Universidad Pontificia Bolivariana
Fundada en 1936

AIRCRAFT DESIGN I

Aeronautical Engineering
School of Engineering
UPB

AIRCRAFT CHARACTERISTICS INITIAL GEOMETRIC SIZING

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So far the design process have give you a set of preliminary (not definitely) values of different parameters (characteristics) of the proposed design

Lets recap all the steps and the results obtained so far:

You start the process by getting a **RFP**, which stablishes the requirements, restrictions and constrains of the proposed design for a given customer

With this you studied the **market forecast** to see if this airplane design can be justify. Also you can stablish which other type of missions apart from those given in the RFP you can develop with this new brand airplane

You studied the market of the airplane category given in the RFP, this is done by obtaining information of **baseline airplanes** with the objective of known better what do you want to design, which are your competitors and determine the design drivers of your proposal

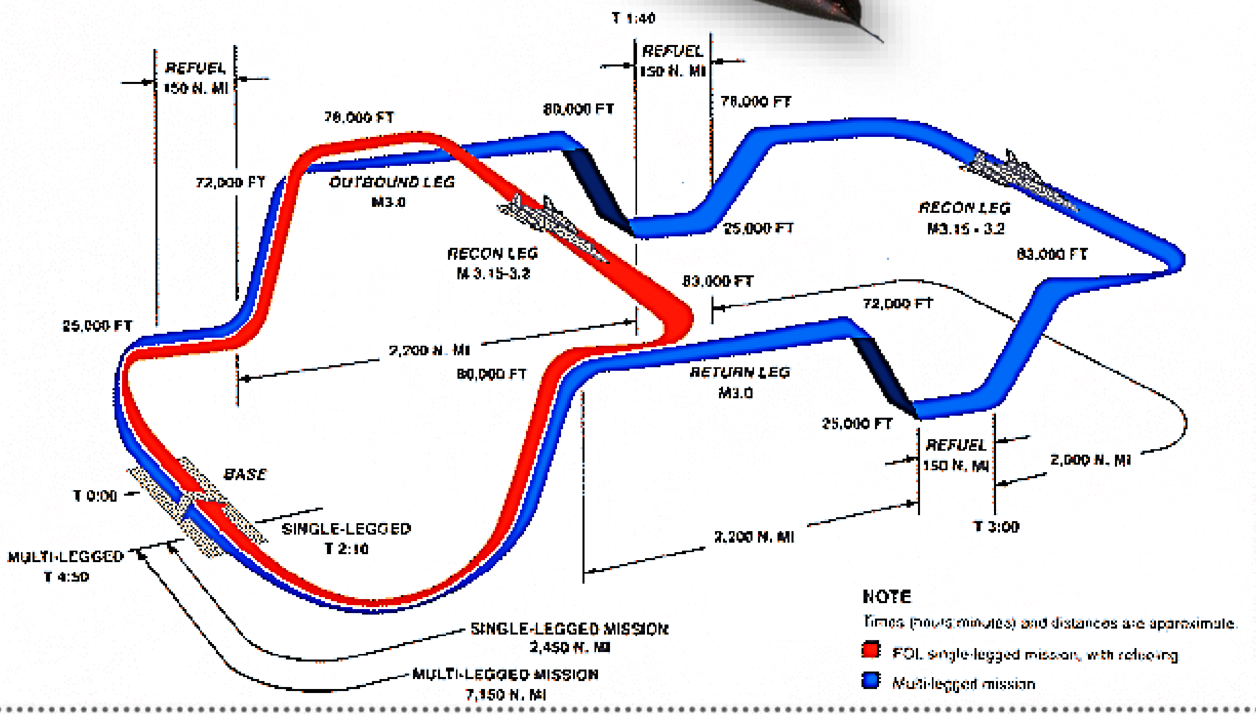
With all this information you **begin the initial sizing design process**

AIRCRAFT CHARACTERISTICS INITIAL GEOMETRIC SIZING

SUMMARY TO PRELIMINARY SIZING

1. Obtain a mission specification and construct from it a mission profile

2. Number the mission phases in sequence



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SUMMARY TO PRELIMINARY SIZING

