Aircraft Design
Annexes

D.Breyne

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Annex 1. The Design Process Milestones

1.1 List of requirements

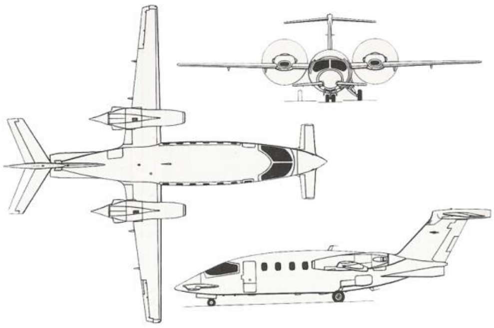
Non exhaustive list of requirements

- Dominant design criteria
- Mission profile
  - Takeoff: altitude
  - Climb: time, altitude
  - Cruise: altitude, maxi range condition, maxi endurance condition, …
  - Loiter: time, altitude
  - Descent: time, altitude
  - Landing: altitude
- Performance
  - Minimum flight speed
  - Takeoff: runway surface, altitude min & max
  - Climb: minimum rate of climb, minimum climb slope, …
  - Cruise: altitude, flight speed
  - Landing: runway surface, altitude min & max
  - Ceiling
  - Performance in turn
  - Maximum level flight speed
- Power plant
  - Type of engine
- Useful load
  - Pax number
  - Mass min & max
  - Maximum volume: H x L x l
  - Description
    - Electronics (Maximum power, voltage, intensity)
    - Droppable load
    - Camera
    - Maximum density
    - …
- Fuel system
- Instruments, Avionics, Furnishing
- Air conditioning
- Costs
  - Market price
  - Operating costs
- Miscellaneous
  - Airworthiness requirements
  - Ecological requirements
  - Material
  - Safety

1.2 Conceptual design

Phases of the Aircraft Conceptual Design

- Check and/or adjustment of Customer's specifications
- Synthesis of Airworthiness Requirements
- Iterative process in order to find the optimal design (according to the specifications)
  - General layout definition
  - Geometry definition
    - Wing
    - Tails (Horizontal Tail, Vertical Tail, Canard Surface, Butterfly Tail, …)
    - Fuselage (according to the Payload, Useful weight and Useful Volume definition)
    - Landing gear (Type, Lateral, Vertical and Longitudinal position)
  - Propulsion definition
    - Engine selection (Type of engine & List of engines to be used)
    - Fuel system (mass & volume)
    - Electric system (type & mass & volume of the batteries)
  - Performance (Stall speed, Takeoff distance, Maximum Rate of Climb, Cruise speed, Landing distance)
    - Wing loading definition
    - Power loading definition
  - Weight analysis
    - Empty weight, Useful weight, Payload, Fuel weight, Maximum Takeoff weight
  - Aerodynamic analysis
    - Global lift & drag
  - 2D Model
    - 3-View drawing
    - Cross Sections
  - 3D Model
    - Visual check
- Marketing analysis
  - Estimated Market Price
- Validation
  - Reverse Engineering
  - Statistical Analysis
- Miscellaneous
  - Reports
  - Meetings
- Final Report



1.3 Preliminary design

Phases of the Aircraft Preliminary Design

- Geometry
    - Lifting surfaces (Wing, Horizontal Tail, Vertical Tail, Canard Surface, Butterfly Tail, …)
        - Planform optimization (span, twist, dihedral, sweep)
        - Position (incidence, vertical, longitudinal, ...)
        - Fuel volume
    - Fuselage
        - Shape optimization
        - Fuel Volume and/or Battery volume
        - Useful Volume
    - Landing Gear (Main & Auxiliary)
        - Tire size according to the runway surface
        - Shock absorber (type, dimension)
        - Length (propeller ground clearance, …)
    - Nacelle
        - Shape optimization
    - Others
        - Hulls, Tailboom, Pylon, Ventral Fin, …
- 3D Model
    - Export to CAD
- Propulsion
    - Uninstalled Engine power Vs Flight speed & Flight Altitude
    - Propeller characteristics (diameter, pitch angle (range), Tip speed, ...)
- Aerodynamic analysis (for different flight conditions)
    - Drag (for each components & interference drag & trim drag & wave drag)
        - Airfoil optimization (airfoil performance)
    - Lift (for each components)
        - Airfoil optimization (airfoil performance)
    - Control surface definition (ailerons, leading edge, trailing edge devices, airbrakes, …)
        - Type & position
        - Dimensions (chord & span & deflection)
    - Aerodynamic centre
        - Lifting surface
        - Wing & Fuselage
        - Airplane
        - - Neutral point stick fixed
        - - Neutral point stick free
        - - Maneuver point stick fixed
        - - Maneuver point stick free
    - Quality
        - Area rules
        - Streamline body check

Cont.

- Graph report
  - Drag polar
  - - Flaps TO, gear down
  - - Flaps TO, gear up
  - - No flaps
  - - Flaps Ld, gear up
  - - Flaps Ld, gear down
  - - One Engine Inoperative (OEI)
  - - Normal flight condition @ different CG position
  - Drag report
  - Lift Vs Angle of Attack
- Performance analysis (for different weight & CG position)
  - Mission specification
  - Stall
  - Deep stall
  - Takeoff
  - Climb
  - Cruise
  - Descent
  - Landing
  - Ground effect
- Systems (Fuel, Electric, Hydraulic, …)
  - Fuel system
    - Tank number & Volume & Position
- Weight Analysis
  - Weight of each component
  - Weight breakdown
  - CG Position of each components
  - CG Position
  - CG Range
  - CG Enveloppe
  - Moment of Inertia
- Load Analysis
  - V-n Diagram
  - Structural loads on the Fuselage
  - Structural loads on the Wing
  - Structural loads on the Horizontal Tail
  - Structural loads on the Canard Surface
  - Structural loads on the Vertical Tail
  - Structural loads on the Landing Gear
  - Structural loads on Control Surfaces
  - Structural loads on Control System

Cont.

- Stability & Control
    - Longitudinal stability derivatives
        - Steady state lift, drag, moment and thrust coefficients
        - Speed derivatives
        - Angle-of-attack derivatives
        - Rate of angle-of-attack derivatives
        - Pitch rate derivatives
    - Lateral-directional stability derivatives
        - Angle-of-sideslip derivatives
        - Rate of angle-of-sideslip derivatives
        - Roll rate derivatives
        - Yaw rate derivatives
    - Longitudinal control derivatives
        - Stabilizer control derivatives
        - Elevator control derivatives
        - Ruddervator control derivatives
        - Canard control derivatives
        - Canardvator control derivatives
        - Elevon control derivatives
        - Elevator tab control derivatives
        - Ruddervator tab control derivatives
        - Canardvator tab control derivatives
        - Elevon tab-control derivatives
    - Lateral-directional control derivatives
        - Aileron derivatives
        - Spoiler derivatives
        - Differential stabilizer derivatives
        - Rudder derivatives
        - Rudder tab derivatives
        - Aileron tab derivatives
    - Hinge moment derivatives
        - Aerodynamic balancing
    - Elevator stick force diagram
    - Aileron stick force diagram
    - Rudder stick force diagram
    - Trim diagram

Cont.

- Dynamic & Control
  - Longitudinal & Lateral-directional dynamic characteristics
  - Airplane transfer functions
    - Speed-to-Elevator
    - Angle-of-Attack-to-Elevator
    - Pitch-Angle-to-Elevator
    - Speed-to-Ruddervator
    - Angle-of-Attack-to-Ruddervator
    - Pitch-Angle-to-Ruddervator
    - Speed-to-Stabilizer
    - Angle-of-Attack-to-Stabilizer
    - Pitch-Angle-to-Stabilizer
    - Speed-to-V-Tail
    - Angle-of-Attack-to-V-Tail
    - Pitch-Angle-to-V-Tail
    - Speed-to-Elevon
    - Angle-of-Attack-to-Elevon
    - Pitch-Angle-to-Elevon
    - Speed-to-Canardvator
    - Angle-of-Attack-to-Canardvator
    - Pitch-Angle-to-Canardvator
    - Speed-to-Canard
    - Angle-of-Attack-to-Canard
    - Pitch-Angle-to-Canard
    - Angle-of-Attack-to-Canardvator
    - Human pilot
    - Sideslip-Angle-to-Aileron
    - Bank-Angle-to-Aileron
    - Heading-Angle-to-Aileron
    - Sideslip-Angle-to-Rudder
    - Bank-Angle-to-Rudder
    - Heading-Angle-to-Rudder
- Cost Analysis
  - Research, development, test and evaluation cost
  - Prototype cost
  - Manufacturing and acquisition costs
  - Operating / Life cycle costs
- Marketing Analysis
  - Market price
  - Comparative analysis
- Optimization
- Pollution / Quality analysis

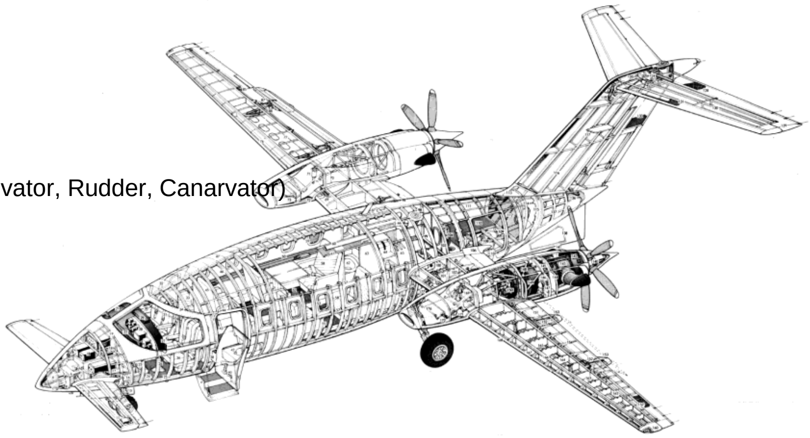
Cont.

- Validation
  - Flight simulator
  - Comparative analysis
- Final checks
  - Compliance with the specifications
  - Compliance with the regulation
  - Compliance with historical value
  - Compliance with rules of thumbs (blanket of the horizontal tail - deep stall)
- Miscellaneous
  - Reports
  - Meetings
- Final Report
- Unusual concept (Wind tunnel test, …)

1.4 Detail design

Phases of the Aircraft Detail Design

- New Techniques
  - Validation of processes
- Airplane
  - 3D Model of each components (position, dimensions, ...) to check the interaction between components
- Lifting surfaces (Wing, Horizontal tail, Vertical Tail, Canard surface, Winglets, …)
  - Stress analysis
  - Spar sizing
  - Ribs sizing
  - Skin sizing
  - 2D / 3D drawings
- Control surfaces (Ailerons, Flaps, Elevator, Rudder, Canarvator)
  - Stress analysis
  - Spar sizing
  - Ribs sizing
  - Skin sizing
  - 2D / 3D drawings



- Engine Mount
  - Stress analysis
  - Sizing
  - 2D / 3D drawings
- Engine Cover
  - Stress analysis
  - Skin sizing
  - 2D / 3D drawings
- Engine Cooling
  - Sizing
  - 2D / 3D drawings
- Bodies (Fuselage, Nacelle, Tailboom, …)
  - Stress analysis
  - Frame sizing
  - Stringer sizing
  - Skin sizing
  - Bulkhead sizing
  - 2D / 3D drawings
- Pylon
  - Stress analysis
  - Spar sizing
  - Ribs sizing
  - Skin sizing
  - 2D / 3D drawings

Cont.

- Landing gear (Main & Auxiliary)
  - Stress analysis
  - Sizing
  - 3D drawings
  - 2D drawings
- Control System
  - Stress analysis
  - Sizing
  - 3D drawings
  - 2D drawings
- Systems (Electric, Pneumatic, Hydraulic, Fuel, Water, Starter, APU, Anti-Ice, …)
  - Sizing
  - 3D drawings
  - 2D drawings
- Instrument Panel
  - Sizing
  - 3D drawings
  - 2D drawings
- Furnishing
  - Sizing
  - 3D drawings
  - 2D drawings
- APU Mount
  - Stress analysis
  - Sizing
  - 3D drawings
  - 2D drawings
- Canopy
  - Sizing
  - 3D drawings
  - 2D drawings
- Tools & jigs
- Documents
  - List of parts
  - Manuals (Flight, Maintenance, …)

1.5 Next phases

Life cycle of the aircraft

Testing
Prototyping
Handling
Manufacturing
Assembling
Testing
Storing
(Distribution)
(Installation)
Operation
Maintenance
Upgrading
Removing
Disposal (recycling)

Annex 2. Common values

			MCR01	Diamond DA42	A320-200	A330-200	A380-800
General	Category	-	Light	Light	Airliner	Airliner	Airliner
	Seat Capacity	-	2	4	150 - (2) 180 - (1)	253 - (3) 380 - (1)	525 - (3) 644 - (2) 853 - (1)
Weight	Empty	kg	230	1268	41 300	119 600	270 364
	Fuel	kg	58	157	23 700	109 185	253 983
	Payload	kg	255	412	19 700	49 000	83 000
	Maximum	kg	490	1700	75 900	238 000	569 000
Weight Ratio	W_{Empty}/W_{MxTO}	-	0.469	0.746	0.544	0.503	0.475
	W_{Fuel}/W_{MxTO}	-	0.118	0.092	0.312	0.459	0.446
	$W_{Payload}/W_{MxTO}$	-	0.520	0.242	0.260	0.206	0.146
Dimensions	Length	m	5.48	8.56	37.57	58.82	72.72
	Span	m	6.63	13.42	34.1	60.3	79.75
	Wing Area	m^2	5.2	16.29	122.6	361.6	845
	Tails Area	m^2	1.602	4.668	52.5		
	Aspect Ratio	-	8.5	11.1	9.5	10.1	7.5
Dimension Ratio	Length / Span	-	0.827	0.638	1.102	0.975	0.912
	Tails Ratio	-	0.308	0.287	0.428		
Power Plant	Engine number	-	1	2	2	2	4
	Power (total)	kW	69	198	-	-	-
	Thrust	daN	-	-	22 237	60 000	142 700
	SFC (propeller)	kg/kW.h	0.238	0.212	-	-	-
	SFC (jet)$_{Cruise}$	kg/N.h	-	-	0.061	0.057	0.059
	Fuel Flow	kg/h	-	-	3023	7622	18763
	Propeller efficiency	-	0.82	0.85	-	-	-
Aerodynamics	Cl cruise	-	0.25	0.34	0.63	0.61	0.58
	Cl_{Mx}		2.36	2.00			
	e	-	0.71	0.78	0.85	0.85	0.85
	Glide Ratio	-	9	10.5			
	Wing loading $_{Mx}$	kg/m^2	94.2	104.4	619.1	658.2	673.4
Performance	Cruise speed	km/h	318	283	828	870	902
	Cruise speed	Mach	-	-	0.78	0.82	0.85
	Stall speed	km/h	91	104			
	Takeoff speed	km/h	105	120			
	Takeoff run	m	155	382	2 090	2 220	2 750
	Rate of Climb $_{Mx}$	m/s	8.89	5.46	12.2		
	Maxi Range	km			7 000	17 000	18 000
	Power-to-Weight Ratio	kW/kg	0.141	0.116			
	Weigh-to-Power Ratio	kg/kW	7.101	8.586			
	Thrust-to-Weight Ratio	daN/kg	-	-	0.293	0.252	0.251
	Weight-to-Thrust Ratio	kg/daN	-	-	3.413	3.967	3.987

			MCR01	Diamond DA42	A320-200	A330-200	A380-800
Cost	Unit Price (2012)	M$	0.11	0.54	88	208	390
	M$ / Seat	M$	0.055	0.135	0.489	0.547	0.457
	$ / kg Empty	$/kg	478	426	2131	1739	1442
	$ / kg Payload	$/kg	431	1311	4467	4245	4699
	$ / kg Maximum	$/kg	224	318	1159	874	685

Annex 3. Forces and moments

An aircraft is nothing else than a car: a means to transport passengers or goods from one point to the other. With the only difference, that we would like not to travel on the ground but in the air.

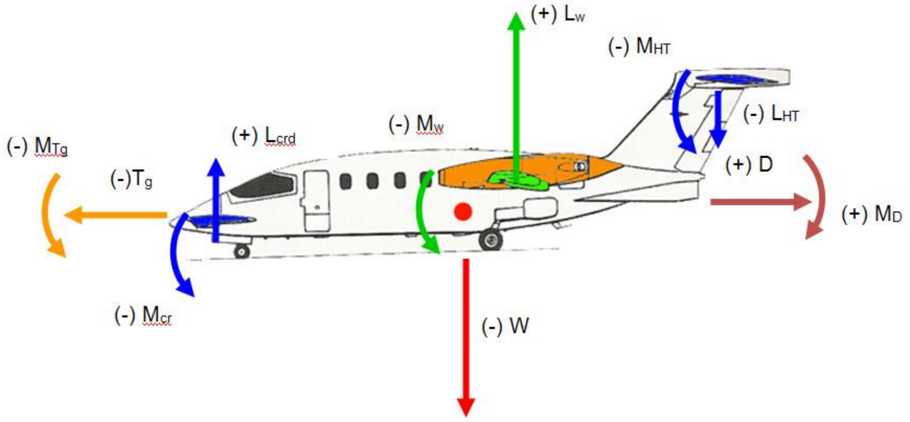
Due to the gravity, this mass (the aircraft) generates a force acting downwards: the weight (W) of the aircraft.

To move the aircraft, we need to generate a force that will pull the aircraft forward. This force (T_g) is generated by the engine (piston engine, turboprop, turbojet, rocket, ...).

