Aircraft Design

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Dernière révision 06/11/19

2017 - 2019

Réservé uniquement aux enseignants et élèves de l'Ecole Centrale Paris

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Objectives

One of the main objectives of this session is to present the design process of an aircraft and more precisely the conceptual design. The other objective is to be aware that is possible to define very quickly the main size of the aircraft only working with order of magnitude.

The class will be divided in different groups of three students. Each group will represent the research department of one company. A customer (the teacher) will present to the groups a set of specifications and will ask the groups to fulfil the conceptual design of the corresponding aircraft.

The conceptual design will be done using a software (ADS). With this tool, it will be easier to consider the aircraft as a whole and visualize the impact of one technical choice on the whole aircraft: its size, its performance and its cost.

At the end of the session, each group will present its work to the customer, in front of the class.

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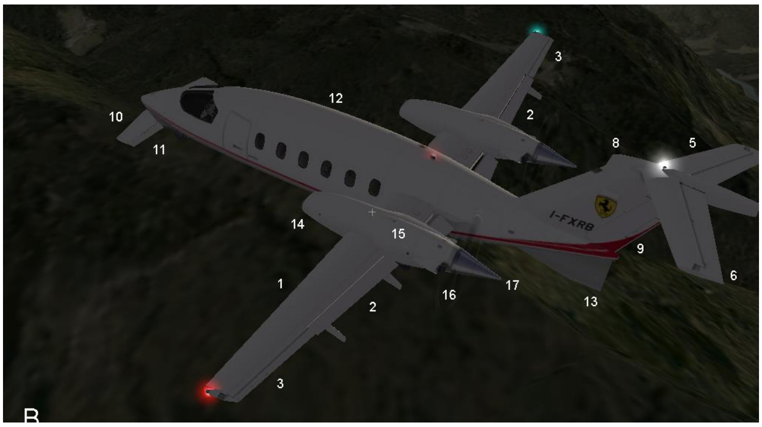
Bloc 1

1.1 Introduction to Conceptual Design

1.1.1 The vocabulary of design (FR/EN)

Conventional, High-tapered wing, Single-tractor engine
Fixed-tricycle landing gear

Canard aircraft, Mid-tapered-swept wing, Single-pusher engine,
Fixed-tricycle landing gear



3-Surface aircraft, Mid-tapered wing, Twin-pusher engine
Retractable-tricycle landing gear

1. Aile (*Wing*)
2. Volets (*High lift devices*)
3. Ailerons (*Aileron*)
4. Saumon d'aile (*Wing tip*)
5. Empennage horizontal (*Horizontal tail*)
6. Gouverne de profondeur (*Elevator*)
7. Compensateur de profondeur (*Elevator tab*)
8. Empennage vertical (*Vertical tail*)
9. Gouverne de direction (*Rudder*)
10. Plan canard (Canard surface)
11. Gouverne de profondeur (*Canard elevator*)
12. Fuselage (*Fuselage*)
13. Quille (*Ventral fin*)
14. Nacelle (*Nacelle*)
15. Moteur (*Engine*)
16. Hélice (*Propeller*)
17. Cône d'hélice (*Spinner*)
18. Train d'atterrissage principal (*Main landing gear*)
19. Train d'atterrissage auxiliaire (*Auxiliary landing gear*)
20. Winglet (*Winglet*)

1.2 The Specifications

The **specifications** refers to a set of requirements to be satisfied by a product. In the frame of this course, 10 sets of requirements will be presented:

A. Sport plane (maximize the comfort)
B. Sport plane (maximize the “green” aspect)
C. Sport plane (maximize the safety)
D. Sport plane (minimize the market price)
E. Sport plane (minimize the operating costs)
F. Sport plane (best compromise)
G. Sport plane (highest speed)
H. Tow plane
I. Light transport airplane (single engine)
J. Light transport airplane (twin-engine)

The requirements are both given through values (flight speed) and subjective criteria (comfort).

1.2.1 Sport plane

	Very Light Aircraft (VLA)
General	
Number of engines	Single
Occupant (80kg)	2
Light aerobatic capabilities	CS-VLA (U)
Performances	
Optimized for …	Cruise
Speed (km/h)	≈ 240 km/h
Altitude (m)	2400
Range (km)	1000
(Rate of climb)	> 10 m/s
(Takeoff run)	< 300 m
Stall speed (km/h)	< 83 km/h
Useful weight	
Luggage/Crew member (kg)	≈ 10 kg
Miscellaneous	
	Comfortable
	Green
	Safe
	Cheap (but realistic)

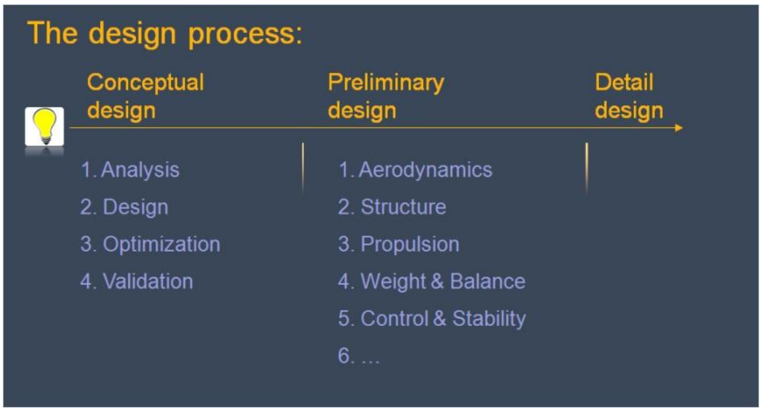
1.2.2 Tow plane

	Tow plane
General	
Number of engines	Single
Occupant (80kg)	1
Strong airplane	FAR 23 (U)
Performances	
Optimized for …	Cruise
Speed (km/h)	≈ 120 km/h
Altitude (m)	0
Range (km)	600
(Rate of climb)	> 10 m/s
(Takeoff run)	< 300 m
Stall speed (km/h)	< 50 km/h
Useful weight	
Luggage/Crew member (kg)	≈ 25 kg
Miscellaneous	
	Green
	Safe
	Cheap (but realistic)
	Highest number of rotation

1.2.3 Light transport (single & twin-engine)

	Light transport
General	
Occupant (80kg)	4
Strong airplane	FAR 23 (U)
Performances	
Optimized for …	Cruise
Speed (km/h)	≈ 360 km/h
Altitude (m)	2400
Range (km)	2000
(Rate of climb)	> 8 m/s
(Takeoff run)	< 400 m
Stall speed (km/h)	< 135 km/h
Useful weight	
Luggage/Crew member (kg)	≈ 20 kg
Miscellaneous	
	Comfortable
	Green
	Safe
	Cheap (but realistic)

1.3 The Design Process



The design process, which starts when the customer writes the first specifications, is divided in 3 major phases: the conceptual design, the preliminary design and the detail design. It is vital to think about the entire life cycle of the product, all the time during the design process!

Most of the time, the **conceptual design** is made by a specific group of engineers trained for this job. Their job is to find the optimum aircraft configuration to fulfil the customer's specifications. They have to work without prejudice, every solution must be considered to be feasible. At the end of their work, the aircraft general layout is frozen.

During the **preliminary design** more and more specialists come into play and the level of detail is steadily increased. The results computed during the previous phase are validated.

The objective of the **detail design** phase is to generate the drawings in order to manufacture the first prototype. The detail design also includes the design of the production tools.

1.4 The Conceptual Design

When you plan to design something new, the first thing you have to do is to look around you to seek something similar to the thing you plan to design. And you will analyse (reverse-engineer) it in detail. After analysis, you will know everything about its performances, dimensions, masses, aerodynamics, and quality and so on. This analysis is vital for both the engineer and salesman. The engineer will come up with orders of magnitude, the salesman will be able to better compare the new product with its competitors.

Then, the next step is to design the aircraft. In this phase, starting from specifications you will have to find the characteristics of the aircraft, its dimensions and how much power is necessary to reach the expected performances. You will find the characteristics of the aircraft (dimensions and power).

You play with a large number of parameters. You will be very lucky to immediately find the optimal combination of these parameters. It is then necessary to make an optimization in order to find the best combination.

It is also very useful to visualize on a 3D model the new design in order to make a rapid control and to check that there is no interference between the different parts of the aircraft.

1.5 The Reverse Engineering

The **Reverse engineering** is the process of extracting design information from a product.

During this process, the engineer will try to retrieve a large number of data relative to different airplanes about their:

- Dimensions: length, width, height, span, areas…
- Shape: aspect ratio, tapered ratio, form coefficient…
- Powerplant: engine power, propeller efficiency…
- Aerodynamics: lift, drag, maximum lift coefficient…
- Performances: cruise speed, rate of climb, takeoff distance…

Some values will be immediately read in the flight manual, others will be obtained from calculations, and others will be measured on a 3-View drawing.

Airplane		**Fuselage**			**Masses**	
Length	m	Width		m	W_{MxTO}	kg
Height	m	Height		m	W_{Empty}	kg
WA	m²	Length		m	W_{Glider}	kg
Wing		Frontal Area		m²	W_{Glider}/W_{MxTO}	-
Area	m²	Cff		m²	W_{Empty}/W_{MxTO}	-
Span	m	Diameter		m	**Performance**	
Aspect Ratio	-	WA fuselage		m²	**Cruise**	
Wetted Area	m²	**Engine**			Vcr	m/s
Osswald efficiency factor	-	Engine Model		-	cfe	-
Tails		Power		W	Cl	-
Semp/Swng	-	W_{Engine}		kg	**Stall**	
Horizontal tail		**Propeller**			Vs	m/s
Area	m²	RPM		rpm	clMx	-
Span	m	Number of blades		-	**Rate of climb**	
Relative Area	-				RC	m/s
Aspect Ratio	-				**Takeoff**	
Wetted Area	m²				TO run	M
Vertical tail					**Unit Cost**	
Area	m²				Cost	$
Span	m					
Relative Area	-					
Aspect Ratio	-					
Wetted Area	m²					

➔ **Cf. Annex 1: Full description of the design process**

1.6 The Main Equations

The reader will find hereunder the main equations to be used at this stage of the design process. The definition of all symbols is available at the end of this document.

1.6.1 Lift

L

$$L = W \cdot g$$
$$L = 0.5 \cdot \rho \cdot V^2 \cdot S_w \cdot C_L$$

N

1.6.2 Lift coefficient

C_L

$$C_L = \frac{2 \cdot W \cdot g}{\rho \cdot V^2 \cdot S_w}$$
$$C_L = \frac{2 \cdot g}{\rho_0 \cdot \sigma \cdot V^2} \cdot \frac{W}{S_w}$$

-

1.6.3 Drag

D

D_0

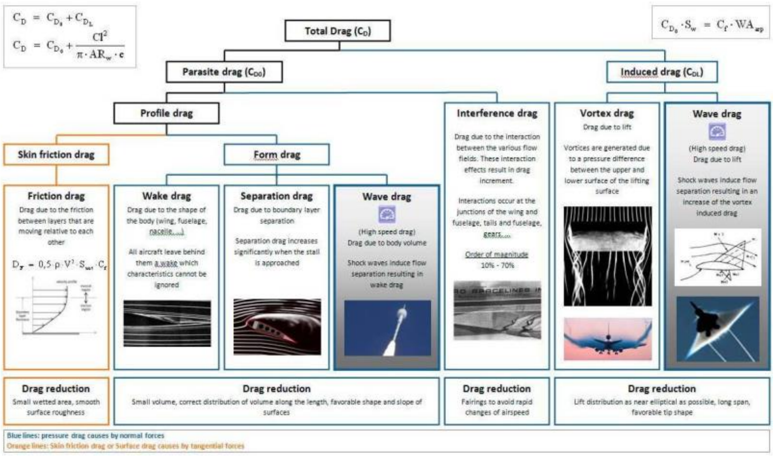
D_L

$$D = 0{,}5 \cdot \rho \cdot V^2 \cdot S_w \cdot C_D$$
$$D = D_0 + D_L$$
$$D_0 = 0{,}5 \cdot \rho \cdot V^2 \cdot S_w \cdot C_{D_0}$$
$$D_L = 0{,}5 \cdot \rho \cdot V^2 \cdot S_w \cdot K \cdot {C_L}^2$$

N

The zero lift drag (D_0) may be expressed as a function of the total wetted area of the airplane and a equivalent friction coefficient.

$$D_0 = 0{,}5 \cdot \rho \cdot V^2 \cdot WA_{arp} \cdot C_f$$



➔ **Cf. Annex 6: Drag breakdown (full size)**

1.6.4 Drag coefficient

C_D	$C_D = \dfrac{2 \cdot D}{\rho \cdot V^2 \cdot S_w}$ $C_D = C_{D_0} + C_{D_L}$ $C_D = C_{D_0} + K \cdot C_L^2$ $C_D = C_{D_0} + \dfrac{{C_L}^2}{\pi \cdot AR_w \cdot e}$ $K = \dfrac{1}{\pi \cdot AR_w \cdot e}$ $C_{D_0} \cdot S_w = C_f \cdot WA_{arp}$	-

1.6.5 Aspect ratio

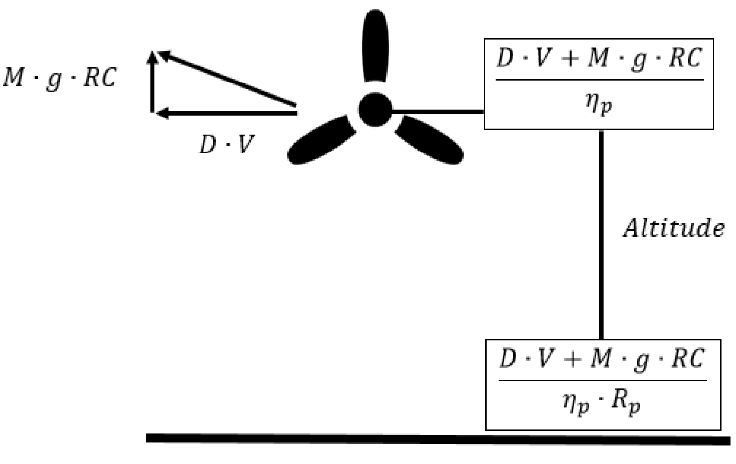
AR_w	$AR = \dfrac{b^2}{S} = \dfrac{b}{SMC}$	-

1.6.6 Taper ratio

TR_w	$TR = \dfrac{ct}{cr}$	-

1.6.7 Power

P_{req}	$P_{req} = D \cdot V$	W
	$P_{req} = 0.5 \cdot \rho \cdot V^3 \cdot C_D \cdot S_w$	
P_{avail}	$P_{avail} \cdot \eta_p = P_{req} + W \cdot g \cdot RC$	W
P_{eng}	$P_{eng} \cdot R_p = P_{avail}$	W



1.6.8 Power ratio (Propeller driven)

R_p	$R_P = \dfrac{\left(\dfrac{\rho}{1.225}\right) - 0.15}{0.85}$	-

1.6.9 Tail Volume

V_{HT}	$V_{HT} = \dfrac{S_{HT}}{S_w} \times \dfrac{\lvert AC_w - AC_{HT} \rvert}{MAC_w}$ $V_{VT} = \dfrac{S_{VT}}{S_w} \times \dfrac{\lvert AC_w - AC_{VT} \rvert}{b_w}$ $V_{crd} = \dfrac{S_{crd}}{S_w} \times \dfrac{\lvert AC_w - AC_{crd} \rvert}{MAC_w}$	-

1.6.10 Thrust (propeller driven)

T_g	$Tg = \dfrac{P_{avail} \cdot \eta_p}{V}$	N

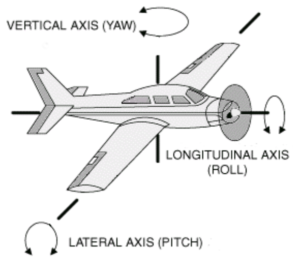
1.6.11 Dynamic pressure

P_{dyn}	$p_{dyn} = 0{,}5 \cdot \rho \cdot V^2$	N/m²

1.6.12 Glide ratio

GR	$GR = \dfrac{L}{D} = \dfrac{C_L}{C_D} = \dfrac{C_L}{C_{D_0} + K \cdot C_L{}^2}$	-

