Module 2

AIRCRAFT CHARACTERISTICS AND MANUFACTURERS

2.1 Classification of flight vehicles

- There are several ways to categorize the flying vehicles.
- A very good characterization has been done in Euromart, which illustrates four different axes of challenges:
    - the axes of speed (ex: Supersonic aircrafts, Interplanetary planes)
    - the axes of maneuverability (ex: Fighter jets)
    - the axes of efficiency (ex: Commercial airplanes) and
    - the axes of vertical take-off capabilities (ex: Helicopters)

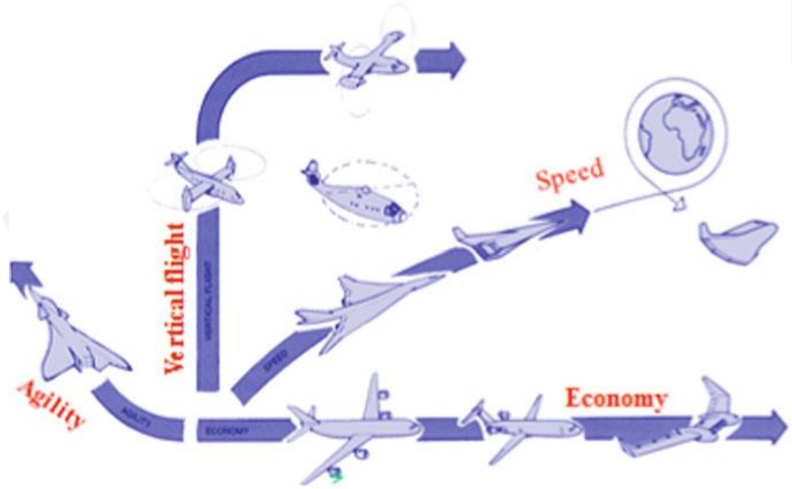
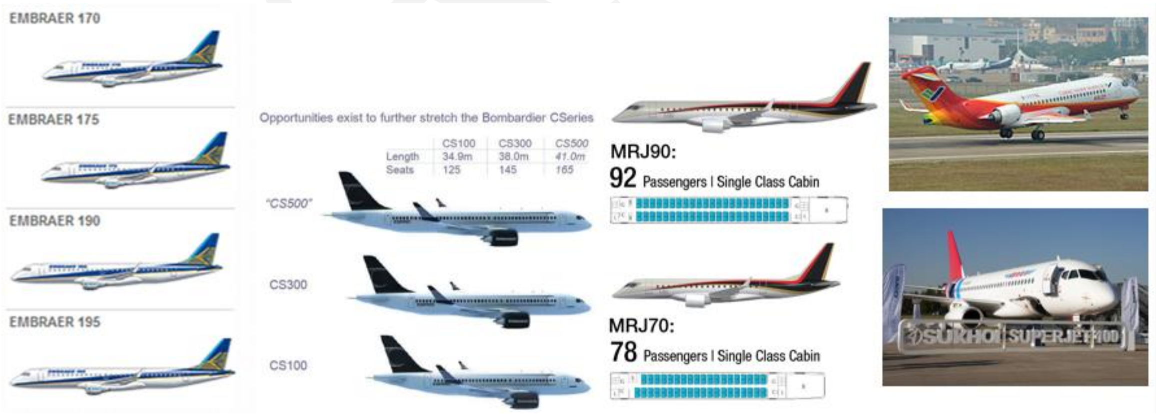


Fig: Classification of flight vehicles as per Euromart

- Another way of differentiation is following the different objectives of the users, who may use the aircraft for:
    - private
    - commercial or
    - military purposes.
- Further differentiate the types of commercial transport aircraft by:
    - Payload:
        - Passengers
        - freight and
        - mail/parcels

- ➢ Range:
  - o short-range SR (2500 nm)
  - o medium range MR (<5500 nm) and
  - o long range LR (>5500 nm)
- ➢ Speed:
  - o low subsonic (Ma < 0.5)
  - o subsonic (Ma = 0.6−0.9)
  - o supersonic (Concorde; Ma = 2.0) or
  - o hypersonic transport concepts (Ma > 3.5)
- ➢ Size:
  - o air taxi: up to 19 seats for passengers
  - o commuter aircraft (up to 100 seats)
  - o airliner aircraft (from *100 seats to 800+)

- From the global aircraft manufacturer, (Airbus—Boeing family concept) certain standardization has been achieved:
  - ➢ Regional Aircraft:
    - o Speed: Ma = 0.75–0.78;
    - o 70–120 seats
    - o Range up to 2500 nm
    - o Examples: Embraer E170-195, Bombardier CSeries, Mitsubishi MRJ, COMAC ARJ, Sukhoi SJ21



  - ➢ Short-range (SR) aircraft:
    - o Speed: Ma 0.76–0.78
    - o 100–200 seats
    - o range up to 3500 nm
    - o Examples: Boeing B737 family, Airbus A320 family

- Medium-range (MR) aircraft:
    - Speed Ma = 0.8–0.85
    - 200–350 seats
    - range up to 6500 nm
    - Examples: Airbus A330, A340, A350 and Boeing B767, B777 and B787

- Long-Range (LR) aircraft:
    - Speed Ma = 0.85
    - 300–800 + seats
    - range up to 8500 nm
    - Examples: Airbus A340, A350, A380 and Boeing B747, B777, B787.

2.2 Cabin design (Focus for the Airlines)

- The cabin is defining the volume and space for an airline, where the passengers can be integrated with their seats, their baggage, where toilets and galleys (kitchen) have to be integrated and where additional services during the flight can be provided.
- Here the airline can define and develop their individual “airline brand”, specific design concept, look and feel, cultural and regional characteristics, symbols and cabin atmosphere, where the passengers will feel at “home” and very comfortable.

2.2.1 Cabin Requirements

- From the aircraft manufacturer’s point of view, the main customers are the different airlines, operating the aircraft. They are purchasing the aircraft and they want to earn money with these flying vehicles. They are defining their specific requirements, i.e. size of aircraft, network which has to be flown (max and min range), airport constraints, environmental constraints, etc.

Table 5.1 Payload elements for the cabin (as seen by Airbus)

Level 1: Products with direct benefit for passenger and airline branding	Level 2: Products of special interest for crew, operations, airline branding
• Layout	• Lining (sidewall, ceiling, supply channel)
• Seat, bed	• Medical + emergency equipment
• In-flight entertainment IFE	• Carpets, non textile floor
• Lavatory, shower, wash room, etc.	• Cabin attendant seat
• Galley	• Galley catering (trolley lift, chiller)
• Hat rack; stowage	• Class divider (curtain,..)
• Lighting (mood light, reading light)	• Video surveillance
• Special cabin, social Area (bar, sales)	• Cargo loading system
• Communication, information system	• Crew rest area
• Humidification	• Cabin communication (attendant panel)
• Lower deck facilities	• Cabin work station
• Auxiliary equipment (magazine, baby)	• Colour and material
• VIP equipment	• Lining (sidewall, ceiling, supply channel)

- The passenger who is flying in the aircraft, who wants to feel comfortable and good in the cabin and who will express his opinion about the good atmosphere, ambience and comfort in the cabin or his dissatisfaction!
- As can be seen it is not so easy who will finally define the cabin requirements! But at the end it is the airline which defines the cabin to be attractive for their specific customers/passengers!
- The table 5.1 shows the main cabin elements, which are needed to define good cabin architecture, following the specific request for each airline and their national interests.

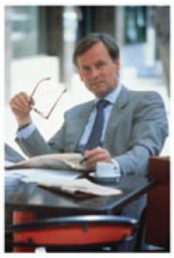
2.2.2 Passenger Requirements

- The passenger requirement will normally be defined by the different airlines following their cultural and national environment.
- On the other hand the aircraft has to fit to nearly all international airline requirements, so the aircraft manufacturer is already defining a certain standard of passengers out of statistical data in order to achieve a maximum of acceptance from the customer airlines afterwards.
- Generally, two groups of passengers can be defined:
  - Passengers, who are paying their tickets themselves. These are normally all private persons, who are travelling by private reasons (holidays, visit of family or friends, etc.).
  - Passengers, who are travelling on behalf of their company, the “business traveler”. He is characterized that somebody else—his company or an organization—is providing him with the ticket and wants him to travel from A to B in order to participate in meetings, discuss scientific or commercial items with customers.

Leisure

- Ticket price is of high importance
- 3 hours before check-in are accepted
- Flight is part of holiday adventure
- A lot of baggage (bike, surfboard, ...)
- Entertainment is very important
- Comfort could be better, but ....

Business



- Ticket price is less important
- Quick check-in (last minute)
- Minimise non-working time
- A lot of hand luggage
- Needs communication on-board
- Comfort and service are important

Fig: Passenger requirements (two different and opposite views)

- But these persons are then expecting a different service on-board. Either they want them during the flight to be connected (internet, email, phone) to their offices or to the outside world or they are using the flight hours to fully relax from all the busy hectic in the office and they just want to use the on-board time to concentrate on some strategic thinking or just relax, detente and sleep.
- All this has to be considered for these different expectations and the cabin items have to provide such wide range of service functionalities.

2.2.3 Reference Passenger

- People all over the world are having different personal sizes and geometrical dimensions. Each cabin design has to take into account that people are quite different in size, arm lengths, body dimensions, etc., and that seat arrangements and accessibility to overhead compartments, overhead lights, screens in front, etc., can easily be ensured for nearly everybody.
- The cabin designers are using therefore standardized persons from different continents and these standardized persons—a very small lady—5 percentile from Japan—and a very tall man—95 percentile of European Nordic men—are then taken for investigations with respect to accessibility, comfort, space volume, etc.
- A 5 % percentile women means, that only 5 % of the total population of this country (i.e. Japan) is smaller than the 5 percentile person. The 95 % percentile man characterizes a male person in this country/population (Northern Europe) where only 5 % of this male population is taller than this person.

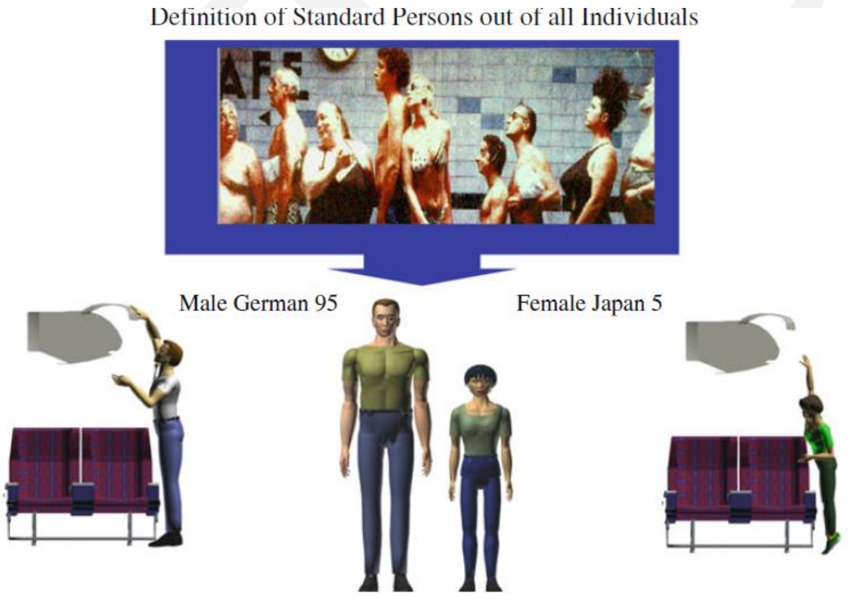


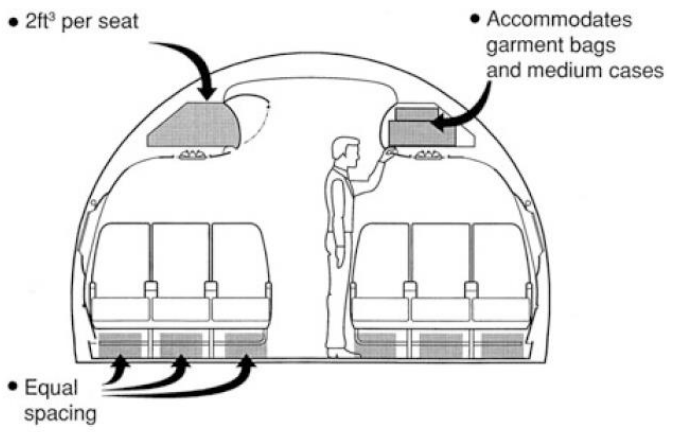
Fig. 5.3 Definition of standard passenger persons for cabin design

- With the physical data of these two fairly extreme persons, all detailed design studies of accessibility are undertaken to ensure that both persons
    - do have a chance to see in the overhead compartment and identify that no personal belongings have been left there,
    - can reach his seat without major disturbances and also be seated comfortably below the overhead compartment without any disturbances,
    - can see all information panels in front or above them and
    - can have access to the overhead buttons for light, service demand, etc.