3. For certain mission phases the fuel fraction can be estimated directly from table 2.1. For other mission phases, estimate the corresponding L/D and sfc values. Table 2.2 can be use as a guide

4. Determine the overall mission fuel fraction, M_{ff}

5. From the mission specification determine the fuel reserves, $W_{F\,res}$ or the fuel reserve fraction M_{res}

6. Follow the next steps:

- Step 1: From the design requirements, the payload weight W_{PL}
- Step2: A likely value for W_{TO} is obtained by looking at data for similar airplanes.
- Step 3: Determining a value for W_F according to the mission phases
- Step 4: A tentative value for W_{OE} found from: $W_{OE_{tent}} = W_{TO_{guess}} - W_F - W_{PL}$
- Step 5: A tentative value for W_E is found from: $W_{E_{tent}} = W_{OE_{tent}} - W_{tfo} - W_{crew}$
- Step 6: The allowable value for W_E is found from figure 2.5
- Step 7: The difference between W_E and $W_{E\,tent}$

- W_{TO}
- W_E
- W_F
- W_{PL} and W_{crew}, follow from mission specification

Remember that: $W_{TO} = W_{OE} + W_F + W_{PL}$

$$\boxed{W_{TO} = W_E + W_{tfo} + W_{crew} + W_F + W_{PL}}$$

Note: If the mission demands dropping or receiving weights, then some of the fuel fractions need to be corrected

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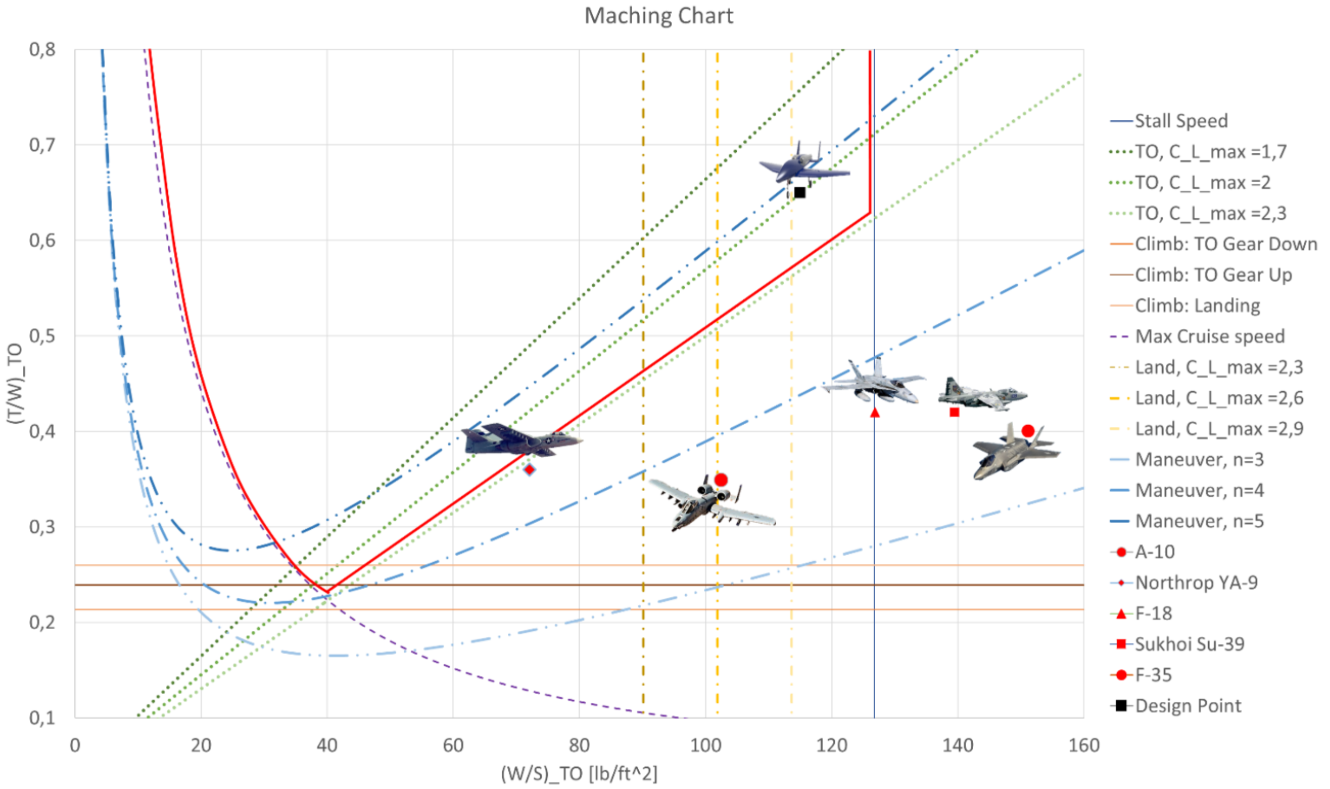
SUMMARY TO PRELIMINARY SIZING