1.6.13 The main axis



X : Longitudinal axis – Roll motion

Y : Vertical axis – Yaw motion

Z : Lateral axis - Pitch motion

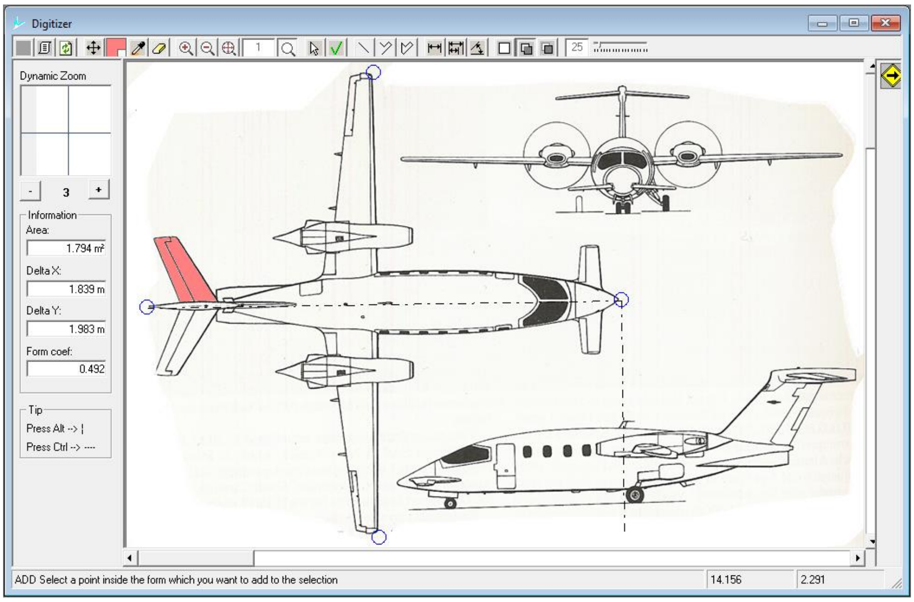
1.6.14 Mean Aerodynamic Chord, MAC

Physically, MAC is the chord of a rectangular wing, which has the same area, aerodynamic force and position of the center of pressure at a given angle of attack as the given wing has. Simply stated, MAC is the width of an equivalent rectangular wing in given conditions.

1.7 The Digitizer

The **Digitizer** module of ADS is a tool that has been developed to:

1. Use quickly and efficiently all the information contained in a **3 view drawing**.
    - To measure distances
    - To measure distance ratios
    - To measure angles
    - To measure surfaces
2. Digitize quickly a curve that will have been scanned previously such as the polar of a glider for example



1.8 Some tips to perform the Reverse Engineering with ADS

At least, 10 airplanes must be analysed!

How to define the best candidates?

1. Same mission
2. Same general layout
3. Same material

Don't forget to check if the analysed airplane fulfils the requirements of the selected regulation.

Information to gather: (everything the designer needs to design the new aircraft):

- General: pictures, 3-view drawing
- Airplane: Length, Height
- Wing: S_{wng}, b_{wng}, AR_{wng} (2)
- (Tails) (1): S_{emp}/S_{wng}
- (Horizontal tail) (1): S_{HT}, b_{HT}, S_{HT}/S_{wng}, AR_{HT}, TR
- (Vertical tail) (1): S_{VT}, b_{VT}, S_{VT}/S_{wng}, AR_{VT}, TR
- (Fuselage) (1): Width, Height, Length, Cfl (2), Cff (2)
- Engine type, Engine Model, Power, W_{Engine} (2)
- (Propeller) (1): rpm, diameter, number of blades
- Masses: W_{MxTO}, W_{Empty}, W_{Glider} (2), W_{glider}/W_{TO} (2), W_{empty}/W_{TO} (2)
- Performance:
  - Cruise : Vcr, cfe (2)
  - Stall : Vs, cl_{Mx} (2), Vcr/Vs (2)
  - Rate of Climb: RC
  - Takeoff : TO run, Runway Surface
- Miscellaneous:
  - Control surface deflection (flaps, elevator, rudder)
- Unit cost

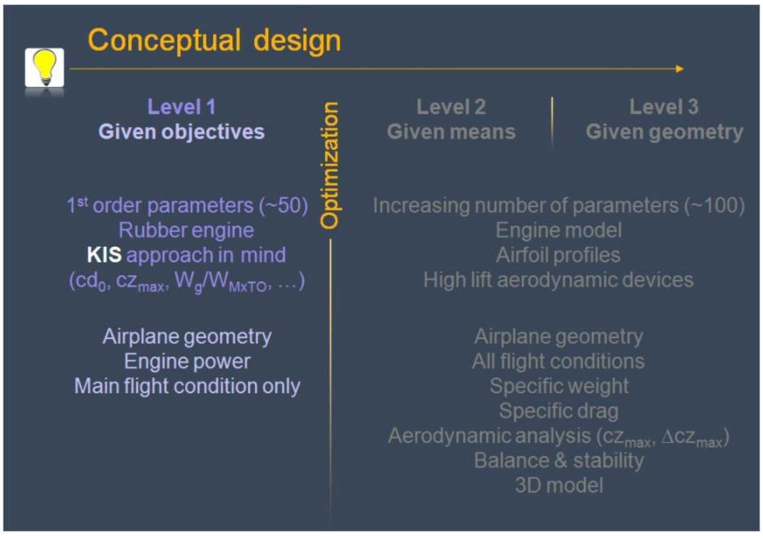
(1) From a 3-View Drawing and using the Digitizer (ADS)
(2) Computed values

> ➔ **Cf. Annex 2: Example of results given by the reverse engineering process**

Bloc 2

2.1 The Conceptual Design – Level 1

The input data. For designing a new aircraft, the designer may start with a set of specifications and use this information as input data. His goal is to find the parameters of the most optimized aircraft configuration which will meet the design specification.



Initially, the designer should start without prejudice and keep all options open. He should consider any imaginable and possible solution (fixed or retractable landing gear, two stroke or four stroke engine, rotary or turbine engine, taildragger or tricycle landing gear, canard or tandem configuration, etc…), including those which may appear unconventional.

The process. To achieve this, he will study a limited set of parameters. Only "1st order parameters" will be evaluated, i.e. those parameters which will significantly affect the results. For example, he will not assume a predetermined engine, but instead he will assume an engine of a predetermined technology.

The Design level 1 uses a "flexible engine" (rubber engine) The engine power required to meet the design specification will be calculated. At a later stage (Design Level 2), the designer will search in an engine database to find "the real engine" which will best match the "flexible engine".

The designer will keep in mind the KIS approach (Keep It Simple). If it is possible to design an aircraft that fulfills the requirements without high lift devices, the designer must adopt this configuration.

We do not compute the maximum lift coefficient but we choose a given value keeping in mind the KIS approach. We do the same with the aerodynamic efficiency of the aircraft. We know that a high value of lift coefficient will lead to a sophisticated and expensive wing design. This is the same for the aerodynamic efficiency. A low value of surface roughness will lead to expensive molds or expensive manufacturing methods.

The results. The results of the level 1 design process will allow the designer to define an aircraft configuration which will meet the design specification. The geometry (wing and tail sizing, etc…) of the aircraft is calculated as well as the thrust (engine power, propeller properties). Different flight conditions (takeoff, climb, cruise, stall) will be explored.

TIPS

Objectives: Find <u>very quickly</u>

1. The main dimensions of the **NEW** aircraft and,
2. How much power it is needed to fly
3. If necessary, update the requirements

Input data:

1. Your requirements (first order parameters ONLY)
2. Statistical data

Results:

1. Aircraft main dimensions,
2. Engine power,
3. Flight performance.

2.2 The Design Process (Level 1)

2.2.1 Input Data

Type	
Aircraft optimized for cruise	
Useful load	
Pilot & passenger	160 kg
Baggage (total)	20 kg
Fuselage	
Mean diameter	1.2 m
Length	6 m
Engine	
Type	4T
Fuel consumption (c)	0,3 kg/kW.h
Specific weight	1 kg/kW
Weight	
Glider weight ratio	0.4
Cruise	
Speed	250 km/h
Flight altitude	0 m
Range	1000 km
Stall performance	
Flight speed	100 km/h
Aerodynamics	
Maximum lift coefficient	2.2
Friction coefficient	0.006

2.2.2 Iterative process

Step 1	$W_0 = 3 \cdot W_{Payload}$ $W = W_0$		
Step 2	$S_w = \frac{2 \cdot W \cdot g}{\rho \cdot V_S^2 \cdot C_{L_{Mx}}}$		
Step 3	$WA_{fus} = cfl \cdot MD \cdot L_{fus}$	with	$cfl \approx 2$
Step 4	$WA_{arp} = WA_w + WA_{wtails} + WA_{fus}$	with	$WA_w \approx 2 \cdot S_W$ $WA_{tails} \approx 0.3 \cdot WA_W$
Step 5	$D = 0.5 \cdot \rho \cdot V^2 \cdot \left(WA_{arp} \cdot Cf_{arp} + S_w \cdot \frac{C_L^2}{\pi \cdot AR_W \cdot e} \right)$	with	$C_L = \frac{2 \cdot W \cdot g}{\rho \cdot V^2 \cdot S_W}$ $AR \approx 7$ $e \approx 0.8$
Step 6	$P_{req} = D \cdot V$		
Step 7	$P_{avai} = \frac{P_{req}}{\eta_p}$	with	$\eta_p \approx 0.8$
Step 8	$P_{eng} = \frac{P_{avai}}{R_p}$	with	$R_p \approx 1$ @ $0\ m\ (SL)$ $R_p \approx 0.75$ @ $2400\ m$
Step 9	$W_1 = W_{glider} + W_{eng} + W_{fuel} + W_{Payload}$	with	$W_{glider} = W \cdot \frac{W_{glider}}{\mathrm{W}}$ $W_{eng} = \mathrm{P}_{eng} \cdot \frac{W_{eng}}{\mathrm{P}_{eng}}$ $W_{fuel} = \mathrm{Sfc} \cdot \mathrm{P}_{avai} \cdot \mathrm{t}_{(h)}$
Step 10	$\Delta_W = \left| \frac{W_0 - W_1}{W_0} \right|$ If $\Delta_W > 0.5\%$ ➔ $W = W_1$ ➔ go to Step 2		

2.3 The Optimisation Process

2.3.1 Introduction

The following method provides a means for rapid sizing studies and evaluations. It makes extensive use of correlations of the characteristics of existing aircraft. This method is only approximate but will yield results of acceptable accuracy for many purposes.

This method has been inspired by the NASA Reference Publication 1060, Subsonic Aircraft: Evolution and the Matching of size to Performance, Laurence K.Loftin, August 1980.

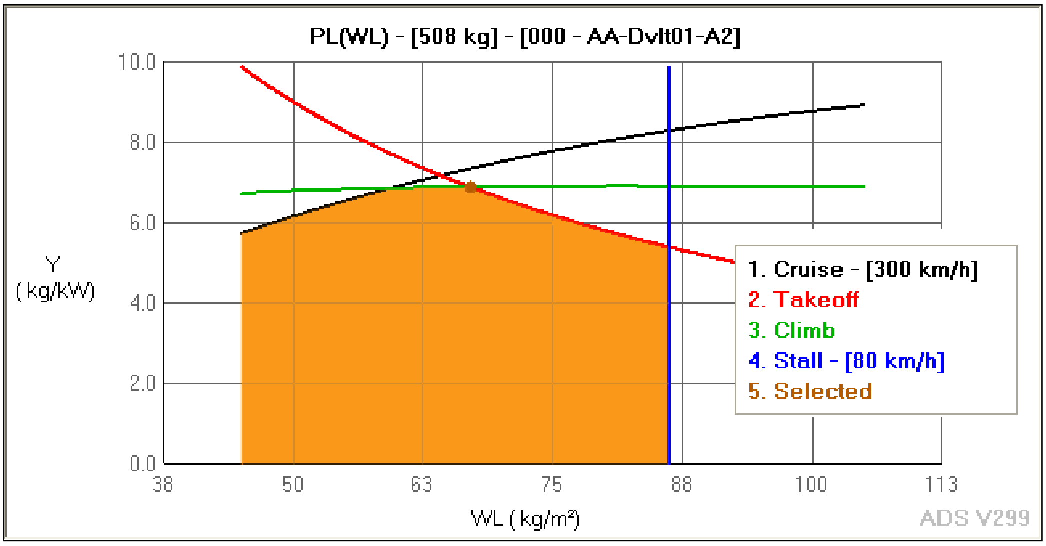
2.3.2 Wing loading and Power loading

A chart will be drawn in order to find the right combination of wing loading and Power loading in order to meet the specified performance requirements. Five flight conditions are analysed:

1. Cruise
2. Stall
3. Landing
4. Takeoff
5. Climb

A relationship between wing loading and power loading is developed. The same relationship for different flight conditions are drawn into the same chart in order to help the designer to select the right combination of wing loading and power loading to satisfy all the requirements at the same time.

2.3.3 Match points



The area below the curves represents all the possible combinations of wing loading and power loading that fulfil all the requirements at the same time. Selecting a point inside this area, the corresponding wing loading and power loading will be read. From these values, the fuel weight, the maximum takeoff weight and the wing area will be computed.

2.3.4 Summary

Propeller driven aircraft:

Cruise	$\frac{W}{P_{eng}} = R_P \cdot \frac{c_2 \cdot W/S_w}{c_3 + c_1 \cdot (W/S_w)^2}$	with	$R_P = \frac{\left(\frac{\rho}{1.225}\right) - 0.15}{0.85}$ $c_1 = \frac{1}{V} \cdot \frac{1}{\pi \cdot AR_w \cdot e} \cdot \frac{4 \cdot g^2}{\rho^2}$ $c_2 = \frac{2 \cdot \eta_p}{\rho}$ $c_3 = V^3 \cdot C_{D_0}$
Takeoff	$\frac{W}{P_{eng}} = R_P \cdot \frac{C_1 \cdot C_5 \cdot \left(\frac{1}{W/S_w}\right)^{0.5}}{(W/S_w) + C_5 \cdot C_6}$	with	$R_p = \frac{\left(\frac{\rho}{1.225}\right) - 0.15}{0.85}$ $C_1 = \eta_p \cdot \left(\frac{\rho \cdot C_L}{2 \cdot g}\right)^{0.5}$ $C_2 = \frac{\rho \cdot C_{D_0}}{2} \cdot \left(\frac{2 \cdot g}{\rho \cdot C_L}\right)$ $C_3 = g \cdot c_{f_{gr}}$ $C_4 = g \cdot \sin\gamma$ $C_5 = \frac{d \cdot \rho \cdot C_L}{g}$ $C_6 = C_2 + C_3 + C_4$
Climb	$\frac{W}{P_{eng}} = R_p \cdot \frac{\eta_p}{0.5 \cdot (2 \cdot g)^{3/2} \cdot (\rho)^{-1/2} \cdot \left(\frac{W}{S_w}\right)^{1/2} \left(\frac{C_D}{C_L^{3/2}}\right) + g \cdot RC}$		
Stall	$\frac{W}{S_w} = \frac{\rho}{2 \cdot g} \cdot V_s^2 \cdot C_{L_2}$		

➔ **Cf. Annex 7: Mathematical development for the five flight conditions**
➔ **Cf. Annex 8: Application of the method**

2.4 Market price

2.4.1 Introduction

A large number of aircraft (147) have been analyzed. To make an estimate of the cost, the first step in the analysis is place the aircraft into one of the following categories:

(1) UL-LSA,
(2) Propeller driven aircraft (piston & turboprop, FAR23) & Very Light Jet aircraft and
(3) Business Jet aircraft (FAR25).