2.2.4 Final Cabin Design

- Due to the need of pressurizing the fuselage for flights above 3000 m, the fuselage cross section is normally defined by cylindrical parts or a complete circular cross section (see Fig. 5.4). This leads to some compromises for the cabin interior.
- The cabin interior is normally designed to make best use of the available cabin floor space. Besides the seats several other important cabin elements have to be integrated which are also taking floor space as:
  - toilets,
  - galleys (including all kitchen-related aspects like refrigerators, coffee machines, coolers, pre-packed trolleys, etc.),
  - flight attendant seats,
  - storage space for cabin baggage, suitcases, coats,
  - coat storage (mainly for business and first class compartments),
  - door entrance clearances.
- For some of these items, the certification requirements demand a certain minimum of equipment, which is highlighted in Table 5.3. But certain line carriers are proposing a better standard to their customers and are exceeding these minimum standards as also can be seen in the same table.
- To get the maximum number of seats in the cabin, a lengthy iteration process is required to make optimum use of the available floor space and integrate as much seats as possible.
- For sure a certain standard of seat pitch, seat width has to be applied. An experienced cabin engineer is required to check the consistency of the final layout with the rules and the feasibility and acceptability of the cabin by the customers and certification authorities.

Fig. 5.4 Cabin space for a 6 abreast cross section



- Figure 5.4 is showing a typical cross section. This cross section is named as “6 abreast”, as there are six seats available per cross section with one aisle. Another nomination for the fuselage cross section is “Single aisle”, as it has only 1 aisle.
- In addition, the storage space for hand luggage is visible, mainly in the “hat rack” above the seats, but also below the seats in front of each passenger.
- It can be seen that this 6-abreast cross section is providing sufficient spare room for passengers, walking in the cabin. Smaller cross sections like a 3- and 4-abreast cross section (Fig. 5.7) are providing less cabin height in the aisle.

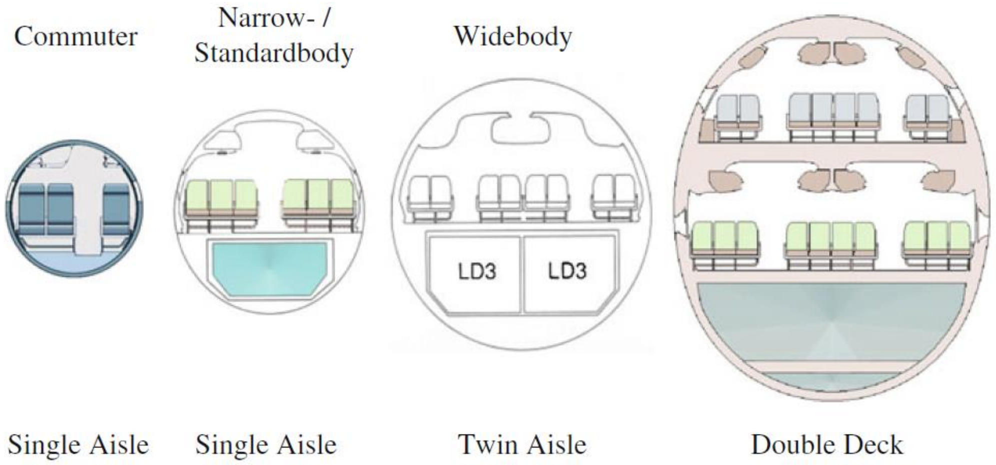


Fig. 5.7 Different aircraft fuselage cross sections and their characteristics

- Cabin comfort is a very important item, but always in direct conflict with the economic side of the configuration. The more comfort will be installed, the less seats will be available for a given cabin size.
- There is first of all the human factor of “comfort”, which includes:
  - Physical, psychological and emotional aspects
  - Individual desires, needs, fears
- Out of the comfort requirements, a technical cabin concept has to be defined which has to include the following elements:
  - Ergonomics
  - Safety
  - Industrial design
- The industrial design will have to include the aspects of:
  - clear shapes and design surfaces
  - optical clearness—interior space—comfort
  - avoiding the “tube effect”
  - lighting design for more spacious effect in the small “tube”, mood lighting

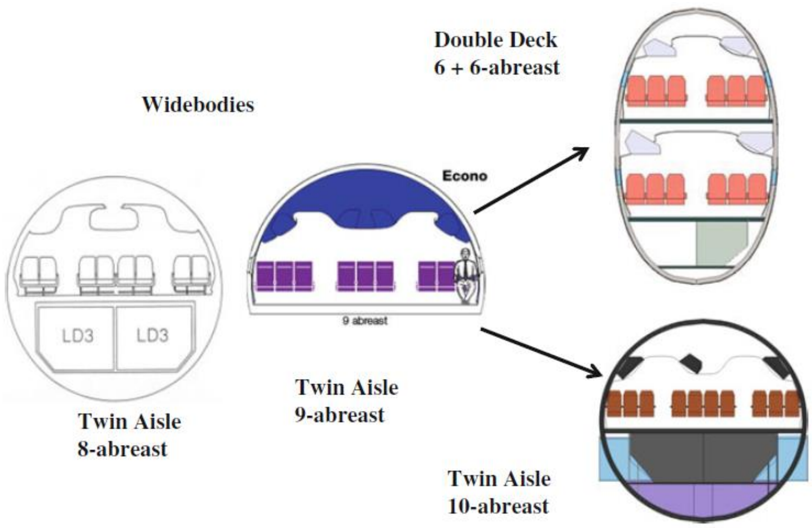


Fig. 5.8 Increase in fuselage cross section and related usage of volume

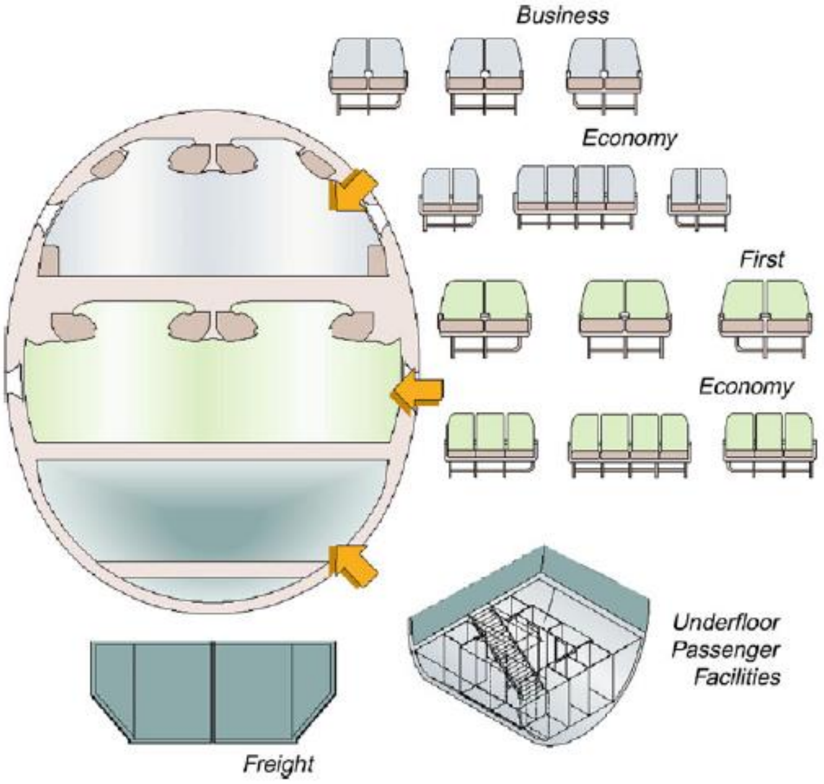
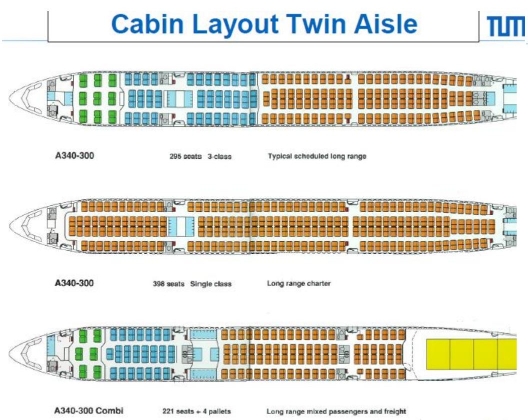
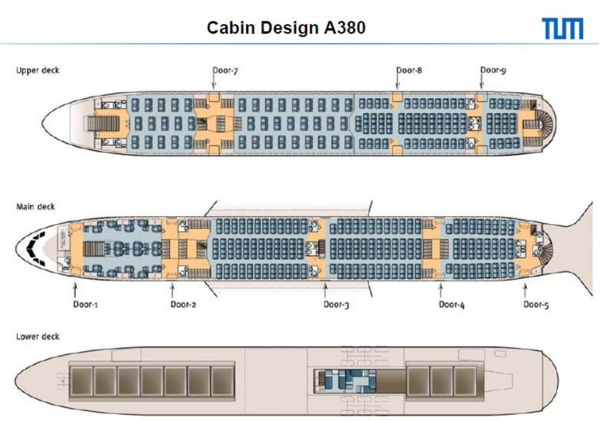


Fig. 5.9 Compromise of different class seats for the 2-deck configuration (A380)





2.3 Basics of Flight Physics

2.3.1 ICAO Standard Atmosphere

- The aircraft is flying in the atmosphere at different flight altitudes. It is therefore important to define the physical conditions of the atmosphere, their basic characteristics like temperature, pressure, and density as a function of the altitude.
- The ICAO has accepted the ISA Standard Atmosphere (ISA), which has been defined in the year 1975 by the ISO and is mainly developed and valid at the northern hemisphere in the range of 40–50º latitude. The measured and average values in this region have been chosen. ISA defines a linear decrease of the air temperature up to an altitude of 11 km.
- At 11,000 m the tropopause is located and fixed. The tropopause is an interlayer between the troposphere and the stratosphere. In reality the tropopause is not a fixed value at 11 km but changing the altitude as a function of the earth latitude (Fig. 5.12).

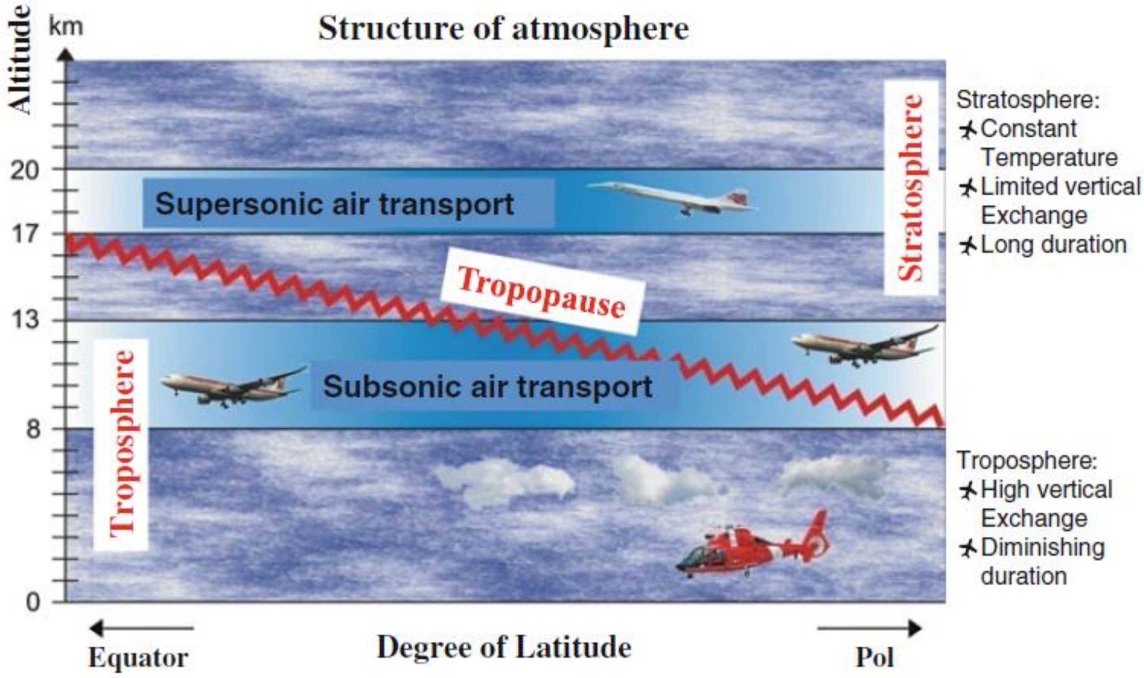
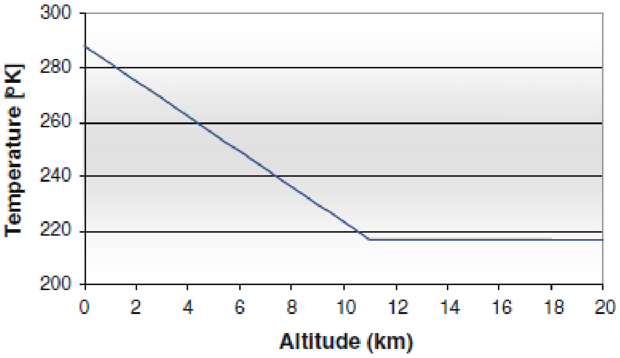


Fig. 5.12 Schematic view of troposphere and stratosphere versus altitude and earth latitude

- At the North and South Pole the tropopause is located at only 8000 m and at the equator the tropopause is located at around 17,000 m. The tropopause is not fixed at a constant altitude; it varies with the earth latitude. However, the ISA standard is assuming a constant point at 11,000 m.

