

Chapter

Military Aviation Principles

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Abstract

Military all over the world uses military aircraft in both offensive and defensive purposes. In offensive role, these aircraft are used in destroying enemy's vital installations, air strips, ordnance depots and supplies. In defensive role, it provides close air support to land-based army and also deters the threats of enemy air strike. In naval warfare, military aircraft plays a significant role to detect and neutralize submarines and warships to keep the seacoast free from enemy attack. Military aircraft also provides logistic supply to forward bases, conducting airlift (cargo and troops), and participates in rescue operations during national disaster. Military aviation includes both transport and warcraft and consisting of fixed wing aircraft, rotary-wing aircraft (RWA) and unmanned aerial vehicle (UAV). From the early days of world war, it has been realized that air power supremacy is vital for winning a war as well as maintaining the sovereignty of any country. This chapter discusses basic flight mechanics, types and roles of aircraft, safety considerations and design and certification procedures.

Keywords: military, aviation, combat, aircraft, aerodynamics, helicopter, UAV

1. Introduction

It was realized that aviation had a great potential in transporting goods as well as passengers in large distances in minimum possible time. The military also realized the advantages of having an offensive and defensive air power during the war and peace time. Today air power has become the essence of military supremacy of any country for maintaining country sovereignty during peace time and offensive attack capability to win war by destroying enemy vital installations, deterring troop transfer and military supplies.

The aircraft can be broadly categorized as lighter-than-air aircraft (balloons and airships) which generate lift due the buoyancy forces and heavier-than-air aircraft (aircraft, helicopters and UAV).

2. Principles of flight

An aircraft is a complex machine using the application of multidisciplinary engineering sciences. The major engineering groups can be indicated as follows:

- a. Aerodynamics and flight mechanics determining aircraft shape, configuration and control law
- b. Airframe structure (fuselage, wings, vertical and horizontal tail planes and control surfaces)

- c. Mechanical system (hydraulics, pneumatics, landing gear, fuel and flight control systems)
- d. Engine/power plant system
- e. Electrical system (power generations, distribution and emergency power)
- f. Avionic (communication, navigation, weapon aiming, displays and warnings and utility management system) and instrument system
- g. Environmental systems (air-conditioning, life support system and cabin pressurization systems)
- h. Armament system (for military aircraft)
- i. Air egress (ejection) system
- j. Software (embedded as well as operational software)

2.1 Atmosphere

For the aerodynamic study, air is considered an ideal gas which follows gas laws. Therefore, the variation of air properties with respect to altitude is important. The International Standard Atmosphere (ISA) is used for comparison of performances of aircraft designed by different countries. The ISA is defined as:

Altitude (H):	sea level (0 m)
Temperature (T):	288.15°K
Pressure (P):	1.01325 MPa (14.7 psi)
Density (ρ):	1.225 kg/m ³

The atmosphere is divided in two layers. The lower layer is called ‘troposphere’ where temperature decreases linearly with altitude (6.5°C/km altitude rise, known as lapse rate). Air pressure decreases with altitude as shown in **Figure 1**. Air density can be estimated from gas equation ($\rho = P/RT$, where R is universal gas constant). **Figure 1** also shows the different types of clouds in the atmosphere [1–5].

The upper layer of the atmosphere is called ‘stratosphere’ where T remains constant at –56°C (ISA condition). In troposphere, with increase in altitude, both pressure and temperature decrease reducing the density, thus lowering engine mass flow reducing thrust, lift and drag. These values optimize at 10–12 km which is known as cruise altitude for jet aircraft. Due to decrease in mass flow, jet engines cannot operate at very high altitude.

2.2 Aerodynamics and flight mechanics

Movement of air over an aircraft generates aerodynamic forces and moments. Due to change in the air properties, the aerodynamic forces and moments also vary with altitude. Flight dynamics looks at these aerodynamic forces and includes thrust and gravity forces to study aircraft motion. Further the aerodynamic forces generated due to deflections of control surfaces are added as applied control forces to study the dynamics of the flight path including stability and controllability of the aircraft [1, 5].

Airflow over a body obeys three basic aerodynamic equations: these are conservation of mass, conservation of momentum and conservation of energy. Solving

these equations, we obtain velocity distribution over the aircraft surfaces from which forces and moments can be estimated.

Airflow over an airfoil (cross section of wing) is shown in **Figure 2**. Due to the airfoil camber, air particles traveling over the upper surface have to cover longer distance than the air flowing on the lower surface. In order to comply with the law of conservation of mass, air particle on the upper surface speeds up to cover longer distance (due to camber) than the airflow over the lower surface. According to the law of conservation of momentum, the increase in speed is compensated by the decrease in pressure. This creates differences in pressures with lower surface air pressure being more than that of the upper surface. This differential pressure gives rise to upward force. The vertical component of this upward force is the wing lift, and axial component is the drag. Further the resultant of the air pressure of the upper surface and lower surface does not pass through the same point, which creates a turning moment known as pitching moment. An airfoil of unit thickness will produce lift, drag and pitching moment coefficients. These are dimensionless quantities and are represented by C_L , C_D , and C_M .

Aerodynamics of supersonic flow is, however, different. A supersonic flow over an airfoil at angle of attack (AOA) is shown in **Figure 3**. On the upper surface, flow

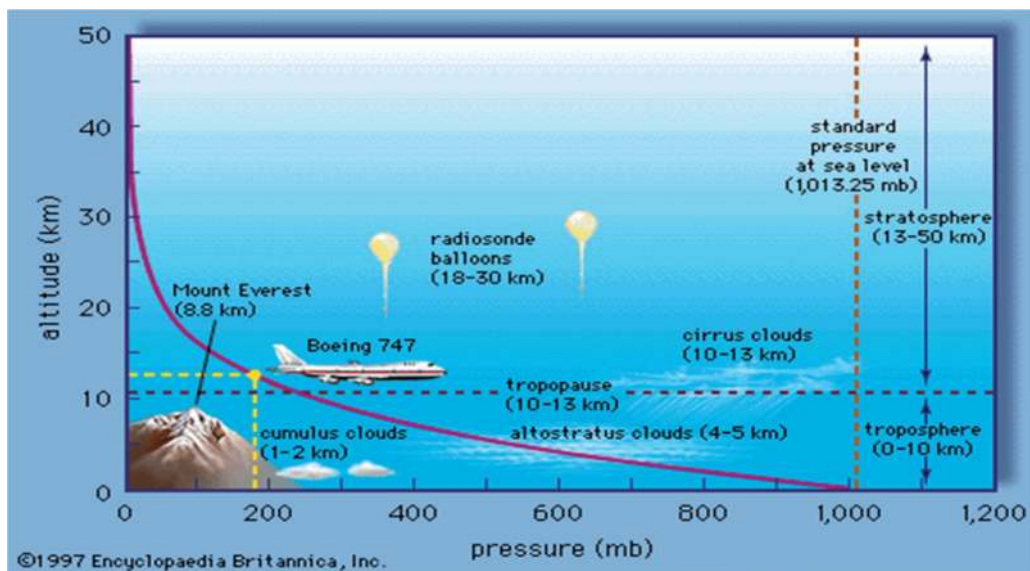


Figure 1.
Variation of pressure of atmospheric pressure with altitude.

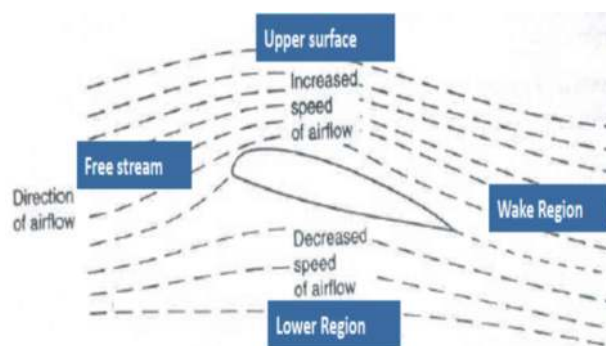


Figure 2.
Subsonic flow over [2].