The analysis has shown that the market price is affected by the general layout (= configuration?) and by the technical options of the aircraft. With a major difference between the UL-LSA category and the others: the market price for the UL-LSA category is also function of the performance of the aircraft (cruise speed), while the market price of the other categories is rather a function of the empty weight of the aircraft.

2.4.2 Propeller driven aircraft (Piston & Turboprop)

In a first step, aircraft of standard configuration (Std.Config.) have been analyzed. For this category, Standard configuration means:

- Four seats
- Metal aircraft
- 4 stroke engine, normally aspirated
- Fixed landing gear
- Unpressurized fuselage
- Standard avionics
- Standard furnishing
- Conventional configuration
- Large production number

From this first analysis, an equation to estimate the market price (USD) against the aircraft glider weight (lbs) has been defined:

$$\mathrm{Pr}_{\text{Market est.}} = 100.000 \cdot \left(0.002444 \cdot W_{\text{glider}} - 0.625269\right) + \mathrm{Pr}_{\text{Engine est.}} + \mathrm{Pr}_{\text{Propeller est.}}$$

In a second step some correction factors (CF) have been defined to take into account some technical options. These correction factors will be applied to the estimated glider price. The engine and propeller prices have been estimated with the method given by J.Roskam, Airplane Design Part VIII.

	Characteristics	Std.Config.	CF	Options	CF	Options	CF
1	Number of seats	4	0%	Lesser than 4	- 3%/occ.	Greater than 4	+3%/occ.
2	Material	Metal	0%	Composite	+10%	Tube	-40%
3	Engine	Piston	0%	Turboprop	+50%	Turbojet	+25%
4	Turbocharger	No	0%	Yes	+10%		
5	Landing gear	Fixed	0%	Retractable	+25%		
6	Fuselage	Unpressurized	0%	Pressurized	+20%		
7	Avionics	Standard	0%	Business	+4%		
8	Furnishing	Standard	0%	Business	+2%/occ.		
9	Configuration	Conventional	0%	3-Surface	+15%		
10	Production	Large number	0%	Business	+30%		

2.4.3 Validation

To validate this method, 30 aircraft with an empty weight range from 830lb (376kg) to 6900 lb (3129kg), have been analyzed. The estimated market price has been compared with the manufacturer's market price. 87% of the estimated market prices are given with an accuracy of +/- 15%

ΔPr		Qty	+/- 5%	+/- 10%	+/-1 5%	+/- 20%
< -30% - < -25%	Under estimation	-				
< -25% - < -20%		-				
< -20% - < -15%		1				
< -15% - < -10%		2				
< -10% - < -5%		4				
<-5% - < 0%		6	50%	77%	87%	97%
< 0% - < +5%	Over estimate	9				
< +5% - < +10%		4				
< +10% - < +15%		1				
< +15% - < +20%		2				
< +20% - < +25%		-				
< +25% - < +30%		-				

2.4.4 Notes

It's obvious that the glider-weight-ratio has a real impact on the weight of the airplane and then on the price. A light airplane will be cheaper than a heavy one. But if the designer wants to minimize the weight, at a given point, the price will become increasing.

We will notice the same effect with the friction coefficient and maybe with other parameters.

2.5 Design parameters

2.5.1 Airworthiness requirements

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.

To be certified in a given category, aircraft must satisfy some rules. Some of them are presented hereunder.

General rules

	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

Rules about structure – Manoeuvring load factors

	n_1[a]	n_2[a]	n_g[b]	n_{flap}[c]
FAR 23 - CS 23 - Normal **FAR 23 - CS 23** - Commuter	≤ 3.8 2.1+(10884/(W+4535))	$-0.4 \cdot n_1$	$1 \pm \frac{K_g.\rho_0.U_{de}.V.a}{2.\frac{W}{S}}$	2
FAR 23 - CS 23 - Utility	4.4	$-0.4 \cdot n_1$		
FAR 23 - CS 23 - Acrobatic	6	$-0.5 \cdot n_1$		
FAR 25 - CS 25	$2.5 \leq n_1 \leq 3.8$ 2.1+(10884/(W+4535))	$-1 \rightarrow V_C$ $-1 \leq n_2 \leq 0$[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 (m²)
ρ_0 : air density at sea level (kg/m³)
ρ : air density at the altitude considered (kg/m³)
c : mean geometric chord (m)
g : acceleration due to gravity (m/s²)
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

Rules about 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 ≤ 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}

➔ **Cf. Annex 9: More detailed information about airworthiness requirements**

2.5.2 Materials in aviation

History

At the beginning	Wood & Fabric
from 1920	Aluminium alloys
from 1950	Titanium alloy
from 1970	Composite

Material proportion in modern airliners

Aircraft	Aluminium	Titanium	Composite	Steel	Others
A310	67%	5%	10%	13%	5%
A320	58%	6%	20%	13%	3%
A330/A340	73%	6.5%	10%	7.5%	3%
A380	75%	7%	8%	7%	3%

The best material in 2017

Material	Weight	Drag	Cost
Tube & Fabric	↘	↗	↘
Metal	→	→	→
Composite	↗	↘	↗

➔ **Cf. Annex 10: More detailed information about Materials in Aviation**

2.5.3 The power-plant

Introduction

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

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.

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

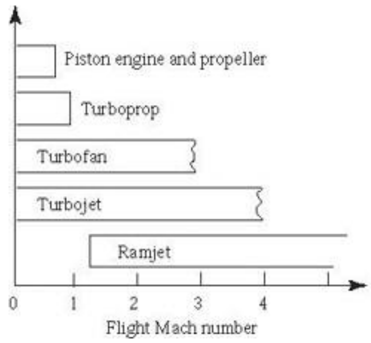
Engine technology

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.



Summary (SI)

Engine type	Piston + Propeller	Turbopropeller	Turbojet	Turbofan	Electric + propeller
Maximum Power Maximum Thrust (SLS ISA)	35-150 kW	3.730 kW 8.210 kW (A400M)	22-133 kN (without A/B)	44 - 440 kN	7,5-75 kW
Flight speed/Mach number	0.4	0.5 0.7 (A400M)	2.0	HBPR: 0.85 LBPR: 3.0	0.2
Flight altitude	2.400 m	7.600-9.100 m	15.000 m	13.000 m	No limit
SFC ou TSFC (SLS ISA)	0,20-0,25 kg/kW.h (4T) 0,400 kg/kW.h (2T)	0,50 kg/kW.h 0.025 kg/N.h	0.081 kg/N.h	0.032 kg/N.h	NA
SFC cruise	4T: idem 2T: idem	0.041-0.051 kg/N.h	0.2 kg/N.h	0.06 kg/N.h	-
Specific power	4T: 1 kW/kg 2T: 1,5 kW/kg	5-6 kW/kg	17,88 N/kg	59.6 N/kg (GE90)	4 kW/kg (Engine) + 0,4 kW/kg (Li-ion battery) = 0.360 kW/kg
Cost / power	170-235 $/kW	400-600 $/hp	45-90 $/N	45 $/N	Expensive
Gearbox	No/Yes	Yes	No	No (except on GTF)	Yes
Advantages/ Drawbacks	High maintenance costs, vibrations	Vibrations, High noise level	Old technology	Widely used	Low noise level, IR
Application	Light aviation, UAV	STOL	High speed	High range	Zero emissions
Other	Low cost	Expensive	Expensive	Expensive	Limitation due to the batteries

Summary (FPSR)

Engine type	Piston + Propeller	Turbopropeller	Turbojet	Turbofan	Electric + propeller
Maximum Power Maximum Thrust (SLS ISA)	50-200 hp	5.000 hp 11.000 shp (A400M)	5-30 klbf (without A/B)	10 - 100 klbf	10-100 hp
Flight speed/Mach number	0.4	0.5 0.7 (A400M)	2.0	HBPR: 0.85 LBPR: 3.0	0.2
Flight altitude	8.000 ft	25-30.000 ft	50.000 ft	45.000 ft	No limit
SFC ou TSFC (SLS ISA)	0,33-0,41 lb/hp.h (4T) 0,658 lb/hp.h (2T)	0,822 lb/hp.h 0.245 lb/lbf.h	0.80 lb/lbf.h	0.32 lb/lbf.h	NA
SFC cruise	4T: idem 2T: idem	0.4-0.5 lb/lbf.h	2 lb/lbf.h	0.6 lb/lbf.h	-
Specific power	4T: 0.608 hp/lb 2T: 0.912 hp/lb	3.04-3.65 hp/lb	1.824 lbf/lb	6.08 lbf/lb (GE90)	2.432 hp/lb (Engine) + 0.243 hp/lb (Li-ion battery) = 0.219 hp/lb
Cost / power	125-175 $/hp	300-450 $/hp	200-400 $/lbf	200 $/lbf	Expensive
Gearbox	No/Yes	Yes	No	No (except on GTF)	Yes
Advantages/ Drawbacks	High maintenance costs, vibrations	Vibrations, High noise level	Old technology	Widely used	Low noise level, IR
Application	Light aviation, UAV	STOL	High speed	High range	Zero emissions
Other	Low cost	Expensive	Expensive	Expensive	Limitation due to the batteries

FF	Fuel Flow (kg/s)
SFC	Specific Fuel Consumption
SLS	Sea Level Static (static = v_a nulle)
ISA	International Standard Atmosphere
BPR	By-Pass Ratio
GTF	Geared Turbofan

1 kW	1.34 hp
1 N	0.225 lbf
1 kg/kW.h	1.644 lb/hp.h
1 kW/kg	0.608 hp/lb
1 kg/kW	1.645 lb/hp
1 kg	2.205 lb
1 kg/daN.h	0.98 lb/lbf.h

➔ **Cf. Annex 11: More detailed information about the different technologies**

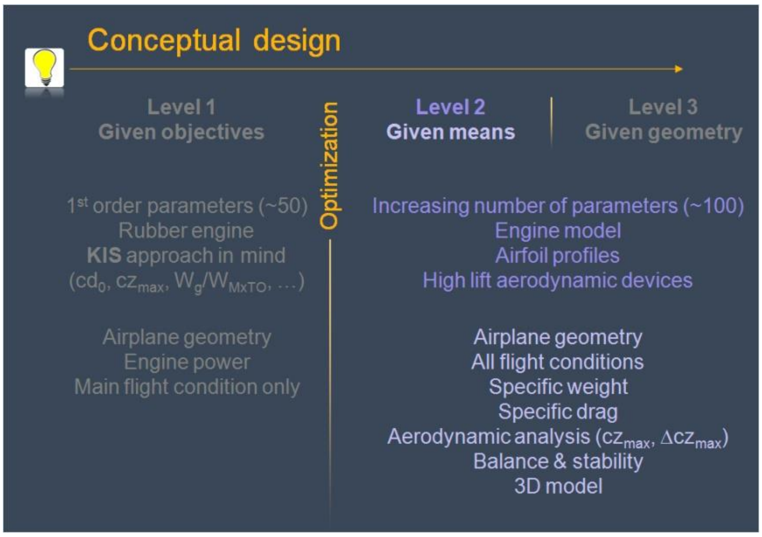
2.6 Some tips to perform the Design Level 1 with ADS

1. Enter the initial requirements
2. Base the inputs from the results of the reverse engineering process (mass efficiency, aerodynamic efficiency)
3. If necessary, adjust the requirements to minimize the cost.
4. Investigate different configurations (as much as possible)
   - General: general layout …
   - Wing: geometry
   - Tails: geometry …
   - Fuselage: geometry …
   - Engine: engine technology, number …
   - Propeller: Fixed pitch vs Constant speed, blade number, diameter
   - Aerodynamics: % interference drag …
   - Performance: runway surface (takeoff & landing), flight altitude, range (cruise), …
   - …
5. Make a list of the different configurations investigated:

File name:	Main characteristics:
1. Dsgn01-GroupA-01 2. Dsgn01-GroupA-02 3. …	

Bloc 3

3.1 The Conceptual Design – Level 2 (Main Flight Condition)



Once satisfied with the results obtained, the designer proceeds to the second stage of the process: the Design with “given means”.

The number of parameters used will increase and the input data will become more accurate. Certain information will be sourced directly from product databases (engines, airfoils, tires, …). The “flexible engine” is substituted by a real engine which closely matches the properties of the “rubber engine”. Values, which in the previous stage (Level 1) were selected by statistical analysis (maximum lift coefficient, glider weight ratio, drag ratio, …), will be verified by extensive algorithms. The increase in lift for the type of flaps used will be computed. The total drag will be defined more precisely as the sum of specific drag components.

A weight estimate will be made. All flight conditions will be explored. The stability will be checked.

Finally, a 3D model will be generated which will enable the results of the design process to be verified and appreciated visually.

TIPS

Objectives: calculate with high accuracy

1. The main dimensions of the **NEW** aircraft,
2. Performances for all flight conditions (takeoff, climb, cruise, landing)
3. Balance and Stability

Input data:

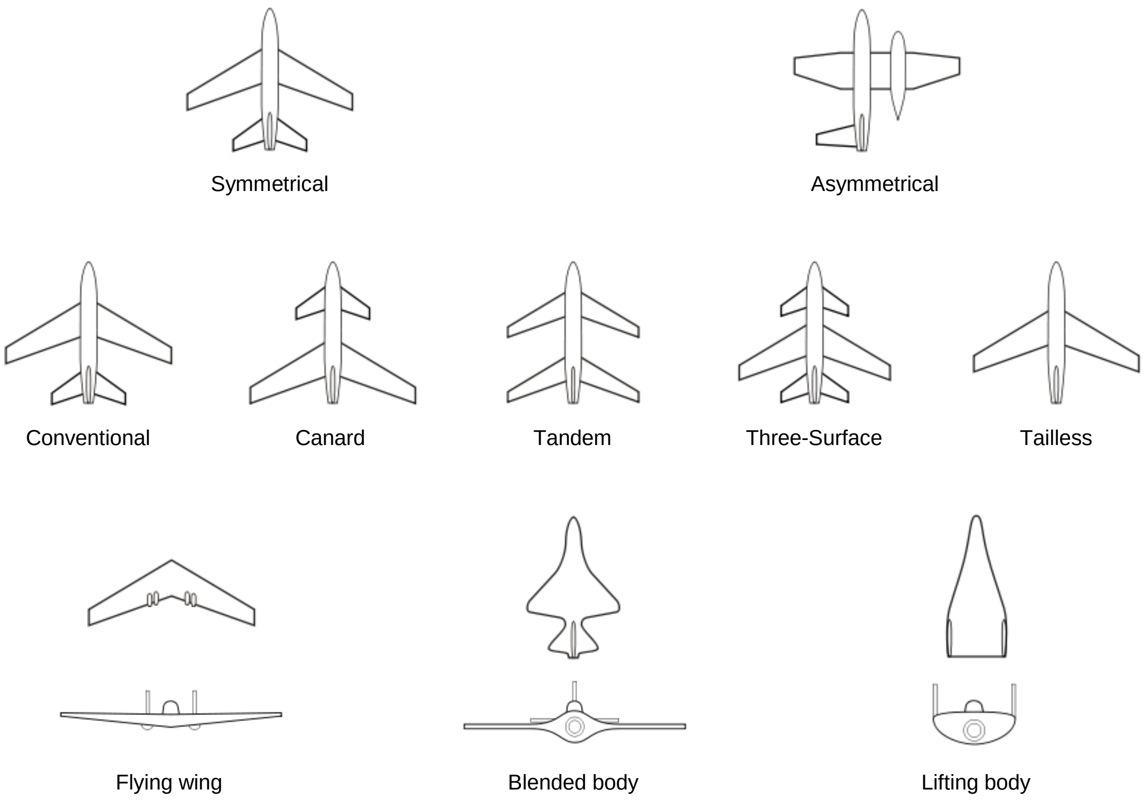
1. Your requirements
2. Data from product databases (engines, airfoils, tires, …)

Results:

1. Aircraft main dimensions,
2. Performances,
3. Balance and Stability,
4. 3D-Model (to be exported to any CAD system and X-Plane flight simulator)

3.2 Design Parameters

3.2.1 Airplane general layout



The general layout is the way the different component of the aircraft are positioned against each other.