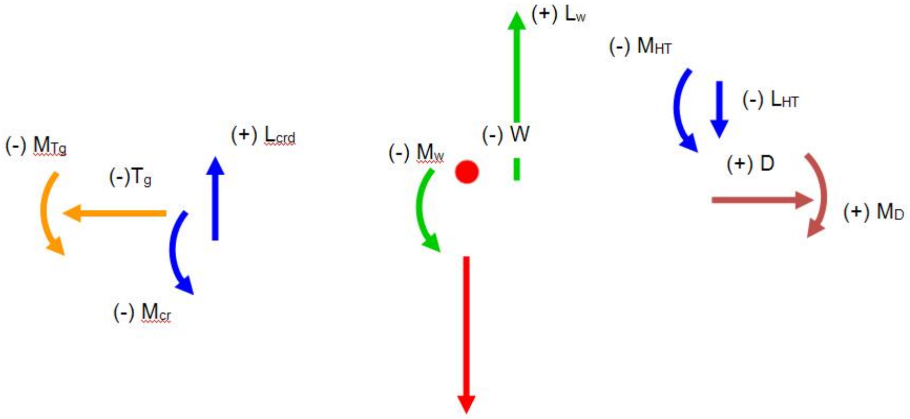
Unfortunately because of the physical properties of the air, every moving generates a drag (D), a force acting in the opposite direction of the motion.

To lift the aircraft in the air, we need to add something to generate a vertical force (L_w) acting upwards: the wing. The wing generates the lift but also a nose-down pitching moment.

To counteract this nose-down pitching moment, we need to generate forces (L_{cr}, L_{HT}) acting upwards and/or downwards depending on their location about de CG position.



An aircraft, in level flight in the air, is nothing else than forces in equilibrium around the CG. The designer will size the aircraft in order that this equilibrium remains for a given CG range.



Annex 4. The standard atmosphere

4.1 Introduction

Since the real atmosphere never remains constant at any particular time or place, a hypothetical model must be used as an approximation to what may be expected. This model is known as the standard atmosphere.

4.2 Assumptions

Some assumptions are made in order to build the standard atmosphere:

1. The air in the model is assumed to be without dust, moisture and water vapour.
2. The air is supposed to be at rest with respect to the earth, this means that there is no wind, no turbulence.
3. The reference altitude is the mean sea level (MSL). At the MSL the conditions are:

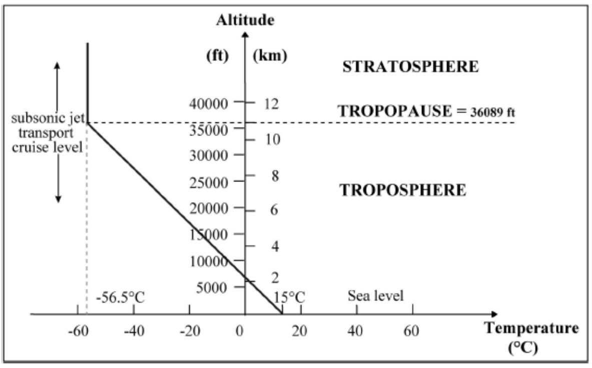
Pressure	p_0	101 325	N/m²
Density	ρ_0	1.225	kg/m³
Temperature	T_0	288.15 15	°K °C
Speed of sound	a_0	340.294	m/s
Acceleration of gravity	g_0	9.80665	m/s²

4. The air is considered to be a perfect gas $\boxed{p = \rho \cdot R \cdot T}$ with R is the real gas constant for the air (287 J/kg.K)
5. The temperature decreases with altitude at a constant rate of -6.5°C/1000m up to the tropopause
6. The standard tropopause altitude is 11 000m
7. The temperature remains constant at a value of -56.5°C from the tropopause up to 20 000 m

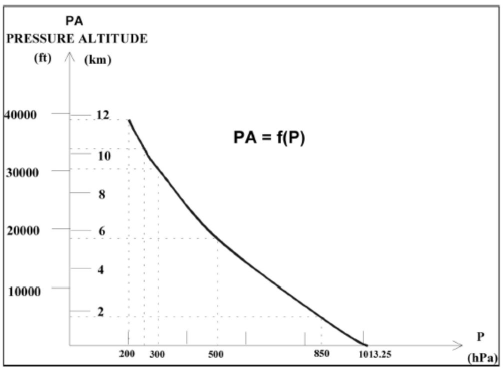
4.3 Standard temperature

The temperature decreases with altitude at a constant rate of -6.5°C/1000m up to the tropopause

$$T = T_0 - 6.5 \cdot \frac{h(m)}{1000}$$



4.4 Standard pressure



To compute the standard pressure (p) at a given altitude, the temperature is assumed standard and the air is assumed to be a perfect gas.

$$p = p_0 \cdot \left(1 - 0.0065.\frac{h}{T_0}\right)^{5.2561}$$

with the unit of T_0 is °K and h is meters

4.5 Standard density

To compute the standard density (ρ), since the pressure and temperature are known for a given altitude, the perfect gas equation is used

$$\rho = \frac{p}{R \cdot T}$$

4.6 Speed of sound

The speed of sound is proportional to the square root of the absolute temperature (K) but is independent of pressure or density for a given ideal gas. The sound travels faster in fluid than it does in air (4.3 times faster in water, 15 times faster in iron than in air at 20°C)

$a = \sqrt{\gamma \cdot R \cdot T}$, with γ , the isentropic coefficient (1.4 for the air).

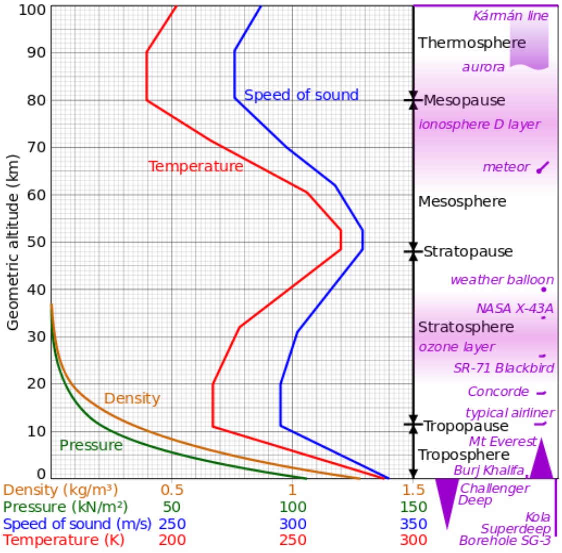
4.7 Notes

The altitude obtained from the measurement of pressure is called the **pressure altitude**.

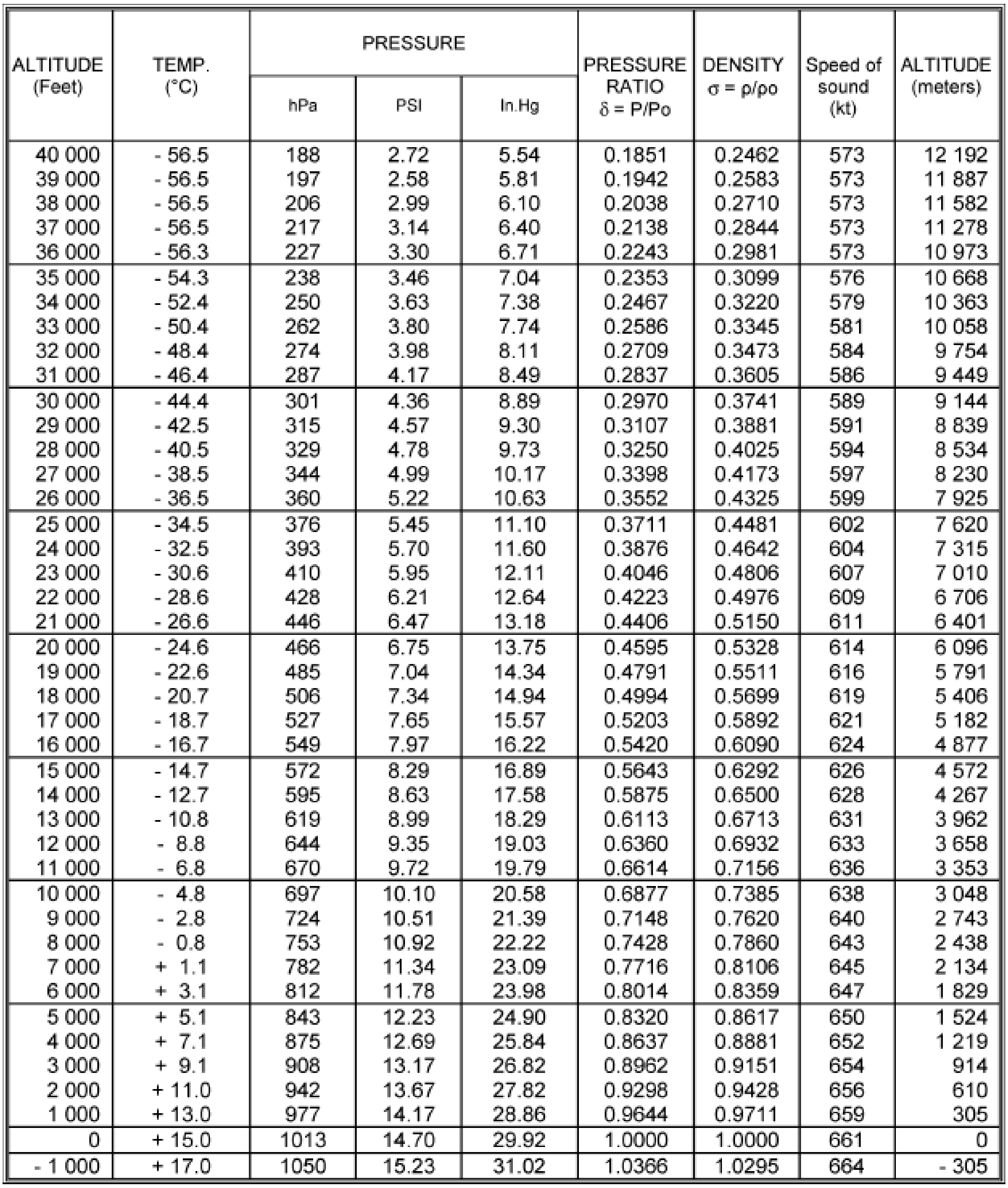
The altitude obtained from the measurement of density is called the **density altitude**. In other words, the density altitude is the altitude in the ISA model at which the air density would be equal to the actual air density at the place of observation.

The ISA model is used as a reference. If the real atmospheric conditions are different, they will be expressed as ISA +/-ΔISA (ISA+10°C)

4.8 The standard atmosphere up to 100.000 m



4.9 Table of the standard atmosphere



ALTITUDE (Feet)	TEMP. (°C)	PRESSURE			PRESSURE RATIO $\delta = P/P_o$	DENSITY $\sigma = \rho/\rho_o$	Speed of sound (kt)	ALTITUDE (meters)
		hPa	PSI	In.Hg				
40 000	- 56.5	188	2.72	5.54	0.1851	0.2462	573	12 192
39 000	- 56.5	197	2.58	5.81	0.1942	0.2583	573	11 887
38 000	- 56.5	206	2.99	6.10	0.2038	0.2710	573	11 582
37 000	- 56.5	217	3.14	6.40	0.2138	0.2844	573	11 278
36 000	- 56.3	227	3.30	6.71	0.2243	0.2981	573	10 973
35 000	- 54.3	238	3.46	7.04	0.2353	0.3099	576	10 668
34 000	- 52.4	250	3.63	7.38	0.2467	0.3220	579	10 363
33 000	- 50.4	262	3.80	7.74	0.2586	0.3345	581	10 058
32 000	- 48.4	274	3.98	8.11	0.2709	0.3473	584	9 754
31 000	- 46.4	287	4.17	8.49	0.2837	0.3605	586	9 449
30 000	- 44.4	301	4.36	8.89	0.2970	0.3741	589	9 144
29 000	- 42.5	315	4.57	9.30	0.3107	0.3881	591	8 839
28 000	- 40.5	329	4.78	9.73	0.3250	0.4025	594	8 534
27 000	- 38.5	344	4.99	10.17	0.3398	0.4173	597	8 230
26 000	- 36.5	360	5.22	10.63	0.3552	0.4325	599	7 925
25 000	- 34.5	376	5.45	11.10	0.3711	0.4481	602	7 620
24 000	- 32.5	393	5.70	11.60	0.3876	0.4642	604	7 315
23 000	- 30.6	410	5.95	12.11	0.4046	0.4806	607	7 010
22 000	- 28.6	428	6.21	12.64	0.4223	0.4976	609	6 706
21 000	- 26.6	446	6.47	13.18	0.4406	0.5150	611	6 401
20 000	- 24.6	466	6.75	13.75	0.4595	0.5328	614	6 096
19 000	- 22.6	485	7.04	14.34	0.4791	0.5511	616	5 791
18 000	- 20.7	506	7.34	14.94	0.4994	0.5699	619	5 406
17 000	- 18.7	527	7.65	15.57	0.5203	0.5892	621	5 182
16 000	- 16.7	549	7.97	16.22	0.5420	0.6090	624	4 877
15 000	- 14.7	572	8.29	16.89	0.5643	0.6292	626	4 572
14 000	- 12.7	595	8.63	17.58	0.5875	0.6500	628	4 267
13 000	- 10.8	619	8.99	18.29	0.6113	0.6713	631	3 962
12 000	- 8.8	644	9.35	19.03	0.6360	0.6932	633	3 658
11 000	- 6.8	670	9.72	19.79	0.6614	0.7156	636	3 353
10 000	- 4.8	697	10.10	20.58	0.6877	0.7385	638	3 048
9 000	- 2.8	724	10.51	21.39	0.7148	0.7620	640	2 743
8 000	- 0.8	753	10.92	22.22	0.7428	0.7860	643	2 438
7 000	+ 1.1	782	11.34	23.09	0.7716	0.8106	645	2 134
6 000	+ 3.1	812	11.78	23.98	0.8014	0.8359	647	1 829
5 000	+ 5.1	843	12.23	24.90	0.8320	0.8617	650	1 524
4 000	+ 7.1	875	12.69	25.84	0.8637	0.8881	652	1 219
3 000	+ 9.1	908	13.17	26.82	0.8962	0.9151	654	914
2 000	+ 11.0	942	13.67	27.82	0.9298	0.9428	656	610
1 000	+ 13.0	977	14.17	28.86	0.9644	0.9711	659	305
0	+ 15.0	1013	14.70	29.92	1.0000	1.0000	661	0
- 1 000	+ 17.0	1050	15.23	31.02	1.0366	1.0295	664	- 305

Annex 5. Airspeed

5.1 Introduction

Airspeed is the speed of the aircraft relative to the air. The measurement is made by a pitot-static system. The indication is made on board by an airspeed indicator.

5.2 Pitot-static system

The airspeed is measured by a pressure-sensitive instrument called the pitot-static system

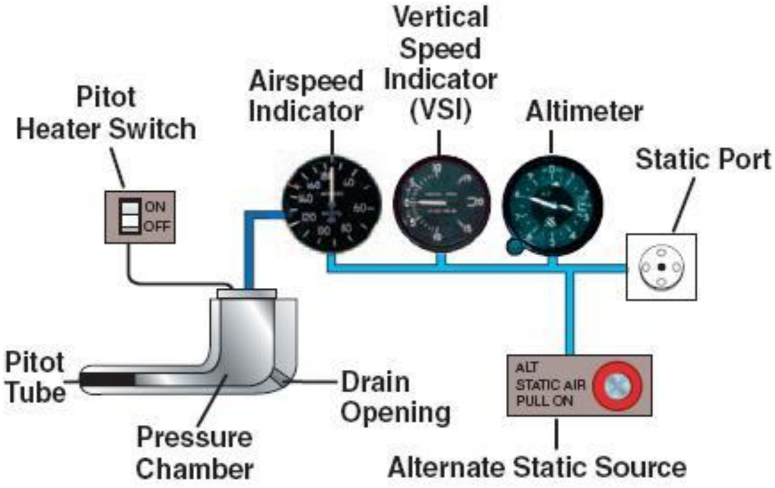


Image 1 : Pitot-static system

Using the Bernoulli's law, which states that the total pressure is the sum of the static pressure and the dynamic pressure.

$$p_t = p_s + \left(\frac{\rho \cdot V^2}{2}\right)$$

Solving that for velocity we get:

$$V = \sqrt{\frac{2 \cdot (p_t - p_s)}{\rho}}$$

5.3 Airspeed indicator

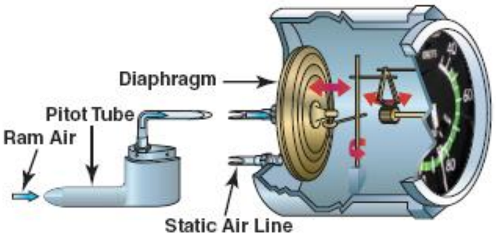


Image 2 : Airspeed indicator

5.4 Altimeter and Vertical airspeed indicator

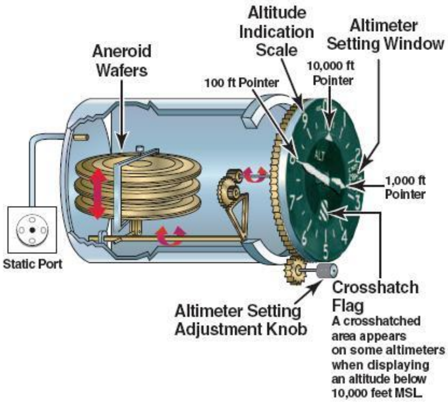


Image 3 : Altimeter

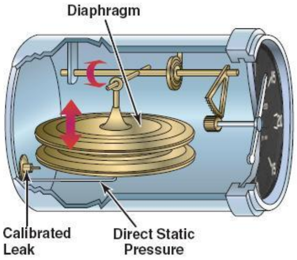


Image 4 : Vertical airspeed indicator

5.5 Pitot-static system on the Airbus A330-200

Location of the pitot probe and static port on the airbus A330-200

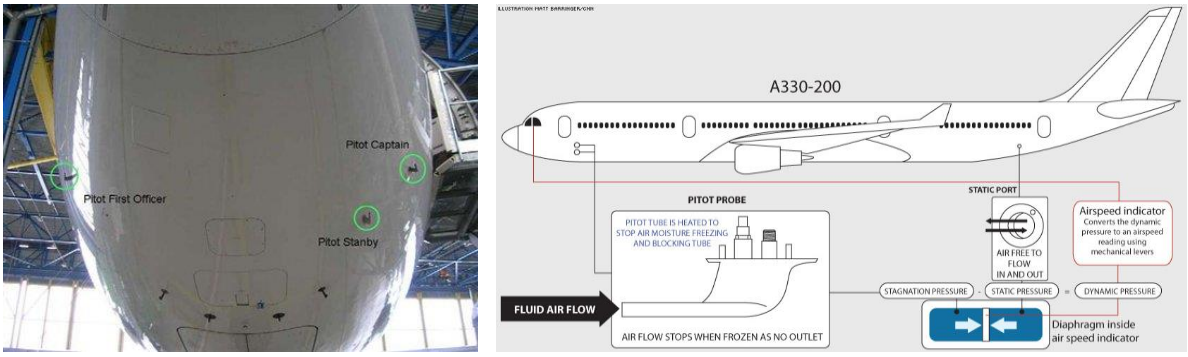


Image 5 : Pitot-static system on the Airbus A330-200

Three pitot probes are located in the front of the fuselage. From right to left:

- Pitot Captain
- Pitot Standby
- Pitot First Officer

5.6 Airspeed relationships

5.6.1 IAS – Indicated airspeed

Indicated airspeed is that shown on the airspeed indicator.