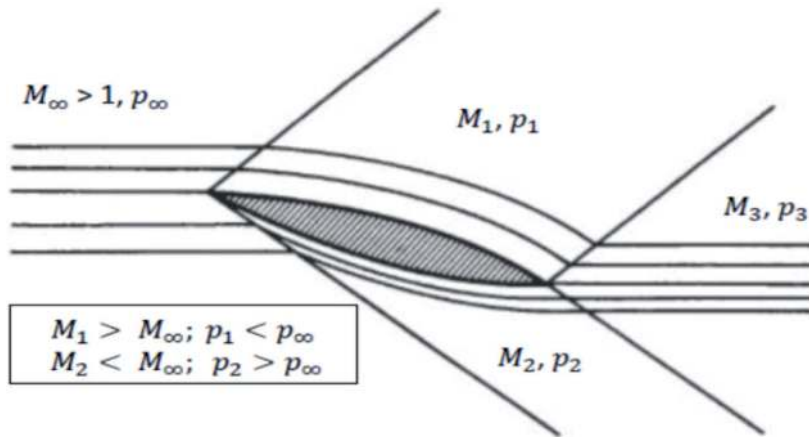


Figure 3.
Supersonic flow [2].

expands having higher flow area, and flow on the lower surface gets compressed due to lower area of flow. Expansion of flow is associated with increase in Mach number and decrease in static pressure. It may be appreciated that at zero AOA, there will be no difference in upper and lower surface flow. As the supersonic airfoil generates lifts only due to AOA, supersonic airfoils are symmetrical airfoils.

The lift produced increases with increase in AOA as shown in **Figure 4**. However, beyond certain AOA, flow separates from the airfoil, lift suddenly drops, and drag rises due to increase of wake area. This is known as ‘stall’. With further increase of AOA, the wake region will increase and thus aggravate the situation. This being a flight safety hazard, airworthiness regulations require stall warning system and protection from stall recovery procedure to be incorporated. Subsonic aircraft stalls around 14–18° of AOA, while supersonic aircraft stalls around 24–28°

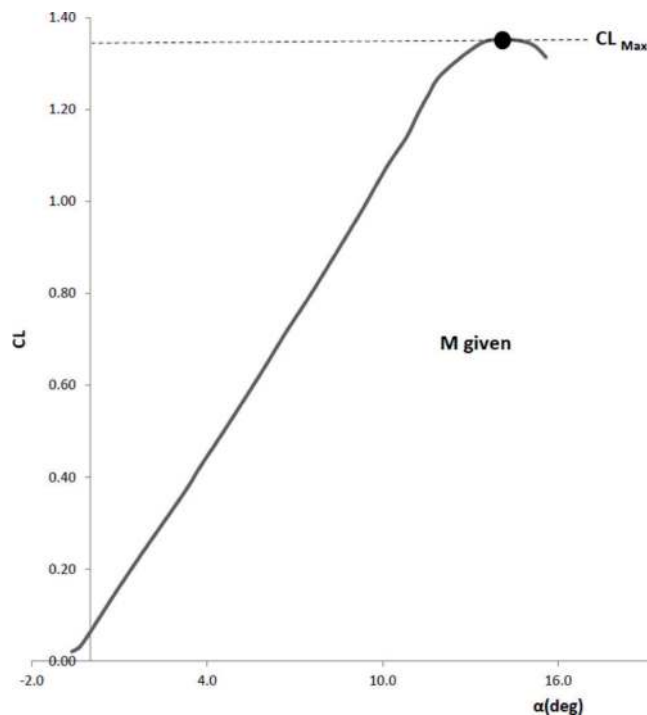


Figure 4.
Stall phenomenon [4].

AOA. In supersonic flow, lift curve slope is very flat, and realization of stall is rather difficult. In view of this in supersonic aircraft, in addition to an AOA indicator, audio warning with stick shaker is installed.

An aircraft in flight has six degrees of freedom (DOF); these are three translations (motion in forward, lateral and vertical directions) and three angular motions, viz. roll (rotation about longitudinal axis), pitch (rotation around lateral axis) and yaw (rotation about vertical axis). An aircraft is steered to the desired direction by operating the respective control surface. This is shown in **Figure 5**.

The lift, drag and pitching moment produced by the wings can be written as $L = \frac{1}{2}\rho V^2 S C_L$; $D = \frac{1}{2}\rho V^2 S C_D$; and $M = \frac{1}{2}\rho V^2 S C C_M$, where S is the total wetted wing area and C is the mean aerodynamic chord length. The force and moments acting on an aircraft in x-z plane during flight are shown in **Figure 6**. The lift, drag and pitching moments act at the aerodynamic centre of the aircraft. The forces and moments are in equilibrium. If the equilibrium is disturbed, the aircraft will move from its flight path. For example, if the lift is increased more than weight, the aircraft will float up, and if the thrust produced is more than the drag, the aircraft will accelerate. The reverses are also true. Similarly, if any control surface is deflected, ΣM about the axis will be disturbed, and the aircraft will rotate about that axis. The degrees of turn of flight path achieved per degree of deflection of control surfaces are the measure of controllability of the aircraft.

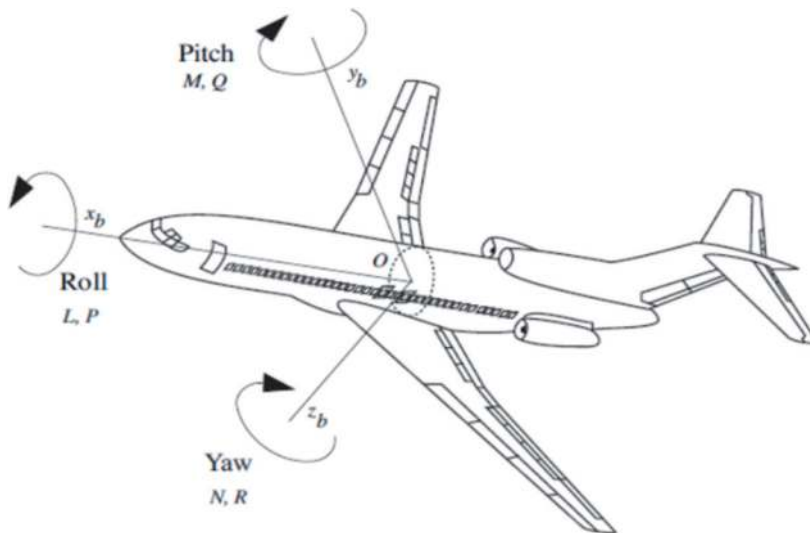


Figure 5.
 6 DOF of air vehicle [4].

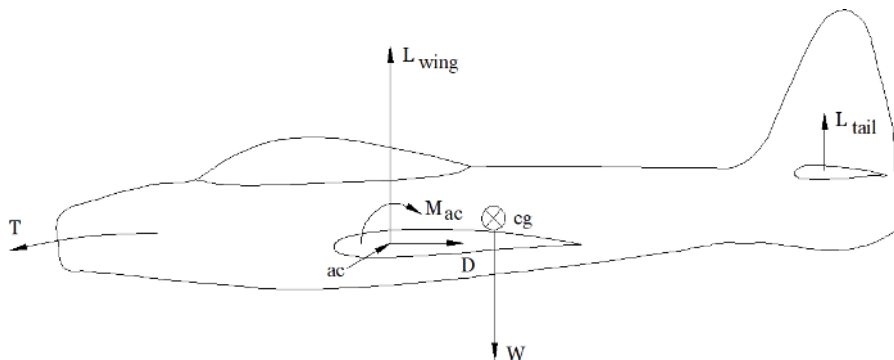


Figure 6.
 The force and moment system working on an aircraft in flight [2].