There exists different configurations with their own characteristics:
- Conventional
- Canard
- Tandem
- Three-Surface
- Tailless

In general the conventional configuration consists of:
- One wing
- One fuselage located in the center of the aircraft
- One horizontal tail located behind the main wing
- One vertical tail located in the same region than the horizontal tail
- One engine located in the front of the fuselage
- One landing gear

With the conventional configuration the tails are located behind the main wing. This configuration is the most common one adopted nowadays. This represents probably the best compromise.

With the canard configuration, the horizontal tail is located in front of the wing. The main advantages are the good stall behavior and the generation of the lift which is partly generated by the canard surface. The drawback is the wake behind the canard surface which alter the aerodynamics in the central part of the wing.

The tandem configuration is similar to the canard configuration. The interaction between the front wing and the aft wing is better controlled. The aft wing provides the longitudinal stability.

A three-Surface configuration has a foreplane, a central wing and a tailplane. The central wing always provide the lift and is usually the largest. The functions of the fore and aft surfaces include lift, control and stability. The advantage of this configuration are safe stalling characteristics and short takeoff and landing performance.

A tailless configuration has no tail besides the main wing. The stability and control functions are incorporated in the main wing. The advantage of the tailless configuration is the low drag due to friction.

3.2.2 The wing

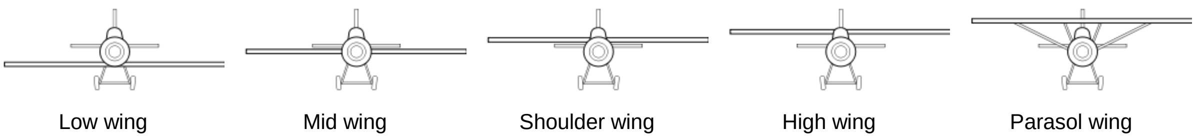
The wing is the horizontal surface that produces most of the lift for flight.

The cross section of the wing is the airfoil, a streamlined shape that produces lift.
The point at the front of the airfoil is called the leading edge.
The point at the rear of the airfoil is called the trailing edge.
The chord line or simply the chord, is the straight line connecting the leading and trailing edges.
The chord located in the center part of the wing is called the root chord
The chord located at the outer position of the wing is called the tip chord

The main function of the wing is to generate the lift, a force which allows the airplane to fly.
The wing geometry is function of the performance of the airplane. An airplane designed to fly at a slow speed won't have the same wing characteristics than an airplane designed to fly at a high speed.
For an aerodynamic point of view, the geometrical characteristics that have influence on the aerodynamic efficiency of the wing are:

- Vertical position of the wing on the fuselage
- Wing number
- Wing support
- Aspect ratio
- Tapered ratio
- Sweep angle
- Dihedral angle

<u>Wing vertical position</u>



The vertical position of the wing on the fuselage has an influence, not only for the aerodynamic of the lifting surface but also for a structural point of view, stability point of view and for safety and visibility.

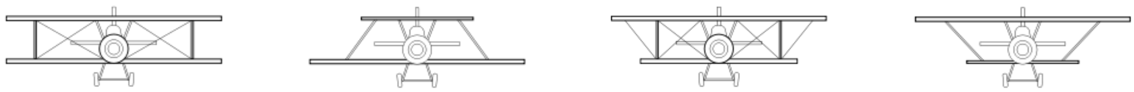
For an aerodynamic point of view a long wing will have a favorable ground effect during takeoff and landing. But will be more sensible to interference problems. To avoid such problem, large fairings should be used between the wing and the fuselage.

For an aerodynamic point of view, a mid-wing configuration is probably the most efficient one.

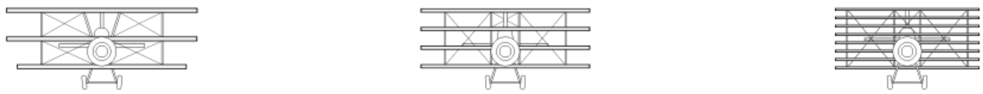
High wing does not have the favorable ground effect but is less sensible to the interference problems

> ➔ **Cf. Annex 12.1 : Some tips to select the right value**

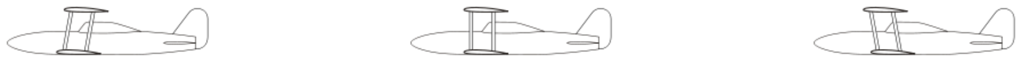
Wing number



Biplane   Unequal-span biplane   Sesquiplane   Inverted sesquiplane



Triplane   Quadruplane   Multiplane



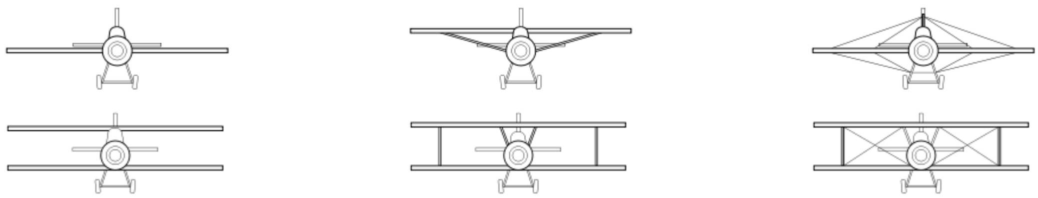
Unstaggered biplane   Forwards stagger   Backwards stagger

Airplanes may have different numbers of wings

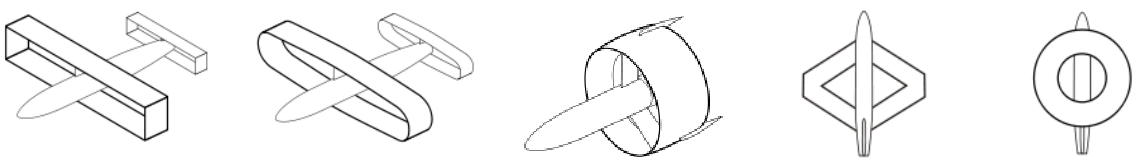
The monoplane configuration is the most common since 1930, when structural problems were solved using thicker wing sections.

The biplane configuration has two wings stacked one above the other. Most of the time the two wings have a similar size. The biplane wing structure has a structural advantage over a monoplane, but it produces more drag than a similar cantilever monoplane wing

Wing support



Cantilever   Strut braced   Wire braced



Box wing   Annular box wing   Cylindrical wing   Rhomboidal wing   Flat annular wing

The wing may support itself or use external bracing. By adding external bracing, the weight of the structure can be greatly reduced. But such bracing causes a large amount of drag at high speed.

The cantilever configuration has all the structure under the aerodynamic skin. This has the main advantage to reduce the drag.

The braced configuration uses external structural members. Such bracing save weight but add drag. There exist two types of braced wing: strut braced or wire braced

Wing aspect ratio

Low aspect ratio | Moderate aspect ratio | High aspect ratio

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. 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.

For an aerodynamic point of view, a high aspect ratio will improve the aerodynamic of the aircraft.

> ➔ **Cf. Annex 12.2 : Some tips to select the right value**

Wing sweep angle

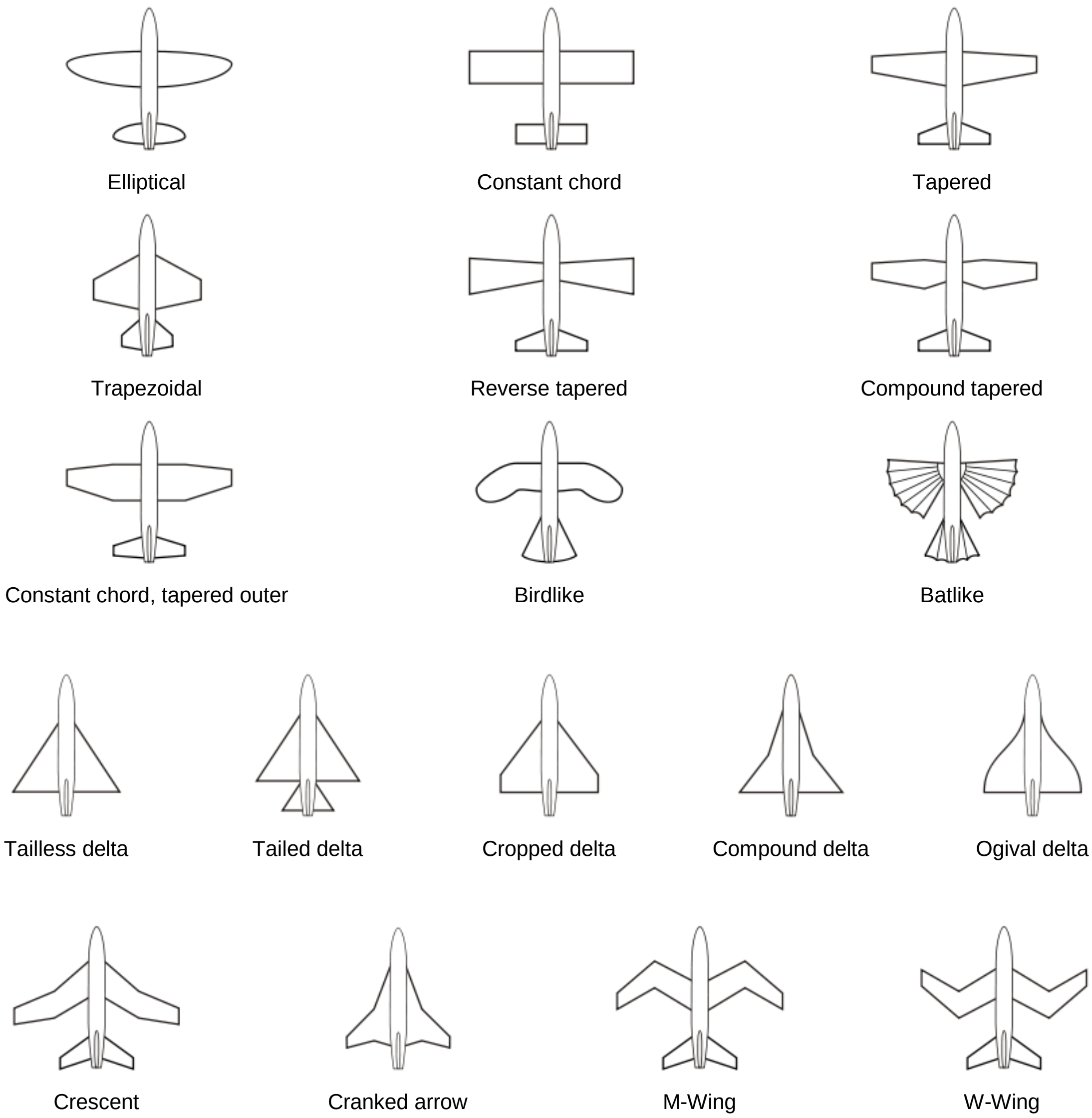
Straight | Swept | Forward swept | Variable sweep | Oblique wing

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.

For an aerodynamic point of view, it’s not necessary to sweep the wing if the maximum speed of the aircraft is lower than 600 km/h. Above that speed is necessary to add a sweep angle.

> ➔ **Cf. Annex 12.3 : Some tips to select the right value**

Wing taper ratio

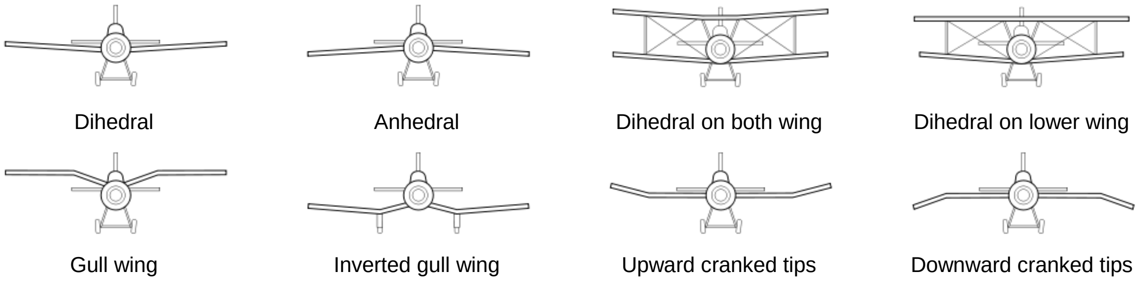


Tapered ratio is the ratio between the tip chord and the root chord. Taper affects the distribution of the lift along the span of the lifting surface. Minimum drag due to lift or “induced” drag occurs when the lift is distributed in an elliptical fashion. For an untwisted and unswept wing, this occurs 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.

For an aerodynamic point of view, tapering the wing improve the aerodynamic efficiency of the wing, with an optimal value of 0,4.

➔ **Cf. Annex 12.4 : Some tips to select the right value**

Wing dihedral angle

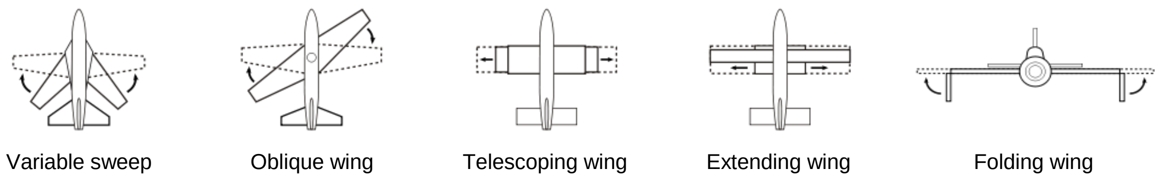


Dihedral is the angle of the wing with the horizontal when seen from the front. Positive when the tip is higher than the root. Dihedral effect tends to roll the aircraft level when side slipping. During a sideslip, the lateral wind coming from the sideslip direction increases the angle of attack and therefore the lift. The resulting moment is approximately proportional to the dihedral angle.

For an aerodynamic point of view, the dihedral angle doesn’t affect the aerodynamic efficiency of the wing. The dihedral angle is one of the most important parameters for the stability in roll.

➔ **Cf. Annex 12.5 : Some tips to select the right value**

Wing variable planform



3.2.3 The tails

The tails or empennage give stability to the aircraft.

The empennage incorporate the horizontal and vertical tail and their control surfaces.

The **horizontal tail** is a lifting surface located behind the wing. If the horizontal tail is located in front of the main wing, it's called a canard surface.

The main function of the horizontal tail is to ensure the longitudinal stability of the airplane. The horizontal tail should be located as far as possible from the lateral axis in order to be efficient with a minimum size.

The horizontal tail may be built either with one fixed part and one moving control surface or with one single all-moving surface. If built with 2 components, the fixed part is called the horizontal stabilizer and the moving part is called the elevator. If built with one all-moving component, it's called the stabilator.

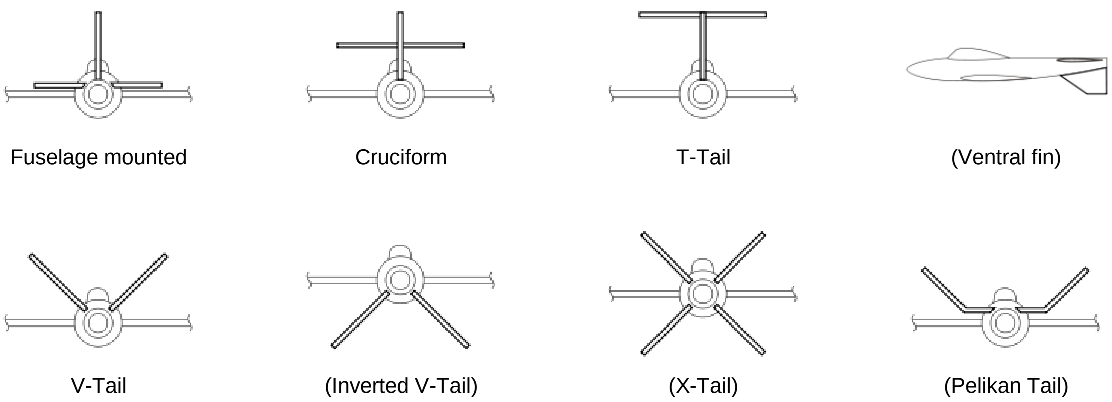
The **vertical tail** is a lifting surface located behind the wing.

