currently implemented, hybrid surveillance uses reception of ADS-B messages from an aircraft to reduce the rate at which the TCAS equipment interrogates that aircraft. This reduction in interrogations reduces the use of the 1030/1090 MHz radio channel, and will over time extend the operationally useful life of TCAS technology. The ADS-B messages will also allow low cost (for aircraft) technology to provide real time traffic in the cockpit for small aircraft. Currently UAT based traffic uplinks are provided in Alaska and in regions of the East coast of the USA.

Hybrid surveillance does not include the use any of the aircraft flight information in the TCAS conflict detection algorithms; ADS-B is used only to identify aircraft that can safely be interrogated at a lower rate.

In the future, prediction capabilities may be improved by using the state vector information present in ADS-B messages. Also, since ADS-B messages can be received at greater range than TCAS normally operates, aircraft can be acquired earlier by the TCAS tracking algorithms.

The identity information present in ADS-B messages can be used to label other aircraft on the cockpit display (where present), painting a picture similar to what an air traffic controller would see and improving situational awareness.

Drawbacks to TCAS and ADS-B

The major demonstrated problem of the ADS-B protocol integration is this added verbosity of the extra information transmitted, which is considered unnecessary for collision avoidance purposes. The more data transmitted from one aircraft in accordance with the system design, the lesser the number of aircraft that can participate in the system, due to the fixed and limited channel data bandwidth (1 megabit/second with the 26/64 data bits to packet length bit capacity of the Mode S downlink data format packet). For every Mode S message of 64 bits, the overhead demands 8 for clock sync at the receiver and Mode S packet discovery, 6 for type of Mode S packet, 24 for who it came

from. Since that leaves only 26 for information, multiple packets must be used to convey a single message. The ADS-B "fix" proposal is to go to a 128 bit packet, which is not an accepted international standard. Either approach increases channel traffic above the level sustainable for environments such as the Los Angeles Basin.

Versions of TCAS

Passive

Collision Avoidance systems which rely on transponder replies triggered by ground and airborne systems are considered passive. Ground and airborne interrogators query nearby transponders for mode C altitude information, which can be monitored by third-party systems for traffic information. Passive systems display traffic similar to TCAS, however generally have a range of less than 7 nautical miles (13 km).

TCAS I

TCAS I is the first generation of collision avoidance technology. It is cheaper but less capable than the modern TCAS II system, and is mainly intended for general aviation use. TCAS I systems are able to monitor the traffic situation around a plane (to a range of about 40 miles) and offer information on the approximate bearing and altitude of other aircraft. It can also generate collision warnings in the form of a "Traffic Advisory" (TA). The TA warns the pilot that another aircraft is in near vicinity, announcing *"Traffic, traffic"*, but does not offer any suggested remedy; it is up to the pilot to decide what to do, usually with the assistance of Air Traffic Control. When a threat has passed, the system announces *"Clear of conflict"*.

TCAS II

TCAS II is the second and current generation of instrument warning TCAS, used in the majority of commercial aviation aircraft. It offers all the benefits of TCAS I, but will also offer the pilot direct, vocalized instructions to avoid danger, known as a "Resolution Advisory" (RA). The suggestive action may be "corrective", suggesting the pilot change vertical speed by announcing, *"Descend, descend"*, *"Climb, climb"* or *"Adjust Vertical Speed Adjust"* (meaning reduce vertical speed). By contrast a "preventive" RA may be issued which simply warns the pilots not to deviate from their present vertical speed, announcing, *"Monitor vertical speed"* or *"Maintain vertical speed, Maintain"*. TCAS II systems coordinate their resolution advisories before issuing commands to the pilots, so that if one aircraft is instructed to descend, the other will typically be told to climb — maximising the separation between the two aircraft.

As of 2006, the only implementation that meets the ACAS II standards set by ICAO was Version 7.0 of TCAS II, produced by three avionics manufacturers: Rockwell Collins, Honeywell, and ACSS (Aviation Communication & Surveillance Systems; an L-3 Communications and Thales Avionics company).