- Above the 11 km threshold starts the stratosphere. The stratosphere is basically defined that the temperature stays constant above 11 km.



$H < 11000m:$

$$T(H) = 288.15K - 6.5K \cdot \frac{H}{1000m}$$

$11000m <= H < 20000m:$

$T = 216.65K$

- The troposphere is characterized by:
  - temperature is constantly decreasing with altitude up to the tropopause
  - High vertical exchange of air due to weather phenomena
  - Diminishing duration of local emissions at a certain position of input.
- The stratosphere is characterized by:
  - Constant temperature with altitude above 11 km
  - Limited vertical movement of air and low exchange rates
- Long duration of emission parameters in this region.

The temperature at sea level is defined with:

$$T_0 = 288.15\,\text{K or } 15\,°\text{C}$$

The air pressure at sea level is defined with

$$P_0 : 1013.25\,\text{hPa} \quad \text{or } 101325\,\text{N/m}^2$$

- Air pressure and air density are calculated as a function of temperature (Fig. 5.14). It is obvious that the density at altitude sea level (0 m) is around five times higher than the density at flight altitude (~11,000 m). But it also has to be mentioned that the speed is changing with temperature and Mach number is slightly decreasing with altitude.

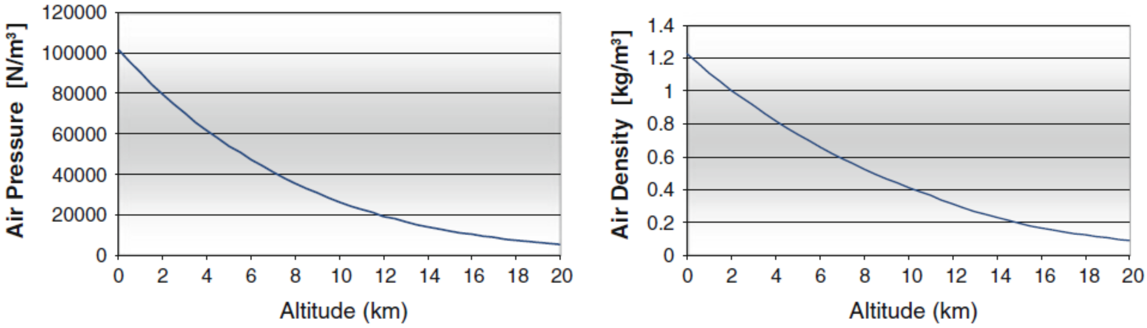


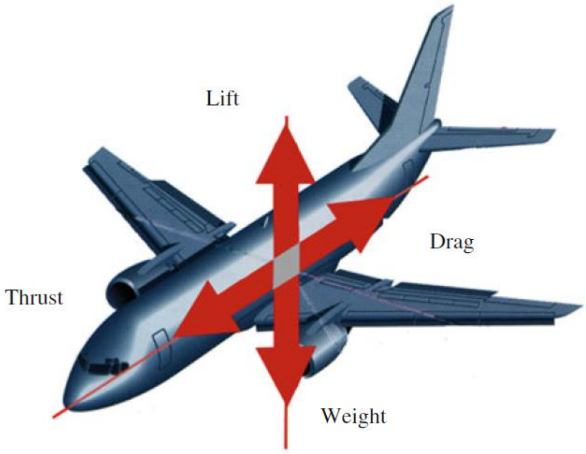
Fig. 5.14 Air characteristics pressure and density as a function of altitude (ISA) [21]

- If an outside temperature of 25º is measured, it can be transferred to a temperature ISA + 10, i.e. 10° above ISA at sea level. With this model, all temperature as function of altitude can be calculated with reference to ISA.
- Very often in specifications, airports with high temperatures and high altitudes (so-called hot and high airports) are referenced where the outside conditions can be, for example 40 °C and 2500 ft altitude. These data can be translated into ISA + 25º at 2500 ft.
- This information is very important for performance calculations. Especially, the engine thrust at take-off is a function of the outside temperature and air density. So it can happen that at airports with hot and high characteristics, the installed engine thrust may lead to some degradation for the take-off performance, which may mean at the end that the aircraft cannot take-off with full passenger load and full fuel tanks at certain outside conditions. This may lead in practice to a reduced payload or reduced fuel volume (reduced range capability) for the aircraft.

2.3.2 Aircraft Forces: Lift, Weight, Drag, Thrust

- To keep an aircraft flying in the atmosphere, a certain aerodynamic upward force is needed, the aerodynamic lift force, which is generated mainly by the wing of an aircraft. In addition a forward force to push the aircraft through the atmosphere is needed, which is called thrust, produced by the engine(s).
- The main forces acting on the aircraft can be described by the following four forces:
  - Lift generated by the wings of the aircraft
  - Weight of the total aircraft including the aircraft empty weight plus payload and fuel
  - Aerodynamic drag
  - Forward thrust of the engines

Fig. 5.15 Aircraft forces in horizontal and vertical axis



- If we consider a steady flight of an aircraft during its cruise phase, i.e. speed is and the flight altitude is constant, then the 4 main forces acting on the aircraft have to be in an equilibrium.
- In a simplified way, the lifting force of the aircraft is needed to balance the aircraft weight. L = W
- And the thrust has to be equal to the aircraft drag in order to fly at constant speed T = D

2.3.2.1 Lift

- An aerodynamic force on a body acting perpendicular to the relative wind.

$$L = C_L \frac{\rho}{2} v^2 S$$

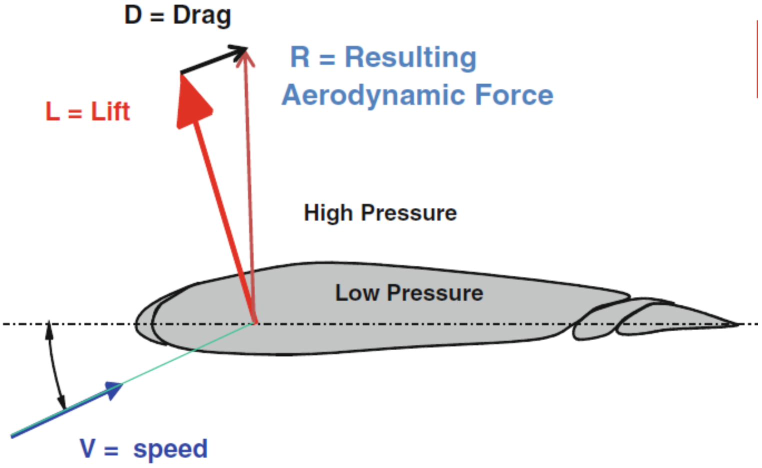


Fig. 5.16 Lift force as resulting force, perpendicular to the speed vector

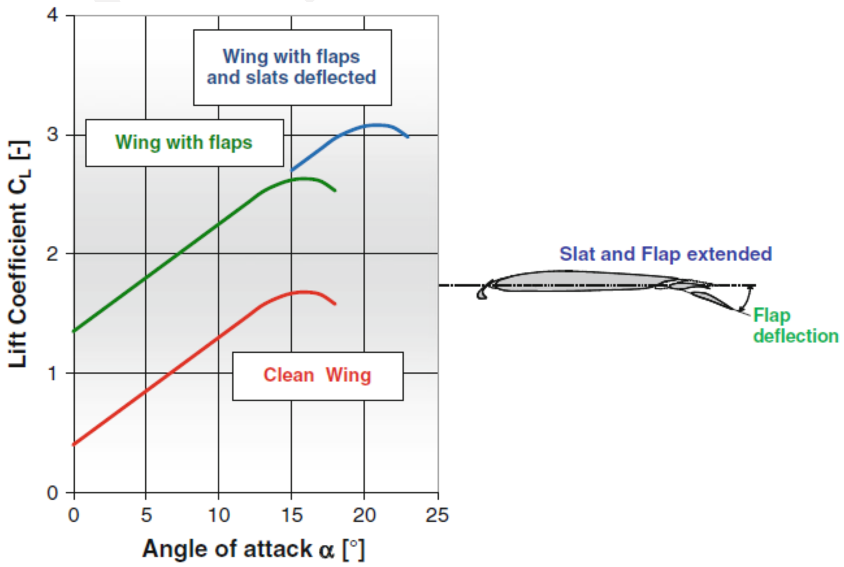


Fig. 5.17 Wing lift as a function of α and slat/flap position

2.3.2.2 Drag

- An aerodynamic force on a body acting parallel and opposite to the relative wind.

$$D = C_D * S * \frac{\rho}{2} * V^2$$

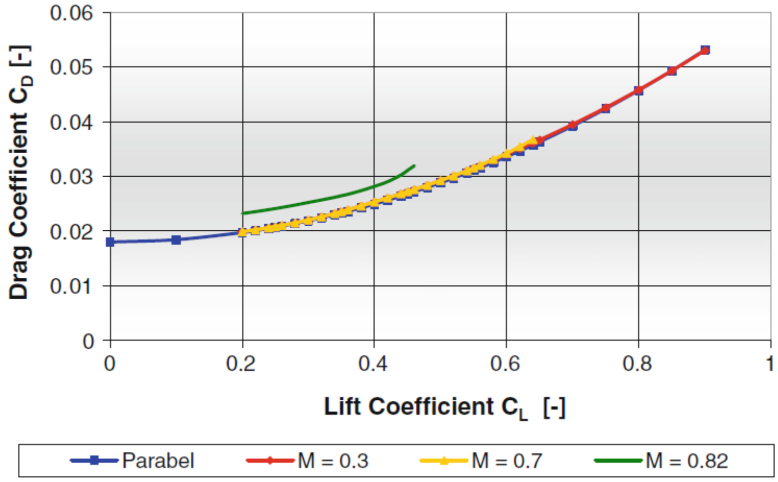


Fig. 5.18 Aerodynamic drag as a function of aerodynamic lift

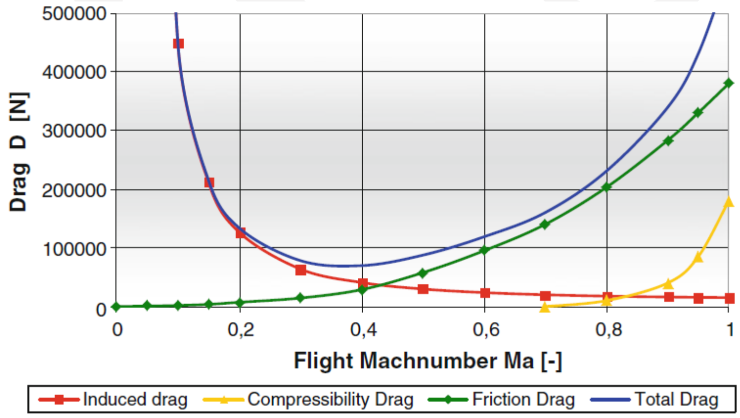


Fig. 5.19 Drag as a function of speed

2.3.2.3 Weight

- The force by which a body is attracted towards the center of earth by gravity.

2.3.2.4 Thrust

- A forward force which parallel the airplane through the air.

2.3.3 Aerodynamic efficiency

- There is another parameter; the aerodynamic quality of an aircraft, defined by the ratio Lift /Drag.

- During the different phases of flight (take-off, climb, cruise, descend) the aircraft is burning fuel and the mass is diminishing. This means, that the needed aerodynamic lifting capability is decreasing between climb, cruise and descend. Especially for a long-range flight, there is quite a big difference between the lift needed at the beginning of the cruise phase and at the end of the cruise phase.