7. Note from mission specification what the certification is for the aircraft: homebuilt (sport light aircraft), FAR 23, FAR 25 or military

8. Make a list of performance parameters to which the aircraft must be sized. Such a list can be put together from the mission specification and from the certification base:
    - Sizing to Stall Speed requirements
    - Sizing to Take-Off distance requirements
    - Sizing to Landing distance requirement
    - Sizing to climb requirements
    - Sizing to manoeuvring requirements
    - Sizing to Cruise Speed requirements

9. Perform the sizing calculations (estimate the drag polar)

10. Construct a sizing Matching graph for all performance sizing requirements



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INITIAL GEOMETRIC SIZING

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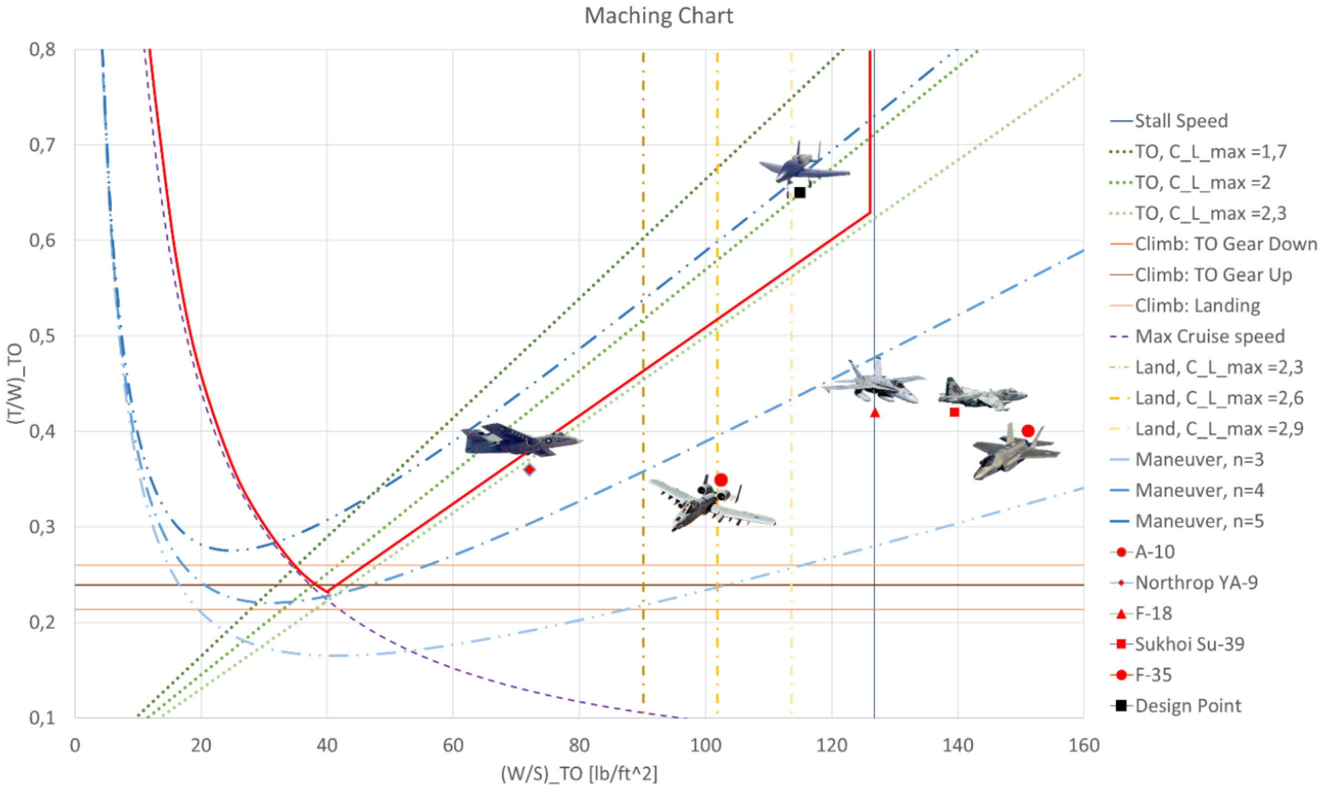
SUMMARY TO PRELIMINARY SIZING