After the Überlingen mid-air collision (July 1, 2002), studies have been made to improve TCAS II capabilities. As a result, by 2008 the standards for Version 7.1 of TCAS II have been issued. This version will be able to issue RA reversals in coordinated encounters, in case one of the aircraft doesn't follow the original RA instructions (Change proposal CP112E). Other changes in this version are the replacement of the ambiguous *"Adjust Vertical Speed, Adjust"* RA with the *"Level off, Level off"* RA, to prevent improper response by the pilots (Change proposal CP115).; and the improved handling of corrective/preventive annunciation and removal of green arc display when a positive RA weakens solely due to an extreme low or high altitude condition (1000 feet AGL or below, or near the aircraft top ceiling) to prevent incorrect and possibly dangerous guidance to the pilot (Change proposal CP116).

Studies conducted for Eurocontrol, using recently recorded operational data, indicate that currently the probability of a mid-air collision in European airspace is 2.7×10^{-8} which equates to one in every 3 years. When TCAS II Version 7.1 is implemented, that probability will be reduced by a factor of 4.

TCAS III

TCAS III was the "next generation" of collision avoidance technology which underwent development by aviation companies such as Honeywell. TCAS III incorporated technical upgrades to the TCAS II system, and had the capability to offer traffic advisories and resolve traffic conflicts using *horizontal* as well as vertical manouevring directives to pilots. For instance, in a head-on situation, one aircraft might be directed, "turn right, climb" while the other would be directed "turn right, descend." This would act to further increase the total separation between aircraft, in both horizontal and vertical aspects. Horizontal directives would be useful in a conflict between two aircraft close to the ground where there may be little if any vertical maneuvering space. All work on TCAS III is currently suspended and there are no plans for its implementation.

Current implementation

Although the system occasionally suffers from false alarms, pilots are now under strict instructions to regard all TCAS messages as genuine alerts demanding an immediate, high-priority response. Windshear Detection and GPWS alerts and warnings have higher priority than the TCAS. The FAA and most other countries' authorities' rules state that in the case of a conflict between TCAS RA and air traffic control (ATC) instructions, the TCAS RA **always** takes precedence (this is mainly because of the TCAS-RA inherently possessing a more current and comprehensive picture of the situation than air traffic controllers, whose radar/transponder updates usually happen at a much slower rate than the TCAS interrogations). If one aircraft follows a TCAS RA and the other follows conflicting ATC instructions, a collision can occur, such as the July 1, 2002 Überlingen disaster. In this mid-air collision, both airplanes were fitted with TCAS II Version 7.0 systems which functioned properly, but one obeyed the TCAS advisory while the other ignored the TCAS and obeyed the controller; both aircraft descended into a fatal collision.

This accident could have been prevented if TCAS was able to reverse the original RA for one of the aircraft when it detects that the crew of the other one is not following their original TCAS RA, but conflicting ATC instructions instead. This is one of the features that will be implemented within Version 7.1 of TCAS II.

Implementation of TCAS II Version 7.1 has been originally planned to start between 2009 and 2011 by retrofitting and forward fitting all the TCAS II equipped aircraft, with the goal that by 2014 the version 7.0 will be completely phased out and replaced by version 7.1. The FAA and EASA have already published the TCAS II Version 7.1 Technical Standard Order (TSO and ETSO, respectively). On 25 March 2010 the European Aviation Safety Agency (EASA) published Notice of Proposed Amendment (NPA) No. 2010-03 pertaining to the introduction of ACAS II software version 7.1. On 14 September 2010 EASA published the Comment Response Document (CRD) to the above mentioned NPA.

ICAO has circulated an amendment for formal member state agreement which recommends TCAS II Change 7.1 adoption by 1 January 2014 for forward fit and 1 January 2017 for retrofit. Following the feedback and comments from airline operators, EASA has proposed the following dates for the TCAS II Version 7.1 mandate in European airspace: forward fit (for new aircraft) 1 March 2012, retrofit (for existing aircraft) 1 December 2015. These dates are proposed dates, subject to further regulatory processes, and are not final until the Implementing Rule has been published.