Table 5.4 Aerodynamic efficiency for different aircraft types

Sailplane	~40–60
Commercial aircraft	~18–22
Military fighter	~9–10
Concorde (supersonic)	~7–10

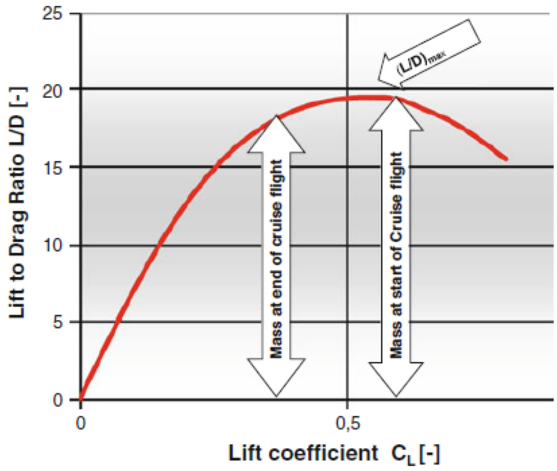


Fig. 5.20 Lift to drag ratio for optimum flight

2.3.4 Aircraft Mass Breakdown

- The aircraft total operating mass consists of four major blocks, which are important for the aircraft operation. These terms are correctly defined as masses of the aircraft.

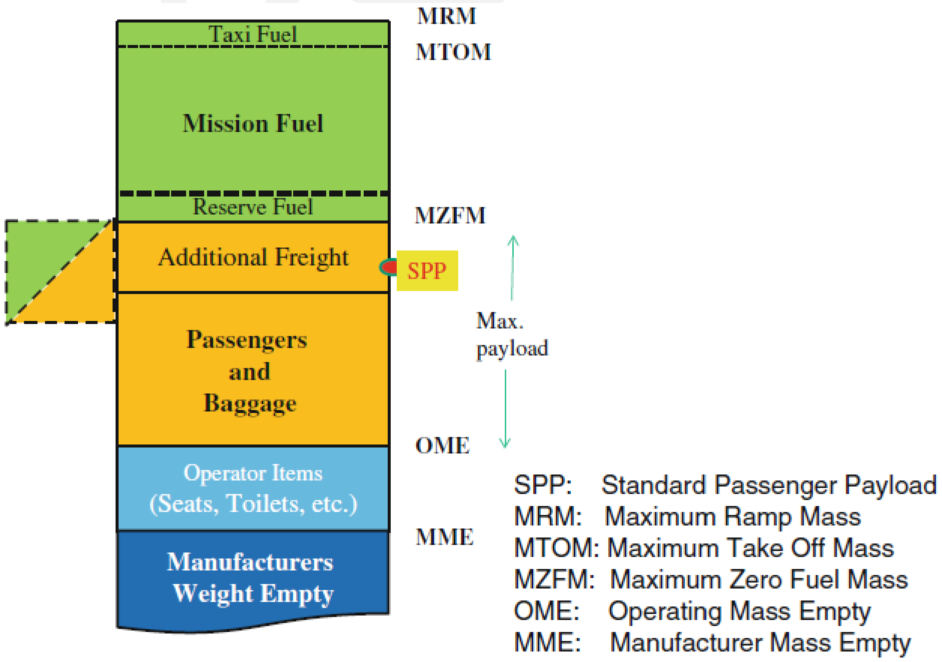


Fig. 5.21 Mass breakdown for a transport aircraft

- The most important aircraft mass terms are the following:
  - **MME: Manufacturer Mass Empty**

    The MME is defined by the aircraft manufacturer. It contains all elements of an aircraft, which are required by the authorities to operate an aircraft, including all masses for safety elements the two pilots, but without specific cabin arrangements.
  - **OME: Operating Mass Empty**

    The OME is defined by the MME plus all elements an airline (the operator) will define to provide a very comfortable cabin including seats, toilets, galleys, entertainment systems, etc., for their passengers. The OME includes also the cabin items. There is a certain minimum of cabin staff requested by the authorities. However, the airline can choose a much higher standard corresponding to the airline image. The OME is therefore defined by the individual airline and its comfort standard and differs from airline to airline.
  - **MZFM: Maximum Zero Fuel Mass**

    The MZFWM is based on the OME plus the maximum payload mass, which is allowed. The MZFM is defined by the aircraft manufacturer and is an important figure for the dimensioning of certain fuselage structural elements. The MZFM is fixed by the aircraft manufacturer and defines the maximum payload mass, which can be used for any operation. MZFM is defined by the MME plus the maximum payload mass including all operator items or in other terms, MZFM is the maximum mass without fuel.
  - **MTOM: Maximum Take-off Mass**

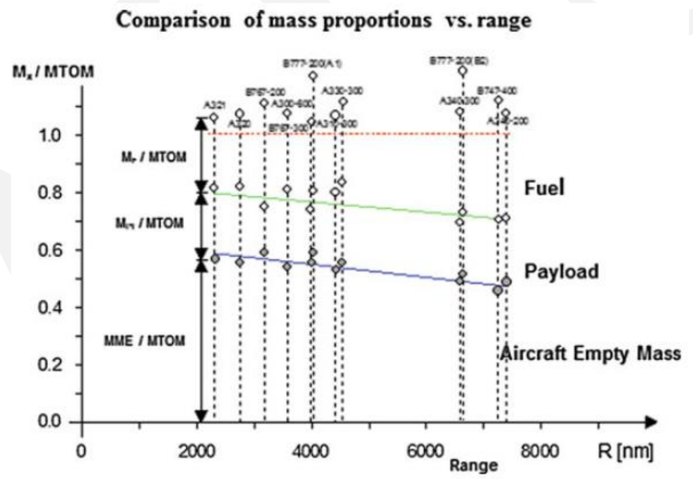
    The MTOW is defined by the aircraft manufacturer and indicates the maximum weight for the aircraft, just before take-off and this includes everything, the payload, the fuel and the MME.
  - **MRM: Maximum Ramp Mass**

    The MRM is fairly close to the MTOM, but it allows an operator to have a bit more fuel in his tanks, while the aircraft is still at the gate. This additional fuel is just a small amount of fuel, which will be needed to taxi the aircraft from the gate to the take-off position. At big hubs, sometimes the aircraft has to wait quite some time in a long queue before arriving finally at the take-off position. To compensate for this fuel needed for taxiing, the aircraft is allowed to have additional fuel in the tank, the MRW. At the take-off position the MTOM should not be exceeded.

- **SPP: Standard Passenger Payload**

  The SPP defines a mean passenger payload, which normally includes different classes in the cabin. It is taken from airline statistics and is a mixture of several airline standards. For this standard payload, a certain flight range can be defined, the standard range, given in the aircraft brochures.

- As can be seen in Fig. 5.22 payload and fuel are normally taking 20 % each of the total aircraft weight. For long-range aircraft, the fuel proportion increases to 30 %.
- Another typical value is given by the "Wing loading"
  - Wing loading is defined as ratio : MTOM/S
  - where S is the reference wing surface of the aircraft.,
- The wing loading describes, how many kg of weight will be lifted by 1 m2 of wing surface.



Typical payload and fuel proportions of weight for different aircraft

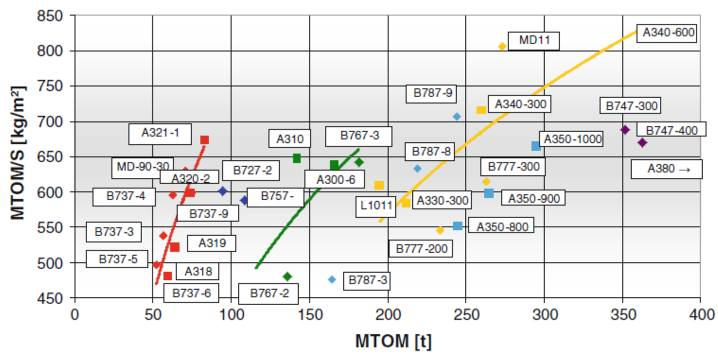
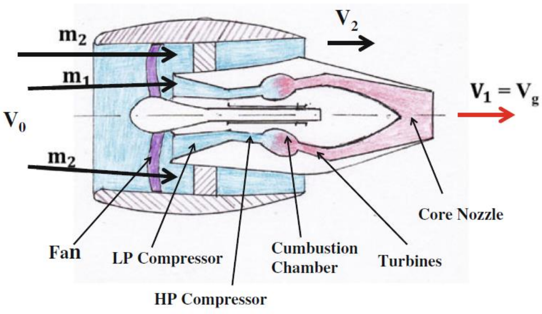


Fig. 5.23 Wing loading for several transport aircraft

A typical value for wing-loading MTOM/S for all transport aircraft is in the order of 500–700 kg/m^2 (see Fig. 5.23).

2.3.5 Thrust Requirements

- A propulsive force, called thrust is needed to overcome the aerodynamic drag in cruise flight. The thrust should at least be as large as the drag, even a bit bigger in order to have some excess power, needed for acceleration and for maneuvering and control.



Schematic representation of a turbofan engine

- The engine thrust can either be achieved by increasing the mass flow, increasing the difference between exhaust and entrance speed or increasing the bypass ratio.

$$F = \frac{(\dot{m}_f + \dot{m}_0)\dot{V}_e - \dot{m}_0 V_0}{g_c}$$

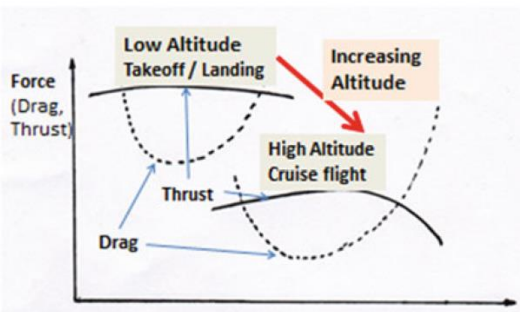
- The ratio between the cold outside flow (fan flow) and the inner hot flow (gas generator) is called the bypass ratio:

$$\text{Bypass} - \text{Ratio BPR} = \frac{\dot{m}f}{\dot{m}g} = \frac{\dot{m}_1}{\dot{m}_2}$$

- The efficiency of a modern jet engine is measured by its “specific fuel consumption (sfc)”. The unit is given in kg fuel/N thrust and per time (sec). The smaller the sfc value, the better the engine efficiency.

$$SFC = \frac{\dot{m}_f}{F}$$

Fig. 5.27 Relation of thrust to drag in different altitudes



- The jet engine development is still continuing at very high and complex level.

- The main routes for further improvement is the increase in pressure ratio, the increase in temperature ratio and the increase in bypass ratio.
- Temperature and pressure increases are the themes for engine specialists.
- The bypass ratio is an interesting engine design parameter, which has been constantly increased over the last 50 years.

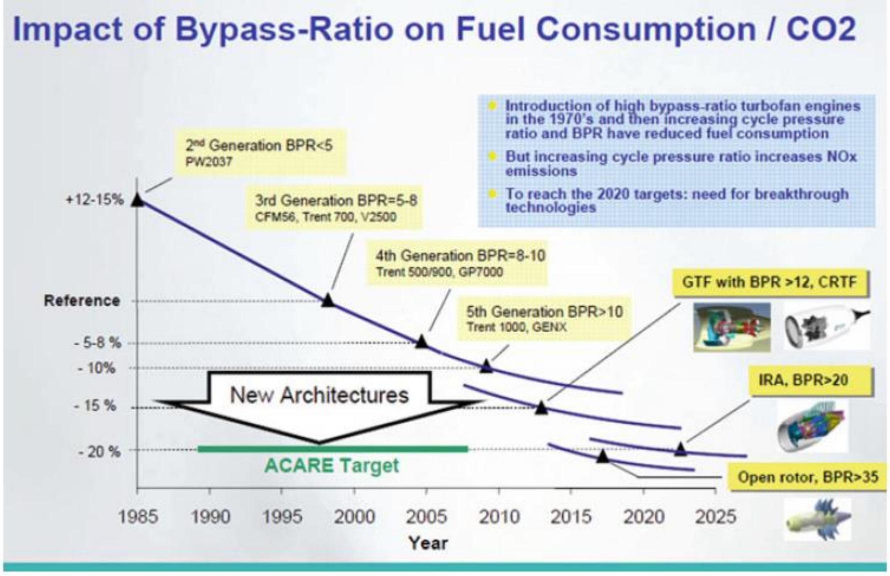


Fig. 5.25 Influence bypass ratio (BPR) versus fuel burn (SFC) (*Source* Rolls-Royce)

2.3.6 Aircraft Stability and Control

- The aircraft has in general 6 degrees of freedom, 3 axial degrees and 3 rotational degrees.
- The forces in longitudinal (thrust and drag) and vertical axes (Lift and weight).
- In addition to the movement along the three axes, there is also the possibility to use the rotational degrees of freedom and turn the aircraft around all 3 axes.
- The movement around the lateral axis is called the “pitch movement”, necessary for take-off and landing, when the aircraft needs to be rotated around the lateral axis.
- The rotation around the longitudinal axis is called the roll movement. Roll movements are needed to change flight directions and start a roll maneuver.
- The rotation around the vertical axis is called “Yaw movement”. This movement is also used—in combination with the roll movement—to change direction of flight in all altitudes.
- In order to produce control forces, the aircraft needs specific control surfaces, which—when deployed during flight—will provide a lift force at the control surface and this force will then act as a force or moment around the centre of gravity of the aircraft and allows the aircraft to be maneuvered in the air space.