The main function of the vertical tail is to ensure the directional stability of the airplane. The vertical tail should be located as far as possible from the vertical axis in order to be efficient with a minimum size.

The vertical tail is built with one fixed part and one moving control surface. The fixed part is called the vertical stabilizer and the moving part is called the rudder.

The most common configuration is one vertical tail located on the fuselage. To increase its power, the vertical tail may be duplicated and located on each side of the fuselage, on each side of the wing or on each side of the stabilizer, or may be located on the tailbooms, if any.

Tail configuration



The Tailplane comprises the horizontal stabilizer and the movable elevator.

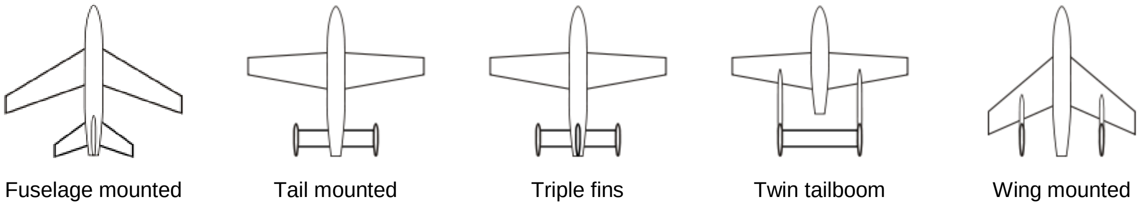
On the cruciform configuration, the horizontal stabilizer is placed at the mid position on the vertical stabilizer. Cruciform tails are often used to move the horizontal stabilizer out of the engine wake.

On the T-Tail configuration, the stabilizer is mounted on the top of the fin. T-tail keep the stabilizer out of the engine wake. The structure of the fin must be stronger in order to withstand the loads on the horizontal stabilizer.

An alternative of the stabilizer-fin assembly is the V-Tail design. In the V-Tail, the tail surfaces are set at diagonal angles, with each surface contributing to both pitch and yaw. V-Tail could be lighter and could produce less drag than conventional tail

Ventral fin are used in addition to a conventional fin. Most of the time added due to a lake of directional stability.

Multi-Tail configuration



The fin comprises the vertical stabilizer and the movable rudder.

Fin is characterized by the number of fins and by the location of the fin.

Fins are mounted at various positions: on the fuselage, on Tailplane, on tailbooms or on wings.

Twin tail consist of two small vertical stabilizer on either side of the horizontal stabilizer.

Twin boom consist of vertical stabilizer on each end of two booms, and a horizontal stabilizer between them

Wing mounted consist of fin mounted at a given position along the wing span

3.2.4 Lifting surface airfoil profile

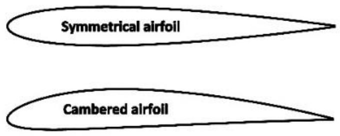
Introduction

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.

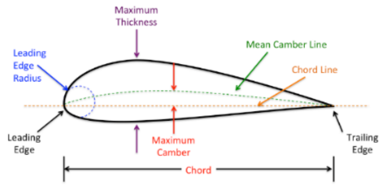
There are two types of airfoils:

- Cambered airfoil
- Symmetrical airfoils



Geometry

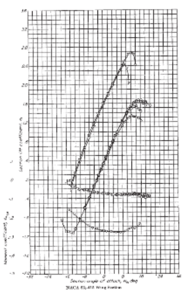
An airfoil section geometry is characterized by:

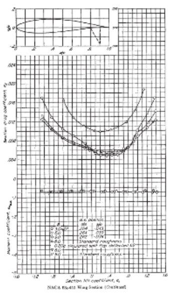


- The leading edge: the front of the airfoil
- The trailing edge: the back of the airfoil
- The chord: distance from the leading edge to the trailing edge of an airfoil section, measured along a straight line joining them.
- The upper surface: surface located above the airfoil
- The lower surface: surface located under the airfoil
- The mean camber line: curvature of the geometric mean line of an airfoil section, measured in terms of distance along and percentage of the chord line.
- The leading edge radius : the “rounded” shape of the nose
- The thickness: distance from the upper surface to the lower surface measured perpendicular to the mean camber line.
- The trailing edge angle : angle between the upper surface and the lower surface at the trailing edge position

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

Geometric parameters that affect the performance of an airfoil

Geometry

- ↗ Thickness: ↗ maximum lift coefficient (Cl_{Mx})
- ↗ Thickness: ↗ minimum drag coefficient (Cd_{Mn})
- ↗ Nose radius : ↗ maximum lift coefficient (Cl_{Mx})
- ↗ Nose radius : good stall behavior
- ↗ Maximum Camber : ↗ maximum lift coefficient (Cl_{Mx})
- ↗ Maximum Camber : ↗ zero lift angle of attack (α_0)
- ↗ Maximum Camber: ↘ minimum drag coefficient (Cd_{Mn})
- Maximum camber position (far forward) : sharp stall, ↗ max lift coefficient (Cl_{Mx})
- Maximum camber position (far rear) : ↘ Cm_0 (more negative)
- ↗ Slope of the camber line at the leading edge : ↘ α_0 (more negative) and ↗ Cl_0
- ↗ Slope of the camber line at the trailing edge : ↘ Cm_0 (more negative)
- ↗ Trailing edge angle : ↗ profile drag (Cd_0)

➔ **Cf. Annex 13 : More information about Airfoil Profiles**
➔ **Cf. Annex 14 : Some tips to select the right Airfoil Profile**

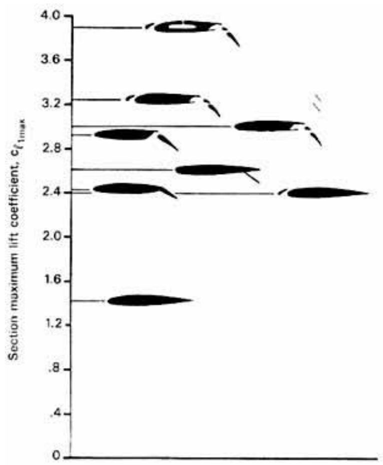
3.2.5 High lift devices

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:

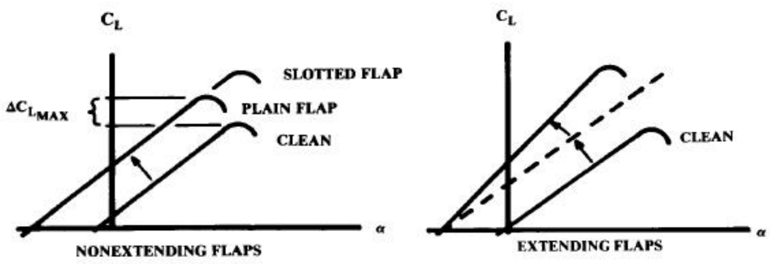
- Trailing edge high lift device
- Leading edge high lift device

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



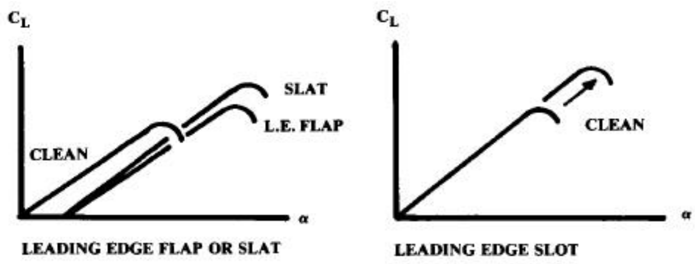
Trailing edge aerodynamic devices

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



Leading edge aerodynamic devices

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



The approximate wing maximum lift coefficient using:

	Cl_{Mx}	Complexity
Plain flap	1.8	➔
Split flap	1.8	➘
Single slotted flap	2.2	➔
Double slotted flap	2.4	➚
Fowler flap	2.6	➚➚

Cf. Annex 15 : More information about High Lift Devices

3.2.6 Propeller design parameters

Introduction

The propeller is one component of the propulsion system of the aircraft which, coupled with a shaft engine, generates thrust to propel the airplane.

The efficiency of the propeller is function of the geometric characteristics of the propeller, the propeller rotational speed and the flight speed. A well designed propeller will have an efficiency of about 80% in its best regime. The efficiency is influenced by the angle of attack of the flow on the blade. The flow direction on the blade is influenced by the propeller rotational speed and the speed of the aircraft.

In order to maintain an optimal angle of attack on the propeller blades as aircraft speed varies, it's interesting to make varying the pitch angle of each blade. This is achieved with the variable pitch propeller and the constant speed propeller.

A propeller governor senses the speed of an aircraft engine and changes the propeller blade angle to maintain a selected rotational speed as aircraft speed varies.

A propeller spinner is a streamlined fairing fitted over the propeller hub. Spinner make the aircraft more streamlined, reducing the aerodynamic drag, and improve the air introduction into the air intakes.

Summary

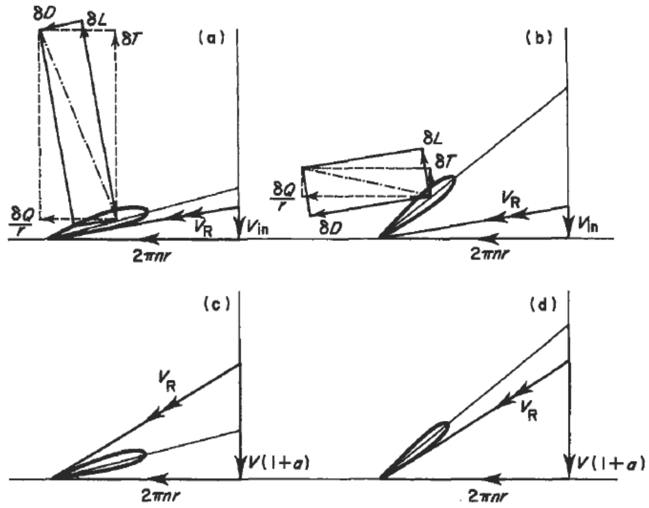
Definition	Mechanical device used to generate thrust from a shaft engine
Design parameters	Propeller diameter Propeller rotational speed Blade pitch angle Number of blades
Type	Fixed pitch Variable pitch Constant speed propeller
Additional components	Propeller governor Propeller spinner

The geometric pitch

$Geometric\ pitch = 2 * \pi * r * \tan\ \theta$

The geometric pitch is frequently constant for all sections of a given propeller. Sometimes the geometric pitch varies from section to section of the blade. In such cases the geometric pitch taken at 75% of the radius is the reference.

The variable pitch propeller



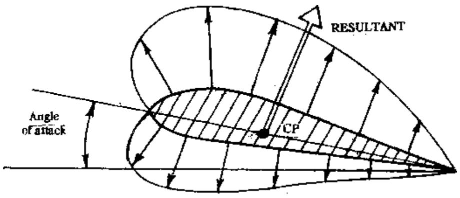
3.3 Centre of Pressure and Aerodynamic Centre

3.3.1 Introduction

An airfoil generates lift by changing the velocity of the air passing above and under itself. The airfoil angle of attack causes the air to travel faster over the upper surface than the lower surface. Bernoulli's equation shows that higher velocity produces lower pressure. So the upper surface tends to be sucked by lower-than-ambient pressure while the lower surface tends to be pushed upward by higher-than-ambient pressure. The pressures acting on the airfoil surface generate the net lifting force

3.3.2 Centre of pressure

The center of pressure is the point where the resultant of a pressure field acts on a body. At that point, all of the aerodynamic pressure field may be represented by a single force vector with no moment.



The projection of this resultant force, perpendicular to the direction of flight, is called the lift.
The projection of this resultant force, in the direction of flight, is called the drag.

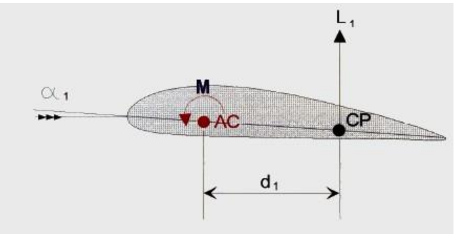
The center of pressure moves with change of lift and with change of angle of attack. This change in position makes the center of pressure unsuitable for use in analysis of the longitudinal stability of the airplane. For this reason it is simpler to use a fixed point, the aerodynamic center, to make the analysis of the stability.

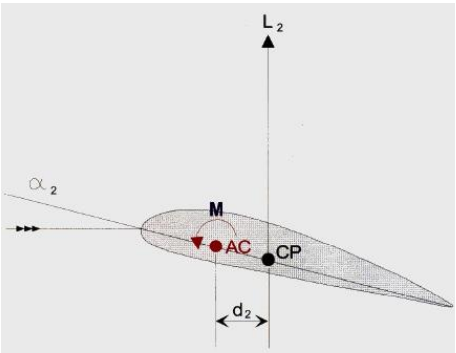
3.3.3 Aerodynamic centre

The aerodynamic center is the point on an airfoil where the pitching moment produced by the aerodynamic forces is constant with lift coefficient.

In other words, the aerodynamic center is the point on the airfoil where the incremental lift (due to change in angle of attack) will act.

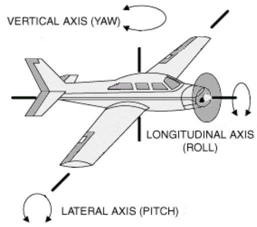
For most airfoil this point is located close to 25% of chord position. For the reason, this point is described as the quarter-chord point





→ **Cf. Annex 16 : More information about Aerodynamic Centre**

3.4 Stability around the Axis



Definition	Longitudinal (pitch stability) : about lateral axis Lateral (roll stability) : about longitudinal axis Directional (yaw stability) : about vertical axis

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

3.4.1 Longitudinal stability

Definition	Longitudinal (pitch stability) : about lateral axis Provided primarily by the horizontal tail CG must be in front of the AC

3.4.2 Lateral stability

Definition	Lateral (roll stability) : about longitudinal axis Provided primarily by the dihedral of the wing

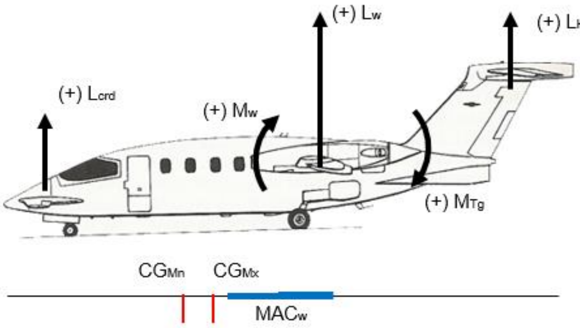
3.4.3 Directional stability

Definition	Directional (Yaw stability) : about vertical axis Provided primarily by the vertical tail

➔ **Cf. Annex 17 : Introduction to Stability**

3.5 Centre of Gravity 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



3.5.1 Most forward CG position (%MAC) – Limit of maneuverability

To be checked for the most critical flight condition (landing)

$$\overline{AC}_{w+fus} = \overline{AC}_{arf} + 100 \cdot \left(-0.6 \cdot \left(\frac{L_w}{l_{fus}} - 0.1 \right) \cdot \left(\frac{l_{fus} \cdot w_{fus}}{S_w} \right) \cdot \left(\frac{w_{fus}}{MAC_w} \right) \right)$$

$$\overline{CG}_{Mn} = \frac{100}{MAC_w} \cdot \left[AC_{w+fus} - \left(\frac{\left(M_w - L_{HT} \cdot \left(L_{AC_{HT}} - L_{AC_{w+fus}} \right) + L_{crd} \cdot \left(L_{AC_{w+fus}} - L_{AC_{crd}} \right) + M_{Tg} \right)}{L_w + L_{HT} + L_{crd}} \right) \right]$$

To move $\overline{CG}_{Mn}$ forward :

↗ fuselage contribution (move the wing backward, increase the fuselage maximum width)