Among the system manufacturers, by February 2010 ACCS certified Change 7.1 for their TCAS 2000 and Legacy TCAS II systems. By June 2010 Honeywell published a white paper with their proposed solutions for TCAS II Version 7.1.

Current TCAS Limitations

While the safety benefits of current TCAS implementations are self-evident, the full technical and operational potential of TCAS is not fully exploited due to limitations in current implementations (most of which will need to be addressed in order to further facilitate the design and implementation of Free flight):

- TCAS is limited to supporting only vertical separation advisories, more complex traffic conflict scenarios may however be more easily and efficiently remedied by also making use of lateral resolution maneuvers; this applies in particular to traffic conflicts with marginal terrain clearance, or conflict scenarios that are similarly restricted by vertical constraints (e.g. in busy RVSM airspace)
- ATC can be automatically informed about resolution advisories issued by TCAS only when the aircraft is within an area covered by a Mode S, or an ADS-B monitoring network. In other cases controllers may be unaware of TCAS-based resolution advisories or even issue conflicting instructions (unless ATC is explicitly informed by cockpit crew members about an issued RA during a high-workload situation), which may be a source of confusion for the affected crews

while additionally also increasing pilot work load. In May 2009, Luxembourg, Hungary and the Czech Republic show downlinked RAs to controllers.

- In the above context, TCAS lacks automated facilities to enable pilots to easily report and acknowledge reception of a (mandatory) RA to ATC (and intention to comply with it), so that voice radio is currently the only option to do so, which however additionally increases pilot and ATC workload, as well as frequency congestion during critical situations.
- In the same context, situational awareness of ATC depends on exact information about aircraft maneuvering, especially during conflict scenarios that may possibly cause or contribute to new conflicts by deviating from planned routing, so automatically visualizing issued resolution advisories and recalculating the traffic situation within the affected sector would obviously help ATC in updating and maintaining situational awareness even during unplanned, ad hoc routing changes induced by separation conflicts.
- Today's TCAS displays do not provide information about resolution advisories issued to other (conflicting) aircraft, while resolution advisories issued to other aircraft may seem irrelevant to another aircraft, this information would enable and help crews to assess whether other aircraft (conflicting traffic) actually comply with RAs by comparing the actual rate of (altitude) change with the requested rate of change (which could be done automatically and visualized accordingly by modern avionics), thereby providing crucial realtime information for situational awareness during highly critical situations.
- TCAS displays today are often primarily range-based, as such they only show the traffic situation within a configurable range of miles/feet, however under certain circumstances a "time-based" representation (i.e. within the next xx minutes) might be more intuitive.
- Lack of terrain/ground and obstacle awareness (e.g. connection to TAWS, including MSA sector awareness), which might be critical for creating feasible (non-dangerous, in the context of terrain clearance) and useful resolution advisories (i.e. prevent extreme descent instructions if close to terrain), to ensure that TCAS RAs never facilitate CFIT (Controlled Flight into Terrain) scenarios.
- Aircraft performance in general and current performance capabilities in particular (due to active aircraft configuration) are not taken into account during the negotiation and creation of resolution advisories (as it is the case for differences between different types of aircraft, e.g. turboprop/jet vs. helicopters), so that it is theoretically possible that resolution advisories are issued that demand climb or sink rates outside the normal/safe flight envelope of an aircraft during a certain phase of flight (i.e. due to the aircraft's current configuration). Furthermore, as all traffic is being dealt with equally, there's no distinction taking place between different types of aircraft, neglecting the option of exploiting aircraft-specific (performance) information to issue customized and optimized instructions for any given traffic conflict (i.e. by issuing climb instructions to those aircraft that can provide the best climb rates, while issuing descend instructions to aircraft providing comparatively better sink rates, thereby hopefully maximizing altitude change per time unit, that is separation)

- TCAS is primarily extrapolation-oriented, as such it is using algorithms trying to approximate 4D trajectory prediction using the "flight path history", in order to assess and evaluate the current traffic situation within an aircraft's proximity, however the degree of data- reliability and usefulness could be significantly improved by enhancing said information with limited access to relevant flight plan information, as well as to relevant ATC instructions to get a more comprehensive picture of other traffic's (route) plans and intentions, so that flight path predictions would no longer be merely based on estimations but rather *actual* aircraft routing (FMS flight plan) and ATC instructions. If TCAS is modified to use data that is used by other systems, care will be required to ensure that the risks of common failure modes are sufficiently small.
- TCAS is not fitted to many smaller aircraft mainly due to the high costs involved (between $25,000 and $150,000). Many smaller personal business jets for example, are currently not legally required to have TCAS installed, even though they fly in the same airspace as larger aircraft that are required to have proper TCAS equipment on board. The TCAS system can only perform at its true operational potential once all aircraft in any given airspace have a properly working TCAS unit on board.