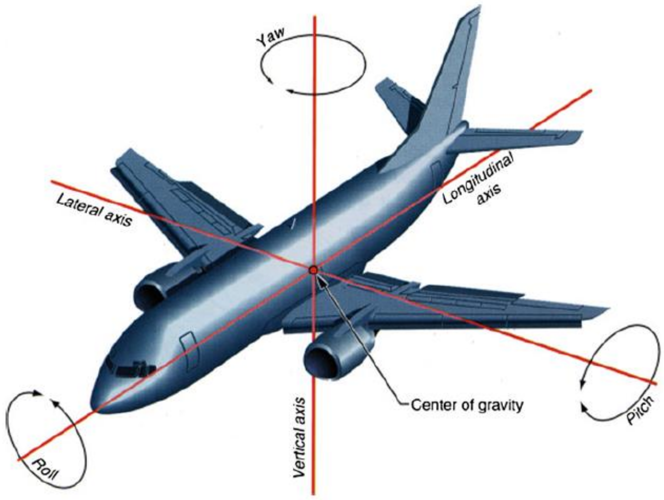


Fig. 5.28 Six degrees of aircraft movement

- Primary control surfaces are the elevator for pitch control, the ailerons for roll control and the rudder for yaw control.
- Secondary flight controls are the
  - high-lift surfaces, i.e. slats and flaps
  - the horizontal tailplane, which is movable and used for trimming the aircraft
  - the airbrakes and spoilers.

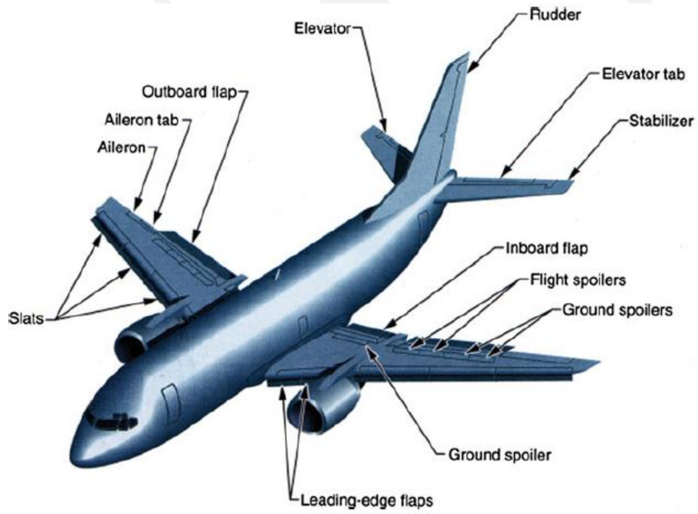


Fig. 5.29 Primary and secondary control surfaces for aircraft control

2.4 Structure, Mass and Balance

2.4.1 Structural Components

- Each aircraft structure consists of six major elements:
  - The wing for generating the lift
  - The fuselage to integrate the payload (passengers and cargo)
  - The tailplane to control the aircraft during all flight phases

  - The engines to provide sufficient thrust during all flight phases
  - The undercarriage, to allow the aircraft to taxi, take-off and land on ground
- The cockpit to provide the pilot with all necessary data and allow the control of the aircraft, which is normally put in the front fuselage to provide sufficient pilot view.

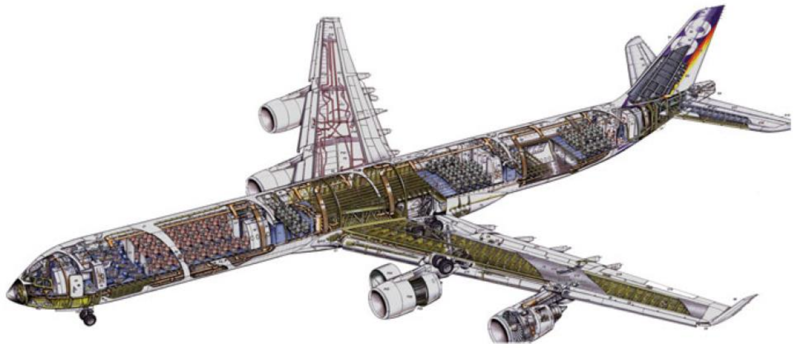


Fig. 5.30 Structural aircraft layout

- Light weight structures are an important element in the aircraft design. As has been indicated in the Lift chapter, the less aircraft mass will be needed, the less lift is necessary and less drag will be generated, reducing the engine thrust and thus improving the fuel burn.
- The basic primary structure consists of aluminum alloys, where different and specific alloys are used for wing surfaces, fuselage primary structure and tailplane structures.
- Very promising classes of material are Carbon Fiber Reinforced Plastics (CFRP), which are not only used in the secondary structure but also in the primary structure. The amount of CFRP in the aircraft structure has increased from 5 % in 1985 (A310) till today (B787 and A350) to over 50 %.
- However, there are also major risks involved to prepare the CFRP technology to such a mature level that the automated manufacturing will provide all the cost benefits expected.

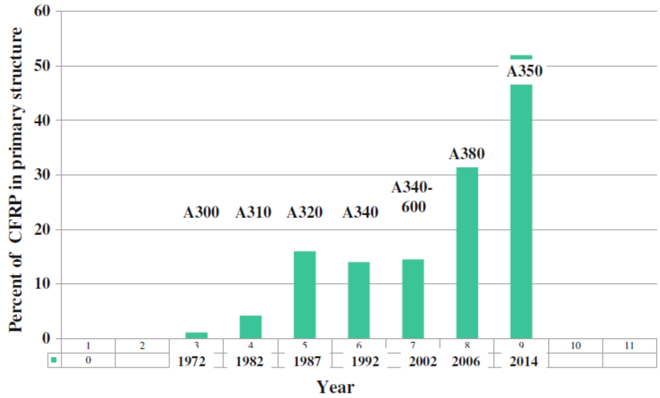


Fig. 5.31 Evolution of composite structure due to time

2.4.2 Mass Breakdown

- The aircraft weight consists of mainly four major elements as outlined in Sect. 2.3.4.
- The statistics identify clearly that for short range aircraft (Range up to 3000 nm) 60 % of the weight consists of the aircraft empty mass (MME). 20 % is linked to the payload and the other 20 % are fuel. For the long-range aircraft, fuel weight increases up to 30 % and the relative part of MME reduces to 50 %. These are just weight proportions.
- It is clear that the total aircraft weight increases considerably for long-range aircraft. 30 % of fuel for a long-range aircraft like A380 means that there are nearly 200 t of fuel possible.

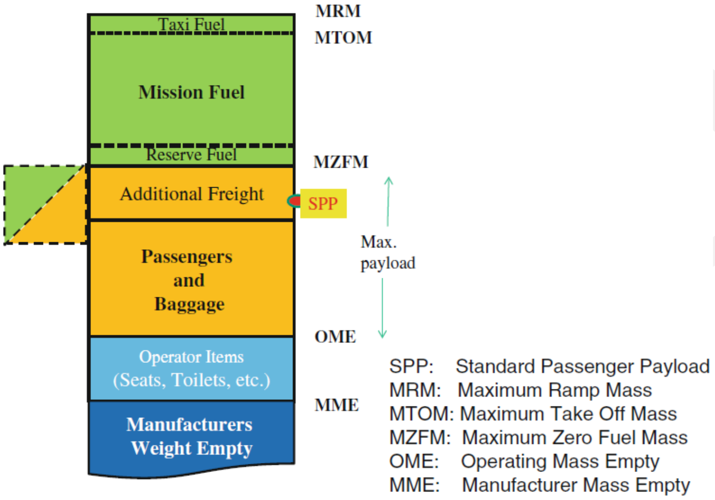


Fig. 5.21 Mass breakdown for a transport aircraft

2.4.3 Payload—Range Diagram

- It describes the capability of an aircraft, which payload it can transport across which range. It is a basic aircraft design parameter, and is fixed—out of market studies—at the beginning of an aircraft programme.
- The wing size is an important factor, as the wing box is usually the natural fuel reservoir. The bigger the wing the more fuel volume can be stored. The bigger aircraft have naturally more range due to their larger wings.
- The typical payload—range diagram has three characteristic borders: There is a maximum payload border, which is defined by the aircraft structural design. With all the fuel, which can be put as a delta between MTOM and MZFM, the aircraft can fly a certain range.
- For safety reasons, the aircraft has always to load a defined quantity of reserve fuel, which in all normal situations has still to be in the fuel tank when landing. So for

the useable fuel the aircraft can fly with max. payload a range, defined as "Max. payload range".

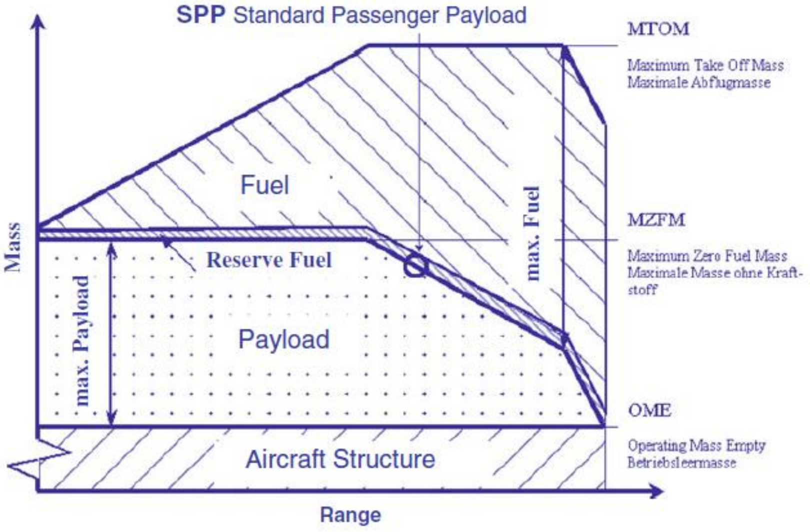


Fig. 5.32 Typical payload—range diagram for an aircraft

- But all aircraft normally are designed in a way, that full payload and maximum fuel volume are exceeding the certified MTOM. So with full payload the aircraft cannot use all the fuel volume capability.
- But the aircraft operator can choose to either fly the aircraft with full payload over a shorter distance or with less payload over a longer distance.
- Figure 5.32 shows the second border—named the MTOM limit in the payload range diagram—where a longer range can be flown with reduced payload. This goes up to a limit, where the full fuel volume will be used and only a limited payload can be transported. The aircraft can still be operated for higher ranges, by further reducing the payload.
- As there is less lift needed, the induced drag is also reduced, less engine thrust needed, which will reduce fuel consumption and will further increase the aircraft range. This third border of the payload range aircraft is called the "maximum fuel limit".
- This does not make real sense for commercial flights, but for specific events—a flight with just some journalists for a specific long range mission or for a ferry or transfer flight of an aircraft—the aircraft can fly with no payload still further.
- The additional range is relatively small and is achieved as the aircraft mass will then be OME + Mfuel, which is less than MTOM.
- The payload range diagram is defined for each transport aircraft. It is defined without wind. For a realistic flight, the pilot or the airline will calculate the required

fuel by defining the flight trajectory, defining the available payload, using actual wind conditions, defining some safety margins and using the performance data of the aircraft.

2.4.4 Weight and Balance

- Another important feature for the aircraft operation is the calculation of the Centre of gravity (CG) for each flight mission.
- For each aircraft, the CG boundaries are defined. There exists a limit for the rear CG location, which is called the stability limit. This rear CG position is close or slightly before the “Neutral point” of the aircraft. (“neutral point” is explained as point in the aircraft centre line, where the aircraft lift is acting as integral force).
- The forward CG limit is defined by the controllability of the aircraft. The CG boundaries of an aircraft are fixed so that there is sufficient CG margin for all reasonable loading cases for an aircraft.
- But if these are chosen very widely, this will lead to bigger control surfaces and reduce the aircraft performance parameters. So again a compromise between good overall performance and sufficient and reasonable flexibility for operational loading with also some restrictions has to be defined and accepted.
- For some special loading case—passengers mainly in the rear cabin (no business class passengers, but economy class is full!) all cargo also stored in the back—the aircraft overall CG position may be pushed so far back, that this could lead to a very rear loaded aircraft, which may cause violations of the boundaries for loading and will not be allowed.
- But there is an easy solution to first fill the forward cargo hold and put the rest of the cargo in the rear cargo part. As can be seen, the CG loading capabilities allow fairly flexible solutions.
- But there are always some cases—full front or full rear loading, where the critical limits can be achieved and restrictions may arise.

2.5 Flight Performance and Mission

2.5.1 Flight Envelope

- The flight envelope is a diagram, which defines the flying envelope of the aircraft with respect to speed and altitude. The basic information here is that the aircraft should never fly too slowly or too fast. The proper speed as a function of altitude is essential.