5.6.2 CAS – Calibrated airspeed

Calibrated airspeed is the indicated airspeed (IAS) corrected for position and instrument error.

5.6.3 EAS – Equivalent airspeed

Equivalent airspeed is calibrated airspeed (CAS) corrected for compressibility effect.

$$EAS = CAS \cdot \sqrt{\frac{p}{p_0} \cdot \left[\frac{(q_c/p + 1)^{0.286} - 1}{(q_c/p_0 + 1)^{0.286} - 1}\right]^{0.5}}$$

With

p	Pressure at the given altitude
p_0	Pressure at sea level
q_c	$p \cdot ([1 + 0.2 \cdot M^2]^{3.5} - 1)$
M	TAS/a
a	Speed of sound

5.6.4 TAS – True airspeed

True airspeed is the equivalent airspeed (EAS) corrected for change in atmospheric density.

$$TAS = EAS \cdot \sqrt{\frac{\rho_0}{\rho}}$$

With

ρ	Density at the given altitude
ρ_0	Density at sea level

5.6.5 GS – Ground speed

Ground speed is the speed relative to the ground.

5.7 Example

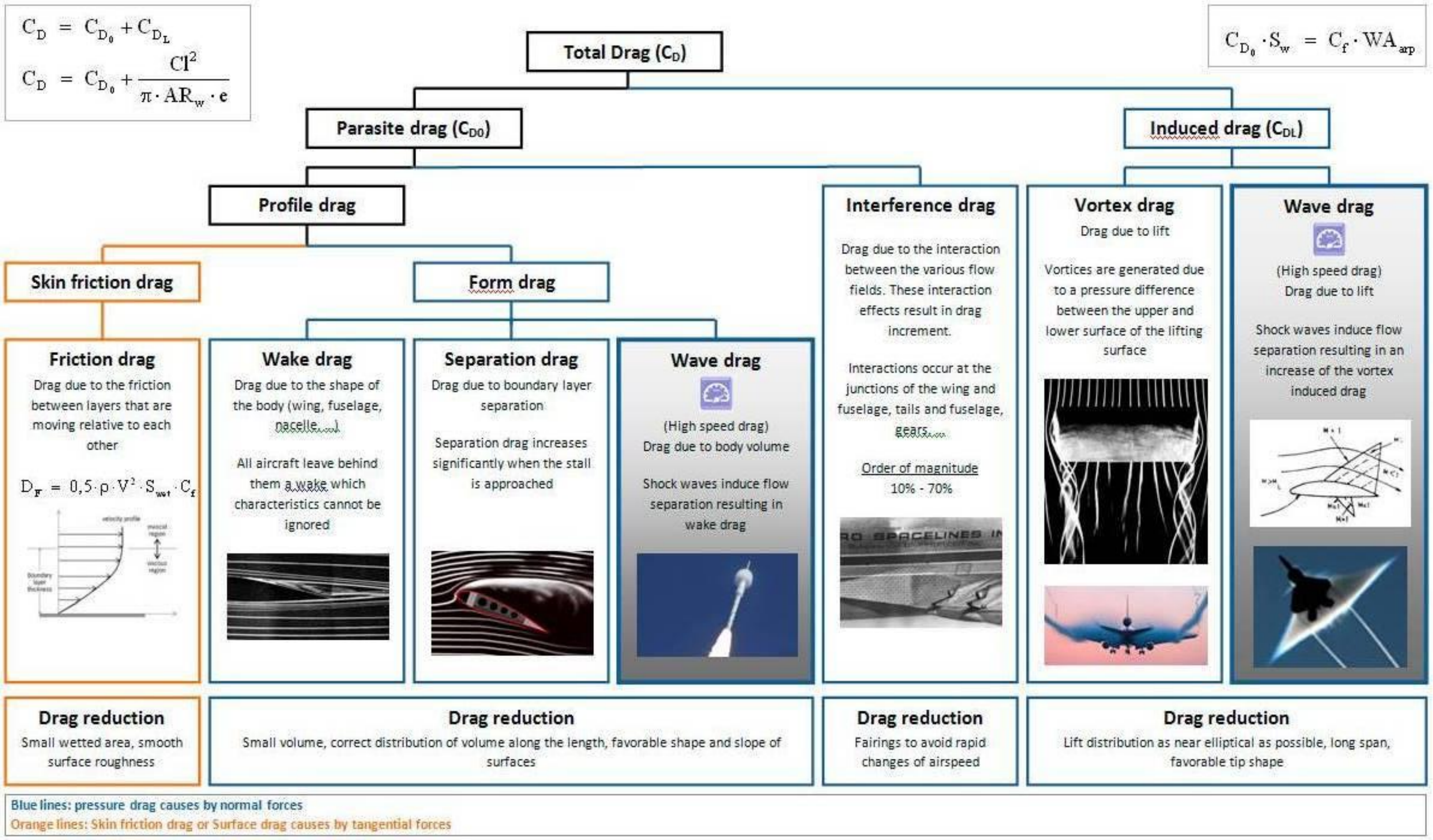
Given

M	0.411
Flight altitude	4000 m
ρ	0.819 kg/m³
p	61 660 N/m²
a	324.6 m/s
ρ_0	1.225 kg/m³
p_0	101.330 N/m²
q_c	7 995 N/m²

Computed

IAS	CAS	EAS	TAS
110 m/s	110 m/s	109 m/s	133 m/s

Annex 6. Drag breakdown



$$C_D = C_{D_0} + C_{D_L}$$

$$C_D = C_{D_0} + \frac{Cl^2}{\pi \cdot AR_w \cdot e}$$

$$C_{D_0} \cdot S_w = C_f \cdot WA_{arp}$$

Total Drag (C_D)

Parasite drag (C_{D0})

Induced drag (C_{DL})

Profile drag

Skin friction drag

Form drag

Friction drag

Drag due to the friction between layers that are moving relative to each other

$$D_F = 0,5 \cdot \rho \cdot V^2 \cdot S_{wet} \cdot C_f$$

Wake drag

Drag due to the shape of the body (wing, fuselage, nacelle,…)

All aircraft leave behind them a wake which characteristics cannot be ignored

Separation drag

Drag due to boundary layer separation

Separation drag increases significantly when the stall is approached

Wave drag

(High speed drag)

Drag due to body volume

Shock waves induce flow separation resulting in wake drag

Interference drag

Drag due to the interaction between the various flow fields. These interaction effects result in drag increment.

Interactions occur at the junctions of the wing and fuselage, tails and fuselage, gears,…

Order of magnitude

10% - 70%

Vortex drag

Drag due to lift

Vortices are generated due to a pressure difference between the upper and lower surface of the lifting surface

Wave drag

(High speed drag)

Drag due to lift

Shock waves induce flow separation resulting in an increase of the vortex induced drag

Drag reduction

Small wetted area, smooth surface roughness

Drag reduction

Small volume, correct distribution of volume along the length, favorable shape and slope of surfaces

Drag reduction

Fairings to avoid rapid changes of airspeed

Drag reduction

Lift distribution as near elliptical as possible, long span, favorable tip shape

Blue lines: pressure drag causes by normal forces

Orange lines: Skin friction drag or Surface drag causes by tangential forces

Annex 7. Optimisation process

7.1 Cruising speed (propeller driven aircraft)

The relationship between wing loading and power loading for a propeller driven aircraft at cruise is given by

$$\boxed{\frac{W}{P_{eng}} = R_P \cdot \frac{c_2 \cdot W/S_w}{c_3 + c_1 \cdot \left(W/S_w\right)^2}}$$

with

$$R_P \;=\; \frac{\left(\frac{\rho}{1.225}\right) - 0.15}{0.85}$$

$$c_1 = \frac{1}{V} \cdot \frac{1}{\pi \cdot AR_w \cdot e} \cdot \frac{4 \cdot g^2}{\rho^2}$$

$$c_2 = \frac{2 \cdot \eta_p}{\rho}$$

$$c_3 = V^3 \cdot C_{D_0}$$

Development of the relationship between wing loading and power loading at cruise

$$P_{avai} \cdot \eta_p \;=\; 0.5 \cdot \rho \cdot V^3 \cdot C_D \cdot S_w$$

$$V^3 = \frac{2 \cdot P_{avai} \cdot \eta_p}{\rho \cdot C_D \cdot S_w}$$

$$V^3 = \frac{2 \cdot \eta_p}{\rho \cdot C_D} \cdot \frac{W/S_w}{W/P_{avai}}$$

$$V^3 = \frac{2 \cdot \eta_p}{\rho \cdot C_D} \cdot \frac{W/S_w}{W/P_{avai}} \text{ and } C_D \;=\; C_{D_0} + \frac{{C_L}^2}{\pi \cdot AR_w \cdot e} \text{ and } C_L \;=\; \frac{2 \cdot g}{\rho \cdot V^2} \cdot \frac{W}{S_w}$$

$$V^3 = \frac{2 \cdot \eta_p}{\rho} \cdot \frac{W/S_w}{W/P_{avai}} \cdot \frac{1}{C_{D_0} + \frac{1}{\pi \cdot AR_w \cdot e} \cdot \left(\frac{2 \cdot g}{\rho \cdot V^2}\right)^2 \cdot \left(\frac{W}{S_w}\right)^2}$$

$$V^3 \cdot C_{D_0} + \frac{V^3}{\pi \cdot AR_w \cdot e} \cdot \frac{4 \cdot g^2}{\rho^2 \cdot V^4} \cdot \left(\frac{W}{S_w}\right)^2 = \frac{2 \cdot \eta_p}{\rho} \cdot \frac{W/S_w}{W/P_{avai}}$$

$$\frac{1}{V} \cdot \frac{1}{\pi \cdot AR_w \cdot e} \cdot \frac{4 \cdot g^2}{\rho^2} \cdot \left(\frac{W}{S_w}\right)^2 - \frac{2 \cdot \eta_p}{\rho} \cdot \frac{W/S_w}{W/P_{avai}} + V^3 \cdot C_{D_0} = 0$$

$$c_1 \cdot \left(\frac{W}{S_w}\right)^2 - c_2 \cdot \frac{W/S_w}{W/P_{avai}} + c_3 = 0$$

$$c_2 \cdot \frac{W/S_w}{W/P_{avai}} - c_1 \cdot \left(\frac{W}{S_w}\right)^2 = c_3$$

$$\frac{W}{P_{avai}} = \frac{c_2 \cdot W/S_w}{c_3 + c_1 \cdot (W/S_w)^2}$$

$$\frac{W}{P_{eng}} = R_P \cdot \frac{W}{BHP_{avai}}$$

$$\frac{W}{P_{eng}} = R_P \cdot \frac{c_2 \cdot W/S_w}{c_3 + c_1 \cdot (W/S_w)^2}$$

7.2 Stall speed

The relationship between wing loading and power loading at stall is given by

$$\boxed{\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_s^2 \cdot C_{L_2}}$$

Development of the relationship between wing loading and power loading at stall

$$L = W \cdot g$$

$$W \cdot g = 0.5 \cdot \rho \cdot V_s^2 \cdot S_w \cdot Cl_2$$

$$\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_s^2 \cdot C_{L_2}$$

The stall performance is independent of the power loading and is only function of the wing loading.

7.3 Landing field length

The relationship between wing loading and power loading at landing is given by

$$\boxed{\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_{approach}^2 \cdot C_L}$$

Development of the relationship between wing loading and power loading at landing

$$L = W \cdot g$$

$$W \cdot g = 0.5 \cdot \rho \cdot V_{approach}^2 \cdot S_w \cdot Cl \text{ and } V_{approach} = 1.3 \cdot V_s$$

$$\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_{approach}^2 \cdot C_L$$

The landing performance is independent of the power loading and is only function of the wing loading

7.4 Takeoff field length (propeller driven aircraft)

The relationship between wing loading and power loading for a propeller driven aircraft at takeoff is given by

$$\boxed{\frac{W}{P_{eng}} = R_P \cdot \frac{C_1 \cdot C_5 \cdot \left(\frac{1}{W/S_w}\right)^{0.5}}{\left(W/S_w\right) + C_5 \cdot C_6}}$$

With

$$R_p \;=\; \frac{\left(\frac{\rho}{1.225}\right) - 0.15}{0.85}$$

$$C_1 = \eta_p \cdot \left(\frac{\rho \cdot C_L}{2 \cdot g}\right)^{0.5}$$

$$C_2 = \frac{\rho \cdot C_{D_0}}{2} \cdot \left(\frac{2 \cdot g}{\rho \cdot C_L}\right)$$

$$C_3 = g \cdot c_{f_{gr}}$$

$$C_4 = g \cdot \sin\gamma$$

$$C_5 = \frac{d \cdot \rho \cdot C_L}{g}$$

$$C_6 = C_2 + C_3 + C_4$$

Development of the relationship between wing loading and power loading at takeoff

$$d \;=\; \frac{a \cdot t^2}{2} = \frac{V^2}{2 \cdot a}$$

$$a = \frac{F}{W} = \frac{T_g - D_0 - F_{Friction} - F_{slope}}{W}$$

with

$$Tg = \frac{P_{avail} \cdot \eta_p}{V} \quad \text{and} \quad D_0 = \frac{\rho}{2} \cdot V^2 \cdot C_{D_0} \cdot S_w \quad \text{and} \quad F_{friction} = W \cdot g \cdot c_{f_{gr}} \quad \text{and} \quad F_{slope} = W \cdot g \cdot \sin\gamma$$

$$a = \frac{1}{W/P_{avail}} \cdot \frac{\eta_p}{V} - \frac{\rho}{2} \cdot V^2 \cdot C_{D_0} \cdot \frac{1}{W/S_w} - g \cdot c_{f_{gr}} - g \cdot \sin\gamma$$

with

$$V^2 = \frac{2 \cdot g}{\rho \cdot C_L} \cdot \frac{W}{S_w}$$

$$a = \frac{\eta_p}{W/P_{avail}} \cdot \left(\frac{\rho \cdot Cl}{2 \cdot g}\right)^{0.5} \cdot \left(\frac{1}{W/S_w}\right)^{0.5} - \frac{\rho \cdot C_{D_0}}{2} \cdot \left(\frac{2 \cdot g}{\rho \cdot C_L} \cdot W/S_w\right) \cdot \frac{1}{W/S_w} - g \cdot c_{f_{gr}} - g \cdot \sin\gamma$$

$$C_1 = \eta_p \cdot \left(\frac{\rho \cdot C_L}{2 \cdot g}\right)^{0.5}, \quad C_2 = \frac{\rho \cdot C_{D_0}}{2} \cdot \left(\frac{2 \cdot g}{\rho \cdot C_L}\right), \quad C_3 = g \cdot c_{f\,gr}, \quad C_4 = g \cdot \sin\gamma$$

$$a = C_1 \cdot \frac{1}{W/P_{avail}} \cdot \left(\frac{1}{W/S_w}\right)^{0.5} - C_2 - C_3 - C_4$$

$$d = \frac{g}{\rho \cdot C_L} \cdot \left(W/S_w\right) \cdot \frac{1}{C_1 \cdot \left(\frac{1}{W/P_{avail}}\right) \cdot \left(\frac{1}{W/S_w}\right)^{0.5} - C_2 - C_3 - C_4}$$

$$C_6 = C_2 + C_3 + C_4$$

$$C_5 = \frac{d \cdot \rho \cdot C_L}{g}$$

$$C_5 = \left(W/S_w\right) \cdot \frac{1}{C_1 \cdot \left(\frac{1}{W/P_{avail}}\right) \cdot \left(\frac{1}{W/S_w}\right)^{0.5} - C_6}$$

$$C_5 \cdot C_1 \cdot \left(\frac{1}{W/P_{avail}}\right) \cdot \left(\frac{1}{W/S_w}\right)^{0.5} - C_5 \cdot C_6 = \left(W/S_w\right)$$

$$C_5 \cdot C_1 \cdot \left(\frac{1}{W/P_{avail}}\right) \cdot \left(\frac{1}{W/S_w}\right)^{0.5} = \left(W/S_w\right) + C_5 \cdot C_6$$

$$\frac{W}{P_{avail}} = \frac{C_1 \cdot C_5 \cdot \left(\frac{1}{W/S_w}\right)^{0.5}}{\left(W/S_w\right) + C_5 \cdot C_6}$$

$$\frac{W}{P_{eng}} = R_p \cdot \frac{C_1 \cdot C_5 \cdot \left(\frac{1}{W/S_w}\right)^{0.5}}{\left(W/S_w\right) + C_5 \cdot C_6}$$

7.5 Climb performances (propeller driven aircraft)

The relationship between wing loading and power loading for a propeller driven aircraft in climb is given by

$$\boxed{\frac{W}{P_{eng}} = R_p \cdot \frac{\eta_p}{0.5 \cdot (2 \cdot g)^{3/2} \cdot (\rho)^{-1/2} \cdot \left(\frac{W}{S_w}\right)^{1/2} \left(\frac{C_D}{C_L^{3/2}}\right) + g \cdot RC}}$$