11. From the Matching graph select:

- Take-Off power loading: $(W/P)_{TO}$ or Take-Off thrust-to-weight ratio $(T/W)_{TO}$
- Take-Off wing loading: $(W/S)_{TO}$
- Maximum clean lift coefficient:
- Maximum Take-Off lift coefficient:
- Maximum Landing lift coefficient:
- Wing Aspect ratio: AR



12. Determine the Take-Off power, P_{TO} or, the Take-Off thrust, T_{TO} from:

$$P_{TO} = \frac{W_{TO}}{\left(W/P\right)_{TO}} \qquad T_{TO} = \left(\frac{T}{W}\right)_{TO} W_{TO}$$

13. Determine the wing reference area: $S = \dfrac{W_{TO}}{\left(W_{TO}/S\right)}$

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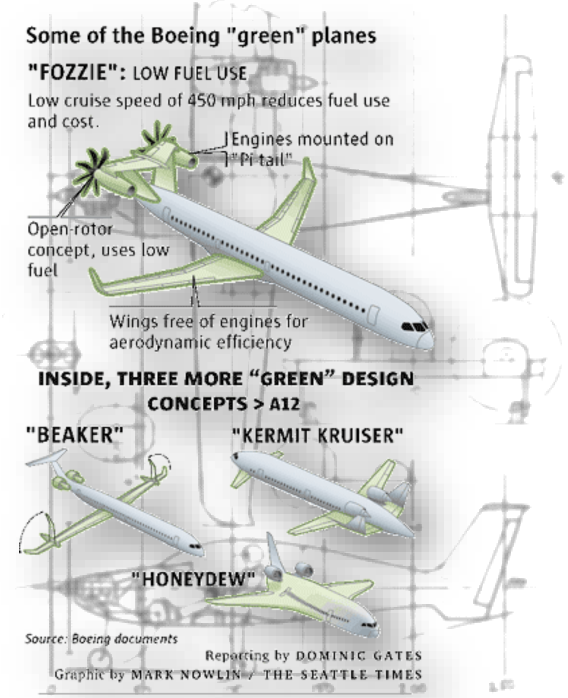
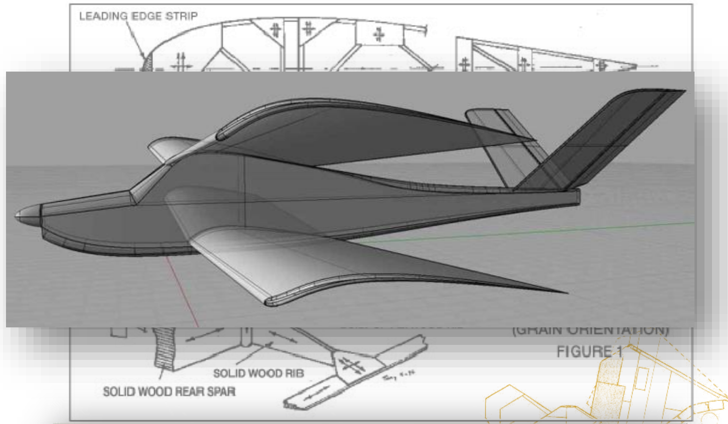
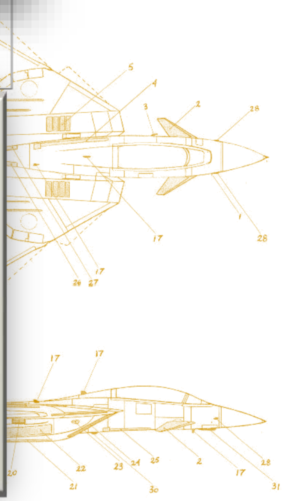
SUMMARY TO PRELIMINARY SIZING