- There is a lower limit in the flight envelope (the left side), which is defining the aerodynamic limit. If the aircraft has not enough speed there will be not enough lift to keep the aircraft weight in balance for flying.
- This aerodynamic limit is also linked to the stall characteristics of the wing, where the wing cannot generate more lift even with higher angle of attack. This aerodynamic limit is a clear border not to fly too slowly and enter into a dangerous situation.
- The other extreme is the right border of the flight envelope. Here the aircraft is not allowed to fly faster or increase the maximum speed for a given altitude, as the aircraft structure will reach its design limits.
- The right hand side has two different limitations, but they are fairly similar in their importance. At lower flight levels (in Fig. 5.33 up to 25,000 ft altitude) there is a speed limit defined by VTAS (true air speed) expressed in knots (kts). At higher altitudes the speed limit is expressed as “maximum Mach number” which never should be exceeded.

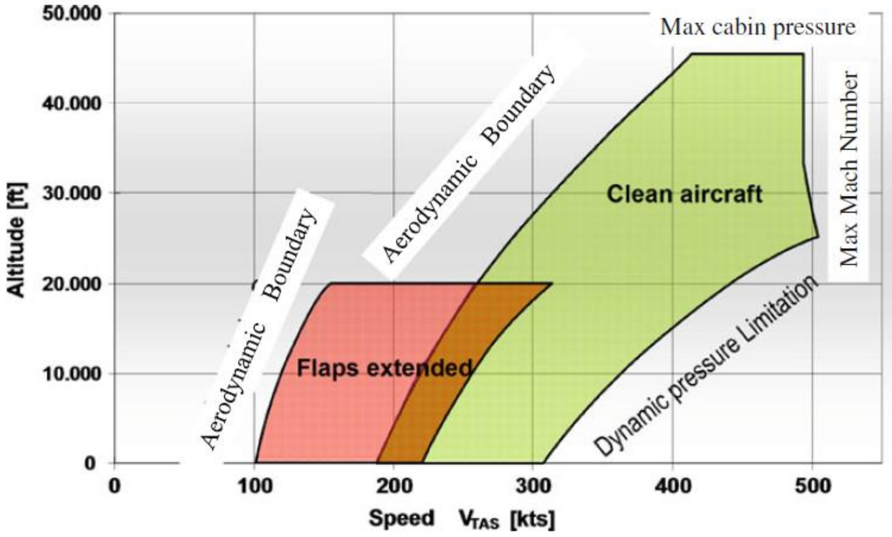


Fig. 5.33 Flight envelope of a transport aircraft

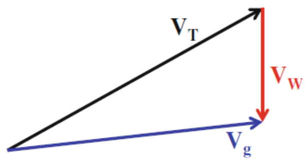
- There is also a design limit in altitude for each aircraft. This can be either an engine limit or it can be defined by the internal cabin pressure. The cabin pressure cannot be less than 8000 ft of ISA.
- In the aircraft design a maximum altitude has to be fixed similar like the minimum cabin pressure. The delta between the maximum altitude and the minimum cabin pressure is an important design parameter during the aircraft optimization process.

- The flight envelope is defining the operating limits in altitude and speed, where the aircraft can be safely operated.
- Figure 5.33 is also showing an area (rose colour), where the high-lift system can be operated. Without any high-lift devices the aircraft could only land at airspeeds of 200 kts and more, where it is very difficult for the pilots to handle the landing process.
- With the flaps and slats operative the aircraft can take-off and land at nearly half the speeds compared to the clean aircraft configuration.
- The operation of flap setting or retracting is therefore limited to a small corridor of speed and altitude and clear procedures are defined for each aircraft, at which speeds and altitudes these transitions have to be done. These data are given in the Flight Crew Operating Manual (FCOM).

2.5.2 Definition of Speed

- The definition of speed is slightly complex, as there are very different speeds for the aircraft operation. The aircraft forces lift and drag and all the aerodynamic characteristics are very much depending on the speed relative to the vehicle.
- The airspeed sensing on-board of an aircraft is done by a pitot system, which has the capability to measure the static pressure and the total pressure and by providing this information to the air speed indicator, the airspeed can then be calculated.
- The measurement of speed is done by a pitot tube, fixed on the aircraft which is sensing the oncoming flow and its total (stagnation) pressure. In parallel, the static pressure is measured at the static board and the difference is giving the measured "Indicated Airspeed" named IAS.
- The directly measured airspeed needs some corrections before it is accurate enough to be used in the aircraft control systems. The Pitot tube is normally too closely linked to the front fuselage of an aircraft and a correction factor is needed to take into account the ratio of measured speed at the pitot tube compared to the free stream speed.

Fig. 5.34 Wind and flight direction



V_g = speed over ground
V_W = speed of wind
V_T = true air speed

- This correction is normally not very large, as the aircraft manufacturer tries to place the pitot tube at a position which requires only small installation corrections. The other corrections needed to achieve the true airspeed or the speed over ground are the following:
  - Indicated Airspeed IAS, directly measured airspeed
  - Calibrated Airspeed CAS, i.e. IAS corrected for compressibility effects
  - Equivalent airspeed EAS, i.e. CAS corrected for pressure at sea level
  - True airspeed TAS, i.e. the reference for a safe operation
  - Ground speed GS, i.e. correct the TAS with the wind effects
- TAS is the final true airspeed, used in all performance calculation and all flight planning and mission monitoring exercises.
- Another method of obtaining speed and position are GPS sensors and the Inertial Navigation System (INS). The INS system measures all accelerations and decelerations of the aircraft using gyroscopes and linear accelerometers. This information can then be integrated in time to obtain speed and position.

2.5.3 Flight Mission

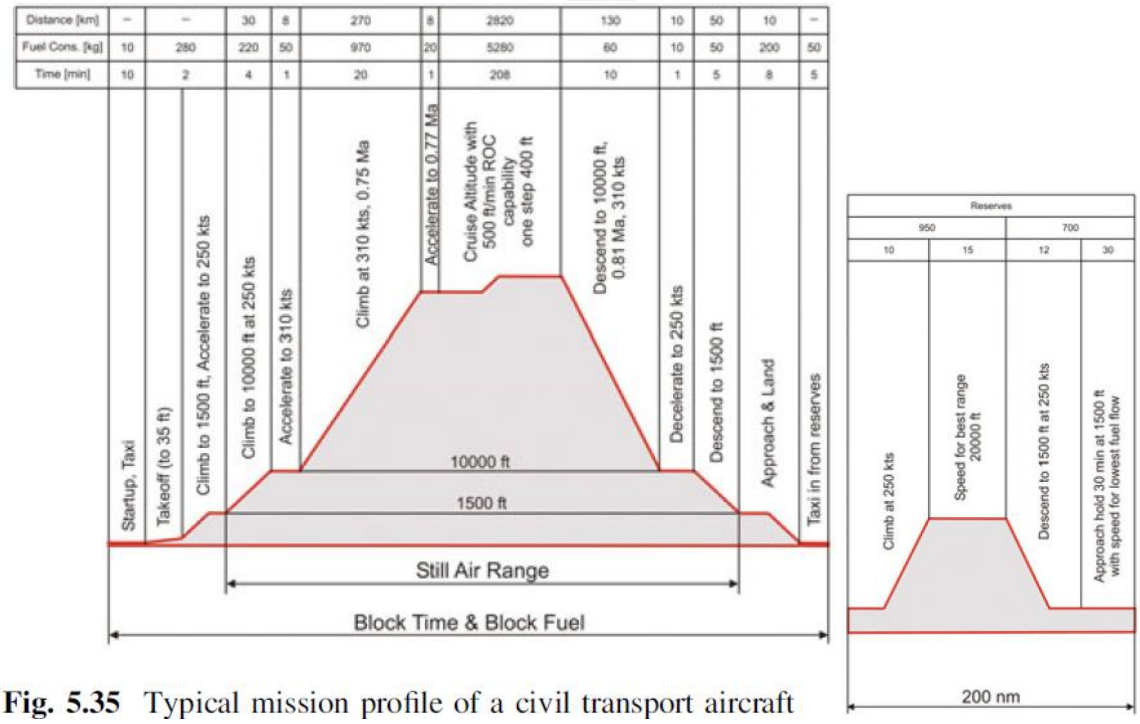


Fig. 5.35 Typical mission profile of a civil transport aircraft

- The flight mission of an aircraft contains all steps from leaving the gate at the airport of departure till arriving at the gate of the destination airport.
- For each of these phases, it is possible to define the given speed, which allows deriving the time at the end of this phase and the distance travelled in this phase. In

addition the necessary thrust setting can be derived from the aircraft performance handbook and with the thrust setting, the fuel flow for each element can be calculated.

- As shown on top of Fig. 5.35, there are time, distance and fuel consumption for each phase calculated and the sum leads to the total distance, total mission time (block time) and the block fuel needed for this mission.
- All calculation is done for a situation without wind. Wind can be favorable (tail wind) or unfavorable as head wind and may change these given numbers. For each realistic mission, the pilot will calculate these data, using the actual meteorological forecast.
- Reserve fuel has to be calculated for the unexpected situation, that the runway of the destination airport is blocked and the aircraft has to divert to the next other airport in the vicinity.
- In the example, a distance of 200 nm has been assumed. But for each real flight planning the nearest alternate airport has to be chosen and the calculated fuel has to be taken on board in addition. This should ensure that the aircraft can always land safely. The pilot may also add some fuel margin for expected holding patterns, depending on the normal situation of the destination airport.

2.5.4 Take-off and Landing

- The aircraft manufacturer are providing in their FCOM and performance manuals all necessary data to calculate take-off and landing distances. There are several rules defined in the certification regulations from FAR and JAR, how these minimum take-off and landing distances have to be calculated.
- The aircraft could have an engine failure during the take-off acceleration.
    - If this engine failure occurs before a critical speed V1, the pilot has to decelerate and stop the aircraft on the remaining length of the runway. The breaking power has to be sufficient to do so and this has to be demonstrated during the certification process.
    - In case, the engine failure occurs after the critical speed V1, the pilot has to continue to take-off and the full thrust of the remaining good engine(s) has to be sufficient to take off the aircraft, climb at a minimum glide angle of 1.2° and return back to the airport for landing if needed.

- When the altitude of 1500 ft is achieved, the engine thrust will be reduced from max. Take-off setting to max Continuous thrust, the flaps will be retracted and the "clean" cruise configuration for the further climb phase will be cleared.
- Today most of the normal airports are providing runways with sufficient length (3000–4000 m), where even the very big aircraft can be safely operated with full payload and MTOM. But there are still a lot of smaller and specific City airports where there are several constraints for aircraft to take off with full payload.
- Critical are also airports, which are situated in regions with a hot climate and at high altitudes. These airports—known as "hot and high"—may also cause restrictions for the airlines, as the engines will not provide full take-off thrust under these conditions and this may lead to restrictions in the maximum payload or in the fuel load needed for long ranges.

2.5.5 Cruise Performance

- **Specific Air Range**
  - Specific air range (SAR or SR) is defined in nm/kg fuel.
  - It is a measure to compare cruise performances of different aircraft types and for different aircraft flight conditions.
  - SAR specifies how many nm the aircraft can fly with 1 kg of fuel.

$$\mathrm{SR} = \frac{V}{\mathrm{sfc} \cdot T}$$

where
sr defines the specific range (nm/kg of fuel burnt)
T defines the thrust level
sfc defines the specific fuel consumption
V defines the actual cruise speed

- **Breguet Formula**
  - The Breguet formula is very often used in aircraft design and aircraft performance comparison.

$$R = -\frac{L/D \cdot V}{\mathrm{sfc} \cdot g} \cdot \ln\left(1 - \frac{m_{\mathrm{Fuel}}}{m_1}\right)$$

With the following parameters:

R aircraft range
M aircraft mass in kg
m_1 aircraft mass at the beginning of the cruise flight
$m2$ aircraft mass at the end of the cruise flight
m_{fuel} mass of fuel used in cruise in kg
V aircraft cruise speed
L/D Lift to Drag ratio
sfc specific fuel consumption.