Regulatory situation around the world

Jurisdiction (Agency)	Classification of aircraft	TCAS mode	Date of mandate
USA (FAA)	All commercial turbine-powered transport aircraft with more than 30 passenger seats (or MTOW above 33,000 lb/15,000 kg)	TCAS II	01 January, 1993
Europe (EASA)	All civil turbine-powered transport aircraft with more than 30 passenger seats (or MTOW above 15,000 kg)	TCAS II	01 January, 2000
Europe (EASA)	All civil turbine powered transport aircraft with more than 19 passenger seats (or MTOW above 5,700 kg)	ACAS II (Effectively TCAS II Version 7.0)	01 January, 2005
Australia (CASA)	All commercial turbine powered transport aircraft with more than 30 passenger seats (or MTOW above 15,000 kg)	TCAS II	01 January, 2000
Hong Kong, China (Civil Aviation Department)	All aircraft in Hong Kong with more than 9 passenger seats (or MTOW greater than 5,700 kg)	TCAS II Version 7.0	01 January, 2000
Brazil (National Civil Aviation Agency)	All transport category aircraft with more than 30 passenger seats	TCAS II Version 7.0	01 January, 2008
Brazil (National	All transport category aircraft with	TCAS II Version	01

Civil Aviation Agency)	more than 19 passenger seats	7.0	January, 2010
Peru (Dirección General de Aeronáutica Civil)	All civil turbine powered transport aircraft with more than 19 passenger seats (or MTOW above 5,700 kg))	ACAS II (Effectively TCAS II Version 7.0)	01 January, 2005

Chapter- 13

Ice Protection System

Ice protection systems are designed to keep atmospheric ice from accumulating on aircraft flight surfaces while in flight. The effects of ice accretion on an aircraft can cause loss of control, resulting in a catastrophic flight event.

Types of ice protection systems

- Pneumatic deicing boots
- Thermal
  - Electrical heating elements
  - ThermaWing
  - Turbine engine bleed air
- Electro-mechanical
  - Weeping Wing
  - Electro-Mechanical Expulsion Deicing System (EMEDS)
  - Hybrid Electro-Mechanical Expulsion Deicing System
- Passive (cover system mainly used in the telecoms and offshore domains)
  - Anti icing cover

The pneumatic boot is a rubber device attached to a wing's leading edge, invented by the Goodrich Corporation (previously known as B.F. Goodrich) in 1923. Portions of the boot are alternately inflated and deflated to break ice off the boot, de-icing the wing. Rubber boots are used on jets and propeller driven aircraft.

The Thermawing, manufactured by Kelly Aerospace Thermal Systems, is an electrical ice protection system. ThermaWing uses a flexible, electrically conductive, graphite foil attached to a wing's leading edge. Electric heaters are usually flexible enough to use as anti-icers or de-icers. Once activated an exact concentration of heat melts the bond between ice and protected surface. Ice no longer sticks to the surface due to aerodynamic forces. As an anti-icer, the heater keeps the surface warm so that ice does not form.

A bleed air system is used by most larger jet aircraft to keep flight surfaces above the freezing temperature required for ice to accumulate (called anti-icing). The hot air is "bled" off the jet engine into tubes routed through wings, tail surfaces, and engine inlets.

Electro-mechanical Expulsion Deicing Systems use a mechanical force to knock the ice off the flight surface. Typically, actuators are installed underneath the skin of the structure. The actuator is moved to induce a shock wave in the protected surface to dislodge the ice. Innovative Dynamics in Ithaca, NY has developed a system that's light weight and low power using actuators called EIDI.