↘ wing lift or flight weight

↗ M_w or <u>reduce</u> the nose down pitching moment

↘ $F_{y\ HT}$ or <u>increase</u> the downward force on the horizontal tail

↗ elevator **<u>up</u>** deflection

↗ horizontal tail area

Move the horizontal tail in the propeller slipstream

↗ $F_{y\ crd}$ or <u>increase</u> the upward force on the canard surface

↗ elevator **<u>down</u>** deflection

↗ canard area

Move the canard surface in the propeller slipstream

Replace the All-Moving type by a Fixed surface and trailing edge device

3.5.2 Most aft CG position (%MAC) – Limit of stability

$$\overline{AC}_{arp} = \overline{AC}_{w+fus} \cdot \frac{a_{0_{w+fus}}}{a_{0_{arp}}}$$

$$+\frac{q_{HT}}{q} \cdot \frac{a_{0_{HT}}}{a_{0_{arp}}} \cdot \left(1 - \frac{d\varepsilon_{HT}}{d\alpha}\right) \cdot \frac{S_{HT}}{S_w} \cdot \left(100 \cdot \frac{\left(L_{AC_{HT}} - L_{AC_w}\right)}{MAC_w} + \overline{AC}_{arf_w}\right)$$

$$-\frac{q_{crd}}{q} \cdot \frac{a_{0_{crd}}}{a_{0_{arp}}} \cdot \left(1 + \frac{d\varepsilon_{crd}}{d\alpha}\right) \cdot \frac{S_{crd}}{S_w} \cdot \left(100 \cdot \frac{\left(L_{AC_w} - L_{AC_{crd}}\right)}{MAC_w} - \overline{AC}_{arf_w}\right)$$

$$\overline{CG}_{Mx} = \overline{AC}_{arp}$$

To move $\overline{CG}_{Mx}$ backwards :

- ↗ $a_{0_{HT}}$
- ↘ ε_{HT}
- ↗ S_{HT}/S_w
- ↗ q_{HT} (put the horizontal tail in the propeller slipstream)
- ↗ $\left(L_{AC_{HT}} - L_{AC_w}\right)$

- ↘ $a_{0_{crd}}$
- ↘ ε_{crd}
- ↘ S_{crd}/S_w
- ↘ q_{crd} (put the canard surface out of the propeller slipstream)
- ↘ $\left(L_{AC_w} - L_{AC_{crd}}\right)$

3.6 Weight estimation

In Design Level 2, the weight is computed for each element taking into account its geometry. As example, the weight of the wing is computed from:

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

The formulas are based mainly on empirical formulas which were derived from studying a large number of existing aircraft.

A correction factor (**MCF**), taking into account the nature of the materials, the skill of the manufacturer, etc. is applied to each result. These correction factors are derived from a detailed analysis of existing aircraft, similar in design to what is planned to be designed.

Historical values for MCF:

- < 1 Wood, Fabric, Tube
- = 1 Light alloy
- **>** 1 Composite

	MCF
Pipistrel Sinus	0.882
MC100	0.905
Van's RV6-A	0.937
Rapid 200	0.943
Piaggio Avanti	0.944
Urban Lambada	0.947
Ikarus C42	0.951
Socata TB20	0.993
Diamond DA42	1.036
Van's RV9-A	1.039
Glasair III	1.053
White-Lightning	1.054
Piper PA-32	1.069
Speed Canard	1.072
Windex	1.101
Adam 500	1.132
Socata TBM850	1.149
Robin ATL	1.232

➔ **Cf. Annex 16 : More information about Weight Estimation**

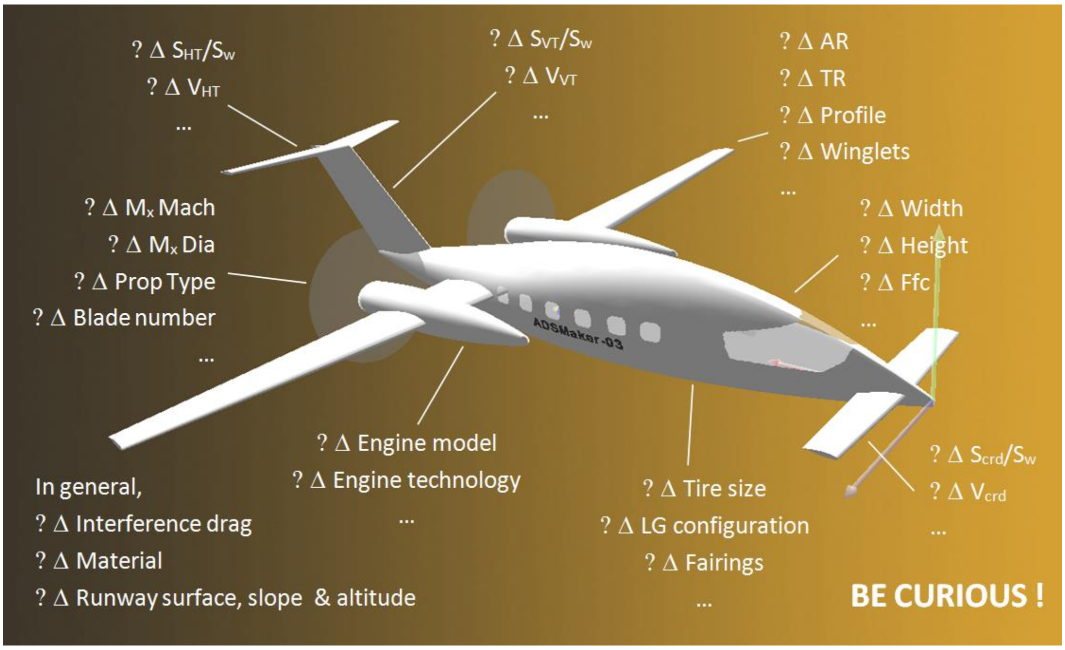
3.7 Some tips to perform the Design Level 2 with ADS

1. Design the aircraft for the main flight condition ONLY
   - Fuselage / Shape : straight
   - Performance / Mission profile : variables = 0
   - Options / Number of climb segments : 1
   - Options / Flight performance: nothing checked

2. Investigate different configurations (as much as possible)
   - General: general layout …
   - Wing: geometry, airfoil selection, high lift devices …
   - Tails: geometry, airfoil selection …
   - Fuselage: geometry …
   - Landing gear: fixed vs retractable, tire size, wheel fairing …
   - Engine: engine technology, number …
   - Propeller: Fixed pitch vs Constant speed, blade number, diameter
   - Aerodynamics: % interference drag …
   - Performance: runway surface (takeoff & landing), high lift device setting, flight altitude, range (cruise)
   - Options: number of climb segments …
   - …

3. Make a list of the different configurations investigated:

File name:	Main characteristics:
1. Dsgn02-GroupA-01	
2. Dsgn02-GroupA-02	
3. …	



Bloc 4

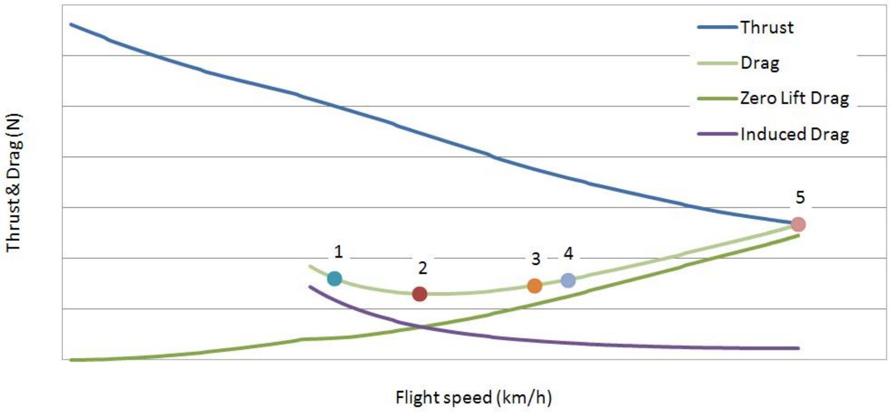
4.1 The Conceptual Design – Design for mission

4.1.1 Introduction

An aircraft is designed according to the main flight condition.

Compute the lift coefficient of these aircraft and locate it on the graph below.

		B737-600	B737-900	B747-400	B757-200	Cessna 172S	Piper PA-28	Predator
Wing area	m²	125	125	541	185	16.17	15.79	14.837
Flight weight	kg	56 245	74 840	362 875	99 790	1 111	1 156	1 065
Altitude	m	12 500	11 310	10 575	11 675	2 440	2 410	7 620
Density	kg/m³	**0.287**	**0.347**	**0.384**	**0.327**	**0.963**	**0.963**	**0.549**
Speed of sound	km/h	**1 061**	**1 061**	**1 068**	**1 061**			
Flight speed	Mach	0.785	0.785	0.850	0.860			
	km/h	**833**	**833**	**908**	**912**	226	237	180
Lift coefficient		0.575	0.632	0.539	0.503	0.355	0.344	1.026



We observe that the lift coefficient for the transport aircraft category is between 0.65 and 0.8, for the light aircraft category, the lift coefficient is between 0.3 and 0.4 and for the UAV category, the lift coefficient is higher than 1.

Each category has its specific purpose. The commercial aviation will try to fly as far as possible with a given quantity of fuel. The UAV category designed for observation purpose, will try to fly as long as possible with a given quantity of fuel. The leisure aviation category will try to fly at relative high speed in cruise.

There exists different categories:

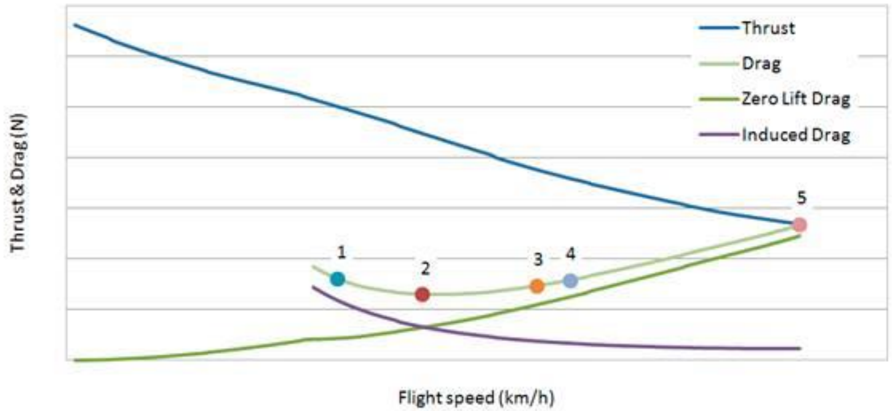
- Aircraft designed for maxi range
- Aircraft designed for maxi endurance
- Aircraft designed for maxi cruise speed
- Aircraft designed for best rate of climb
- Aircraft designed for maxi speed

4.1.2 Optimized for the main flight condition

An aircraft is optimized for the main flight condition. The most common ones are the maxi-range flight condition and maxi-endurance flight condition.

Propeller driven aircraft	Jet aircraft
Notes For propeller driven aircraft, the fuel consumption is expressed in terms of power and is given by $c = \frac{kg}{kW\ .\ h}$ For piston power aircraft, the engine power is roughly constant with velocity	Notes For jet aircraft, the fuel consumption is expressed in terms of thrust and is given by $c_t = \frac{kg}{N\ .\ h}$ For jet aircraft, the engine thrust is roughly constant with velocity
Endurance Endurance has something to do with time $h = \frac{kg}{kW\ .\ c}$ To maximize the endurance (h), we have to minimize the power (kW)	Endurance Endurance has something to do with time $h = \frac{kg}{N\ .\ c_t}$ To maximize the endurance (h), we have to minimize the thrust or the drag (N) and fly at the minimum drag flight condition.
Range Range has something to do with distance $d = v \cdot t$ $d = v \cdot \frac{kg}{kW\ .\ c}$ To maximize the range (d), we have to maximize the ratio (v/kW) or to minimize the ratio (kW/v), or to fly at minimum drag flight condition.	Range Range has something to do with distance $d = v \cdot t$ $d = v \cdot \frac{kg}{N\ .\ c_t}$ To maximize the range (h), we have to maximize the ratio (v/N) or to minimize the ratio (N/v)

4.1.3 Particular flight conditions



	Flight condition	Cd_0 vs Cd_L	V	V vs V_2	Cl	WL
1	End_{Mx} (piston)	$Cd_0 = \frac{1}{3} \cdot K \cdot Cl^2$ $3 \cdot Cd_0 = K \cdot Cl^2$	$\left(\frac{2 \cdot WL}{\rho} \cdot \left(\frac{K}{3 \cdot Cd_0}\right)^{0.5}\right)^{0.5}$	$0,76 \cdot V_2$	$\left(\frac{3 \cdot Cd_0}{K}\right)^{0.5}$	$0,5 \cdot \rho \cdot V^2 \cdot \left(\frac{3 \cdot Cd_0}{K}\right)^{0.5}$
2	$Range_{Mx}$ (piston) End_{Mx} (jet)	$Cd_0 = K \cdot Cl^2$	$\left(\frac{2 \cdot WL}{\rho} \cdot \left(\frac{K}{Cd_0}\right)^{0.5}\right)^{0.5}$	V_2	$\left(\frac{Cd_0}{K}\right)^{0.5}$	$0,5 \cdot \rho \cdot V^2 \cdot \left(\frac{Cd_0}{K}\right)^{0.5}$
3	$Range_{Mx}$ (jet)	$Cd_0 = 3 \cdot K \cdot Cl^2$	$\left(\frac{2 \cdot WL}{\rho} \cdot \left(\frac{3 \cdot K}{Cd_0}\right)^{0.5}\right)^{0.5}$	$1,32 \cdot V_2$	$\left(\frac{Cd_0}{3 \cdot K}\right)^{0.5}$	$0,5 \cdot \rho \cdot V^2 \cdot \left(\frac{Cd_0}{3 \cdot K}\right)^{0.5}$
4	Long Range (jet) : 7% faster, 1% fuel consumption increase					
5	Maximum level flight speed					

4.2 The Conceptual Design – Level 2 (All Flight Conditions)

The next step consists to compute the other flight conditions:

- The takeoff distance
- The maximum rate of climb
- The maximum range
- The maximum endurance

The performance must be in accordance with the specifications.

Note that in level 2 the performance are computed for the **maximum takeoff weight**

4.3 Some tips to perform the Design Level 2 with ADS

1. Design the aircraft for all flight conditions
   - Options / Flight performance: everything checked
   - Select the option Maximum Rate of Climb

2. Excepted indicated in the specifications
   - The stall altitude: SL
   - The takeoff altitude: SL
   - The climb altitude: SL

3. Make a list of the different configurations investigated:

File name:	Main characteristics:
4. Dsgn02-GroupA-01 5. Dsgn02-GroupA-02 6. …	

Bloc 5

5.1 The Conceptual Design – Level 3

The final stage in the process is the design with “given geometry”.

Off-target effect. One goal is to show what the effect would be of parameters that are “off-target”. What will be the impact on the aircraft performance if the weight of the aircraft turns out to be slightly different? What margins are acceptable? Where is the limit to be set?

Impact of modifications to an existing aircraft. What is the overall impact on the aircraft of a wing or landing gear modification? Change in weight, change in drag, change in performance,… The improvements obtained in reality can often be very different from what was initially expected or aimed for.

It is also possible to analyse the performances (take-off, climb and cruise) of a given aircraft for different flight conditions (flight weight, flight altitude, CG position).