The ease with which an aircraft can be operated is judged by the handling qualities (HQ) of an aircraft. The HQ is directly related to the aircraft stability and controllability. An aircraft is said to be statically stable if an aircraft while flying in a steady path, if unintentionally disturbed by some external forces like gust or any other reason, the aerodynamic forces and moments so created due to the disturbances bring the aircraft back to its original stable condition. This property of the aircraft is termed as stability. However, higher the stability, higher will be the demand for control power to steer the aircraft and lower will be the controllability of the aircraft. Thus, a compromise is made, and the stability requirements are specified in design regulations formulated by the airworthiness authorities. The advantages of lower stability have brought the concept of 'relaxed static stability' or 'statically unstable' aircraft. The high-performance military fighters like F-16, F-17 and F-18 are statically unstable in order to obtain dramatic increase in manoeuvrability. The vehicle is kept under control by 'fly-by-wire' (FBW) control system. In FBW, accelerometers and rate gyros are mounted in each axis which senses the aircraft position and attitude, and a FBW computer continuously monitors these data and commands the control actuators to move the control surfaces to keep the aircraft under control. In this approach, very high manoeuvrability advantages can be realized without heavily taxing the pilot. Even in the transport aircraft, this leads to smaller tailplane resulting in lesser weight and drag. The light combat aircraft of India, Mirage-2000 and SU-30, belong to this category of unstable aircraft [1-5].

2.3 Flight Mach number

At low flight speeds, compressibility of air may be neglected (ρ assumed constant), but as the flight speed increases, air gets compressed, and change in ρ cannot be neglected. Above $M > 0.3$ (M = Mach number; defined as the ratio of aircraft speed and speed of sound, named after Austrian Physicist Ernst Mach), compressibility effect cannot be neglected. The solution of a three-dimensional flow with air viscosity terms included at higher speed thus becomes complex.

Depending on the flow M , the aerodynamic studies are classified as:

- a. *Subsonic flow*—the flight M No. is 0–0.8.
- b. *Transonic flow*—the flight M No. is 0.8–1.2. In this flow, the local M No. over some parts of the airfoil is supersonic, while it is subsonic in some other parts. Transonic flight regime is associated with very high drag and instability due to formation of shock and shock oscillation. No aircraft therefore does sustain flight in transonic regime.
- c. *Supersonic flow*—the flight $M > 1.2$. In supersonic flow the normal shock formed at $M = 1$ becomes bow shock forming a conical region over the aircraft. The half angle of the cone is $\sin^{-1} \frac{1}{M}$. Due to formation of shock, supersonic drag is 50–80% higher than the subsonic drags. The drag arises due to the thickness effect, and a hypothetical zero-thickness flat-plate airfoil in supersonic flow will produce no drag. However, practical aircraft wings required adequate thickness for storage of fuel in wing tanks and to provide adequate structural stiffness.
- d. *Hypersonic flow*—the flight M No. > 7 . When an airflow is brought to rest (like in the leading edges of wings, fuselages, tail planes, etc.), the kinetic energy of air is converted to thermal energy and temperature rises; this is called stagnation temperature (T_s). T_s can be estimated from the equation $T_s = T_0[1 + 0.2M^2]$. For flow with $M = 7$ and above, the temperature rise may be so high that the air

may be ionized and ideal gas equations may no more be applicable, and we may use equations from gas dynamics.

3. Military aircraft

Any aircraft that is operated by a legal or insurrectionary armed force may be called military aircraft. Military uses aircraft for both combat and noncombat applications.

3.1 Combat aircraft

Combat aircraft are designed and developed for use by military to destroy enemy assets using on-board armaments/stores. Military aircraft and their applications include the following [1, 3, 5].

3.1.1 Fighters (air superiority, interceptor and fighter)

Fighters are meant to engage in air-to-air combat with enemy aircraft and outclass them. They are therefore light and have high speeds and manoeuvrability. Fighters are used for both offensive and defensive roles. Interceptor is intended to be light and agile and has high acceleration and rate of climb to intercept an enemy aircraft spotted by the ground surveillance radar and engage in dogfight. The main weapons these aircraft carry are air-to-air combat missile and air gun. Many fighters have a secondary role of ground attack capabilities where it carries bombs and air-to-surface missiles (ASM). This is how the concept of multirole combat aircraft (MRCA) has evolved.

A fighter's main purpose is to establish and maintain 'air superiority' which means it denies the air power of opposing air forces for effective interference. Since the early days of aerial combat, armed forces have constantly invested to develop technologically superior fighters and attain air supremacy over the adversaries. Substantial proportion of the defence budgets of modern armed forces is spent for these purposes. Some of the modern fighters include General Dynamics F-16 Fighting Falcon, Dassault Rafale, Dassault Mirage 2000, Russian Su-30MKI, Mikoyan MiG-29, Saab JAS 39 Gripen, etc.

3.1.2 Bombers (bombers, strategic bombers, tactical bomber and interdictor)

A bomber is a combat aircraft designed to attack ground and naval targets by dropping air-to-ground weapons like bombs (dumb and smart bombs); firing ASM, torpedoes and bullets; or deploying air-launched cruise missiles. Heavy bombers (known as strategic bombers) armed with powerful conventional or nuclear weapons are used for long-range bombing missions against strategic targets such as supply bases, bridges, factories, shipyards and cities and thus cripple the enemy infrastructure and capability to continue war or stage new attacks. B-2 Spirit, B-52, Tupolev TU-95, etc. are some of the present days' strategic bombers.

Tactical bombers are smaller bombers with shorter range and weapon capability and used for battlefield tactical operations like countering enemy military activity and military troop transport/supplies and supporting offensive operations.

An interdictor is an attack aircraft designed to interrupt enemy supply operation by aerial bombing. A deep penetration aircraft is a version of interdictor having longer range and capabilities. The main purpose of these aircraft is to prevent or cause delays to enemy forces and supplies reaching the battlefield. Russian MiG-23BN/MiG-27, Dassault-Breguet Mirage 2000D and Panavia Tornado are some of the present-day bombers.

3.1.3 Multirole combat aircraft (multirole, fighter bomber, strike fighter)

The MRCA roles may include air-to-air combat, bombing operation, aerial photo reconnaissance, etc. The main motivation for developing multirole aircraft is cost reduction in using a common airframe. Multirole means an aircraft with major roles, a primary air-to-air combat role and a secondary role like air-to-surface attack. It may be appreciated that an aircraft optimized for a particular role may not fulfil some other role efficiently; however, they may be gainfully used for secondary roles. For example, air superiority fighters designed for higher manoeuvrability over the contemporary aircraft are also capable of ground attack. Similarly an interceptor having high rate of climb and acceleration and equipped with close combat missiles and air guns can also be used to chase enemy aircraft and neutralize them in air. Aircraft roles can be changed by changing on-board armament stores/role equipment. Some aircraft are retro modified for additional role. The F-14 was envisioned originally for air superiority and fleet interception defence with some variants later receiving secondary ground attack capability.

The Euro fighter Typhoon and Dassault Rafal are classified as multirole fighters. Euro fighter Typhoon was however, originally designed as an air superiority fighter.

3.1.4 Electronic warfare (EW) aircraft

An EW aircraft is a military aircraft equipped with EW system meant to degrade the effectiveness of enemy radar and radio systems by using radar jamming deception methods. EW is a technology to detect, identify the frequency spectrum and locate the source of electromagnetic energy and use of self-protective jammer to deny the opponent access to the EM spectrum. EW can be deployed from land, sea or air. Various types of self-protective jammers like noise/frequency jamming and counter-measure dispensing systems (CMDS) are used. This gives the aircraft stealth capability to deceive the enemy radars. F-35 has very advanced EW capability which enables it to reach well-defended targets and suppress enemy radars that threaten the F-35.