Hybrid Electro-Mechanical Expulsion Deicing Systems combine an EMEDS de-icer with an electrical heating element anti-icer. The heater prevents ice accumulation on the leading edge of the airfoil and the actuators of the EMED system remove ice that accumulates aft of the heated portion of the airfoil.

A weeping wing system, also known as a TKS system, uses a liquid based on ethylene glycol to coat the surface and prevent ice from accumulating. The leading edges of the wings, horizontal and vertical stabilizer are made of porous, laser-drilled titanium panels, through which the fluid is pumped during flight in icing conditions. A "slinger ring" may be used to distribute fluid on propellers, and a spray bar can be used to apply fluid to the windshield. This system is commonly used on small-to-medium-sized propeller-driven aircraft, and a number of business jet aircraft. It also has some applications in military use.

The Passive systems are a new conceptual non-thermal anti-icing and pollution solution based on textile. This innovative textile has the properties characterized by a high level of water resistance which has a natural self-cleaning effect to repel water, thereby eliminating the build of ice, with a high resistance to UV radiation and harsh climatic conditions and has a durable protective function.

Airframe icing

Ice accumulates on the leading edge of wings, tailplanes, and vertical stabilizers as an aircraft flies through a cloud containing super-cooled water droplets. Super-cooled water is water that is below freezing, but still a liquid. Normally, this water would turn to ice at 32°F (0°C), but there are no "contaminants" (Ice nucleus) on which the drops can freeze. When the airplane flies through the super-cooled water droplets, the plane becomes the droplet nucleus, allowing the water to freeze on the surface. This process is known as accretion.

Droplets of supercooled water often exist in stratiform and cumulus clouds.

A popular misconception is that aircraft icing events result from the *weight* of accreted ice on the airframe. This is not the case. Rather, airframe icing causes problems by modifying the airflow over flight surfaces upon which the ice accretes. When ice accretes on aerodynamic lift surfaces, such as the wing and tailplane, the modification of airflow

changes the aerodynamics of the surfaces by modifying both their shape and their surface roughness, typically increasing their drag and decreasing their lift. The particular effect of icing on the aerodynamics of a lift surface is a complicated function of the ice shape and location as well as of the amount of ice. These characteristics in turn depend in a complicated fashion on atmospheric conditions such as the amount, temperature, and droplet size of water in the air. The composite effect of this aerodynamic deterioration over all lift surfaces is a degradation of aircraft flight dynamics. In severe atmospheric conditions, dangerous levels of icing can be obtained in as little as 5 minutes. Small to moderate amounts of icing generally cause a reduction in aircraft performance in terms of climb rates, range, endurance, and maximum speed and acceleration. Icing effects of this type are known as *performance events*. As icing increases, separation of air flow from the flight surfaces can cause loss of pilot control and even wildly unstable behaviour. These more severe icing events, known as *handling events*, are often precipitated by a change in the aircraft configuration or an aircraft maneuver effected by a pilot unaware of the flight-dynamics degradation. This was the case with American Eagle Flight 4184 where the aircraft experienced an uncontrolled roll of 120 degrees in five seconds after the pilot initiated a flap retraction. Another icing event that lead to a major crash was the Aero Caribbean Flight 883 that experienced icing conditions at 20,000 feet height after a crew request of course change. They lost control of the aircraft after they initiated a roll to change the aircraft's direction. This loss of control can be defined as a handling event. Handling events generally can be classified into either *tailplane stall*, where the aircraft pitches forward, or asymmetric wing effects causing a *roll upset* (or *roll snatch*) as in the American Eagle Flight 4184 accident.

Rotary-surface icing

Ice can also accumulate on helicopter rotor blades and aircraft propellers. The accretion causes weight and aerodynamic imbalances that are amplified due to the rapid rotation of the propeller or rotor.

Engine-inlet icing

Ice accreting on the leading edge (lip) of engine inlets causes flow problems and can lead to ice ingestion. In turbofan engines, laminar airflow is required at the face of the fan. Because of this, most engine ice protection systems are anti-ice systems (prevent build up).