Development of the relationship between wing loading and power loading in climb

$$P_{avail} \cdot \eta_p = P_{req} + W \cdot g \cdot RC$$

$$P_{req} = 0.5 \cdot \rho \cdot V^3 \cdot S_w \cdot C_D$$

$$P_{req} = 0.5 \cdot \rho \cdot \left(\frac{2 \cdot g}{\rho \cdot C_L} \cdot \frac{W}{S_w}\right)^{3/2} \cdot S_w \cdot C_D$$

$$P_{req} = 0.5 \cdot \rho \cdot S_w \cdot \frac{C_D}{C_L^{3/2}} \cdot \left(\frac{2 \cdot g}{\rho} \cdot \frac{W}{S_w}\right)^{3/2}$$

$$P_{avail} \cdot \eta_p = 0.5 \cdot \rho \cdot S_w \cdot \frac{C_D}{C_L^{3/2}} \cdot \left(\frac{2 \cdot g}{\rho} \cdot \frac{W}{S_w}\right)^{3/2} + W \cdot g \cdot RC$$

$$\frac{P_{avail}}{W} = \frac{1}{\eta_p} \cdot 0.5 \cdot (2 \cdot g)^{3/2} \cdot \left(\frac{1}{\rho}\right)^{1/2} \cdot \left(\frac{W}{S}\right)^{1/2} \cdot \frac{C_D}{C_L^{3/2}} + g \cdot RC$$

$$\frac{W}{P_{eng}} = R_p \cdot \frac{\eta_p}{0.5 \cdot (2 \cdot g)^{3/2} \cdot (\rho)^{-1/2} \cdot \left(\frac{W}{S_w}\right)^{1/2} \left(\frac{C_D}{C_L^{3/2}}\right) + g \cdot RC}$$

Annex 8. Optimisation process (example)

8.1 Requirements (input data)

General	
Aspect ratio	8.5
Oswald factor (e)	0.80
g	9.81 m/s^2
Propeller efficiency (η_p)	0.84
Engine specific fuel consumption (csf)	0.274 kg/kW.h
Payload ($W_{payload}$)	200 kg
Useful weight ratio (W_{useful}/W_{MxTO})	0.475

[1] Cruise	
Flight speed (V_{cr})	300 km/h
Zero lift drag coefficient (C_{D0})	0.0207
Air density (ρ_0)	0.996 kg/m^3
Power ratio (R_p)	0.78
Range	800 km

[2] Stall speed - [3] Landing	
V_s	80 km/h
C_{LMx}	2.80

[4] Takeoff	
Takeoff run (d)	150 m
Lift coefficient (C_{LTO})	1.52
Rolling friction coefficient (C_{fgr})	0.02
Runway angle (γ)	0°
Air density (ρ_0)	1.225 kg/m^3
Power ratio (R_p)	1

[5] Climb	
Rate of climb (RC)	8.05 m/s
Propeller efficiency (η_p)	0.78
Zero lift drag coefficient (C_{D0})	0.0219
Air density (ρ_0)	1.225 kg/m^3
Power ratio (R_p)	1

8.2 Equations

[1] Cruise	$\frac{W}{P_{eng}} = R_P \cdot \frac{c_2 \cdot W/S_w}{c_3 + c_1 \cdot \left(W/S_w\right)^2}$
[2] Stall	$\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_s^2 \cdot C_{L_2}$
[3] Takeoff	$\frac{W}{P_{eng}} = R_P \cdot \frac{C_1 \cdot C_5 \cdot \left(\frac{1}{W/S_w}\right)^{0.5}}{\left(W/S_w\right) + C_5 \cdot C_6}$
[4] Climb	$\frac{W}{P_{eng}} = R_p \cdot \frac{\eta_p}{0.5 \cdot \left(2 \cdot g\right)^{3/2} \cdot \left(\rho\right)^{-1/2} \cdot \left(\frac{W}{S_w}\right)^{1/2} \left(\frac{C_D}{C_L^{3/2}}\right) + g \cdot RC}$

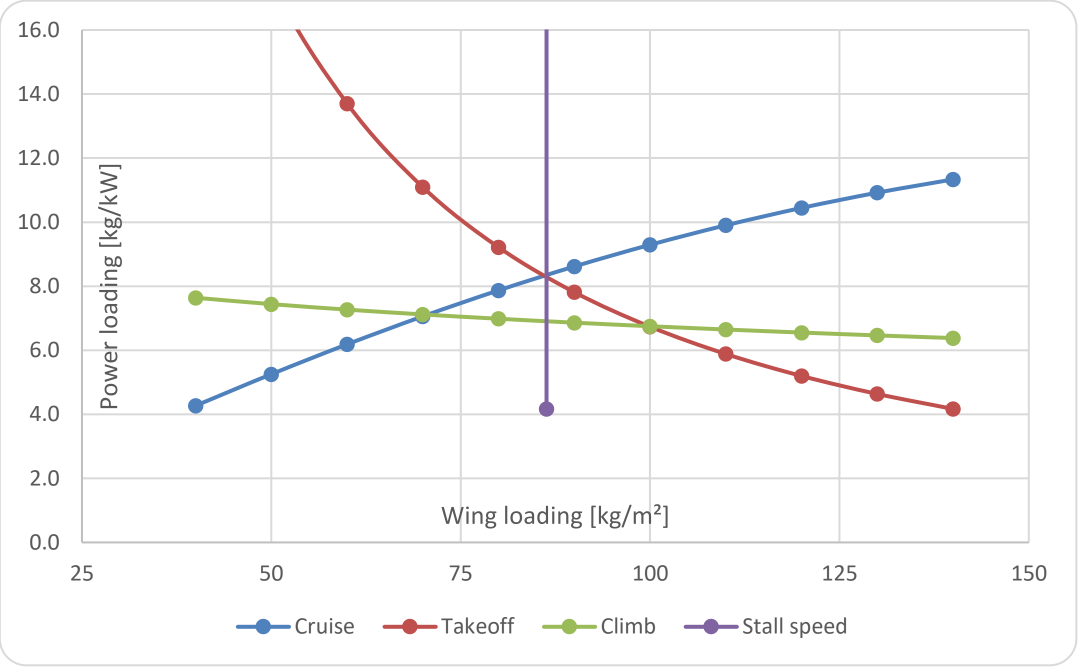
8.3 Table

	[1]	[2]	[3]	[4]
W/S	W/BHP	W/BHP	W/BHP	W/BHP
40	4.3		23.6	7.6
50	5.3		17.5	7.4
60	6.2		13.7	7.3
70	7.1		11.1	7.1
80	7.9		9.2	7.0
90	8.6		7.8	6.9
100	9.3		6.7	6.8
110	9.9		5.9	6.6
120	10.4		5.2	6.6
130	10.9		4.6	6.5
140	11.3		4.2	6.4

From the selected wing loading (W/S) and power loading (W/P), the following values may be computed:

Fuel weight	$W_{fuel}/W_0 = 1-\frac{1}{e^{R/B}}$ With $B = \frac{1000\cdot 3600}{9.81}\cdot\frac{\eta_p}{Sfc}\cdot GR$ From the Breguet range equation $R = \frac{1000\cdot 3600}{9.81}\cdot\frac{\eta_p}{Sfc}\cdot GR\cdot\ln\left(\frac{W_0}{W_1}\right)$ $R = \frac{1000\cdot 3600}{9.81}\cdot\frac{\eta_p}{Sfc}\cdot GR\cdot\ln\left(\frac{W_0}{W_0-W_{fuel}}\right)$ $R = \frac{1000\cdot 3600}{9.81}\cdot\frac{\eta_p}{Sfc}\cdot GR\cdot\ln\left(\frac{1}{1-W_{fuel}/W_0}\right)$ $W_{fuel}/W_0 = 1-\frac{1}{e^{R/B}}$
Maximum takeoff weight	$W_{TO} = \frac{W_{payload}}{\frac{W_{useful}}{W_{TO}}-\frac{W_{fuel}}{W_{TO}}}$ And $\frac{W_{payload}}{W_{TO}} = \frac{W_{useful}-W_{fuel}}{W_{TO}}$
Empty weight	$W_{empty} = W_{TO}-W_{payload}-W_{fuel}$
Wing area	$S_w = \frac{W}{W/S_w}$
Maximum engine power	$P_{eng} = \frac{W}{W/P_{eng}}$

8.4 Chart



The selection of a given match point defined by a given value of wing loading and the corresponding value of power loading will allow the designer to compute the wing area and maximum engine power of the aircraft that fulfills the requirements.

➔W/S	86 kg/m²
➔W/BHP	7.6 kg/kW

Cruise	
C_L	0.24
C_{D0}	0.02070
C_{DL}	0.00279
GR	10.39
B	11685796
W_{fuel}/W	0.07
W	489 kg
W_{fuel}	32 kg
W_{empty}	257 kg

S_w	**5.69 m²**
BHP_{eng}	**64.4 kW**

Annex 9. Airworthiness requirements

9.1 Introduction

Airworthiness is a term used to describe whether an aircraft has been certified as suitable for safe flight.

The **Federal Aviation Regulations**, or **FAR**s, are rules prescribed by the Federal Aviation Administration (FAA) governing all aviation activities in the United States. The FARs are part of Title 14 of the Code of Federal Regulations (CFR). A wide variety of activities are regulated, such as airplane design, typical airline flights, pilot training activities, hot-air ballooning, lighter-than-air aircraft, man-made structure heights, obstruction lighting and marking, and even model rocket launches and model aircraft operation. The rules are designed to promote safe aviation, protecting pilots, passengers and the general public from unnecessary risk.

The FARs are organized into sections, called *parts* due to their organization within the CFR. Each part deals with a specific type of activity. For example, *14 CFR Part 141* contains rules for pilot training schools.

- Part 1 – Definitions and Abbreviations
- Part 13 – Investigation and Enforcement Procedures
- Part 21 – Certification Procedures for Products and Parts
- Part 23 – Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Airplanes
- Part 25 – Airworthiness Standards: Transport Category Airplanes
- Part 27 – Airworthiness Standards: Normal Category Rotorcraft
- Part 29 – Airworthiness Standards: Transport Category Rotorcraft
- Part 33 – Airworthiness Standards: Aircraft Engines
- Part 34 – Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes
- Part 35 – Airworthiness Standards: Propellers
- Part 39 – Airworthiness Directives
- Part 43 – Maintenance, Preventive Maintenance, Rebuilding, and Alteration
- Part 45 – Identification and Registration Marking
- Part 47 – Aircraft Registration
- Part 61 – Certification: Pilots, Flight Instructors, and Ground Instructors
- Part 65 – Certification: Airmen Other Than Flight Crewmembers
- Part 67 – Medical Standards and Certification
- Part 71 – Designation of Class A, Class B, Class C, Class D, and Class E Airspace Areas; Airways; Routes; and Reporting Points
- Part 73 – Special Use Airspace
- Part 91 – General Operating and Flight Rules
- Part 97 – Standard Instrument Approach Procedures
- Part 101 – Moored Balloons, Kites, Unmanned Rockets and Unmanned Free Balloons
- Part 103 – Ultralight Vehicles
- Part 105 – Parachute Operations
- Part 119 – Certification: Air Carriers and Commercial Operators
- Part 121 – Operating Requirements: Domestic, Flag, and Supplemental Operations
- Part 125 – Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Payload Capacity of 6,000 Pounds or More
- Part 133 – Rotorcraft External-Load Operations
- Part 135 – Operating Requirements: Commuter and On Demand Operations and Rules Governing Persons on Board Such Aircraft
- Part 136 – Commercial Air Tours and National Parks Air Tour Management
- Part 137 – Agricultural Aircraft Operations
- Part 139 – Certification of Airports
- Part 141 – Flight Schools
- Part 142 – Training Centres
- Part 145 – Repair Stations

- Part 147 – Aviation Maintenance Technicians Schools
- Part 183 – Representatives of The Administrator

Part 23 contains airworthiness standards for airplanes in the normal, utility, aerobatic, and commuter categories. It dictates the standards required for issuance and change of type certificates for airplanes in these categories.

This Part has a large number of regulations to ensure airworthiness in areas such as structural loads, airframe, performance, stability, controllability, and safety mechanisms, how the seats must be constructed, oxygen and air pressurization systems, fire prevention, escape hatches, flight management procedures, flight control communications, emergency landing procedures, and other limitations, as well as testing of all the systems of the aircraft. It also determines special aspects of aircraft performance such as stall speed (for single engine airplanes - not more than 61 knots), rate of climb (not less than 300 ft/min), take off speed (not less than 1.2 x Vs1), weight of each pilot and passenger (170 lb for airplanes in the normal and commuter categories, and 190 lb for airplanes in the acrobatic and utility categories). The Cessna 177, Cirrus SR20 and Piper PA-34 Seneca are well-known airplanes types that were certificated to FAR Part 23.

Most of the Federal Aviation Regulations, including Part 23, commenced on February 1, 1965. Prior to that date, airworthiness standards for airplanes in the normal, utility and acrobatic categories were promulgated in Part 3 of the US Civil Air Regulations. Many well-known types of light airplane are type certificated to CAR Part 3, even though they remained in production after 1965. For example, the Cessna 150 and Piper Cherokee are type certificated to CAR Part 3.

Part 25 contains airworthiness standards for airplanes in the transport category. Transport category airplanes are either:

- Jets with 10 or more seats or a maximum takeoff weight (MTOW) greater than 12,500 pounds (5,670 kg); or
- Propeller-driven airplanes with greater than 19 seats or a MTOW greater than 19,000 pounds (8,618 kg).

The Boeing 737 and later types, and Airbus A300 series, are well-known airplane types that were certificated to FAR Part 25.

Most of the Federal Aviation Regulations, including Part 25, commenced on February 1, 1965. Prior to that date, airworthiness standards for airplanes in the transport category were promulgated in Part 4b of the US Civil Air Regulations. The Boeing 707 and 727 are two well-known airplane types that were certificated to CAR Part 4b.

9.2 Miscellaneous

	FAR 23 CS 23				FAR 25 CS 25
	N[a]	U[a]	A[a]	C[a]	
Maximum takeoff weight [b]	≤ 12500 lb ≥ 170.s +Δ_1 ≥ MC +Δ_2	≤ 12500 lb ≥ 190.s +Δ_1 ≥ MC +Δ_2	≤ 12500 lb ≥ 190.s +Δ_1 ≥ MC +Δ_2	≤ 19000 lb ≥ 170.s +Δ_1 ≥ MC +Δ_2	Not restricted
Minimum weight [b]	EW + MC + WFC				Not restricted
Number of engines	≥ 1	≥ 1	≥ 1	≥ 2$_{(FAR\ 23)}$ 2$_{(CS\ 23)}$	≥ 2
Maximum number of Occupants [a]	≤ 9+pilot(s)	≤ 9+pilot(s)	≤ 9+pilot(s)	≤ 19+pilot(s)	Not restricted
Type of engine	All	All	All	Propeller-driven	All$_{(FAR\ 25)}$ TP$_{(CS\ 25)}$ [c]
Maximum operating altitude, ft	35000 ft	35000 ft	35000 ft	35000 ft	Not restricted

[a] Cf. FAR 23.3 : Airplane categories for the definition of each category - CS 23.1 : Applicability
[b] Cf. FAR 23.25 - CS 23.25 : Weight limits

[c] Turbine-powered, including Turbopropeller

N : Normal
U : Utility
A : Acrobatic
C : Commuter
s : Number of seats
Δ_1 : Oil at full capacity + Weight of fuel for 30' of operation at maximum continuous power (if VFR$_{day}$)
Δ_1 : Oil at full capacity + Weight of fuel for 45' of operation at maximum continuous power (if VFR$_{night}$ or IFR)
Δ_2 : Oil at full capacity + Fuel at full capacity
EW : Empty weight
MC : required minimum crew (assume 170 lb for each crew member)
WFC : minimum fuel weight

Turbojet powered airplanes	WFC : weight of 5% of the total fuel capacity
Other airplanes	WFC : weight of the fuel necessary for 30' of operation at maximum continuous power

9.3 Structure – Manoeuvring load factors

	n_1[a]	n_2[a]	n_g[b]	n_{flap}[c]
FAR 23 - CS 23 - Normal	≤ 3.8	-0.4 . n_1	$1 \pm \frac{K_g.\rho_0.U_{de}.V.a}{2.\frac{W}{S}}$	2
FAR 23 - CS 23 - Commuter	2.1+(10884/(W+4535))			
FAR 23 - CS 23 - Utility	4.4	-0.4 . n_1		
FAR 23 - CS 23 - Acrobatic	6	-0.5 . n_1		
FAR 25 - CS 25	2.5 ≤ n_1 ≤ 3.8 2.1+(10884/(W+4535))	-1 → V_C -1 ≤ n_2 ≤ 0[d]	$1 \pm \frac{K_g.\rho_0.U_{ref}.V.a}{2.\frac{W}{S}}$	2

[a] Cf. FAR 23.337 - CS23.337 - FAR 25.337 - CS 25.337 : Limit manoeuvring load factors
[b] Cf. FAR 23.341 - CS23.341 - FAR 25.341 - CS 25.341 : Gust load factors
[c] Cf. FAR 23.345 - CS23.345 - FAR 25.345 - CS 25.345 : High lift devices
[d] Varies linearly from the value at V_C to zero at V_D

n_1 : positive maneuvering load factor
n_2 : negative maneuvering load factor
n_g : gust load factor
W : design maximum takeoff weight (kg)
K_g : gust alleviation factor
μ_g : airplane mass ratio
S : aerodynamic reference wing area (m^2)
ρ_0 : air density at sea level (kg/m^3)
ρ : air density at the altitude considered (kg/m^3)
c : mean geometric chord (m)
g : acceleration due to gravity (m/s^2)
V : aircraft equivalent speed (m/s)
a : slope of the airplane normal force curve (/rad)
U_{de} : derived gust velocity (m/s)
U_{ref} : The reference gust velocity in equivalent airspeed (m/s)
W/S : wing loading (N/m²)

$K_g = \frac{0.88\mu_g}{5.3+\mu_g}$	$\mu_g = \frac{2\left(\frac{W}{S}\right)}{\rho \cdot c \cdot a \cdot g}$
U_{de} @ V_C	15.24 m/s (SL → 6096 m)
U_{de} @ V_D	0.5 U_{de} @ V_C
U_{ref} @ V_C	17.07 m/s (SL)
	17.07 m/s → 13.41 m/s (SL → 4572 m)
	13.41 m/s → 7.92 m/s (4572 m → 15240 m) for FAR 25
	13.41 m/s → 6.36 m/s (4572 m → 18288 m) for CS 25
U_{ref} @ V_D	0.5 U_{ref} @ V_C