3.1.5 Maritime patrol aircraft

A maritime patrol aircraft is designed to operate for long duration over coast-line/water territory in order to detect, identify enemy ships and submarines and destroy them using air-to-surface weapon, torpedoes and underwater mines. These aircraft are equipped with various sensors including sonar and radars and are also used in maritime search and rescue operations. Jaguar maritime patrol aircraft is one such aircraft that is in use for a long time.

3.2 Fighter aircraft generations

Aircraft is designed for an economic life of 20 years from the consideration of obsolescence. However, as the cost of procurement of new aircraft is continuously rising, aircraft are operated for longer period, and midlife update is carried out to make the aircraft competitive to contemporary aircraft. This has brought a concept of fighter generation categories created to identify major technology leaps in the historical development of jet fighters. Though there is no sound technological basis, this is more of a creation of aerospace webs and magazines. A general grouping is done based on the operational capabilities, handling qualities and pilot work load as well as the year of design. The aircraft generation is discussed below [6, 7]:

- a. First-generation fighters (1945–1955)—the first-generation fighters were those built in the beginning of the jet age (World War II). These were fitted with jet but otherwise similar to earlier piston engine aircraft. They were subsonic, did not have radar and had conventional weapons like gun, dumb bombs and rockets.
- b. Second-generation fighters (1955–1960)—the second-generation fighters were a class superior to the first-generation fighters as regards their speed of operation and combat effectiveness. These were fitted with radar and equipped with guided air to air missiles. This generation also took advantage of the new development of electronics in the aircraft systems.
- c. Third-generation fighters (1960–1970)—the third-generation fighters were designed specifically as multipurpose fighters capable of performing both air defence and ground attack missions. McDonnell Douglas F4H Phantom, British Aerospace Harrier and MiG-23 belong to this class.
- d. Fourth-generation fighters (1970–1990)—the fourth-generation (4G) fighters are high-maneuverability multirole fighters with sophisticated avionics and weapon systems and long-range AAM. During this generation, FBW and relaxed static stability FCS concept were introduced. The advance of microcomputers in the 1980s and 1990s permitted rapid upgrades to the avionics over the lifetimes of these fighters, incorporating system upgrades such as AESA, digital avionics busses and infra-red search and track (IRST). 4+ generation fighters (1990–2000) are also sometimes used to indicate more advanced features that might be seen in fifth-generation fighters. F-16, Mirage 2000 and MiG-29 are 4G fighters, while F/A-18 Hornet, Eurofighter Typhoon and Dassault Rafale can be designated as 4+ generation fighters.
- e. Fifth-generation fighters (2000 onwards)—the fifth-generation (5G) designation is used that encompasses the fighter technologies developed during the first part of the twenty-first century. The 5G jet fighters are expected to have ‘pilot associates’: integrated avionics and computer system capable of networking with other elements that provide the pilot with complete picture of the battlespace and situational awareness. The other features include the use of low-observable ‘stealth’ and high-performance airframes. Some of 5G fighters are the Lockheed Martin F-22 Raptor with USAF (2005) and the Lockheed Martin F-35 (USAF 2015) and the Chengdu J-20 with the People’s Liberation Army Airforce (2017). Sukhoi SU-57 being developed for the Russian Air Force and Indian AMCA is in early stages of development.

3.3 Fighter aircraft operational profile

Combat radius or radius of action (ROA) of military aircraft refers to the maximum distance the aircraft can travel from the operating base with operational load, complete operational mission and return without refueling, allowing for reserve fuel and all other safety requirements. The thumb rule is that ROA is one third the distance an aircraft can fly on full load and total fuel. Operational mission planning is done for offensive roles to maximize the ROA without taking undue risk of enemy detection and attack. Some considerations are [1, 5]:

- a. Low-level flight missions will have smaller ROA due to higher drag and fuel consumption; however, it will have low radar detection probability.

- b. Aircraft with higher ordnance (weapon payload) will have low ROA.
- c. A high-level mission will have higher radius of action.
- d. Drop tank (D/T) increases ROA due to extra fuel, and D/T once empty can be dropped and permit aircraft to run away from the area of action.

Many offensive attack missions are normally planned a mix of hi-lo-hi mission. A typical profile is shown in **Figure 7**. The F-16 Fighting Falcon has the combat radius of 550 km (340 mi) on a hi-lo-hi mission with six 450 kg (1000 lbs) bombs.

3.4 Noncombat aircraft (NCA)

The NCA are not designed for combat as their primary function but may carry weapons for self-defence. NCA mainly operate in support roles and may be developed by either military forces or civilian derivative aircraft (CDA). NCA military applications include many different types as discussed below [1, 5]:

1. *Military transport (MT) aircraft*—both fixed-wing and rotary-wing aircraft are used for MT operation for transferring military personnel and cargo including military weapons and equipment for routine as well as urgent military operations. The operations may include rescue, tactical and strategic airlifts onto places with unprepared or semi-prepared runways. The transfers are effected to forward bases as well as areas where commercial air operations are not available.
2. *Airborne early warning and control (AEW&C)*— is an airborne platform equipped with radar, electronic intelligence (ELINT), gathered through sensors to monitor communication and radar emissions and electronic support measure (ESM) system designed to detect aircraft, ships and vehicles at long ranges and perform command and control of battle management (C2BM) in an air engagement by directing fighter and attack aircraft strikes. As the aircraft flies at altitude, the radar and other sensors have better visibility, and the on-board processor can detect, identify and track both ground and slow-moving targets. Thus, AEW&C units carry out surveillance and using the command data link act as C2BM. The AEW&C aircraft are equipped with EW system and self-protective jammers so as not to be vulnerable to counter-attack. Airborne warning and control system (AWACS) is the name of the specific system installed in the E-3 and Japanese Boeing E-767 aircraft but is often used as a general synonym for AEW&C. The Indian Defence Research and Development Organization (DRDO) is developing AEW&C on Embraer ERJ145 platform.

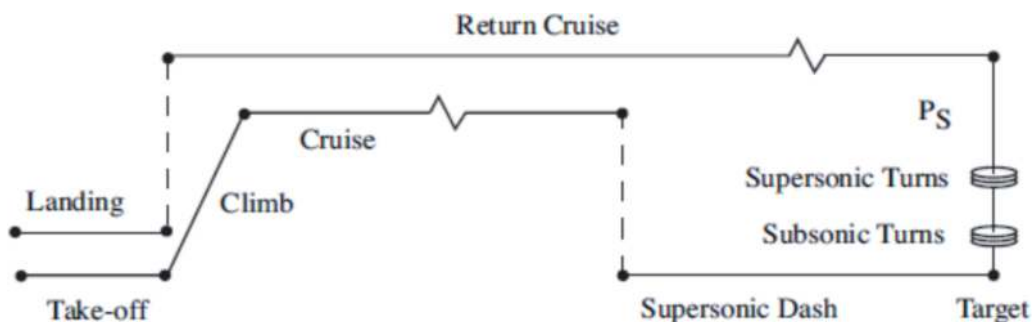


Figure 7. Military aircraft combat mission profiles (hi-lo-hi) [5].