TIPS

Objectives: calculate with high accuracy

1. Performances for all flight conditions (takeoff, climb, cruise, landing) of the existing (modified) aircraft
2. Balance and Stability

Input data:

1. The characteristics (dimensions, equipments) of the existing aircraft
2. Data from product databases (engines, airfoils, tires, …)

Results:

1. Performances for all flight conditions,
2. Balance and Stability,

5.2 Some tips to perform the Design Level 3 with ADS

1. Compute the performance of the aircraft for different flight condition
   - Flight altitude: Min to Max
   - Flight weight: Min to Max
   - CG position: Min to Max

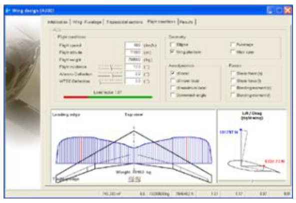
2. Compute the performance of the aircraft for different “out-of-target” parameters
   - Empty weight: +5%, +10%, …
   - Drag efficiency: +5%, 10%, …
   - Investigate different modifications in order to fulfil the initial requirements
   - Figure out the maximum deviation beyond which the project must be stopped.

3. Make a list of the different configurations investigated:

File name:	Main characteristics:
7. Dsgn03-GroupA-01	
8. Dsgn03-GroupA-02	
9. …	

Bloc 6

6.1 The Lift distribution



The lift distribution must be computed in order to optimize the geometry of the lifting surface in order to make it aerodynamically clean, safe, light and easy to build.

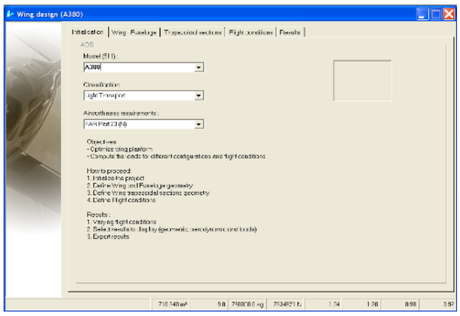
The lift distribution must also be computed in order to compute the loads on the lifting surface for different flight conditions, and especially for the flight conditions corresponding to the limits of the flight envelope.

The theory is based on the replacement of the wing by a simple lifting-line vortex. This is based on the Biot-Savart law. This method is described in detail in the book written by Alan Pope, titled “Basic Wing and Airfoil Theory”.

The method is very accurate to model a lifting surface with a moderate sweep angle (up to 15°). If the sweep angle becomes higher, the accuracy is reduced and another method should be used (the vortex lattice method for example which is, for a computing point of view, much more time consuming).

This tool is available in the professional version and education version of ADS. It must be used to optimize the geometry of any lifting surface and to compute the loads on it for different flight conditions. In addition, for en educational point of view, this tool could be used to explain the differences between rectangular and tapered wings for different aspects: weight, safety, aerodynamics, and manufacturing

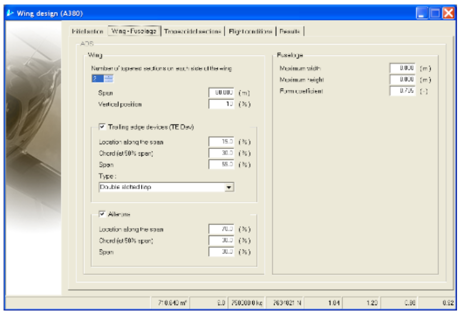
6.2 Project initialization



On the first tab, the user will need to:

1. Enter or select the name of the plane
2. Select the aircraft classification, to store the files in the right folder
3. Select the airworthiness requirement,

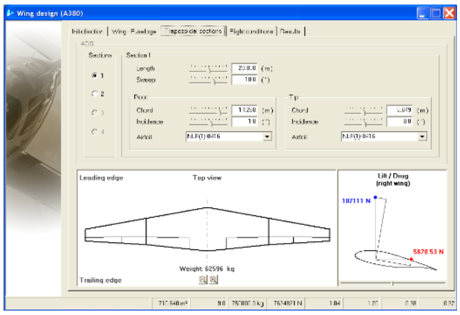
6.3 Wing and fuselage geometry definition



On the second tab, the user will need to:

1. Define the number of trapezoidal sections (up to 4) to define the shape of the lifting surface
2. Define the geometry of the lifting surface: span and vertical position on the fuselage
3. Define the geometry of the high lift device, if any
4. Define the geometry of the aileron, if any
5. Define the geometry of the fuselage

6.4 Trapezoidal section geometry definition



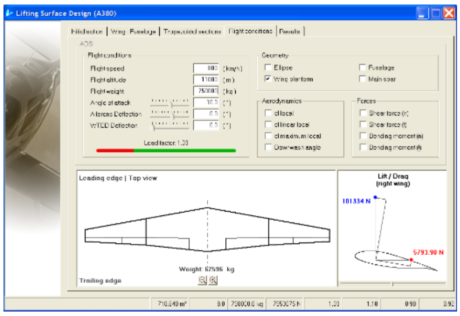
On the third tab, the user will need to define the geometry and characteristics of every trapezoidal section.

- Length of the current trapezoidal section and its leading edge sweep angle
- The characteristics (chord, incidence and airfoil profile) at the root position
- The characteristics (chord, incidence and airfoil profile) at the tip position

The selection of the current trapezoidal section is done when clicking on one option button located in the frame titled “Sections”.

> The incidence is the angle between the chord line and the horizontal axis (most of the time the fuselage datum)

6.5 Definition of the flight conditions

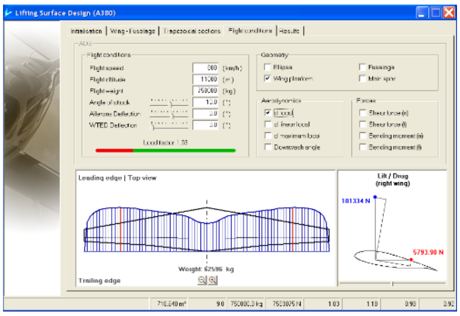


On the fourth tab, the user will need to define the flight conditions: flight speed, flight altitude and flight weight in order to be able to compute the loads on the lifting surface. When 100% of the required information has been introduced, ADS computes and displays the selected results (local lift coefficient by default).

The user may select which results he wants to display on the picture selecting the appropriate checkbox button:

- Ellipse: to display an ellipse in order to define a wing planform as close as possible to the ellipse
- Wing planform: to display the top view of the lifting surface
- Fuselage: to display the front view of the fuselage
- Main spar: to display the main spar of the lifting surface. Most of the time the designer will try to design a lifting surface with a straight main spar
- Cl local: to display the distribution of the local lift coefficient along the span
- Cl linear local: display the distribution of the local lift along the span
- Cl maximum local: to display the distribution of the maximum local lift coefficient along the span
- Downwash angle: to display the distribution of the downwash angle along the span
- Shear force (n): to display the distribution of the normal component of the shear force along the span
- Shear force (t): to display the distribution of the tangential component of the shear force along the span
- Bending moment (n): to display the distribution of the normal component of the bending moment along the span
- Bending moment (t)): to display the distribution of the tangential component of the bending moment along the span

6.6 Results display



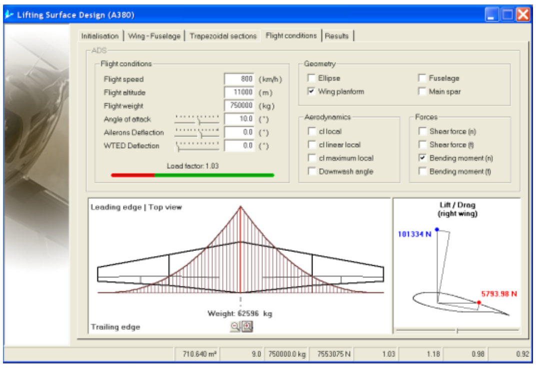
In addition, the user may play with different sliders to modify the input data:

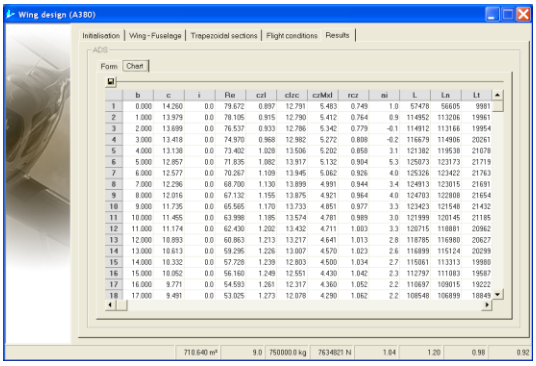
- The angle of attack may be modified in order to reach the desired load factor or to locate the place where the stall will occur
- The flap and aileron deflection may be modified in order to compute the loads for these specific configurations
- The geometry of the lifting surface (span), the characteristics of the control surfaces and the geometry of the trapezoidal sections may be modified

Moving the slider under the airfoil profile, on the right lower corner, the user will display the local forces (lift and drag) at a given position along the span (blue line)

Different information are displayed at the bottom of the window. From left to right:

- Lifting surface area
- Lifting surface aspect ratio
- Flight weight
- Total lift generated by the lifting surface
- Load factor
- Total lift coefficient of the lifting surface
- Oswald efficiency factor of the wing alone
- Oswald efficiency factor of the wing & fuselage





All the results are displayed on the fifth tab. The user may save these results in a .csv file in order to retrieve them in another application (stress analysis software for example).

6.7 Examples

6.7.1 Example 1

Compute the loads on the lifting surface at the point C of the flight envelope.

1. Enter the corresponding flight speed (Vc)
2. Enter the flight weight (maximum flight weight)
3. Enter the flight altitude (most of the time Sea Level Altitude)
4. Adjust the angle of attack until the maximum load factor is reached. A flag will be displayed if the maximum load factor is exceeded.

6.7.2 Example 2

Locate the point where the stall will occur on the lifting surface.

1. Enter the corresponding flight speed (Vs)
2. Enter the flight weight (most of the time maximum flight weight)
3. Enter the flight altitude (most of the time Sea Level Altitude)
4. Increase the angle of attack until the maximum lift coefficient is reached. A flag will be displayed if the maximum lift coefficient is exceeded.

6.7.3 Example 3

Define the geometry of the lifting surface in order to be as close as possible to the ellipse in order to minimize the induced drag.

1. On tab 2, select 4 under Number of tapered sections on each side of the wing
2. On tab 4, check Ellipse in order to visualize the ellipse
3. On tab 3, adjust the size of each tapered section (length, root chord, tip chord and sweep angle) to be as close as possible to the ellipse.
4. During the adjustment, take a look at:
   a. The Oswald Efficiency Factor (e), the second number, starting from the right side, of the status bar. An elliptical shape would have a value close to 1, depending of the size of the fuselage.
   b. The distribution of the local lift along the span (should be close to the elliptical shape)
   c. The distribution of the local lift coefficient along the span (should be close to a rectangular shape)

Bloc 7

7.1 The Flight envelope

The Flight envelope is also known as the V-n Diagram (Speed-Load Factor)

Compliance shall be shown at any combination of airspeed and load factor on the boundaries of the flight envelope. The flight envelope represents the envelope of the flight loading conditions.

Each of the following requirements shall be met at the most critical weight and CG configuration. Unless otherwise specified, the speed range from stall to V_D or the maximum allowable speed for the configuration being investigated shall be considered

Minimum flight speeds and load factors are imposed by the Airworthiness Requirements

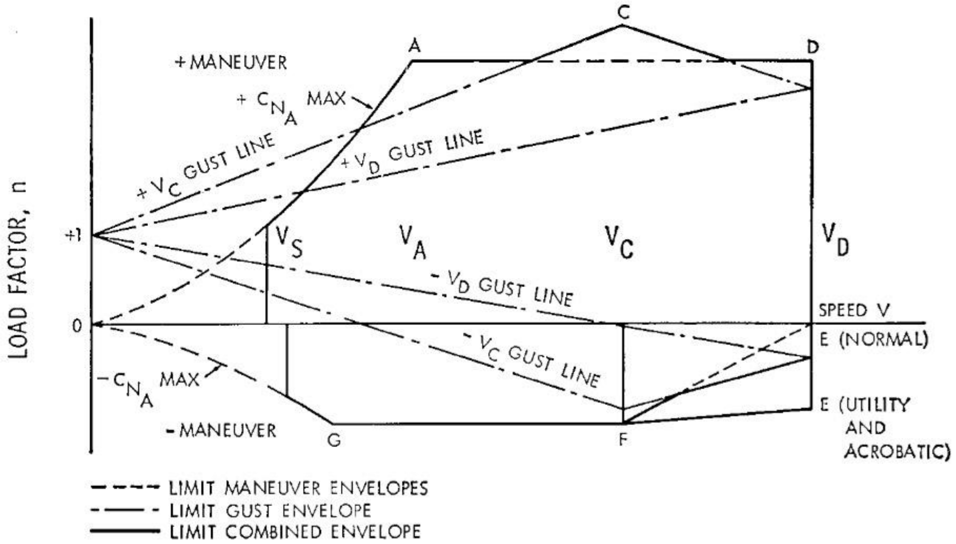


Image 1 : Flight envelope (FAR 23)

[a] Cf. FAR 23.333 Flight envelope

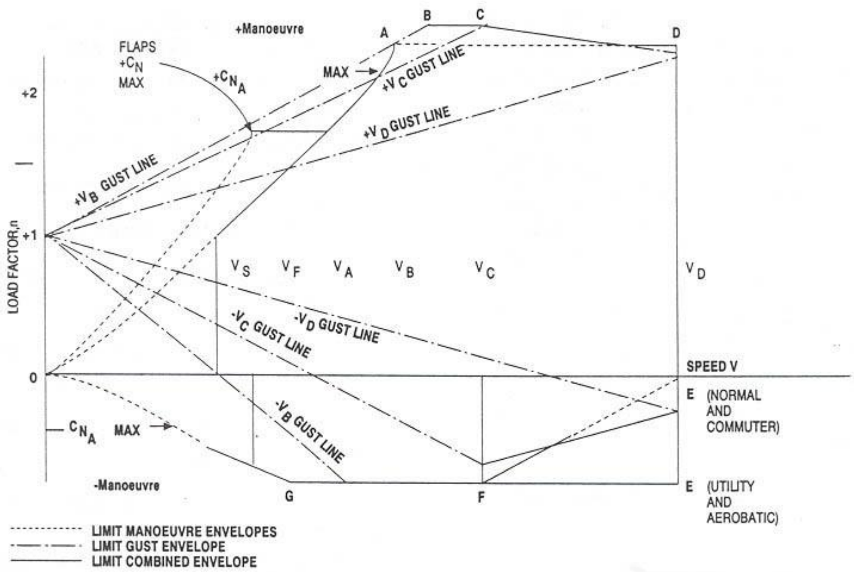


Image 2 : Flight envelope (CS 23)

[a] Cf. CS 23.333 Flight envelope

7.2 Design airspeeds

	FAR 23 CS 23				FAR 25 CS 25
	N[a]	U[a]	A[a]	C[a]	
V_{S+}	$\sqrt{\frac{W}{S}.\frac{2}{\rho}.\frac{1}{1.1\,.C_{LMx+}}}$				
V_{S-}	$\sqrt{\frac{W}{S}.\frac{2}{\rho}.\frac{1}{1.1\,.C_{LMx-}}}$				
V_S[b]	≤ 61 kts **if** n ≤ 1 ≤ 61 kts **if** (n > 1 **and** W < 6000 lb **and** RC OEI < RC_{Min} OEI)				
V_{SR}[c]					$\geq \frac{V_{CLMx}}{\sqrt{n_{zw}}}$
V_F[d]	$\geq 1.4\ V_S$ $\geq 1.8\ V_{SF}$				$\geq 1.6\ V_{S1\ TO\ config.}$ $\geq 1.8\ V_{S1\ App\ config.}$ $\geq 1.8\ V_{S0}$
V_A[e]	$\geq V_S \cdot \sqrt{n_1}$ $\leq V_C$				$\geq V_{S1\ Up\ Config}\ n_1^{0.5}$
V_B[e]	$\geq V_{S1}\ n_g^{0.5}$ $\leq V_C$				$\geq V_{S1}\ n_g^{0.5}$ $\leq V_C$
V_C[e]	$\geq k \cdot \sqrt{W/S}$ $< 0.9 \cdot V_H$				$\geq V_B + 1.32\ U_{ref}$
V_D[e]	$> 1.4\ V_{Cmin}$ [f] $\geq 1.25\ V_C$	$> 1.5\ V_{Cmin}$ [f] $\geq 1.25\ V_C$	$> 1.55\ V_{Cmin}$ [f] $\geq 1.25\ V_C$	$> 1.4\ V_{Cmin}$ [f] $\geq 1.25\ V_C$	$\geq 1.25\ V_C$