9.4 Performances- Stall speed

	FAR 23 **CS 23**				**FAR 25** **CS 25**
	N^a	U^a	A^a	C^a	
V_S [b]	≤ 61 kts **if** $n \le 1$ ≤ 61 kts **if** ($n > 1$ **and** $W < 6000$ lb **and** RC OEI < RC_{Min} OEI)[c]				
V_{SR}[b]					$\geq \frac{V_{CLMx}}{\sqrt{n_{zw}}}$

[a] Cf. FAR 23.3 Airplane categories for the definition of each category

[b] Cf. FAR 23.49 - CS 23.49 : Stalling speed - FAR 25.103 - CS 25.103 : Stall speed

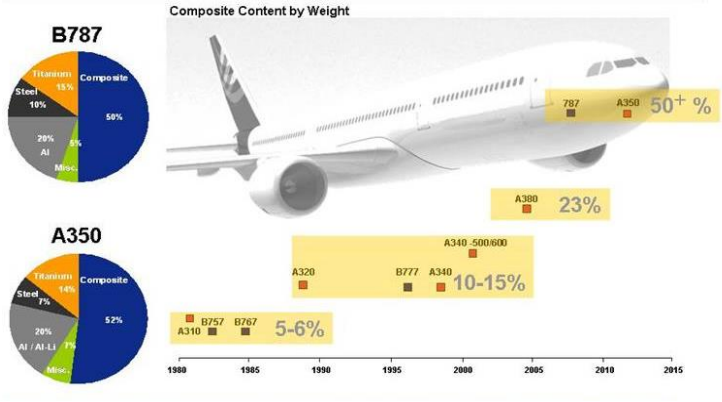
[c] Cf. FAR 23.67 - CS 23.67 : Climb: One engine inoperative

n : Number of engines

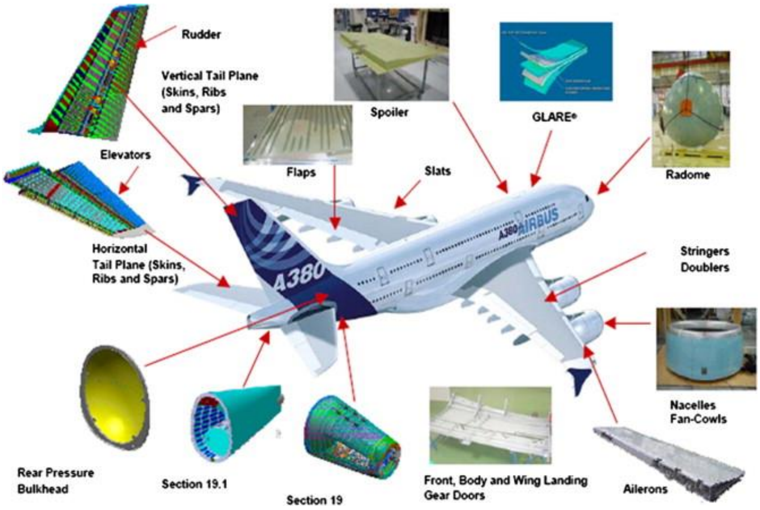
n_{zw} : Load factor normal to the flight path at V_{CLMx}

Annex 10. Materials in aviation

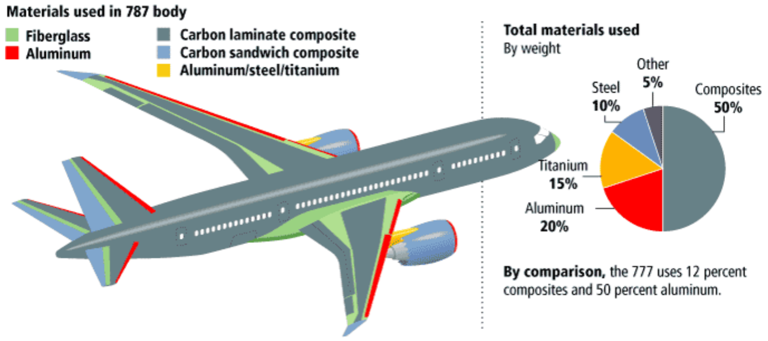
10.1 Percentage of composite



10.2 Current aircraft



10.2.1 Next generation aircraft



Annex 11. The power-plant

11.1 Introduction

The engine is one component of the propulsion system of the aircraft that is used to generate the thrust.

In aviation, most of the engine are internal combustion engine. They could be classified in 2 categories: shaft engines which drive a propeller, and reaction engines which generate thrust. Electric motors are used on very small aircraft (radio controlled aircraft or unmanned aerial vehicles)

The selection of engine type is function of different parameters: the maximum power required, the flight speed and the flight altitude.

A single engine aircraft has the engine in the fuselage in a tractor or pusher configuration. A multi engine aircraft, most of the time, has the engines on both sides of the fuselage, on or below the wing.

Sometimes a twin engine propeller driven aircraft may have the engines located in the fuselage in a push-pull configuration, one engine in the front and one engine in the rear of the fuselage.

11.2 Summary

Definition	Mechanical device used to generate power
Category	Internal combustion engine - Shaft engine o Piston o Turboprop o Turboshaft - Reaction engine o Turbojet o Turbofan Electric
Application	Piston : Light aviation, UAV Turboprop : low speed and high power aircraft (transport aircraft) Turboshaft : Helicopter Turbojet : High speed (military aircraft) Turbofan : Long range, high speed aircraft Electric : UAV
Position	Single engine : on the fuselage, in a tractor or pusher configuration Multi engine: - Under the wing for transport aircraft, - In the fuselage for military fighters

11.3 Thrust

The equation of the thrust provided by the propulsion system is:

$$T = m \cdot a = \dot{m} \cdot (V - V_0)$$

With:

T	Thrust [N]
$\dot{m}$	Mass flow rate [kg/s]
a	Fluid acceleration [m/s²]
V_0	Free stream fluid velocity [m/s]
V	Exhaust fluid velocity [m/s]

The thrust will be maximized if

1. The mass flow rate is maximized (➚)
2. The fluid acceleration is maximized (➚), high fluid velocity.

11.4 Propulsion efficiency

The propulsion efficiency is defined as the ratio between the thrust (or power) obtained to the thrust (or power) expanded

$$\eta_P = \frac{P}{P_{expended}} = \frac{2}{V/V_0 + 1}$$

With:

V_0	Free stream fluid velocity [m/s]
V	Exhaust fluid velocity [m/s]

There is an unavoidable tradeoff between thrust and efficiency. For maximum thrust, the ratio between exhaust and free stream velocity must be very high. But for maximum efficiency, this ratio must be close to unity…

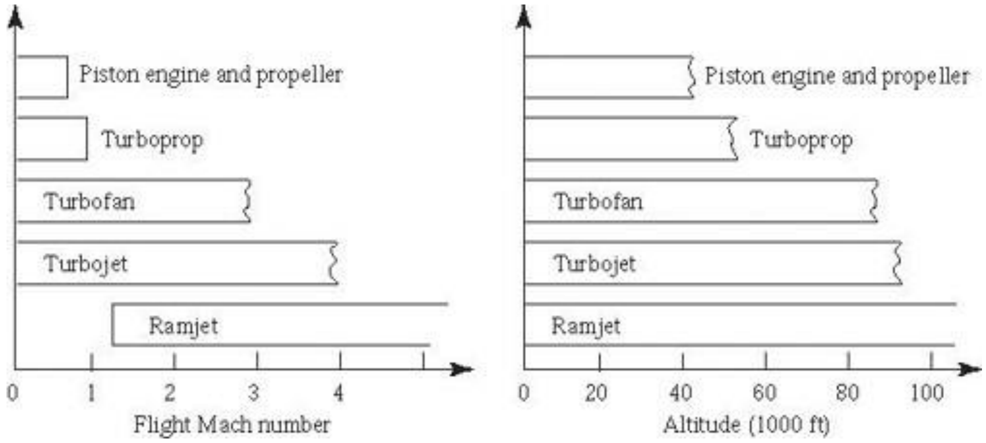
11.5 Engine technology

11.5.1 Introduction

There exist different types (technology) of propulsion systems:

- Electric engine & propeller
- Piston engine & propeller
- Turbopropulsor
- Turbofan
- Turbojet

According to the flight speed and flight altitude, one propulsion system will be preferably used from another.



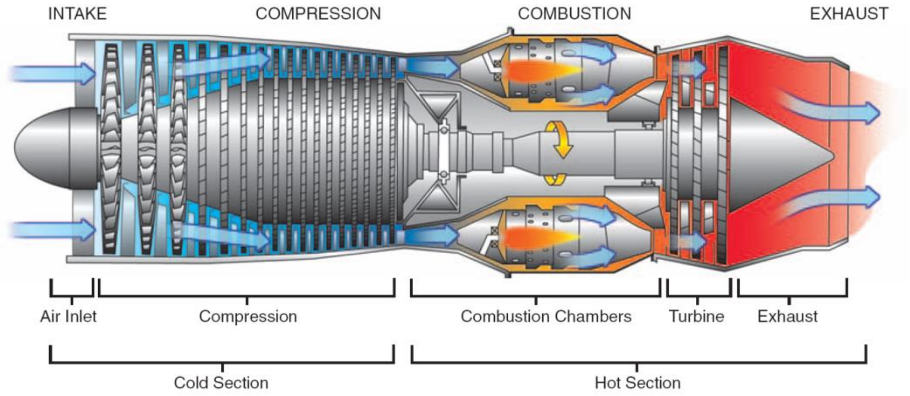
11.5.2 Turbojet

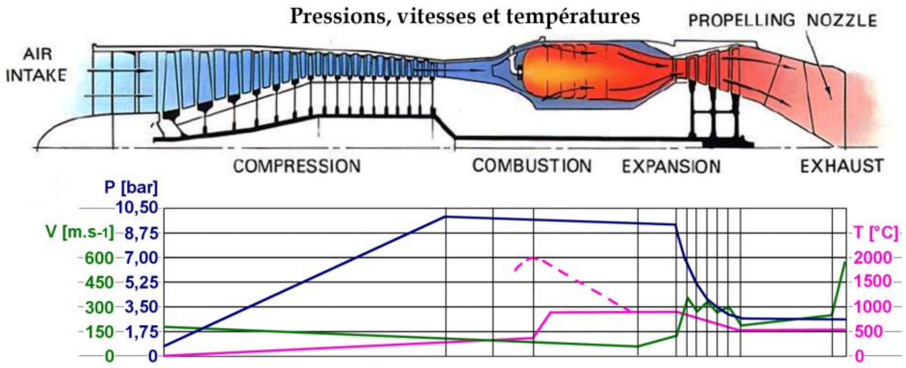
Advantages

- Low friction
- Little wear
- Long service life (20.000 – 30.000 h)
- Simplicity
- Low cost
- Low drag

Drawbacks

- High exhaust gas velocity (500 – 600 m/s) in order to reach a high thrust
- Low efficiency (30%) at subsonic flight speed





Turbojet engines are used on high speed (supersonic) aircraft.

11.5.3 Turbofan

In order to improve the propulsion efficiency, the exhaust fluid velocity is reduced. In order to increase the thrust, the mass flow is increased using a fan, which works like a compressor with a low compression ratio.

The bypass ratio is the ratio between the mass flow passing through the fan and the mass passing through the turbine (used for combustion).

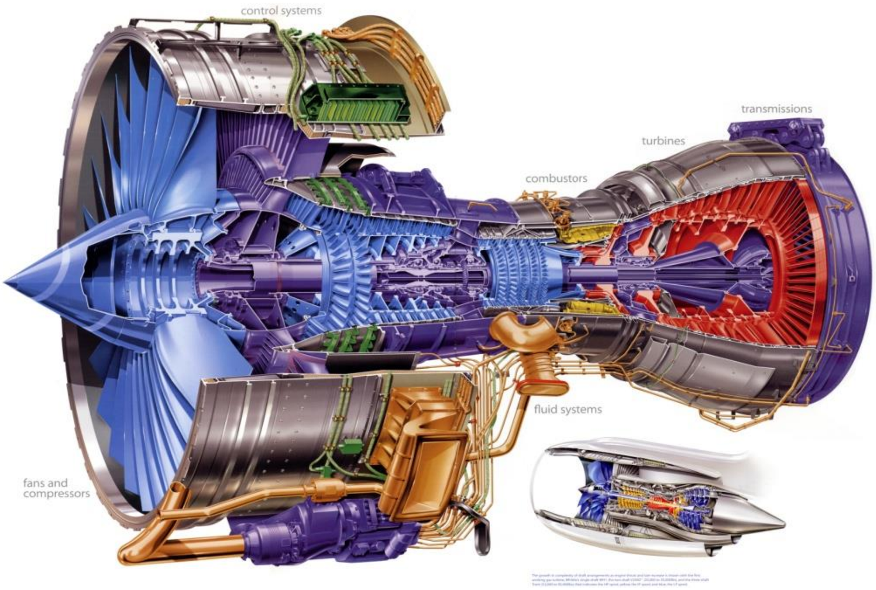
$$T = m \cdot a = \dot{m}_{jet} \cdot (V_{jet} - V_0) + \dot{m}_{fan} \cdot (V_{fan} - V_0)$$

Advantages

- High global efficiency (50%)
- Low fuel consumption (0.03 kg/N.h @ TO, SL, ISA conditions)
- Low $C0_2$ emissions

Drawbacks

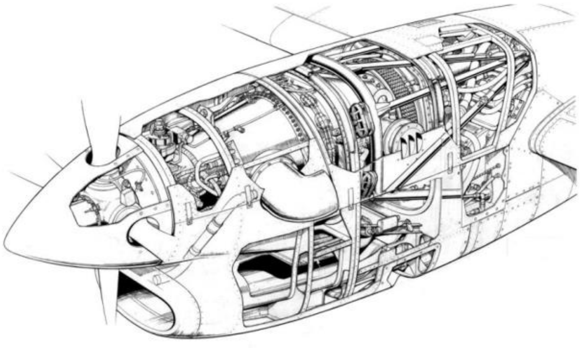
- Higher weight
- Higher drag



High bypass turbofan engines are used on subsonic transport aircraft.

11.5.4 Turbopropulsor

A turbopropulsor is a low-power turbofan with a very high bypass ratio. The fan is replaced by a propeller. In order to have a good propeller efficiency (> 80%), a gearbox is used between the turbine (@ 8.000 – 15.000 t/min) and the propeller (800 – 2000 t/min).

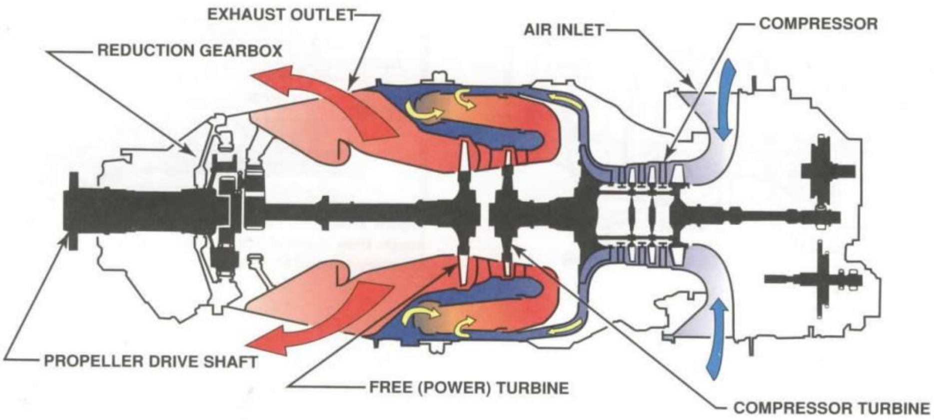


Advantages

- High power-to-weight ratio
- Very low fuel consumption
- STOL capability

Drawbacks

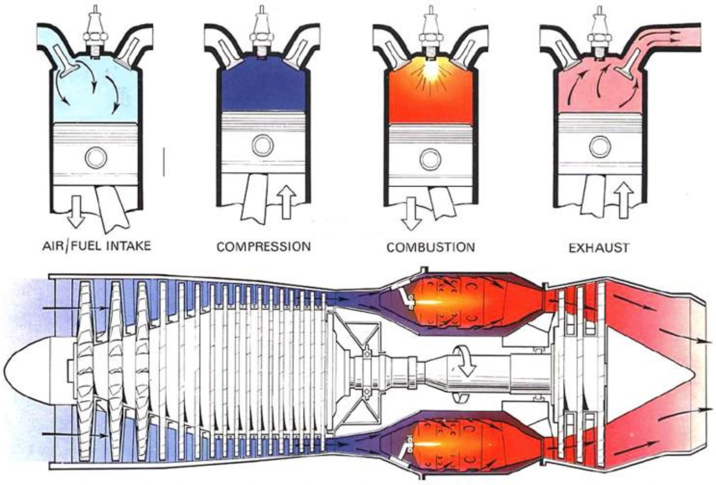
- Limited flight speed
- High noise level
- High weight due to the gearbox
- Lubrication
- Vibrations



Turbopropulsor engines are used on low speed transport aircraft.

11.5.5 Piston & propeller

Most commonly used propulsion system when the need of power is lower than 230 kW (300 hp).



A comparison between the working cycle of a turbo-jet engine and a piston engine.

Advantages

- Low cost

Drawbacks

- Heavy
- High level of vibrations due to the oscillating motion of the pistons
- High friction
- Low efficiency (30%)
- Short service life (2.000 – 3.000 h)

11.5.6 Electric & propeller

More and more used for low-powered systems like micro-UAS.

Advantages

- Low cost
- No limit in altitude (except for the propeller)
- No vibration
- No gearbox
- Light (if the engine is taken alone)
- High efficiency (95%)

Drawbacks

- Heavy (if the batteries are taken into account)
- Short endurance

Annex 12. Lifting Surface Design Parameters

Some very important design criteria will be explained in such a way to understand their impact on the whole aircraft. The reader will understand that, most of the time, the designer will need to make compromises.