All aircraft parameter needed to begin the developing of a configuration are now defined







AIRCRAFT CHARACTERISTICS INITIAL GEOMETRIC SIZING

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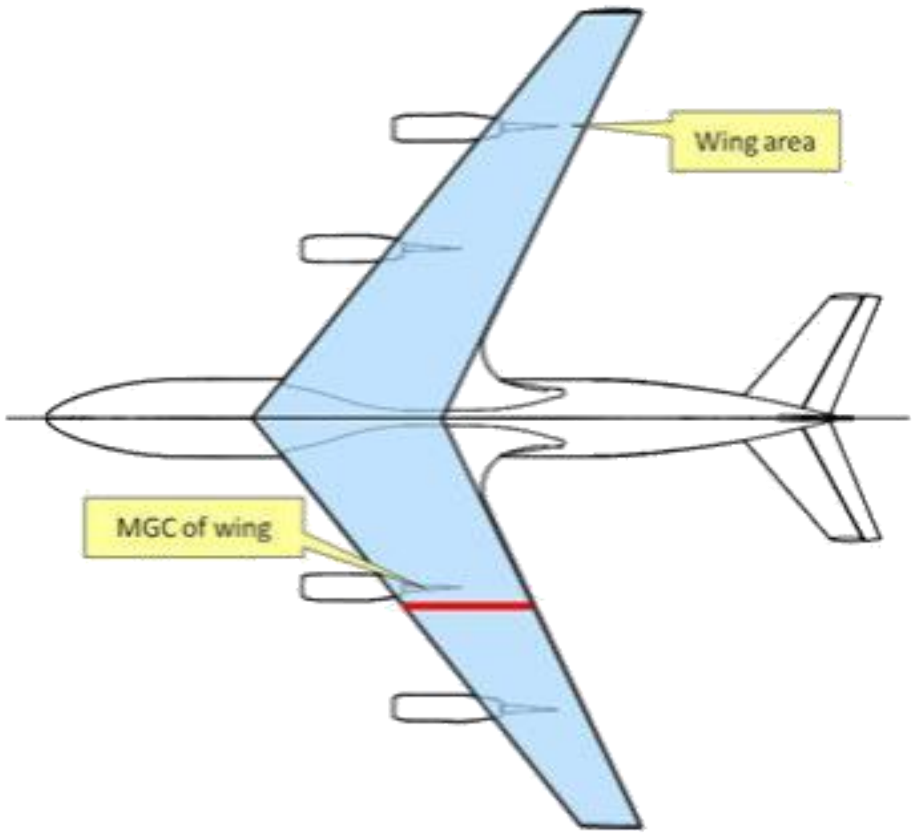
With the previous characteristics (weights, power/thrust, wing area, lift coefficients, etc.), and together with some statistical formulas (approximations), it is possible to **geometrically size an airplane** (preliminary dimensions). This process will be complemented by the lofting of different parts of the designed airplane