[a] Cf. FAR 23.3 - CS 23.3 : Airplane categories for the definition of each category
[b] Cf. FAR 23.49 - CS 23.49 : Stalling speed
[c] Cf. FAR 25.103 - CS 25.103 : Stall speed
[d] Cf. FAR 23.345 - CS 23.3 - FAR 25.345 : High lift devices
[e] Cf. FAR 23.335 - CS 23.335 - FAR 25.335 : Design Airspeeds

[f] : if *W/S* > 20 lb/ft², the multiplying factors may be decreased linearly with *W/S* to a value of 1.35 where *W/S* =100 lb/ft²
n : number of engines

k (V_C in kts)	N, U, C : k=33 for W/S < 20 lb/ft², k = 28.6 for W/S > 100 lb/ft², k = linear variation between
	A : k = 36
k (V_C in m/s)	N, U, C : k=2.453 for W/S < 958 N/m², k = 2.126 for W/S > 4789 N/m², k = linear variation between
	A : k = 2.676

U_{ref} : The reference gust velocity in equivalent airspeed

U_{ref} @ V_C	56 ft/s (SL)
	56 ft/s → 44 ft/s (SL → 15000 ft)
	44 ft/s → 26 ft/s (15000 ft → 50000 ft)
U_{ref} @ V_D	0.5 U_{ref} @ V_C

7.3 Structure – Load factors

	n_1[a]	n_2[a]	n_g[b]	n_{flap}[c]
FAR 23 - CS 23 - Normal **FAR 23 - CS 23** - Commuter	≤ 3.8 2.1+(10884/(W+4535))	-0.4 . n_1	$1 \pm \frac{K_g.\rho_0.U_{de}.V.a}{2.\frac{W}{S}}$	2
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	$2.5 \le n_1 \le 3.8$ 2.1+(10884/(W+4535))	-1 → V_C $-1 \le n_2 \le 0$[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 maneuvering 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 (m²)
ρ_0 : air density at sea level (kg/m³)
ρ : air density at the altitude considered (kg/m³)
c : mean geometric chord (m)
g : acceleration due to gravity (m/s²)
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

Bloc 8

8.1 Validation process

The final phase of the conceptual design is probably the most important. Now it's time to check the feasibility of the project. How to check that the aircraft could fly? How to check that we don't have been too optimistic in the choice of one or several parameters?

You may answer that you are going to build a mock-up and you will order some tests in a wind tunnel or you will use a CFD code to check the main aerodynamic characteristics of the aircraft. Yes, that could work. But how much does it cost and how long does it take?

The easiest way and the cheapest way to check the new design is to compare it with all the existing aircraft contained in a database. Aircraft that have already flown. You will make an analysis on different parameters, weight related parameters, drag related parameters, efficiency, and so on… The result of this analysis is a graph of dots.

If your new project seems to be far better than the best aircraft, you may have 2 different attitudes. The first one is to think that you are a genius and tomorrow you will be a millionaire. The second one, safer, is to think that there is something wrong with your project, and you would better check your design. It is very interesting to use this method to go to the past and check some figures that have been announced by some manufacturers before the first flight of their new revolutionary aircraft.

Where should you be located in the graph? It depends of your experience. If it is your first aircraft and you have no experience in designing aircraft, probably in the side of the worst. If you have some experience, in the middle, between the best and the worst. If you have a great experience, you may pretend to be as good as the best, maybe better than the best, but not too far.

Another way to check the feasibility of the project is to fly the aircraft in a flight simulator. The 3D model may be exported in one click to the flight simulator X-**Plane.**

8.2 Statistics

The **Statistics** make it possible to make an immediate analysis of the existing aircraft.

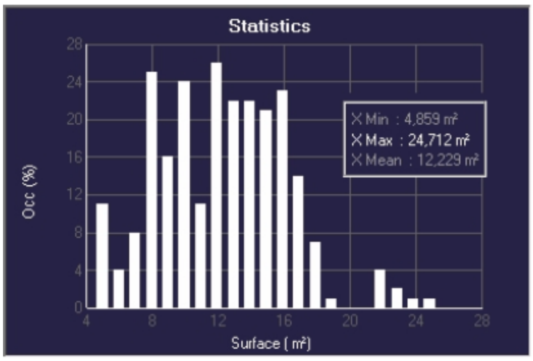
During the design process and more particularly during the conceptual design, the statistical analysis is essential to:

- Assess the current state of the art and compare the developing product with its direct and indirect competitors and
- Start the design process in a quick and efficient way by determining realistic orders of magnitude

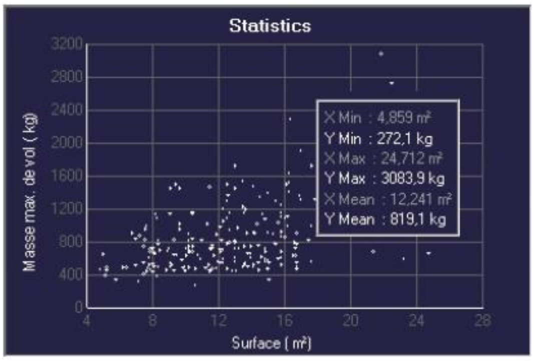
The definition of the statistical analysis is carried out in 3 steps:

- Step 1: definition of the target (airplane category & material)
- Step 2: definition of the analysis criteria (single or double)
- Step 3: definition of the results display options.

The result of a single statistical analysis is a bar chart



The result of a multiple statistical analysis is a graph of dots

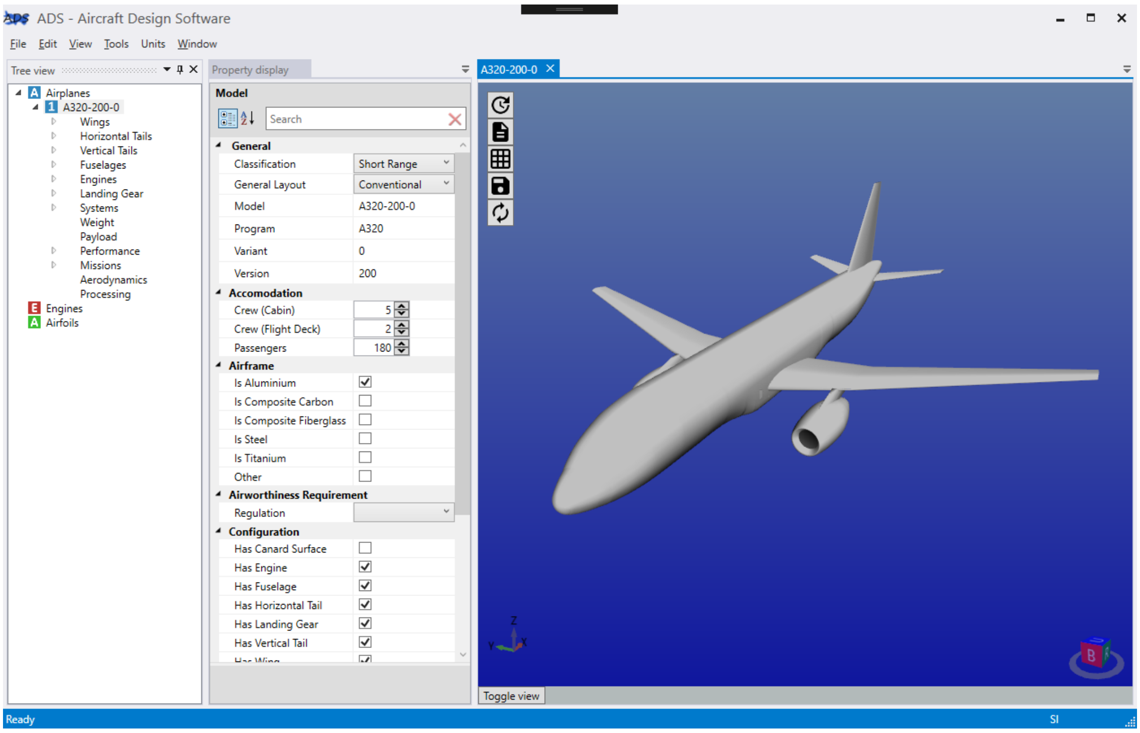


8.3 Flight Simulator

Using the flight simulator X-Plane, it's possible to check the performance of the new airplane. A simple click on the command button creates all the files for the flight simulator.

Bloc 9

9.1 ADS V4



9.2 TMF-Analysis

The **TMF-Analysis** (Technical, Marketing and Financial), which aims to help project leaders to develop the business plan for their project design / aircraft construction.

The **TMF-Analysis** includes:

- A Technical Analysis
- A Market study
- A Financial analysis

The Technical analysis consists to perform the conceptual design of the project.

The Marketing analysis aims to analyse the competitors and assessing potential market size.

The Financial analysis allows to quantify the R&D costs, as well as the manufacturing and operating costs in order to fix the selling price of the product, to follow the cash-flow and determine the breakeven point, according to different scenarios (3).

The **TMF-Analysis** is essential and should be done as soon as possible. It will give a clear idea of the budget required to conduct the project. The **TMF-Analysis** will also be used to plan the evolution of financial needs. Moreover, this analysis is essential to validate the initial specifications and adjust them if necessary.

The **TMF-Analysis** may be performed incrementally. The basic analysis gives a clear idea of the budget required for the project. This information is vital before making the decision to become more involved in the project. To quantify the profitability of the project, it will be necessary to make a deeper technical, marketing and financial analysis.

Bloc 10

10.1 Visit of the Museum

- Boeing 747
- Hall Concorde (1 prototype and 1 series' airplane)
- Hall dedicated for the second world war
- Hall dedicated for prototypes
- Hall dedicated for general aviation
- Hall dedicated for helicopters
- Hall dedicated for the history of aviation

Bloc 11

11.1 Test

A review will be organize to assess trainees' knowledge.

11.2 Final presentation

The final presentation must:

1. **Not exceed 5 minutes**
2. Will be limited to 5 slides
3. Must include an isometric view of the airplane
4. Must include the main dimensions of the airplane
5. Must include the results of the optimisation process.

The designer must be able to explain all of his choices.

11.3 Criteria for evaluating projects

Initial requirements
Stall speed
Takeoff
Climb
Cruise
Technical aspect
Airfoil profile selection
Wing geometry (Aspect Ratio, Taper Ratio, Sweep angle, Dihedral angle, ...) …
Ecology
kg CO_2/km/pax
kg fuel/km/pax
Noise level …
Costs
Market price
Price/km/pax …
Quality
Aerodynamic efficiency
Mass efficiency …

Complexity	
	Total wetted area
	Maximum lift coefficient
	Friction coefficient
	Interference drag coefficient
	Glider weight ratio
	Mass correction factor …
Presentation	

List of symbols

A

a	acceleration	m/s²
Alt	Altitude	m
AR_w	Wing aspect ratio	-

B

B	Breguet factor	-
b_w	Wing span	m

C

C_D	Drag coefficient (total)	-
C_{D0}	Zero lift drag coefficient	-
C_{DL}	Induced drag coefficient	-
C_{farp}	Airplane friction coefficient	-
C_{fgr}	Rolling friction coefficient	-
CG, $\overline{CG}$	Centre of gravity position	m, %MAC
C_L	Lift coefficient	-
C_{L1}	Maximum lift coefficient (clean)	-
C_{L2}	Maximum lift coefficient (dirty)	-

D

d	Distance	m
D	Drag	N
D0	Zero lift drag	N
DL	Induced drag	N
D_p	Propeller diameter	m

E

e	Oswald coefficient	-
E	Endurance	h

F

G

GR	Glide ratio	-

H

H	Height	m

L

l_{fus}	Length of fuselage	m
L	Lift	N
L_w	Lift generated by the wing	N

M

M	Mach number	-
M_w	Moment, wing	N.m
MCF	Mas correction factor	-
MD_{fus}	Fuselage mean diameter	m

N

n_1	Positive manoeuvring load factor	-
n_2	Negative manoeuvring load factor	-
n_3	Positive gust load factor	-
n_4	Negative gust load factor	-
n_{eng}	Engine rpm	t/s
n_p	Propeller rpm	t/s
N_{eng}	Number of engines	-
N_{occ}	Number of occupants (pilot(s) included)	-

P

p	Pressure	N/m²
p_{stat}	Static pressure	N/m²
p_{dyn}	Dynamic pressure	N/m²
P_{avail}	Power available	W
P_{eng}	Engine brake horse power	W
P_{req}	Power required	W

Q

q_{cr}	Dynamic pressure at cruise	N/m²

R

R	Range	km
RC	Rate of climb	m/s
Ri	Installation ratio	-
R_P	Power ratio	-

S

S_{tails}	Area, tails	m²
S_w	Area, wing	m²
Sfc	Specific fuel consumption	kg/W.h
SF	Frontal area	m²
SMC	Standard Mean Chord	m

T

$(t/c)_w$	Relative thickness of the wing	-
t	Time	h
T	Thrust	N
TR	Taper ratio	-

V

V	Flight speed	m/s
$V_{approach}$	Flight speed, landing approach	m/s
V_s	Stall speed	m/s

W

W_{empty}	Empty weight	kg
W_{flight}	Weight of flight	kg
W_{fuel}	Weight of fuel	kg
W_{gl}	Weight of the glider	kg
$W_{payload}$	Weight of payload	kg
W_{useful}	Weight useful	kg
W_{TO}	Take off weight	kg
W_w	Wing weight	kg
WA_{arp}	Airplane wetted area	m²
WA_w	Wing wetted area	m²
WL	Wing loading	N/m²

Symbol

α	Angle of incidence	°
α_0	Zero lift angle of incidence	°
$\Delta_{press\ fus}$	Cabin pressure differential	
ε	Downwash angle	°
$d\varepsilon_{HT}/d\alpha$	Downwash gradient at the horizontal tail	-
$d\varepsilon_{crd}/d\alpha$	Downwash gradient at the canard	-
ρ	Air density	kg/m³
σ	Density ratio	
γ	Runway angle	°
η	Efficiency	-
η_p	Efficiency, propeller	-
Λ_0	Sweep angle at leading edge	rad
Λ_{25}	Sweep angle at 25% MAC	rad
Λ_{25crd}	Sweep angle at 25% MAC, canard surface	rad
Λ_{25HT}	Sweep angle at 25% MAC, horizontal tail	rad
Λ_{25VT}	Sweep angle at 25% MAC, vertical tail	rad
Λ_{25w}	Sweep angle at 25% MAC, wing	rad
Λ_{25wgl}	Sweep angle at 25% MAC, winglet	rad
τ	Twist	rad

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Books

Dr. Jan Roskam • Soft cover • 496 pp • Print: 2007

Lessons Learned in Aircraft Design presents examples of lessons learned in airplane design since 1945. The lessons are largely drawn from the aircraft design and accident/incident literature. The author hopes that this book will contribute to the safety of flight.

A brief summary is presented of safety statistics, certification and operational standards, safety standards and their relationship to design in general.

Accident/incident discussions are presented in the following areas:

- Operational experience
- Structural design
- Flight control system design
- Powerplant installation design
- Systems design
- Manufacturing and maintenance
- Aerodynamic design
- Configuration design and aircraft sizing

In each case the discussion starts with the recounting of a problem which arose. Then the probable cause of the problem is identified, one or more solutions are indicated and finally a lesson learned is formulated.

Since many designers will eventually become program managers, it is instructive to recount some trials and tribulations associated with marketing, pricing and program decision making.

As is shown by many examples in this book, safety of airplanes often starts in the design phase. However, sometimes the certification process itself, for whatever reason, fails.

This book will be useful to practicing design engineers, test pilots and program managers. It can be used in the classroom to help in the education of future aircraft designers and engineering/maintenance personnel.

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Feedback Form

I liked…

I didn't like…

I suggest…

Thank you for your feedback

DB