1. Wing vertical position on the fuselage
2. Lifting surface aspect ratio
3. Lifting surface sweep angle
4. Lifting surface taper ratio
5. Lifting surface dihedral effect
6. Lifting surface airfoil selection

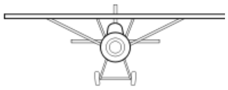
12.1 Wing vertical position on the fuselage

Low wing

Mid wing

Shoulder wing

High wing



Parasol wing

	Low	**High**
Structure & Aerodynamics		
Favorable ground effect in takeoff & landing	+	-
Moving surfaces closer to the ground are more easily damaged	-	+
High wings tend to be strutted because they are often thinner so as to leave enough headroom. (more draggy than low-winged arrangements)	+	-
Low wing structure is useful anchorage and stowage for landing gear	+	-
Landing gear can be made shorter and lighter	+	-
Deeper spar can be used (can be incorporated into seat structure)	+	-
Increase the depth of the fuselage if deeper spar is needed	+	-
Fairing between wing root and fuselage more critical aerodynamically (upper surface of the wing generates 66% of the total lift and some is lost by imperfect fillets, while imperfections beneath the root of a high wing increase static pressure and increase lift)	-	+
➔ **Stability**		
High wing provides more lateral stability through dihedral effect	-	+
No dihedral needed, easy to build (a high wing augments dihedral, while a low wing works against dihedral. So that low-winged airplanes need more dihedral than those with high wing)	-	+
➔ **Safety & Visibility**		
Better fields of view from above the horizon, downwards (better touring aircraft)	-	+
Better fields of view from above the horizon, upwards (agile aircraft)	+	-
Visibility in the direction of turn	+	-
Manoeuvrability, Agility (good fields of view in the direction of turn and manoeuvre)	+	-
Crashworthiness, tough and resilient structure is needed to take the weight of the aircraft when on its back	-	+
Crashworthiness, easily exit from the aircraft	-	+
Note: the extend of cockpit glazing should be determined by the pilot needs. An agile airplane which regularly exceeds angles of bank of 60° needs wider fields of view than a stately transport machine, which rarely exceeds 30°		
➔ **Aircraft category**		
Touring aircraft	-	+
Agile aircraft	+	-

12.2 Lifting surface aspect ratio


Low aspect ratio

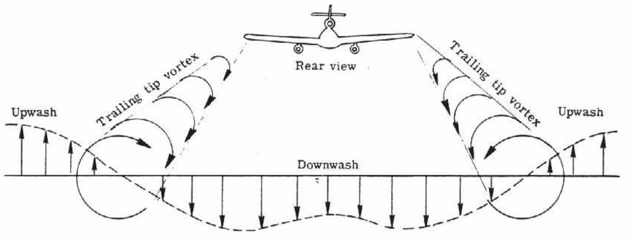

Moderate aspect ratio


High aspect ratio

In selecting the lifting surface aspect ratio the designer must give considerations to several general requirements. These requirements are related to:

1. Aerodynamics
2. Structural weight
3. Safety

Introduction



When a wing is generating lift, it has a reduced pressure on the upper surface and an increased pressure on the lower surface. This pressure difference tends to move the air from the bottom of the wing, moving to the top. This is not possible for a 2D-flow (airfoil profile) but for a real 3D-flow (3D-wing) the air can escape around the wing tip. Air escaping around the wing tip lowers the pressure difference between the upper and lower surfaces. This reduces lift near the wing tip and generates vortices. A wing with a high aspect ratio has smaller tips, less sensitive, than a wing of equal area with a low aspect ratio.

➔ Aerodynamics

AR as high as possible (➚) to reduce the induced drag.

Flight conditions concerned: climb, maxi range and maxi endurance

$$C_D = C_{D_0} + \frac{C_L^{\ 2}}{\pi \cdot AR_w \cdot e}$$

➔ Structural weight

AR as low as possible (➘) to reduce the structural weight of the lifting surface

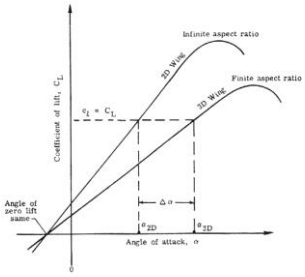
$W_w = fct\left(AR_w^{\ 0,6}\right)$

Δ(AR)	ΔW$_w$
-20%	-12.5%
-10%	-6.1%
10%	5.9%
20%	11.6%

➔ Safety

AR changes modify the stalling angle. Surface with low aspect ratio will stall at a higher angle of attack than surface with high aspect ratio

<u>A canard surface</u> (➚) can be made to stall before the main wing by making it a very high aspect ratio surface. <u>Horizontal tails</u> (➘) tend to be of lower aspect ratio.

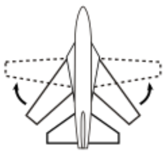


12.3 Lifting surface sweep angle

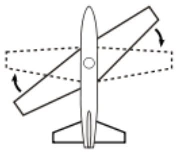
Straight

Swept

Forward swept



Variable sweep



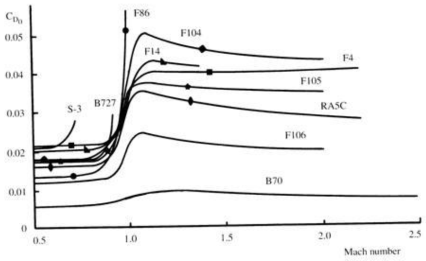
Oblique wing

In selecting the lifting surface sweep angle the designer must give considerations to several general requirements. These requirements are related to:

1. Aerodynamics
2. Structural weight
3. Balance & Stability

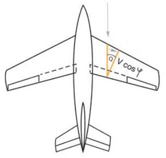
Introduction

Wing sweep is used preliminary to reduce the adverse effects of transonic and supersonic flow. The speed of the air passing on the upper surface of wing is increased. The critical Mach number is the speed at which the local flow on the upper surface reaches the speed of sound. If the speed continues to increase, a shock wave will appear and the drag will drastically increase.



➔ High speed aerodynamics

Sweep angle (↗) is favorable for high speed flight to delay the apparition of wave drag. Shock formation on a swept wing is determined by the air velocity in a direction perpendicular to the leading edge of the wing.



➔ Structural weight

Sweep angle as low as possible (↘) to reduce the structural weight of the lifting surface

$$W_w = fct\left(\cos(\Lambda)^{-0,9}\right)$$

Λ	ΔW$_w$
0°	0,0%
10°	1,4%
20°	5,8%
30°	13,8%

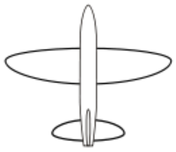
➔ Balance & Stability

Sweep Angle (↗,↘) is necessary to balance the aircraft in order to move the Aerodynamic Center (AC) far enough from the CG position for balance.

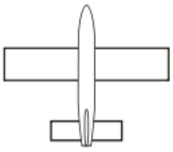
Sweep angle (↗) improves stability. A swept wing has a natural dihedral effect (rolling moment caused by sideslip). Roughly speaking, 10° of sweep provides about 1° of effective dihedral.

If an aircraft has its vertical tails at the wing tips, sweeping the wing (↗) will push the tails aft, increasing their effectiveness.

12.4 Lifting surface taper ratio



Elliptical



Constant chord

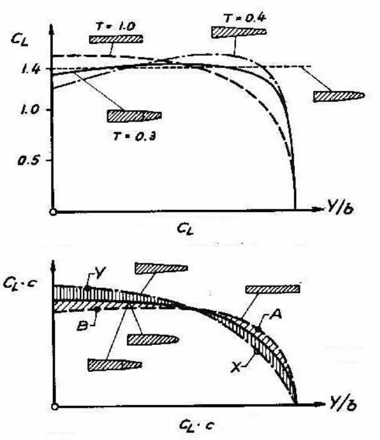
Tapered

In selecting the lifting surface taper ratio the designer must give considerations to several general requirements. These requirements are related to:

1. Aerodynamics
2. Structural weight
3. Manufacturing

Introduction

Taper ratio is the ratio between the tip chord and the root chord. Taper affects the distribution of the lift along the span of the lifting surface. Minimum drag due to lift or “induced” drag occurs when the lift is distributed in an elliptical fashion. For an untwist and unswept wing, this occurs when the wing planform is shaped as an ellipse. An elliptical planform is difficult and expensive to build. However, a wing with a taper ratio 0.4, which is simpler to build, produces lift distribution very close to the elliptical shape.



➔ Aerodynamics

Taper ratio (➘) up to 0.4 will reduce the induced drag.

➔ Structural weight

Taper ratio as low as possible (➘) to reduce the structural weight of the lifting surface

$$W_w = \text{fct}\left(TR^{0.04}\right)$$

Δ(TR)	ΔW_w
-10%	-0.4%
-20%	-0.9%
-30%	-1.4%
-40%	-2.0%
-50%	-2.7%
-60%	-3.6%

➔ Manufacturing

A wing with a taper ratio lower than 1 is more difficult and more expensive to build than a rectangular wing (TR = 1)

A wing with a given taper ratio is easier and less expensive to build than an elliptical wing.

12.5 Lifting surface dihedral angle

Dihedral

Anhedral

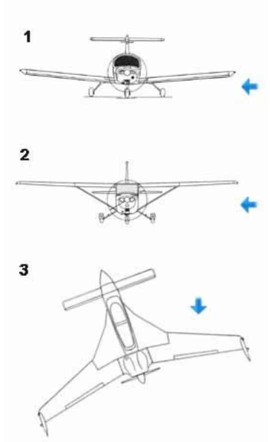
Inverted gull wing

Upward cranked tips

Introduction

Dihedral effect tends to roll the aircraft level when side slipping.
Dihedral is the angle of the wing with the horizontal when seen from the front. Positive when the tip is higher than the root.
Three characteristics of the wing have an influence on the dihedral effect:

1. The wing dihedral angle itself
2. The vertical position of the wing on the fuselage
3. The wing sweep angle



➔ **The wing dihedral angle**

During a sideslip, the lateral wind coming from the sideslip direction increases the angle of attack and therefore the lift. The resulting moment is approximately proportional to the dihedral angle.

➔ **The vertical position of the wing on the fuselage**

The position of the wing on the fuselage has an influence on the dihedral effect, with the greatest effect provided by a high position. The fuselage in sideslip pushes the air over and under itself. If the wing is high-mounted, the air pushed over the top increases the angle of attack between the air and the wing and therefore increases the lift. The reverse is true for a low-mounted wing.

➔ **The wing sweep angle**

Wing sweep produces a rolling moment due to sideslip caused by the change in relative sweep of the left and right wings. Roughly speaking, 10° of sweep provides about 1° of effective dihedral.

Notes

Due to additive effect of sweep and wing position, many high-winged transports such as the Lockheed C-5 require a negative geometric dihedral angle to avoid an excess of effective dihedral, which produces “Dutch Roll”, a repeated side-to-side motion involving roll and yaw. To counter a Dutch roll tendency, the vertical tail must be increased, which increases weight and drag.

Historical values

	Wing position		
	Low	Mid	High
Unswept	5° to 7°	2° to 4°	0° to 2°
Subsonic swept wing	3° to 7°	-2° to 2°	-5° to -2°
Supersonic swept wing	0° to 5°	-5° to 0°	-5° to 0°

Annex 13. Lifting surface airfoil profile

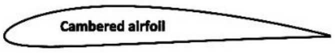
13.1 Introduction

If a horizontal wing is cut by a vertical plane, parallel to the center line, the shape of the section is the airfoil section.

The airfoil is probably one of the most important characteristics of an airplane. It affects the cruise speed, the stall speed, the takeoff and landing distances, handling qualities and overall aerodynamic efficiency during all phases of flight.

There are two types of airfoils:

- Cambered airfoil
- Symmetrical airfoils



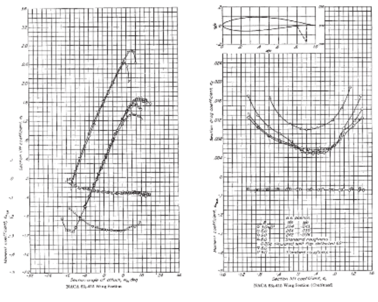
The cambered airfoil will be used on the wings to generate the upward lift. The symmetrical airfoils will be used on the stabilizers to generate lift in both directions (up and down for the horizontal stabilizer or left and right for the vertical stabilizer)

The shape of the airfoil will be function of the flight speed of the airplane. An airfoil designed to operate in supersonic flow will have a sharp leading edge to reduce supersonic drag, compared to a slow-speed airplane which will have a round nose.

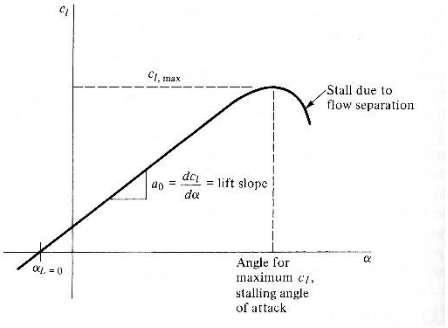
13.2 Aerodynamic performance

The aerodynamic performance of an airfoil are given in general in three graphs.

- One graph which shows the correlation between the lift coefficient and the angle of attack
- One graph which shows the correlation between the drag coefficient and the lift coefficient. This graph is also named the drag polar
- One graph which shows the correlation between the pitching moment coefficient and the lift coefficient



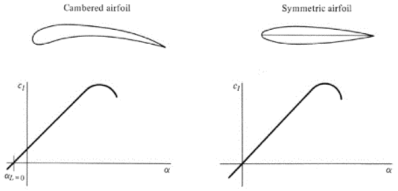
13.2.1 Lift Curve



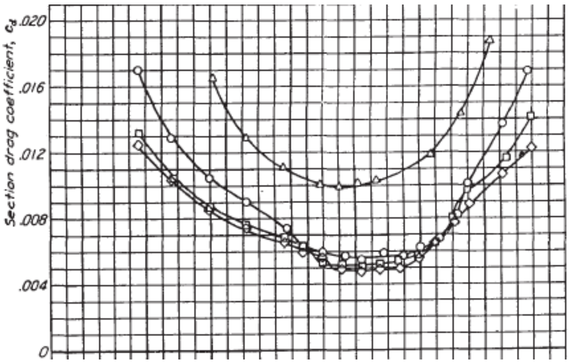
The lift curve is characterized by:

α	is the angle of attack. This value is always small with a maximum value of about 15°
Cl	is the lift coefficient
α_0	is the zero-lift angle of attack
α_{ClMx}	is the angle of attack for maximum lift coefficient, also named stalling angle of attack
Cl_0	is the lift coefficient which is reached at zero angle of attack
Cl_{Mx}	is the maximum lift coefficient. Typical values of this maximum lift coefficient lie between 0,8 and 1,6
a_0	is the lift gradient. This value is close to 2 π

Looking at the curve of the lift coefficient, a symmetrical airfoil will generate no lift at zero angle of attack, while a cambered airfoil will generate no lift at a negative angle of attack.



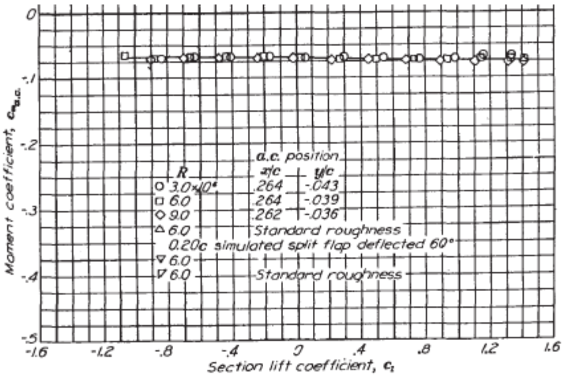
13.2.2 Drag Curve



The drag curve is characterized by:

C_{DMin}	is the minimum drag coefficient
Laminar bulkhead	is the range of C_l where the drag is minimum

13.2.3 Moment Curve

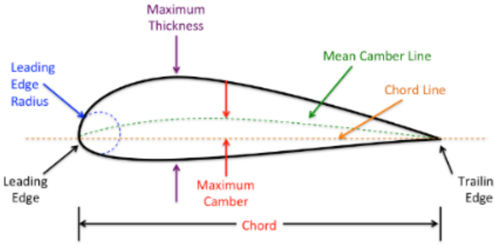


The moment curve is characterized by:

C_{m0}	is the moment coefficient at zero lift coefficient

13.3 Geometric parameters that affect the performance of an airfoil

Cl_{Mx} increases with increasing the relative thickness up to 15%, beyond Cl_{Mx} start decreasing.



The minimum drag coefficient increases with the relative thickness.

The nose radius strongly affects the angle of attack capability. A large radius of curvature will lead to a high lift coefficient and gentle stall break. A small leading edge radius has sharp stall break.

The maximum camber affects the value of a_0, Cl_0 and Cm_0

The maximum camber also affects the maximum lift coefficient and the minimum drag coefficient.

The slope of the camber line at the leading edge position affects the values of α_0 and Cl_0

The slope of the camber line at the trailing edge position affects the values Cm_0

The slope of the camber line affects the drag raise characteristics

The trailing edge angle affects the profile drag

A high glide ratio is reached with a low maximum relative thickness and a low camber

Annex 14. Lifting surface airfoil selection

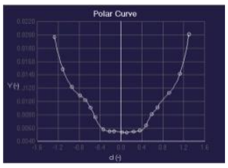
In selecting the airfoil sections the designer must give considerations to several general requirements. These requirements are related to:

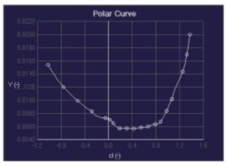
1. Aerodynamics
2. Structural weight
3. Manufacturing
4. Safety

➔ Aerodynamics

Maximum lift coefficient, as high as possible to minimize wing wetted area

Drag coefficient during the main flight condition (flight at a given lift coefficient and Reynolds Number) as low as possible to minimize required power





Drag coefficient during low speed flight (takeoff and climb) as low as possible to minimize required power

Pitching moment coefficient as low as possible to avoid high torsion loads and high trim drag

Critical Mach Number must be sufficiently high to ensure that critical compressibility effects are avoided in the case of aircraft flying at high speed (> Mach 0.7)

Sensitivity to contamination and dirt must be as low as possible

➔ Structural weight

Relative thickness must be as high as possible in the interest of low structural weight

$\Delta(t/c)$	ΔW_w
-20%	6.9%
-10%	3.2%
10%	-2.8%
20%	-5.3%

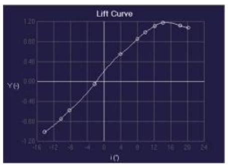
$$W_w = fct\left(\left(t/c\right)_w^{-0.3}\right)$$

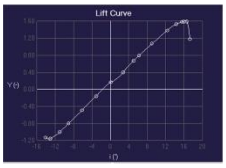
➔ Manufacturing

Sensitivity to manufacturing variations must be as low as possible

➔ Safety

Stall characteristics must be as gentle as possible to warn the pilot that a loss of lift will occur and to minimize the loss of altitude during the stall





Unfortunately all of these requirements cannot be satisfied at the same time and compromise must be done.