2.6 Aircraft Manufacturer

- **The role of the aircraft manufacturer** and the industrial supply chain is very important in the air transport system.
- The industry is responsible for the major innovations in the air transport sector, if it is the introduction of new aircraft designs (A380 and B787) or the introduction of new cockpit architectures or navigation systems, which are also interchanging with some other players like the airlines, the air navigation system or the airport infrastructure. New aircraft concepts, new aircraft cockpit architectures, new navigation systems, new engine concepts and new aircraft technologies can only be introduced via the industrial side.
- In the past, nearly all innovative features have been pushed by the industry in order to improve their competitive situation with their customers, the airlines. This can be shown by two examples:
  - The introduction of the B747 in the beginning of the 1970s was leading to a major problem at the airports, as they were not properly and early enough informed that a new large aircraft vehicle had to be handled by the big airports. Major modifications at taxiways, gate positions, etc. were necessary to accommodate these new big aircraft types. A new aircraft class for airports had to be introduced. To avoid a similar surprise when Airbus announced the introduction of a new big aircraft, the A380, the airport association ACI had fixed a new category F with the famous 80m×80m×80ft box, which should not be exceeded by any new aircraft design.
  - Another example is the introduction of the standard glass cockpit and the "fly by wire"—concept for the A320. The real major benefit for all operators has been only realized later, when the big benefit on the cost side became visible, like reduction of crew cost, training cost, simulator cost, etc. It was not obvious by the view of the airlines that these new cockpit technologies will not have some additional risk and a lot of airline pilots were heavily opposing.
- The launch of a new aircraft program like the development of the A380 from Airbus or the B787 from Boeing is a major investment for the aircraft manufacturer. The cost estimation for the development of the A380 have been said in the press to be in the order of 12 billion $ without taking into account the interest for the

investment. With interest, Airbus is supposed to have spent for the A380 program in the order of 25 billion $. Even the upgrading of the A320 program with the introduction of new engines and some small airframe adaptations will cost around 4–5 B$!! No normal commercial company can take such a risk, as the return on their financial investment (ROI) will only start to happen after about 15 years.

- There are only two solutions to overcome such a commercially critical situation:
  - The national government has to provide a financial guarantee in case of risk
  - The risk has to be shared between a lot of other shareholders (engine manufacturers, supply chain, system suppliers, etc.)
- In reality, both solutions are normally combined: the national government has to provide some financial guarantees and several risk sharing partners are integrated into the program.
- In the airliner market (aircraft with more than 120 seats) there are today only two aircraft manufacturers active and successful,
  - The Boeing Company from the USA and
  - The Airbus SAS Company from Europe.
- In the market of regional airliners and aircraft up to 130 passengers, there is starting a new and strong competition between seven companies:
  - Bombardier/Canada: CRJ 200/700/900 and the new project CS100
  - Embraer/Bresil: EJ 170 – 195
  - Sukhoi/Russia: Superjet – 100
  - UAC/Russia MS-2
  - Mitsubishi/Japan MRJ
  - AVIC/China COMAC
  - Alenia + partners GRA
- In this 100-seater market are too many new entrants and there will be a very hard and competitive situation. Some countries will see this design of an 80–100 seater only as the first step and entry card to develop the own industry further into the big airliner market. This is assumed to be the case for China and Russia.

2.6.1 Industry Mergers

- During the 1960s and 1970s started a wave of industrial regrouping and concentration in the civil market.

- The first steps were done in the US where Lockheed in 1981 left the civil aircraft market and McDonald Douglas was integrated into the Boeing Company in 1997, leaving only one company for large civil transport aircraft in the US.
- Figure 6.1 shows the integration of the aeronautical industry in Europe within a period of 10 years, in order to achieve a reasonable company size. Most changes were done in two steps,
    - First step to align the national strength by merging the national companies into a single unit (ex. In Germany is the creation of DASA in Germany).
    - In second step, a European integration was started with the merger of Aerospatiale, DASA and CASA into the new EADS consortium. In 2014 the name EADS was changed into "Airbus group", to use the brand of airbus for all other aerospace activities.

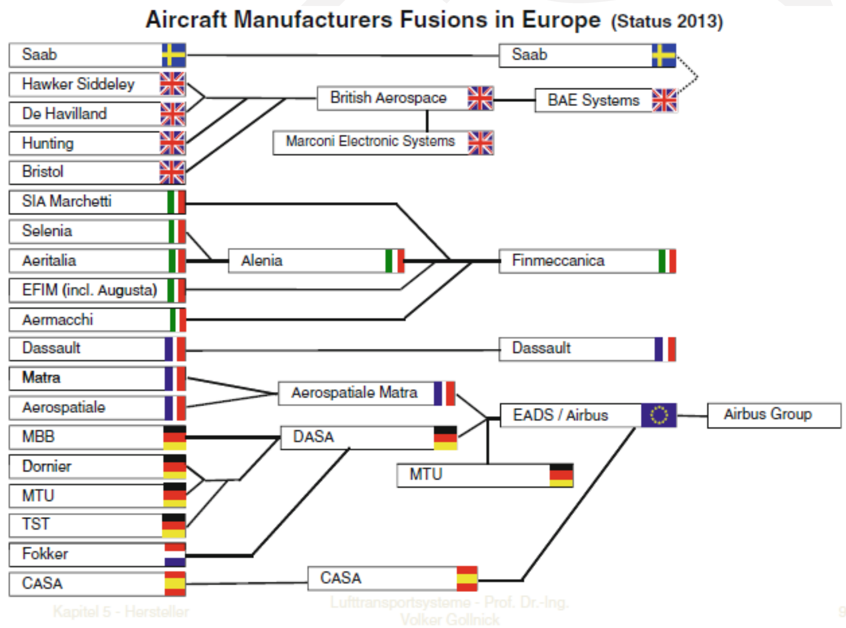


Fig. 6.1 History of aerospace mergers in Europe

- It can be seen that there is in Europe a concentration of aerospace companies in France, which is part of the French national industrial strategy. The aerospace industry was always seen in some countries like USA and France as a strategic industry, where besides the military side also the civil side was seen as a strategic complementary part to the military autonomy.

2.6.1.1 Market Duopoly "Airbus versus Boeing"

- The civil aircraft market for aircraft bigger than 100 seats is today dominated by two manufacturers: Boeing and Airbus.

- They have in total a fairly similar market share, in some sectors a 65–35 % share in others a 35–65 % share, but in total, both are at about equal level and airlines and leasing companies are interested to keep this head-on competition in the magnitude of 50–50 % and keep a strong competition of these two players.
- The following Fig. 6.3 is showing the standardization of the aircraft program in Europe.

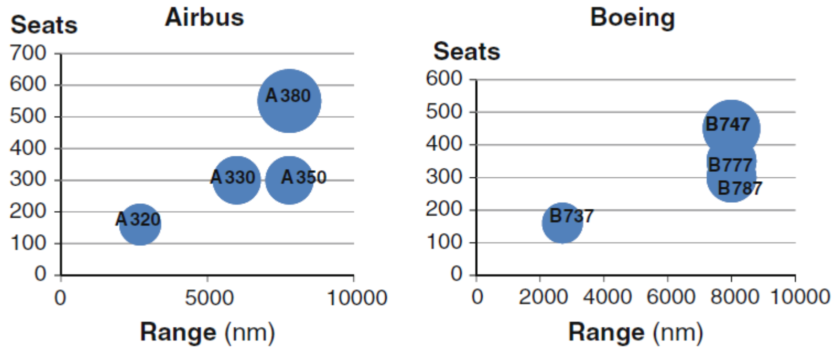


Fig. 6.3 Airbus and Boeing aircraft family in 2015

- The aircraft families—as well from Airbus as from Boeing —are covering the whole range of aircraft sizes between 100 and 700 seats and a range of 2500 nm till more than 8000 nm.
- Both families show a clear tendency:
  - small aircraft are only designed for short range missions
  - the bigger aircraft have considerably more range.
- This follows a clear engineering paradigm: Small aircraft with a certain technology need an optimum wing size, which allows naturally a fuel volume for normally 3000 nm. Taking the same technology standard the wing size in [m2] increases roughly with the number of passengers. The fuel, stored in the inner wing section, is increasing with the additional volume, i.e. with fuel volume ~ (Wing size) $^{3/2}$. This is normally defined as “Square–Cube law”, allowing larger aircraft to have more fuel volume and thus more range.

2.7 Industrial Organization

- An aircraft manufacturer company is acting as overall system integrator. Very often this is also named as Overall Equipment Manufacturer (OEM).
- The system integrator is necessary at the top level of the aircraft industry and has the overall responsibility for the product. In this role the system integrator has at least to

  - specify the aircraft
  - market the aircraft
  - final assemble the parts into a complete aircraft and test it
  - integrate the different component and aircraft elements
  - certify the aircraft and give guarantees for its performance
  - act as a single interface to the customers (airlines)
  - ensure a lifelong support to all flying aircraft.
- In order to reduce the financial risk, the aircraft manufacturer is interested to find some strong financial partners, with whom he will/can share some technical, commercial and financial risks.
- Obvious risk sharing partners for the aircraft manufacturers are:
  - Engine manufacturers, where the engine is worth about 30 % of the total aircraft price.
  - Supply chain companies, be it from the structural side or the systems side.
  - Financial investors from the airline side (Leasing companies, airlines, etc.).
- The operational side is normally not a candidate for risk sharing. They prefer to stay independent from the different manufacturers. The obvious risk sharing partners are therefore mainly partners in the production chain.
- Figure 6.4 is providing a rough scheme of the supply chain structure. Three main blocks are outlined:
  - the aircraft structure,
  - the systems and
  - the propulsion units.
- In order to keep the management of all the detailed parts at a reasonable level, there are different levels of suppliers.

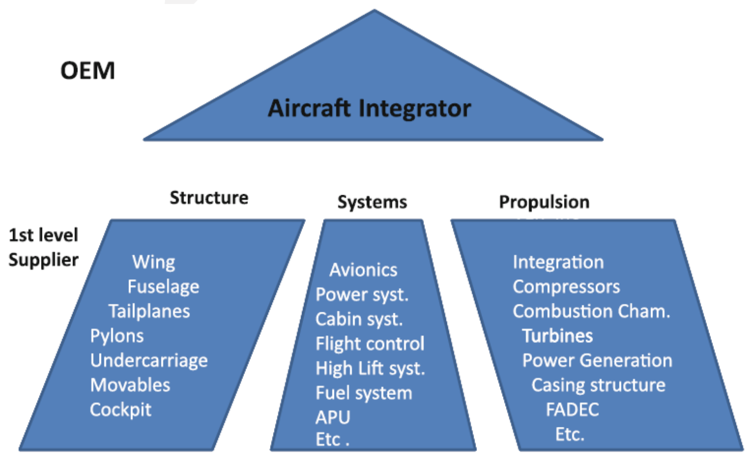


Fig. 6.4 The supply chain in the aerospace industry

- The first level suppliers are strong and large companies who have strong competencies in
    - Engine design
      – Combustion part, turbines, compressors, generators, systems
    - structural component design
      – wing, fuselage, tailplanes, undercarriage, cabin interior
    - system design.
      – Hydraulics, electrics, avionics, environmental system, flight controls, etc.
- The level 1 supplier (sometimes also called "tear 1 supplier") can provide a complete section (wing, tailplane, etc.), a propulsion component or a complete subsystem design (hydraulic system, environmental system, undercarriage, etc.)
- These first level suppliers are organizing themselves also in a way to have some component suppliers (level 2 suppliers) and those will have some lower level suppliers for detailed components, subsystem elements or specific services.

2.8 Development Process (From Idea to Product)

- The aircraft development process is fairly complex and it needs a lot of very experienced persons to keep the right balance between good standardized processes and flexible structures for further innovations.
- Figure 6.5 specifies the four main aircraft process domains, which are:
    - Research, technology development and Innovation
    - Development of a new aircraft
    - Production of aircraft
    - Product support for the flying fleet.

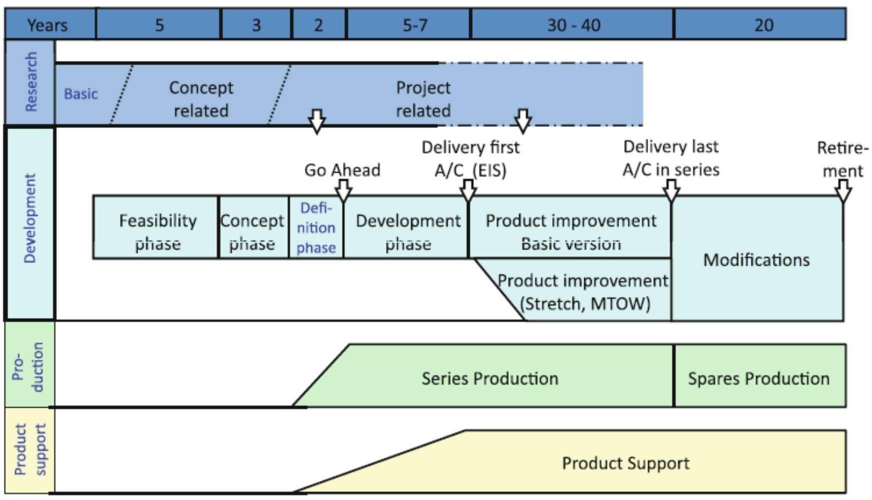


Fig. 6.5 Typical life cycle of a civil aircraft program

- Research is and should be a continuous process. Research has to cover the wide range of basic research up to project related research. Research can be grouped in different "Technology Readiness Levels", so-called TRL's.
- The aircraft development process is normally divided into three main phases:
  - The predevelopment phase, also called product definition or definition phase
  - The real development phase, characterized by bringing the aircraft from the virtual definition into a real built and certified product
  - The continuous improvement development process, leading to upgrades and recovery of definition deficiencies.
- The predevelopment phase, often also named as product definition phase can again be subdivided into three phases:
  - Feasibility phase
  - Concept phase
  - Definition phase.
- The Feasibility phase is the first part of a new aircraft development process, where still all possible aircraft concepts are open, i.e. engine location, wing sweep (forward or backwards), fuselage cross sections, tail design, under carriage, etc.
- The Concept phase, which follows will deepen the selected concept in such a way, that the all essential aircraft parameters will have to be specified precisely (cabin diameter, wing area, wing sweep, tail size, door concept, cockpit philosophy, system architectures, specifications for all subsystems available, etc.).
- The Definition phase, which lasts about 2 years, will refine all definitions to such a detail, that the build process (production phase) can be launched immediately after.