3. *Air-to-air fuel tanker*—air-to-air refuel procedure has become very popular in modern aviation and especially in military. In this, aviation fuel is transferred from one aircraft (tanker) to another aircraft (receiver). The aerial refueling permits the receiver aircraft to take off with greater payload (weapon, cargo or personnel) and less fuel to keep the AUW limitations. The aircraft after being airborne can be topped up with extra fuel by the tanker to increase the operational range or endurance for loiter on target location. However, both the receiver aircraft and the tanker have to be specially equipped with the precision probe and drogue system, where the receiving aircraft has fuel probe in the forward zone and the tanker is equipped with drogue to transfer the fuel. India uses IL-76 aircraft as an aerial fuel tanker.
4. *Other NCA roles*—military also uses many other aircrafts for noncombat operation. These include experimental aircraft, trainer (basic trainer and advanced trainer), reconnaissance and surveillance, search and rescue aircraft, etc.

4. Rotary-wing aircraft (RWA)

A RWA (also known as helicopter) does not have wings, but its rotor blades perform an identical role of the wings of an aeroplane. When rotor blades spin, flow of air takes place over the wings or rotor blades—hence the name rotary-wing aircraft. The magnitude of the lift can be changed by altering the angle of attack (AOA) of air over the rotor blades. The AOA is changed by mechanically increasing or decreasing the rotor blade pitch angle. For this, the pilot uses a control called ‘collective’ which is on his left side in the cockpit. The pilot can change the altitude of flying as well as hover the helicopter at a place by operating the collective.

Another control known as ‘cyclic’ is used to move the helicopter in different directions. The cyclic is operated by the pilot using his right hand. When cyclic is operated, the pitch angle of the rotor blades is changed, but it alters each blade individually by a different amount. When cyclic is operated, the total vertical force produced by rotor blades is inclined, the vertical component keeps the helicopter afloat and horizontal component moves the helicopter in the desired direction. The helicopter cyclic control system is designed in such a way that when the cyclic is moved forward, the helicopter moves forwards, when it is moved sideways the helicopter moves sideways and when cyclic is moved aft the helicopter moves backwards (which a fixed wing aircraft cannot do). The third helicopter control is the yaw pedals. These alter the pitch angle of the tail rotor—the small rotor at the end of the helicopter. Doing this enables the pilot to turn the helicopter either left or right (yaw) [8].

4.1 Military application of helicopters

The helicopter is a very useful machine for military applications. Due to its design features, helicopters can hover at a point, fly at very low altitude and above all take off from the land at any place it desires. Military helicopters are also installed with protective armor/windshield against bullets. Some of the typical applications are:

1. *Attack helicopter*—attack helicopters are used in the antitank and close support roles. These helicopters are equipped with antitank-guided missiles, guns and rockets. To enable them to find and identify their targets, some modern attack helicopters are equipped with very capable sensors such as a millimetre wave radar system.

2. *Antisubmarine warfare (ASW) helicopters*—helicopters used for ASW roles can be ship based or land based and are equipped with winch for use of dunking sonars to detect, identify, locate and track the target submarines. To destroy submarines, both torpedoes and naval mines are used, launched from air, surface and underwater platforms. It is also used to protect friendly ships.
3. *Observation helicopter*—the ability to both manoeuvre and hover at one location makes the helicopter ideal for reconnaissance. Modern observation helicopters are equipped with optical sensor systems. These include low-light video and forward-looking infra-red cameras. Often, these are mounted on a stabilized platform along with multifunction lasers capable of acting as laser range finder and targeting designators for weapon systems. Advanced observation helicopters are equipped with sensor suits capable of providing terminal guidance to ATGWs, laser-guided bombs and other missiles and munitions fired by other aircraft.
4. *Transport helicopter*—transport helicopters are used for transporting personnel (troops) and cargo in support of military operations. The benefit of using helicopters for these operations is that personnel and cargo can be moved to and from locations without requiring a runway for takeoffs and landings. Cargo is carried either internally or externally by slung load suspended from cargo hook. In difficult terrains where helicopters cannot land, personnel may be picked up and dropped off using rescue hoists or special rope lines, while the aircraft hovers overhead. Helicopters are also used in air assault, where customized assault force assembled on the pickup zone with their equipment is transported to a landing zone (LZ). The use of helicopter in air assault permits transport and lands a large number of troops and equipment in a relatively short time, near the LZ. The transfer is done in stages and sequentially thus supports the assault by continually resupplying the force during the operation.
5. *Medical evacuation (MEDEVAC) helicopter*—MEDEVAC is the timely and efficient movement and en route care provided by medical personnel to wounded personnel being evacuated from a battlefield or to injured patients being evacuated from the scene of an accident to receive medical facilities. Helicopters are used as air ambulance.
6. *Combat search and rescue (CSAR) operation helicopters*—search and rescue (S&R) operation includes search and supply provision to people who are in distress or imminent danger. Normally S&R is carried out by specially trained volunteers. CSAR are search and rescue operations that are carried out within or near the combat zone during war. A CSAR mission may be carried out by a task force of helicopters, ground attack aircraft, aerial refueling tankers and an airborne command post from which a commander controls and organizes his forces.
7. *Utility helicopters*—a utility helicopter is a multipurpose helicopter. A utility military helicopter can fill roles such as ground attack, air assault, military logistic, medical evacuation and troop transfer. Hindustan Aeronautics Limited (HAL), India, is developing a light utility helicopter for the services of the Indian Armed Forces.

5. Unmanned aerial vehicle (UAV)

An airborne vehicle capable of being flown without a pilot on board is termed as pilotless or unmanned aerial vehicle (UAV). UAVs are broadly in two types, namely, remotely piloted vehicle (RPV) and autonomous and preprogrammed air vehicle [9, 10].

5.1 Application of UAV

UAV has the potential to serve varieties of application both in civil and military uses. These include border and port security, homeland surveillance, scientific data collection, cross-country transport and telecommunication services. Many non-aviation business applications include:

1. Aerial photography, film, video, still, etc.
2. Agriculture crop monitoring and spraying
3. Conservation, pollution and land monitoring
4. Electricity companies for their power line inspection.

5.2 Military UAV

UAVs used for armed forces, police, border security and coast guard are considered owned by the state commonly known as military UAV. These UAVs are under direct control of the government of the state, and the state is directly responsible for safety of operation and third-party damage in the event of UAV failure. This direct control of operations is a significant advantage of operation in segregated space at the same time accepting a safety of operation by imposing operational restriction to compensate for uncertainties over airworthiness.

5.3 Military application of UAV

UAV in military is used as a force multiplier for carrying out very dull, dirty missions that are long and considered very hazardous and risky for manned flight. Some of these tasks are round-the-clock reconnaissance, surveillance and target acquisition (RSTA); nuclear, biological and chemical (NBC) war; and combat search and rescue (CSAR) operation. In offensive role UAV can be employed for arm dropping as well as suppression of enemy air defence (SEAD).

Unmanned combat air vehicle (UCAV) is used for offensive war application. These are designed to possess:

- a. High accuracy and probability to 'strike the target capability'
- b. All weather operation
- c. High speed and manoeuvrability for war zone penetration
- d. Autonomous programme with rerouting facility

5.4 UAV vs. manned aircraft

UAVs are aircraft within the meaning of the International Civil Aviation Organization (ICAO) Convention, 1944 (§8 of Chicago Convention). As per §3 of Chicago Convention, the ICAO rules do not apply to state (military) aircraft. The airworthiness and safety associated with flying UAV in segregated area (military airspace) are therefore state responsibility. However, special political agreement will be required if the military UAVs fly over the territory of another state (§8 of the ICAO). Further, §20 of the ICAO requires each UAV to bear registration and nationality mark, and §8 requires special authorization of state (military) for UAV to fly over its area. And above all article, §33 requires UAVs to have current certificate of airworthiness.