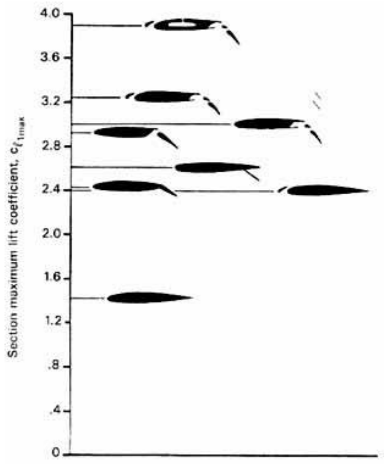
Annex 15. The high lift devices

The main objective of the high lift device is to increase the maximum lift coefficient of a lifting surface. This is achieved most of the time by increasing the wing camber and sometimes the wing area at the same time.

There are two types of mechanical high lift devices:

- Trailing edge high lift device
- Leading edge high lift device

The choice will affect the maximum lift coefficient, and therefore the stall speeds and the takeoff and landing distances of the aircraft.



15.1 Trailing edge aerodynamic devices

- Plain flap
- Split flap
- Single slotted flap
- Double slotted flap
- Fowler flap

The approximate maximum lift contribution is:

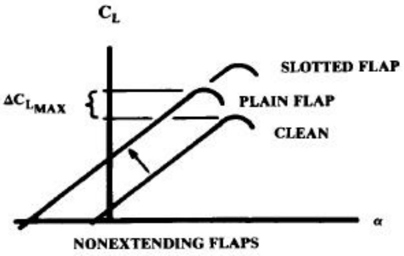
Plain flap	0.9
Split flap	0.9
Single slotted flap	1.3
Fowler flap	1.3.c'/c
Double slotted flap	1.6 c'/c

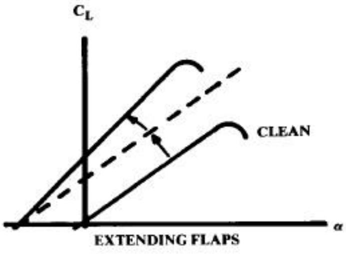
The plain flap is the hinged part of the trailing edge that moves downward in order to increase the camber of the airfoil.

The split flap is like the plain flap except that only the lower surface of the airfoil moves downward. The lift increment is the same than the plain flap but the drag increment is HIGHER and the change in pitching moment is LOWER.

The slotted flap is a plain flap with a gap between the wing and the flap. The hole allows high-pressure air from the lower surface of the wing to reach the upper surface of the wing in order to delay separation and stall

The Fowler flap is a slotted flap which moves rearward when deflected. This provides 1) an increase of the camber of the airfoil, 2) an increase in wing area.





15.2 Leading edge aerodynamic devices

- Leading edge flap
- Kruger flap
- Leading edge slot
- Leading edge slat

The approximate maximum lift contribution is:

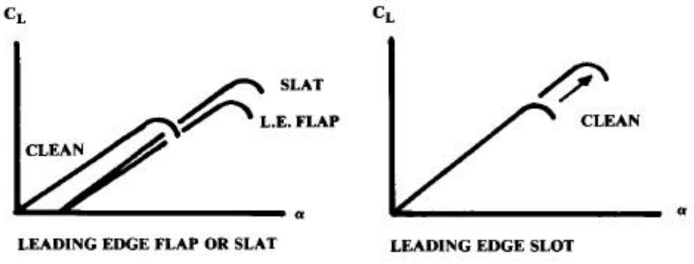
Leading edge slot	0.2
Leading edge flap	0.3
Kruger flap	0.3
Leading edge slat	0,4 c'/c

The leading edge slot is a hole which allows high-pressure air from the lower surface of the wing to reach the upper surface of the wing in order to delay separation and stall.

The leading edge flap is the hinged part of the leading edge that moves down in order to increase the camber of the airfoil.

The leading edge slat provides 1) an increase of the camber of the airfoil, 2) a slot and 3) an increase in wing area

The Kruger flap works as a deflector, forcing the air to go over the top of the wing. Mostly used by large airliners



15.3 Effects of high lift devices

The non-extending flaps such as the plain, split or slotted flaps act as an increase in camber, which moves the angle of zero lift to the left and increases the maximum lift. The slope of the curve remains unchanged, and the angle of stall is somewhat reduced.

An extending flap such as the Fowler flap acts much like the other flaps as far as zero-lift angle and stall angle are concerned. However, the wing area is increased as the flap deflects, so the wing generates more lift at any given angle of attack compared to the non-extending flap.

Because the lift coefficient is referenced to the original wing area, not the extended wing area, the effective slope of the lift curve for an extending flap is increased by approximately the ratio of the total extended wing area to the original wing area.

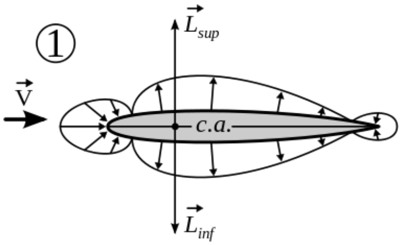
Annex 16. The aerodynamic centre

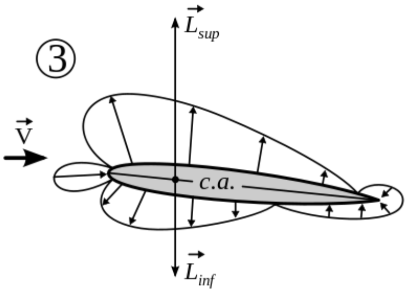
16.1 Aerodynamic centre / Symmetric airfoil

For symmetric airfoils, the center of pressure does not vary with lift coefficient. The center of pressure coincide with the aerodynamic center.

In subsonic flight, for symmetric airfoils, the aerodynamic center is located at 25% of the chord, measured from the leading edge of the airfoil.

In supersonic flight, due to compressibility effects, the aerodynamic center moves to the 50% chord position.



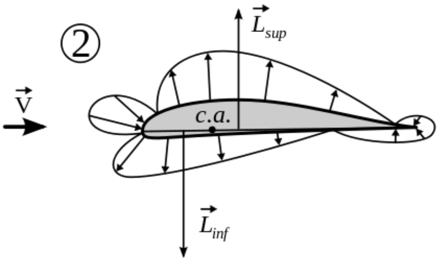


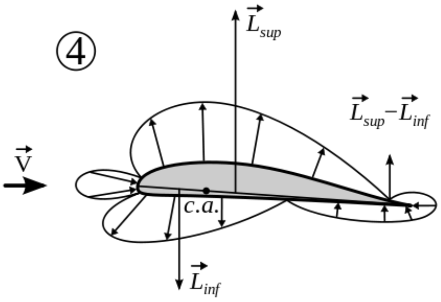
16.2 Aerodynamic centre / Cambered airfoil

For non-symmetric airfoils, or cambered airfoils, the center of pressure varies with lift coefficient. The center of pressure does not coincide with the aerodynamic center.

In subsonic flight and for incidences up to 10°, the aerodynamic center is located close to, not in general on, the chord line, between 23% and 25% of the chord, behind the leading edge. Compressibility tends to move it backwards. For thin airfoil in supersonic flow, the aerodynamic center is theoretically at 50% chord position.

For a conventional cambered airfoil, at high lift coefficient, close to the maximum lift coefficient, the center of pressure lies a little behind the quarter-chord point. When the lift coefficient reduces, the center of pressure moves to the rear. When the lift coefficient is equal to zero, a cambered airfoil generates a nose-down pitching moment. That means that the center of pressure is located at an infinite distance behind the airfoil



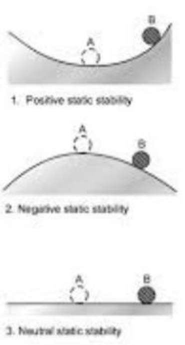


Annex 17. Introduction to stability

17.1 Static stability

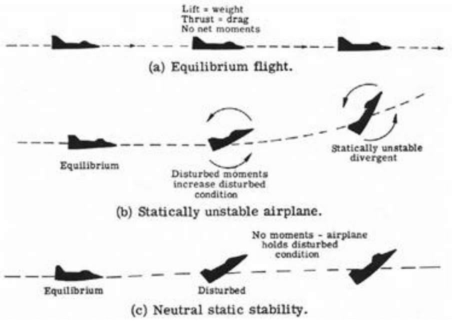
Static stability of a ball in a U-Shape describes the tendency of the ball to go back to its original position.

- Statistically stable, the ball will roll back to its original position
- Statistically unstable, the ball goes further and further its original position
- Statistically neutral, the ball remains in the disturbed position



Static stability of an aircraft describes the tendency to go back to its original position when subjected to disturbance acting on it.

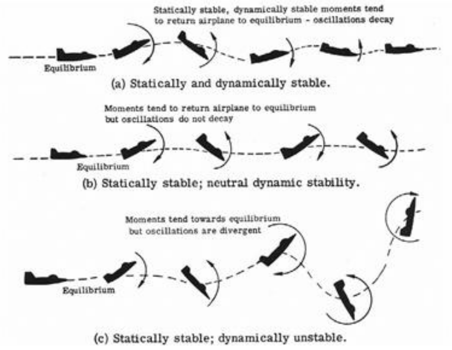
- Statically stable means that the aircraft is able to go back to its original position after disturbance.
- Statically unstable means that the aircraft continues to diverge from its original position
- Statically neutral means that the aircraft remains in its disturbed position



17.2 Dynamic stability

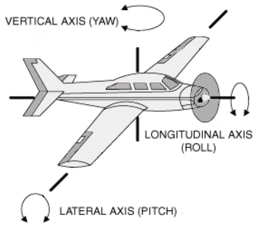
Dynamic stability describes the form of the motion of an aircraft when it tries to return to its original position.

- Dynamically stable means that the original position will be retrieved after a series of decaying oscillations
- Dynamically neutral means that the aircraft continues the oscillatory motion without decay in magnitude.
- Dynamically unstable means that the oscillatory motion increases in magnitude



17.3 Stability about the Axis

The stability of an airplane determines its ability to be trimmed to fly hands-off at any speed.



17.3.1 Longitudinal stability

The longitudinal or pitch stability is stability about the lateral axis.

Longitudinal stability is provided primarily by the horizontal tail surface

Because the aerodynamic center is behind the center of gravity, an increment of lift will produce a nose down pitching moment. This nose down pitching moment will reduce the angle of attack, and at the same time the lift. The airplane goes back automatically in its original position.

The position of the center of gravity, in front of the aerodynamic center, is the condition for longitudinal stability. The greater this distance the more stable the aircraft. The lesser this distance the less stable the aircraft, but the more agile the aircraft

17.3.2 Lateral stability

The lateral or roll stability is stability about the longitudinal axis.

Lateral stability is provided primarily by the dihedral of the wing

Dihedral is the angle between the wing and the lateral axis. Positive when the tip of the wing is at a higher position than the root of the wing. When an airplane enters in a downward sideslip toward the low wing, the direction of the relative wind changes. The low wing experience an increase of lift while the high wing experience a reduction of lift. This is due to a modification of the angle of attack. The combined forces tend to roll back the aircraft in its wings-level attitude

17.3.3 Directional stability

The directional or yaw stability is stability about the vertical axis.

Directional stability is provided primarily by the vertical tail surface.

Most airplane are designed with more projected area behind the center of gravity than forward it. When an airplane enters a sideslip, the relative wind strikes the side of the fuselage and the vertical tail. Since the force exerted on the airplane is behind the center of gravity, the airplane tends to yaw in the direction of the relative wind

Annex 18. Weight estimation

18.1 Wing, W_w (3)

$$W_w = MCF_w \cdot 0{,}14278 \cdot TR_w^{0{,}04} \cdot \left(\frac{AR_w}{\left(\cos \Lambda_{25w}\right)^2} \right)^{0{,}6} \cdot \left(\frac{100 \cdot (t/c)_w}{\cos \Lambda_{25w}} \right)^{-0{,}3} \cdot q_{cr}^{0{,}006} \cdot S_w^{0{,}758} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}49} \cdot W_{fw}^{0{,}0035}$$

18.2 Horizontal Tail, W_{HT} (3)

$$W_{HT} = MCF_{HT} \cdot 0{,}044194 \cdot TR_{HT}^{-0{,}02} \cdot \left(\frac{AR_{HT}}{\left(\cos \Lambda_{25HT}\right)^2} \right)^{0{,}043} \cdot \left(\frac{100 \cdot (t/c)_{HT}}{\cos \Lambda_{25HT}} \right)^{-0{,}12} \cdot q_{cr}^{0{,}168} \cdot S_{HT}^{0{,}896} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}414}$$

18.3 Vertical Tail, W_{VT}

$$W_{VT} = MCF_{VT} \cdot N_{VT} \cdot 0{,}22136 \cdot TR_{VT}^{0{,}039} \cdot \left(1 + 0{,}2 \cdot a\right) \cdot \left(\frac{AR_{VT}}{\left(\cos \Lambda_{25VT}\right)^2} \right)^{0{,}357} \cdot \left(\frac{100 \cdot (t/c)_{VT}}{\cos \Lambda_{25VT}} \right)^{-0{,}49} \cdot q_{cr}^{0{,}122} \cdot S_{VT}^{0{,}873} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}376}$$

With:

	a
Conventional	0
T-tail	1

18.4 Canard Surface, W_{crd} (3)

$$W_{crd} = MCF_{crd} \cdot 0{,}044194 \cdot TR_{crd}^{-0{,}02} \cdot \left(\frac{AR_{crd}}{\left(\cos \Lambda_{25crd}\right)^2} \right)^{0{,}043} \cdot \left(\frac{100 \cdot (t/c)_{crd}}{\cos \Lambda_{25crd}} \right)^{-0{,}12} \cdot q_{cr}^{0{,}168} \cdot S_{crd}^{0{,}896} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}414}$$

18.5 Winglets, W_{wgl}

$$W_{wgl} = MCF_{wgl} \cdot N_{wgl} \cdot 0{,}22136 \cdot TR_{wgl}^{0{,}039} \cdot \left(\frac{AR_{wgl}}{\left(\cos \Lambda_{25wgl}\right)^2} \right)^{0{,}357} \cdot \left(\frac{100 \cdot (t/c)_{wgl}}{\cos \Lambda_{25wgl}} \right)^{-0{,}49} \cdot q_{cr}^{0{,}122} \cdot S_{wgl}^{0{,}873} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}376}$$

18.6 Fuselage, W_{fus} (3)

$$W_{fus} = MCF_{fus} \cdot 0{,}13274 \cdot q_{cr}^{0{,}241} \cdot \left(\frac{L_{fus}}{MD_{fus}} \right)^{-0{,}072} \cdot L_{APfus}^{-0{,}051} \cdot WA_{fus}^{1{,}086} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}177} + W_{press}$$

18.7 Nacelle, W_{nac}

$$W_{nac} = MCF_{nac} \cdot 0{,}13274 \cdot q_{cr}^{0{,}241} \cdot \left(\frac{L_{nac}}{MD_{nac}} \right)^{-0{,}072} \cdot WA_{nac}^{1{,}086} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}177}$$

18.8 Tailboom, W_{tb}

$$W_{tb} = MCF_{tb} \cdot N_{TB} \cdot 0{,}13274 \cdot q_{cr}^{0{,}241} \cdot \left(\frac{L_{tb}}{MD_{tb}}\right)^{-0{,}072} \cdot WA_{tb}^{1{,}086} \cdot \left(1.5 \cdot n_1 \cdot W_{TO}\right)^{0{,}177}$$

18.9 Landing gear (main), W_{LGM} (6)

$$W_{LGM} = MCF_{LGM} \cdot a \cdot b \cdot c \cdot W_{TO}$$

With:

	a	b	c
Conventional, fixed	1.0	0.8	0.045
Conventional, retractable	1.5	0.8	0.045
Tricycle, fixed	1.0	0.7	0.055
Tricycle, retractable	1.5	0.7	0.055
Single wheel, fixed	1.0	0.4	0.045
Single wheel, retractable	1.5	0.4	0.045

18.10 Landing gear (auxiliary), W_{LGA} (6)

$$W_{LGA} = MCF_{LGA} \cdot a \cdot b \cdot c \cdot W_{TO}$$

With:

	a	b	c
Conventional, fixed	1.0	0.2	0.045
Conventional, retractable	1.5	0.2	0.045
Tricycle, fixed	1.0	0.3	0.055
Tricycle, retractable	1.5	0.3	0.055

18.11 Propulsion, W_p (6)

$$W_p = MCF_p \cdot N_{eng} \cdot \left(a \cdot W_{engdry} - W_{prop}\right)$$

With:

	a
4 stroke	1.30
2 stroke	1.30
4 stroke, Diesel	1.30
2 stroke, Diesel	1.30
Rotary	1.90
Turbopropeller	1.70
Turbojet	1.25
Electric	1.00

18.12 Propeller, W_{prop}

$$W_{prop} = MCF_{prop} \cdot N_{prop} \cdot a \cdot \left(\frac{P_{eng}}{1000} \right)$$

With:

	a
Hydraulic (variable pitch – constant speed)	0.0888
Electric (variable pitch – constant speed)	0.1167
Fixed – Ground adjustable	0.0572

18.13 Propeller Shaft, W_{PS}

$$W_{PS} = MCF_{PS} \cdot 1.1 \cdot \left[\pi \cdot \left(0.5 \cdot 0.01 \cdot D_{PS} \right)^2 \cdot 79 \right] \cdot l_{PS}$$

18.14 Fuel System, W_{FSyst} (3)

$$W_{FSyst} = MCF_{FSyst} \cdot 0{,}4299 \cdot N_{eng}^{\ 0{,}157} \cdot N_{F\tan k}^{\ 0{,}242} \cdot V_{Ftot}^{\ 0{,}726}$$