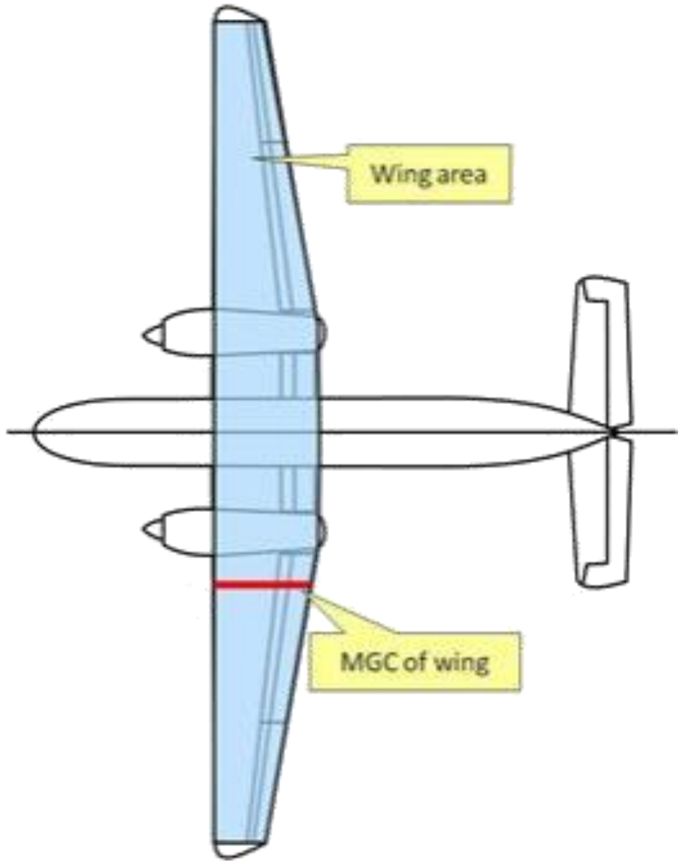
It is important to know some **features that can drive the design decisions**. First, it is advice to the designer that review the requirements and constrains set in the RFP, this will help him/her to keep in mind **what´s the real purpose of the design**. A good way to do this is by checking the baseline airplanes of the same category, with the information obtained here the designer will create an idea that can be interpreted as the design drivers

Also the **reviewing of airplanes similar to the one that is going to be design (if that is the case)** is to know as much as possible of the problems and solutions that other companies (designers/engineers) have had so far. A remarkable point here is that this will help to decide which technological advantages has to be pursue (**tendencies**)

WING GEOMETRY

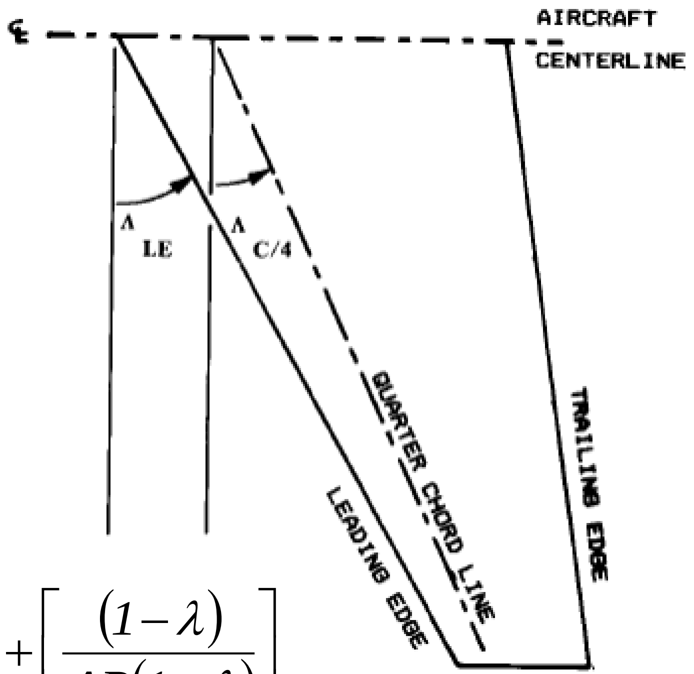
The **reference wing area** is fictitious, and extends through the fuselage to the aircraft centre line, thus, the reference wing area includes the part of the reference wing which sticks into the fuselage