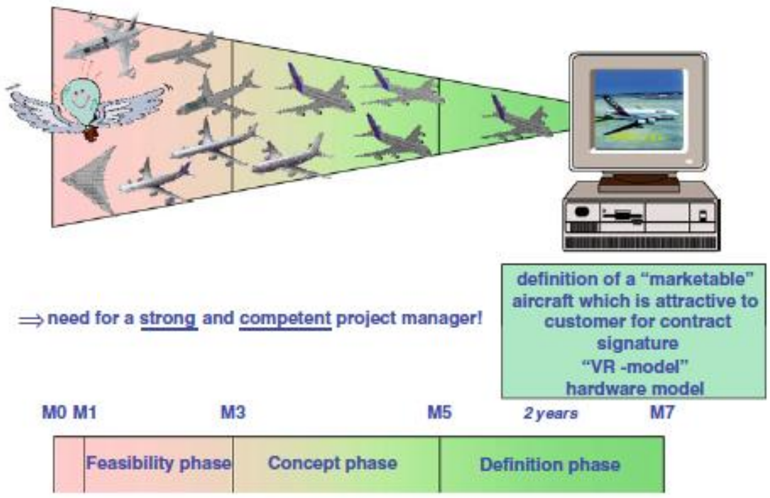


Fig. 6.6 Product definition phase—from the first idea to a valid aircraft definition

- In the Development phase, all detailed drawings for the manufacturing process have to be prepared, the main suppliers have to be selected, big investment for all the
- New production facilities have to be done, the production concept and the final assembly concept and place, where all the big parts will be assembled, has to be fixed.
- The production process starts already parallel to the product definition and development phases.

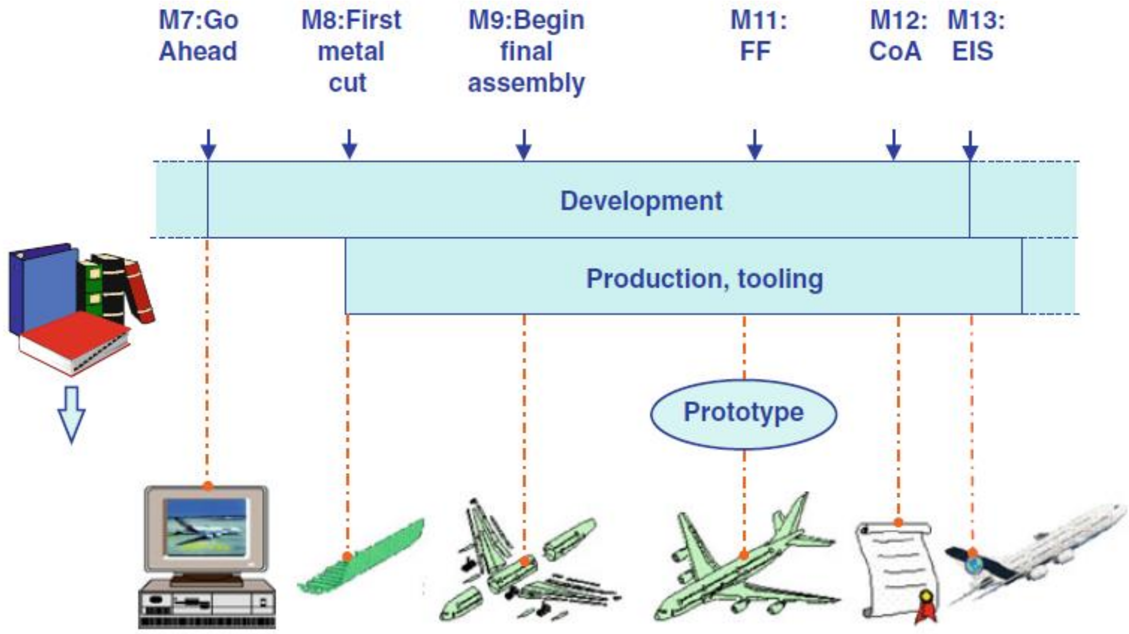


Fig. 6.8 The development phase—from aircraft launch to "Entry into service"

- Development and production are linked today much closer than in the past. Design and production feasibility are closely linked to achieve the weight and cost targets for each aircraft component and all equipment items.
- As major aircraft components, and system equipment will be developed by partners a clear definition of the aircraft, the production process as well as all interfaces has to be developed. Competent and knowledgeable partners have to be identified and a "Make or Buy"—policy has to be established upfront.

2.9 Production Process and Work Share

- The aircraft is a very complex product with several millions of different parts. In order to manage the complexity the total amount of work, the tasks for the engineering development, for the production of the components, for flight testing and certification etc. have to be defined. For the aircraft production a certain A/C decomposition in components, elements, parts and services, etc. has to be done.

- Figure 6.9 is showing the main production work sharing of an aircraft (A321) and also the main contractors who will produce individual components of the aircraft.
- Table 6.1 is showing one possible Breakdown structure for the production parts. Here all aircraft components are identified; each component is then broken down in the major level-1 parts and each level-1 part broken down further in the corresponding level-2 parts etc.

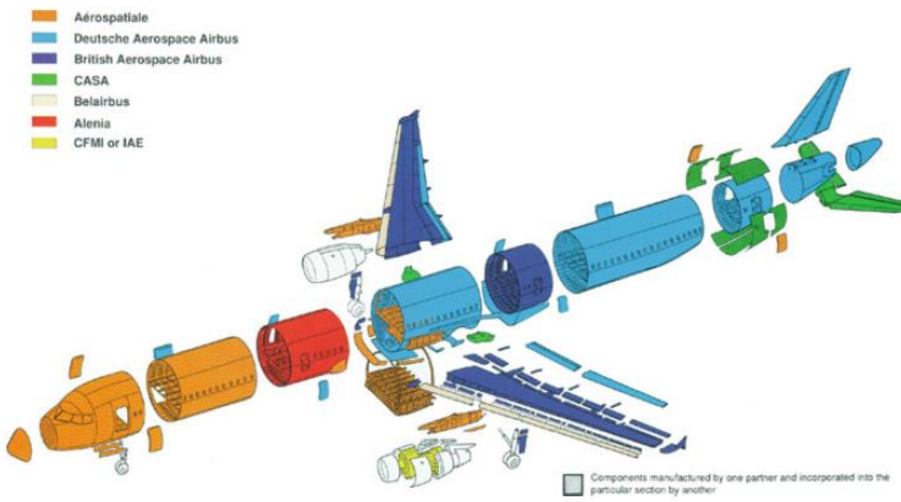


Fig. 6.9 Typical production work share for a new aircraft program (example Airbus A321)

- The General Cost Breakdown Structure includes besides the major hardware components additional cost elements (Fig. 6.10).

Fig. 6.10 Typical Aircraft component breakdown structure

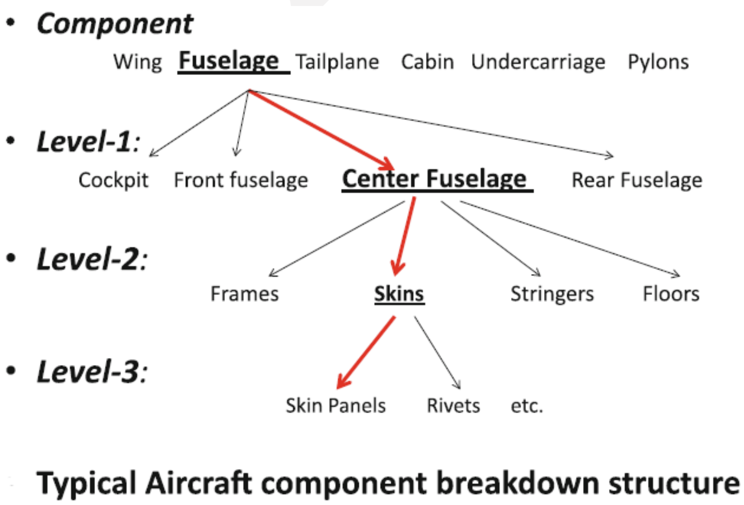


Table 6.1 Typical cost chapter breakdown for an aircraft program

Typical cost chapters for the aircraft development are	
1	Non-specific design
2	Specific design
3	Tests (aerodynamic [Windtunnel], structural, system tests)
4	Production
5	Jigs and tools
6	Modifications
7	Ground support equipment
8	Component development
9	System and equipment development
10	Documentation
11	Certification
12	Engine and nacelle development
13	etc.
50	Management

- As usually in industry, it will need one or more successful aircraft developments till the aircraft manufacturer will have a database, which is realistic enough to develop the second or further aircraft in much better detail and with a more experienced and consolidated technical and financial database for design and production.
- This is one of the reasons, why it is said in the aeronautical industry, that the entry barriers for a new entrant are quite high, i.e. it will need about 20 years and one or two successful aircraft programs till the new company is well enough established in the market.
- Having seen all the long development cycles, this is not an easy and open market, where any new entrant can enter. It will need at the start a lot of national/governmental support to reach this acceptance level on the market side and a lot of engineering, production and management knowledge in the new company.

2.10 Supply Chain

- The aircraft and engine manufacturers have specialized during the last years and are changing and adapting their business models continuously. At the moment, there is a clear trend, to concentrate on the aircraft resp. engine integration task. This means, they need strong partners to support them as integrators or so-called OEMs.
- The selected suppliers should take a major share of the risk and cost in the development and production and partly also in the responsibility for the overall aircraft program, i.e. finance their own development and even participate in the cost

of certification. But will be participating by the sales of each aircraft, according to their negotiation of their work share in the overall aircraft program.

- Referring to the overall aircraft Work breakdown structure, the integrator (engine or aircraft manufacturer) has to clearly identify, which parts of the aircraft resp. engine he will produce under his own responsibility and which are open to be offered to the market and ask for proposals.
- This is part of the “Make or Buy”—policy, which has to be established. This “Make or Buy”—policy needs a set of criteria, which will help to establish the company policy.
- The OEM has to define the overall system architecture, send it to his partners and waits for proposals. But there are very different levels of specifications possible:
    - The OEM is specifying all expected technical solutions in all details and is just waiting for the most cost-effective proposal
    - The OEM is just defining the performance parameters the physical interfaces and the certification requirements and the modifications processes for necessary customer adaptations as well as weight, size, cost and leaves several technological options open for the supplier.
- The supply chain will only provide the expected benefit if a very sophisticated “Supply Chain Quality Control”—process will be defined and properly managed. The supply chain controlling has to integrate at least
    - the development management,
    - the material purchase management,
    - the production management,
    - the transport—and distribution management,
    - the product support management and
    - the specification modification management.
- At the end, the Integrator has to make a financial calculation of all cost aspects involved, the own quality control cost included to decide whether it is cost efficient to outsource the system/component to the market and make a careful assessment of all offers received. Price should not be the main criteria for the selection of the supplier, it is only one amongst others.
- Figure 6.15 is giving a rough overview about the main systems and the important companies for this domain.

	1st level Supplier			
Avionics	Thales, Honeywell; UTC –S; Safran; Rockwell Collins			
Com – Nav - Surv	Honeywell, UTC-S, Rockwell Collins,Thales; Safran			
Electrical System	Honeywell, Thales, Hamilton-Sundstrand; Rockwell/Collins	Safran,		
Hydraulic System	Parker, UTC -S			
Flight Control system	Honeywell; Rockwell-Collins; Parker, Liebherr, Moog, etc.	Nabtesco,		
Fuel system	Parker; Moog			
Landing Gear	Safran, Liebherr, UTC-S, Goodrich	SPP,		
Wheels & Break	Goodrich, Safran, Honeywell	Messier-Dowty		
Environmental Control system	Liebherr, UTC-Systems, Honeywell			
In-Flight Entert. IFE	Honeywell, Thales, Rockwell-Collins			

Fig. 6.15 Some major suppliers for system components