5.5 Integration of UAV into national airspace

Though UAVs are employed in segregated areas at present, there is a consensus view within the aerospace industry that the time is ripe when both manned and unmanned aerial vehicles will share the common airspace. Thus, the process of integrating the manned aircraft and UAV in the national airspace has to be accepted and regulated. This needs to regulate the operation of UAV on the one hand, and at the same time, the UAVs themselves have to be certified to be airworthy by regulatory organizations. Further, regulatory activities of air traffic management for integrating UAV in non-segregated airspace operations have to be considered:

- a. *Certification consideration for UAV*—as technology advances, legislations need to be enacted to avoid proliferation. Existing regulatory procedure for manned flight cannot readily be made applicable to UAV. Therefore, suitable developments or amendments in UAV design process need to be initiated to make them acceptable in the common airspace. Besides the specialized infrastructure facilities in the air traffic management also have to be developed to fly UAV and manned aircraft in the same airspace.
- b. *Type certification standard*—UAV-type certification standard should in addition to manned aircraft requirement consider the following:
 - Emergency recovery capability
 - Communication link and link loss criticality
 - Level of autonomy
 - Human-machine interface (UAV pilot is deprived of the physical senses and feeling of flying as in manned aircraft pilots)
 - Ground control system and launch and recovery system should be subjected to functional hazard analysis and accordingly certified.

5.6 Collateral damage

UAV operation has a great risk of collateral damage in the event of UAV failure. The regulatory principles thus aim to take all precautions to reduce the risk of collateral damage. The considerations are:

- a. Design for low collateral damage—by designing with high precision and accuracy in striking the target using high-accuracy sensor and doing proper mission planning to hit the target and not the structure/people around (third party).
- b. Approach for damage prevention—the damage is proportional to the kinetic energy (KE) during the impact. The KE depends on the mass and velocity at the time of impact. The V_{impact} will be based on the cause of the failure, namely, engine or control failure. The general rule is to assume $V_{\text{impact}} = 1.3$ times the V_{stall} for the case of unpremeditated descent or engine failure and $V_{\text{impact}} = 1.4 V_{\text{stall}}$ in the event of loss of control.
- c. Design safety consideration—the basic safety criterion should be that catastrophic failure conditions must be extremely improbable and, for all other failure conditions, the probability of occurrence of the event should be inversely proportional to the damage potential of the failure. From airworthiness point of view, the risk to third parties on the ground would become the most severe risk to be minimized. Depending on the ‘hit’ probability on the ground (a function of population density and UAV lethal area), some operational limitation with regard to ‘overflowed zone’ may be imposed.

5.7 Emergency recovery system

Flight termination systems (FTS) should be installed as a means of recovering UAVs from system failures. FTS can be an automatic flight guidance system which navigates the aircraft to a suitable location and completes a normal landing or devices which bring the aircraft down immediately, e.g. by deployment of a parachute, e.g. JAR 1309 (ballistic recovery system (BRS)). It is noteworthy that BRS has been fitted for some time to certain manned civil aircraft, notably microlights. The current CAA policy on such systems is that they may be installed on a ‘no hazard, no benefit’ basis only. A parachute may be fitted if desired, but it is not to be relied upon to prevent an accident. Applicants for the approval of aircraft embodying FTS have to show that the system is protected from inadvertent operation or that the consequences of inadvertent operation are acceptable.

6. Airworthiness and flight safety

6.1 Airworthiness

Airworthiness in a simple term can be defined as ‘fit to fly’; however, in an actual sense, it is defined as ‘demonstrated capability of an airborne store to perform satisfactorily and fulfil the mission requirements, throughout the specified life in the prevailing environments with acceptable level of safety and reliability’. The ‘Federal Aviation Administration’ (FAA) declares an aircraft is airworthy if it conforms to its type design and if it is in a condition for safe flight. The first part of the FAA definition describes the airworthiness requirement for ‘certification’, and the second part of the definition refers to the ‘continued airworthiness’ which regulates the repair, maintenance and operation throughout the life span of the aircraft [11–27].

6.2 Airworthiness and flight safety in military aviation

The phrase ‘acceptable level of safety’ in the definition of airworthiness is a complex consideration as absolute safety is hypothetical and can be achieved only at

infinite cost. Therefore, the airworthiness standards have to balance between safety concerns on the one hand and the cost and practicability from design and manufacture point of view on the other.

In aviation, safety may be defined as freedom from death, injury or damage to people on board and loss property and life on ground (accident). Safety of any flying effort or machine would depend primarily upon, whether we are operating below or above a particular level known as ‘risk threshold’. The risk threshold is the level of risk beyond which accidents are inevitable. It also must be appreciated that this ‘risk threshold’ is not a stationary one and it keeps varying based on the role, function and a host of other associated factors. It needs therefore to be reassessed under each changing scenario. Airworthiness control is to minimize the risk and maximize the effectiveness. All the airworthiness standards, military or civil, whether that of the USA, Europe or Russia, have a common point of reference which is that an inverse relation should exist between probability of occurrence of an event and the degree of hazard inherent in its effect.

For military aircraft in the US Department of Defense (DoD) document, Mil-STD-882 defines the safety requirements during design of an airborne stores. The decision matrix of system safety as per Mil-STD-882 is shown in **Figure 8**. The safety requirement of any failure event is based on the hazard index of the failure which is defined as the product of the probability of the failure and the damage consequent of the failure event. The damage consequences can range from ‘catastrophic’ (loss life, aircraft and property) to negligible (minor inconvenience). The frequencies of occurrences are grouped under ‘frequent’ (1 in 10 h of flight) to ‘extremely improbable’ (1 in 10⁷ flight hours).

6.3 Flight safety directorate

The operational branches of both military and civil aviation are expected to have effective ‘flight safety directorates’. The primary responsibility of the flight safety directorate is to estimate the risk threshold under all dynamic condition, take appropriate measures and ensure that operational risk does not exceed this value. The basic aim of the flight safety studies is to ensure that the chances of achieving the mission tasks be optimal, while operational risks are minimal. In military aviation, the flight safety directorate has a very complex duty to perform. On the one hand, the military training must give a high level of exposures to possible war scenario and threats,

↑ Criticality	Catastrophic I	HAWR	HUD	HUA	HUA	HUA
	Critical II	HAWR	HUD	HUD	HUA	HUA
	Marginal III	HAWR	HAWR	HUD	HUD	HUA
	Negligible IV	HA	HA	HA	HAWR	HAWR
Frequency →		Level E Improbable	Level D Remote	Level C Occasional	Level B Probable	Level A Frequent



Figure 8.
Mil-STD-882: design safety decision matrix [14].

while it must ensure that the high level of risks are to be avoided in peace time within the stated training syllabi. This is because the accidents have very deleterious effects on the morale of the flier. During the war time, however, task achievement is paramount, and hence risks are to be taken even at high degrees if the operational requirements dictate. The main purposes of the flight safety studies are therefore to:

- a. Identify and minimize those risks which may contribute accidents
- b. Avoid very high cost of losses and damages
- c. Identify all risk hazards real or potential at all levels and all phases of flying
- d. Risk thresholds are dynamic, and they need to be reassessed under all conditions and make necessary readjustments

7. Military aircraft design and certification

7.1 Military aircraft design consideration

All modern military aircraft are designed to perform multiple missions. This is inherent in the design of such aircraft, for example, the A400M military transport aircraft is designated as a tactical airlifter with strategic capabilities and can also be configured to perform long-range cargo and troop transport, medical evacuation, aerial refueling and electronic surveillance missions. *Military aircraft* is capable of operating from semi-prepared runways under varied climatic and environmental conditions [1, 13, 28].

Military aircraft design requirement is driven by operational capabilities derived from threat perception and defence preparedness strategy of a country, whereas commercial aircraft design and development are driven by the market forces. A comparative study of the design *considerations for civil and military* aircraft is shown in **Table 1**.