18.15 Control System, W_{CSyst} (3)

$$W_{CSyst} = MCF_{CSyst} \cdot 2{,}7519 \cdot 10^{-4} \cdot L_{fus}^{\ 1{,}536} \cdot b_w^{\ 0{,}371} \cdot \left(1.5 \cdot n_1 \cdot W_{TO} \right)^{0{,}8}$$

18.16 Electrical System, W_{ESyst} (6)

$$W_{ESyst} = MCF_{ESyst} \cdot 0{,}03 \cdot W_{TO}$$

18.17 Hydraulic System, W_{HSyst} (6)

$$W_{HSyst} = MCF_{HSyst} \cdot 0{,}03 \cdot W_{TO}$$

18.18 Avionics, Winst (6)

$$W_{inst} = MCF_{inst} \cdot 0{,}015 \cdot W_{TO}$$

18.19 Furnishings, W_{furn}

$$W_{furn} = MCF_{furn} \cdot \left(0{,}000004 \cdot W_{TO}^{\ 2} + 0{,}0325 \cdot W_{TO} \right)$$

18.20 Air Conditioning, $W_{AirCond}$ (3)

$$W_{AirCond} = MCF_{AirCond} \cdot 0{,}20743 \cdot W_{TO}^{\ 0{,}52} \cdot N_{occ}^{\ 0{,}68} \cdot W_{inst}^{\ 0{,}17} \cdot M^{0{,}08}$$

18.21 Pressurization, W_{press} (3)

$$W_{press} = MCF_{press} \cdot \left(5{,}4026 + 2{,}4621 \cdot \left(V_{press} \cdot \Delta_{press\ fus}\right)^{0{,}271}\right)$$

Annex 19. Inboard isometric drawings

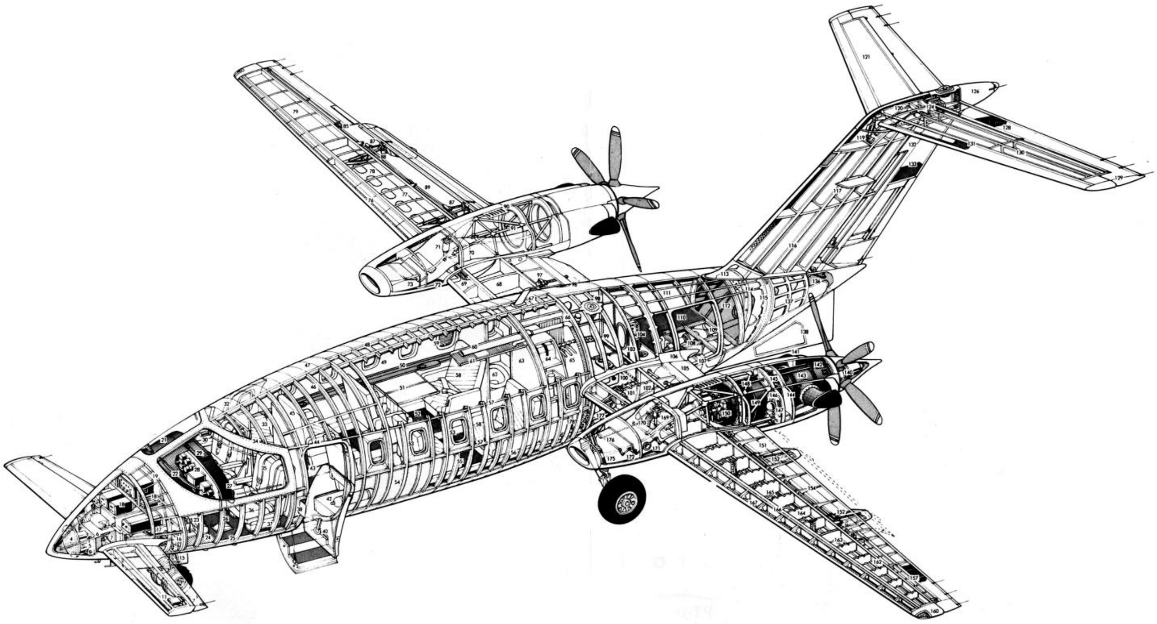
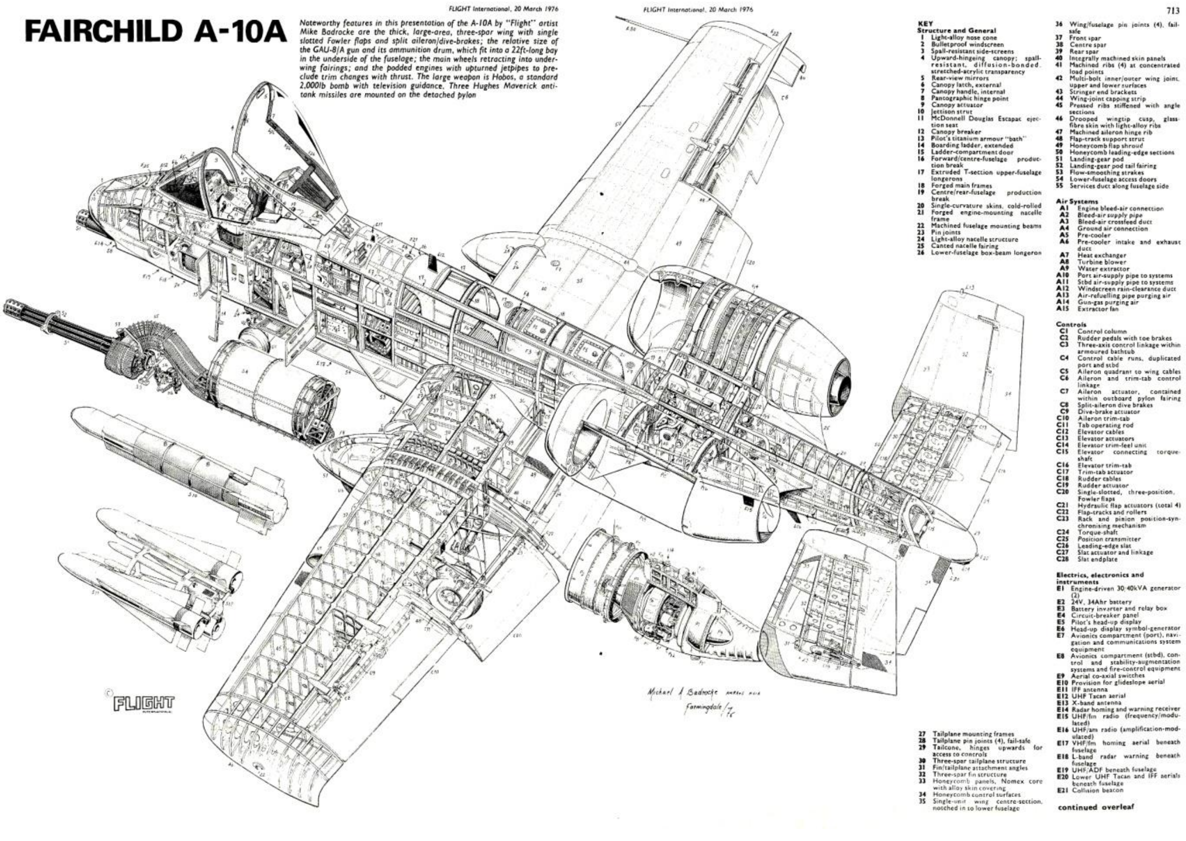


Figure 1: Avanti Piaggio



FAIRCHILD A-10A

FLIGHT International, 20 March 1976

Noteworthy features in this presentation of the A-10A by "Flight" artist Mike Badrocke are the thick, large-area, three-spar wing with single slotted Fowler flaps and split aileron/dive-brakes; the relative size of the GAU-8/A gun and its ammunition drum, which fit into a 22ft-long bay in the underside of the fuselage; the main wheels retracting into underwing fairings; and the podded engines with upturned jetpipes to preclude trim changes with thrust. The large weapon is Hobos, a standard 2,000lb bomb with television guidance. Three Hughes Maverick anti-tank missiles are mounted on the detached pylon

FLIGHT International, 20 March 1976

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KEY

Structure and General

1 Light-alloy nose cone
2 Bulletproof windscreen
3 Spall-resistant side-screens
4 Upward-hingeing canopy; spall-resistant, diffusion-bonded, stretched-acrylic transparency
5 Rear-view mirrors
6 Canopy latch, external
7 Canopy handle, internal
8 Pantographic hinge point
9 Canopy actuator
10 Jettison strut
11 McDonnell Douglas Escapac ejection seat
12 Canopy breaker
13 Pilot's titanium armour "bath"
14 Boarding ladder, extended
15 Ladder-compartment door
16 Forward/centre-fuselage production break
17 Extruded T-section upper-fuselage longerons
18 Forged main frames
19 Centre/rear-fuselage production break
20 Single-curvature skins, cold-rolled
21 Forged engine-mounting nacelle frame
22 Machined fuselage mounting beams
23 Pin joints
24 Light-alloy nacelle structure
25 Canted nacelle fairing
26 Lower-fuselage box-beam longeron
27 Tailplane mounting frames
28 Tailplane pin joints (4), fail-safe
29 Tailcone, hinges upwards for access to controls
30 Three-spar tailplane structure
31 Fin/tailplane attachment angles
32 Three-spar fin structure
33 Honeycomb panels, Nomex core with alloy skin covering
34 Honeycomb control surfaces
35 Single-unit wing centre-section, notched in to lower fuselage
36 Wing/fuselage pin joints (4), fail-safe
37 Front spar
38 Centre spar
39 Rear spar
40 Integrally machined skin panels
41 Machined ribs (4) at concentrated load points
42 Multi-bolt inner/outer wing joint, upper and lower surfaces
43 Stringer end brackets
44 Wing-joint capping strip
45 Pressed ribs stiffened with angle sections
46 Drooped wingtip cusp, glass-fibre skin with light-alloy ribs
47 Machined aileron hinge rib
48 Flap-track support strut
49 Honeycomb flap shroud
50 Honeycomb leading-edge sections
51 Landing-gear pod
52 Landing-gear pod tail fairing
53 Flow-smoothing strakes
54 Lower-fuselage access doors
55 Services duct along fuselage side

Air Systems

A1 Engine bleed-air connection
A2 Bleed-air supply pipe
A3 Bleed-air crossfeed duct
A4 Ground air connection
A5 Pre-cooler
A6 Pre-cooler intake and exhaust duct
A7 Heat exchanger
A8 Turbine blower
A9 Water extractor
A10 Port air-supply pipe to systems
A11 Stbd air-supply pipe to systems
A12 Windscreen rain-clearance duct
A13 Air-refuelling pipe purging air
A14 Gun-gas purging air
A15 Extractor fan

Controls

C1 Control column
C2 Rudder pedals with toe brakes
C3 Three-axis control linkage within armoured bathtub
C4 Control cable runs, duplicated port and stbd
C5 Aileron quadrant to wing cables
C6 Aileron and trim-tab control linkage
C7 Aileron actuator, contained within outboard pylon fairing
C8 Split-aileron dive brakes
C9 Dive-brake actuator
C10 Aileron trim-tab
C11 Tab operating rod
C12 Elevator cables
C13 Elevator actuators
C14 Elevator trim-feel unit
C15 Elevator connecting torque-shaft
C16 Elevator trim-tab
C17 Trim-tab actuator
C18 Rudder cables
C19 Rudder actuator
C20 Single-slotted, three-position, Fowler flaps
C21 Hydraulic flap actuators (total 4)
C22 Flap-tracks and rollers
C23 Rack and pinion position-synchronising mechanism
C24 Torque-shaft
C25 Position transmitter
C26 Leading-edge slat
C27 Slat actuator and linkage
C28 Slat endplate

Electrics, electronics and instruments

E1 Engine-driven 30/40kVA generator (2)
E2 24V, 34Ahr battery
E3 Battery invarter and relay box
E4 Circuit-breaker panel
E5 Pilot's head-up display
E6 Head-up display symbol-generator
E7 Avionics compartment (port), navigation and communications system equipment
E8 Avionics compartment (stbd), control and stability-augmentation systems and fire-control equipment
E9 Aerial co-axial switches
E10 Provision for glideslope aerial
E11 IFF antenna
E12 UHF Tacan aerial
E13 X-band antenna
E14 Radar homing and warning receiver
E15 UHF/fm radio (frequency/modulated)
E16 UHF/am radio (amplification-modulated)
E17 VHF/fm homing aerial beneath fuselage
E18 L-band radar warning beneath fuselage
E19 UHF/ADF beneath fuselage
E20 Lower UHF Tacan and IFF aerials beneath fuselage
E21 Collision beacon

continued overleaf

Michael A Badrocke

Farmingdale

Figure 2: Fairchild A-10A

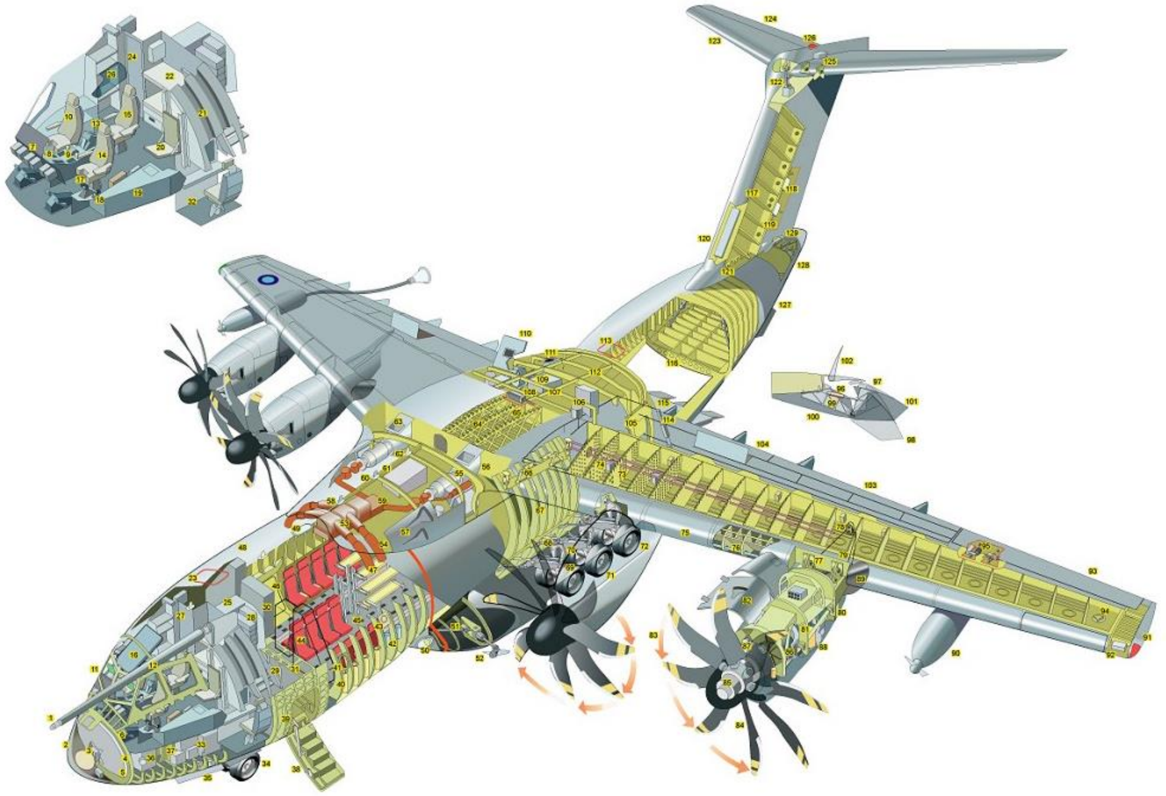

Figure 3: Airbus A400M

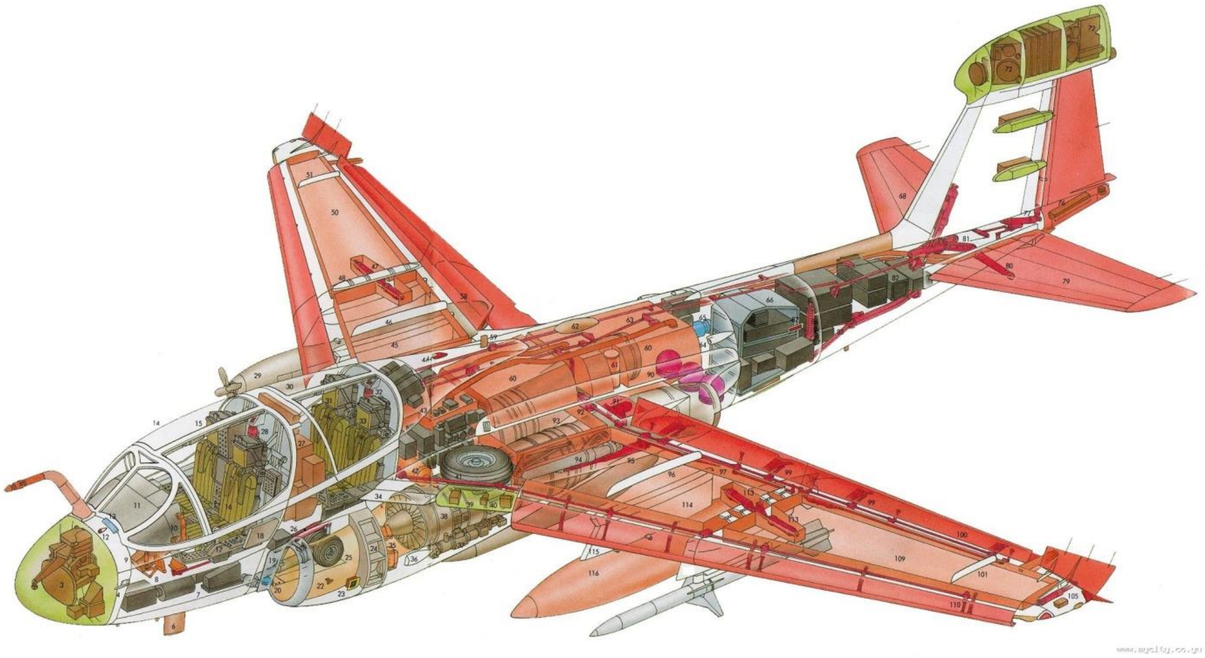

Figure 4: Grumman A-6 Intruder