7.2 Certification of aircraft

Certification is a process of evaluation and documentation of compliance of a product to its specified requirements and declares it 'safe to fly'. It is a third-party assurance to the user that the product has been designed, developed, evaluated and produced in such a manner that its quality, reliability and integrity meet the requirements. An aircraft can really be considered airworthy when [13]:

- a. Its type has been designed and certified meeting design standards.
- b. It has been manufactured by an approved organization as per type design.
- c. It has been maintained by qualified people as per approved system and inspected in accordance with all applicable airworthiness directives.
- d. Further, on compliance of (c), no significant defects have been found and not rectified.

7.3 Military certification

There is a difference in concept of civil and military aircraft certification. While military certification has a general concern of airworthiness as well as

Objectives	Civil aircraft design	Military aircraft design
Requirement	Independent market survey	Military staff requirement
Certification goal	Civil-type certification used by airlines	Providing national security Issue operational clearance
Accepted failure tolerance/flight	Level 2: $p < 10^{-4}$ Level 3: $p < 10^{-6}$	Level 2: $p < 10^{-2}$ Level 3: $p < 10^{-4}$
Design safety	As per SAE ARP 4671; permitted failure rate 1 in 10^9 flying hours	As per Mil-STD-882; permitted failure rate 1 in 10^7 flying hours
Avionics architecture	Better FCS, navigation, reduce pilot workload, increase payload	High performance, navigation and weapon aiming, secure COM and reduction in pilot workload
Use of advanced technology	Only certified material/technology	Cutting edge technology; certified/ under development
Stealth tech/EW protection	Not considered	Most essential consideration
Design life	High economic life	High maneuverability, extreme operating envelope

Table 1.
Design consideration—Civil and military aircraft [13].

rules for design and performance evaluations, each country has its own rule to ‘self-certify’ its state aircraft as airworthy and compliant to some specified and controlled airspace performance requirements. While certifying a military aircraft, the operational risk and operational process are defined for each type of aircraft. Even though the purpose of airworthiness control is the same, the civil and military certification differs on the fact that [13]:

- a. Governments can ‘self-certify’ their state aircraft.
- b. Operational risk is defined and accepted by the service.
- c. Military certifications differ on the degree and coverage of the evidences needed. This is in general limited by contract, budget, lack of past legal liability and aircraft type and legacy.
- d. Acceptance of specific tasks and the risk levels can vary with aircraft purpose and type.

Military certification also differs from civil procedure due to the fact that military certification looks for induction of the aircraft into service use. The certification tasks also include vehicle performance evaluation and system qualification for induction into service. The induction clearance is given through issue of ‘release to service’ document. The general certification procedure follows the following routes:

- a. Approval builds up in a building block method.
- b. The first-level clearance includes qualification of component and equipment through lab-level test.
- c. The second-level clearance includes demonstration of systems’ performance through aircraft on ground tests and system simulations.

- d. Finally the aircraft-level performance is evaluated through flight test programme.
- e. A compliance document is prepared capturing the evidences generated through analysis, lab test, aircraft inspection, system integration test and flight tests.
- f. Finally a 'release to service document' is issued.

7.4 Military certifications in different countries

Military aviation is an important factor in security and defence preparedness of each state. All military airworthiness activities are conducted and regulated on a national basis, and in general most military authorities have not published military airworthiness design standards for an acceptable level of safety. In general for the military airplanes, the military specification and documents nominate some specified elements like:

- a. Handling qualities
- b. Weapons, ammunition stores and self-defence suites
- c. Specific operations in wartime
- d. Military role and mission and tasks

While the principle remains the same, the practices evolved in different countries over a period of time, differ from each other to a varying degree. The range of control over all the activities in design, development evaluation, and testing varies from total control to delegated system of working, with emphasis on contracts and penalties for shortfalls in performance, time and cost overruns [13, 14, 18–27, 29].

7.4.1 Military certification procedure in the United Kingdom

With effect from 1 April 2010, the Secretary of State (SofS) for Defence created the Military Aviation Authority (MAA) by charter as the single independent regulatory body for all defence aviation activities in the United Kingdom. The Director General of the MAA (DGMAA) is accountable to SofS, for:

- a. Providing airworthiness regulatory framework
- b. According airworthy clearance through certification
- c. Approving aircraft inspection process for the acquisition
- d. According airworthiness assurance of all air systems held in the inventory of defence aviation environment

Accordingly DGMAA prepares and releases regulatory publications (MRP) and has the authority to issue them on behalf of the SofS. The MAA has published the document 'RA 1500 – Certification of UK Military Air Systems'. This document has now been superseded by RA 5800 and RA 5820 [19–21].

7.4.2 Military certification procedure in America

According to the US Air Force (USAF) Policy Directive No. AFPD 62-6 on 11 Jun 2010 issued by the Secretary of Defense, the USAF is responsible for assuring the airworthiness of all the aircraft which it operates. The directive establishes policies for formal airworthiness evaluations to ensure that AF-operated aircraft are airworthy over their entire life cycle and maintain high levels of safety. This policy is implemented through USAF Instruction AFI 62-601, dated 15 Jun 2010 and supplemented on 12 May 2011. According to this AFI, a Technical Airworthiness Authority (TAA) and an AF Airworthiness Board (AFAB) have been created in the AF Materiel Command (AFMC) to provide independence in airworthiness evaluations. AFAB is chaired by the TAA. AFAB defines the requirement for *design-based (DB) airworthiness certification* and also provides *non-design-based (NDB) special flight release* of aircraft when design-based certification is not possible. AFAB provides acceptance of FAA certifications, evaluations and inspections and disestablishes the Airworthiness Certification Criteria Control Board (AC³B). Based on the technical evaluations, the Project Manager (PM) proposes one of the two possible alternatives of DB certification or NDB special flight release. The former one is the preferred approach, while the latter is chosen 'by exception' on unique aircraft or situations.

7.4.2.1 Design-based airworthiness assessment

The DB certification is carried out in stages of design evaluation, issuance of military experimental flight release and finally issuance of military-type certificates (MTC). Issuance of MTC indicates that aircraft design documentation accurately defines the configuration which meets the certification basis and the aircraft design is in compliance with requirement.

7.4.2.2 Non-design-based airworthiness assessment

A Non Design Based (NDB) assessment is conducted when it is found by the TAA that a DB airworthiness certification cannot reasonably be accomplished, but there is a compelling military need to operate the air system. On successful conclusion of NDB evaluation, the TAA may issue a special flight release. The NDB special flight releases process identifies and assess the inherent risks of operating these aircraft and the services formally acknowledge these risks during their flight operations.

7.4.2.3 Commercial derivative aircraft (CDA)

The USAF prefers FAA-type certification for newly developed military transport and CDA for USAF operation, when it is found that the criticality of military usage is no severe than the FAA-certified flight envelope and operational environment. FAA Form 8130-2 or 8130-31 can be used for FAA-type certification. CDA require the issuance of a MTC by the TAA. For this, FAA TC is used for the basic aircraft, and a compliance analysis is carried out with the approved military certification basis for items not covered by FAA (e.g. EW suits or other military appliances). MIL-HDBK-516 is to be used to define applicable military airworthiness certification criteria. CDA used in the USAF are to be maintained as per AFI 21-107: maintaining Commercial Derivative Aircraft.

7.4.3 Military airworthiness of Australia

In 2014, the Chief of Defence, Australian Defence Forces (ADF) and Secretary of Defence decided that the procurement and maintenance of all aviation fleet of

ADF be regulated to meet the requirement of Australian Defence Safety Objectives. DoD, Australia, issued Australian Air Publication AAP 7001.048, 'Defence Aviation Safety Program (DASP) Manual' on 30 Jun 2014. As per the above publication, the Chief of Air Force will be the 'Defence Aviation Authority'. He will be responsible for creating and implementing DASP. He will be supported by Deputy Chief of Air Force (DCAF) as Operational Airworthiness Regulator (OAR) and Directorate General Technical Airworthiness (DGTA).

7.4.4 Military airworthiness in Russia

The military aviation design and development and certification were carried out by various aviation design bureaus and manufacturing complexes. Military forces decide the operational requirements and release design specification. The aviation design bureaus and the manufacturing units carry out necessary designs to meet the requirements. The design bureaus take support from the state research institutes on aerodynamics and other aircraft systems. In fact the design bureau creates a number of alternate designs. The designs are evaluated, and the chosen design is then assigned to one or more manufacturing complexes. During D&D and manufacture of the aircraft, state standards GOST are to be used. The production and quality system 'Oboronsertifika' followed by the defence industries are similar to international quality standards like ISO, AS9100 [13].

7.4.5 Military airworthiness and certification in India

The Indian military airworthiness certification process has been modeled after the earlier British system. The system is based on concurrent design and clearance leading to eventual certification. This approach was adopted since the certification authority, viz. the Chief Resident Engineer (CRE), and the inspection authority Chief Resident Inspector (CRI) were co-located with defence public sector Hindustan Aeronautics Limited who is responsible for design and development (D&D). D&D milestones are agreed between the design and certification authorities, and the design is reviewed for safety and airworthiness by a team of experts. At appropriate stages, test procedures are examined and approved, and tests are carried out. The test results are reviewed for acceptance, redesign or retest. The CRE and CRI organizations have been changed to CEMILAC and DGAQA; however, the inspection and design certification procedure have practically remained the same.

However, this process conceptually differs from those followed in the United States and Europe, where both D&D and manufacture are delegated to approved design/production organization. The Defence Project Managers (PM) monitor the project progress. At mutually accepted major milestones, reviews are carried out as per the agreed documentation of the contract. The government, through the certification provision, holds the authorized personnel within the firm responsible for the airworthiness certification of the aircraft. In contrast, in India, CEMILAC and DGAQA interact with the D&D team on a day-to-day basis and carry out spot checks to identify design/production deficiencies during the D&D stage [3, 4, 13, 29].

MOD Document DDPMAS 2002 (Procedures for Design Development of Military Aircraft and Airborne Stores) guidelines are as follows. DDPMAS 2002 volume 2 is used as a procedure for certification of airborne software. These documents also lay down airworthiness assurance procedures during manufacture, overhaul and upgrade of military aircraft. The military airworthiness functions are shown in **Figure 9**, and aircraft certification procedure is shown in the block diagram in **Figure 10**.

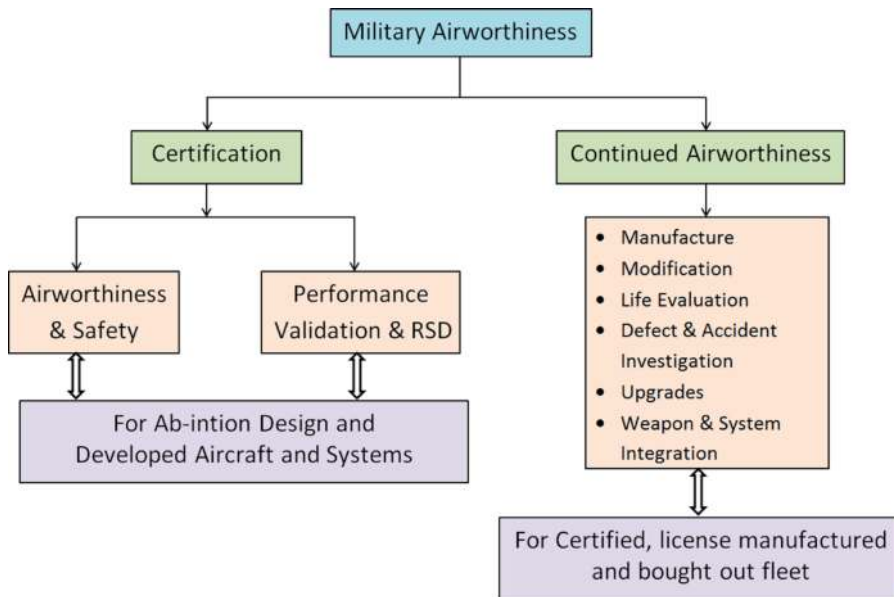


Figure 9. Airworthiness functions [13].

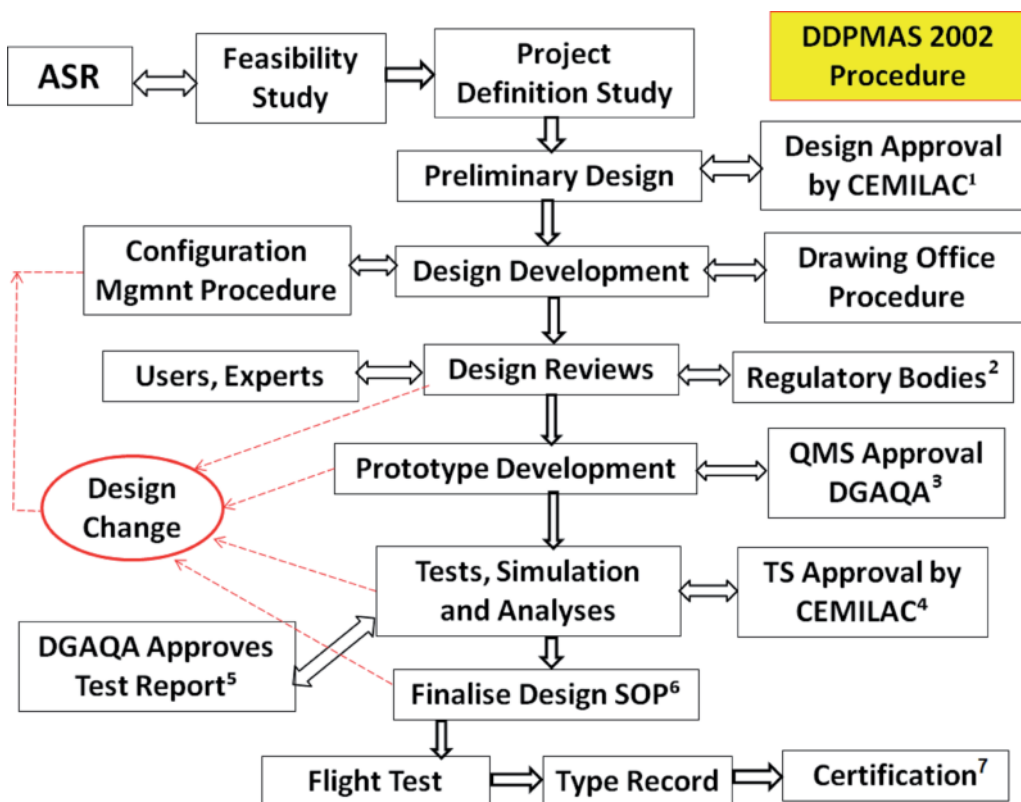


Figure 10. Certification procedure [13].

8. Conclusion

In the modern warfare, air power plays a very significant role in both offensive attack role and defending the country's land and water space. Judicious mix of

various types of combat and noncombat aircraft increases the war power of both army and navy. Competition to develop more effective air weapon is thus never-ending. Huge research effort is being spent on development of sophisticated military aircraft with precision navigation, weapon aiming and targeting along with improvement of air armament lethality.

Aviation is also associated with various safety issues. While in civil aviation, ICAO regulations take care of aviation safety issues of the member states, military aviation safety is controlled by each state according to their own military doctrine. To make military aviation safe, the authorities must exercise effective regulatory control during design and development, operation and maintenance of the military aviation assets.

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