WING GEOMETRY

$$\lambda = \frac{C_{tip}}{C_{root}} \qquad C_{root} = \frac{2 \cdot S}{b(1+\lambda)}$$



There are two key swept angles:

- Leading edge swept is the angle concern in supersonic flight – to reduce drag it is common to swept the leading edge behind the *Mach* cone
- The swept of the quarter chord line is the swept most related to subsonic flight

$$\tan \Lambda_{LE} = \tan \Lambda_{c/4} + \left[\frac{(1-\lambda)}{AR(1+\lambda)} \right]$$

WING GEOMETRY

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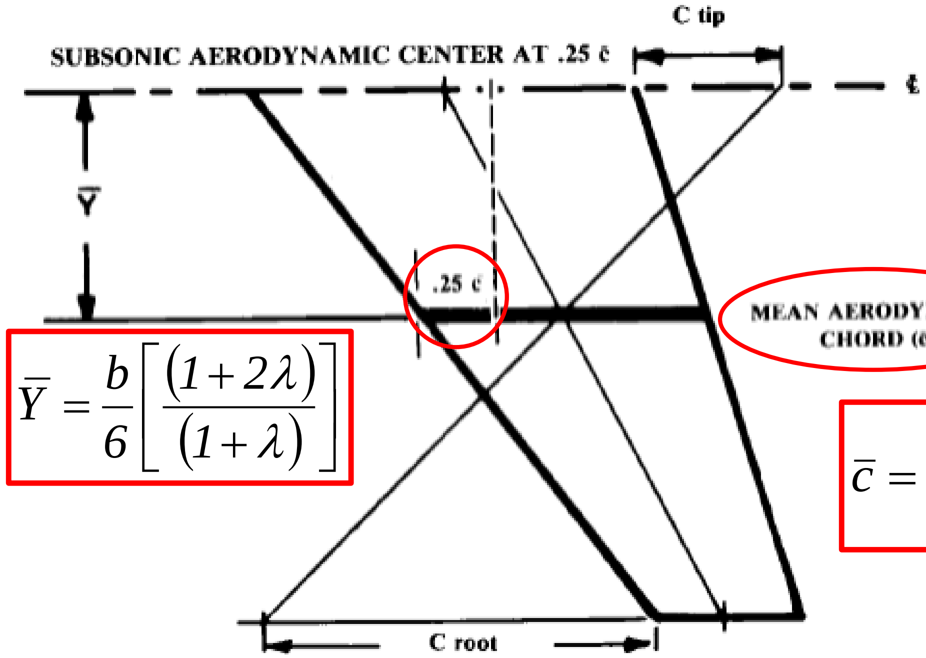
Typical, wing aerodynamic centre:

- = $0.25\ \bar{c}$ for subsonic
- = $0.40\ \bar{c}$ for supersonic

Aerofoil pitching moment data in subsonic flow is generally provided about a quarter-chord point, where the aerofoil pitching moment is essentially constant with changing the angle of attack. In a similar fashion, such a point is defined for the complete trapezoidal wing and is based on the concept of the "*Mean Aerodynamic Chord*" (*MAC*)



$$\bar{Y} = \frac{b}{6}\left[\frac{(1+2\lambda)}{(1+\lambda)}\right]$$

$$\bar{c} = \frac{2}{3}C_{root}\frac{(1+\lambda+\lambda^2)}{(1+\lambda)}$$

WING GEOMETRY

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The entire wing has its mean aerodynamic centre at approximately the same percent location of the *MAC* as that of the aerofoil alone

In subsonic flow, this is at the quarter-chord point on the *MAC*

In supersonic flow the aerodynamic centre moves back to about 40% of the *MAC*

The designer uses the *MAC* and the resulting aerodynamic centre point to position the wing properly

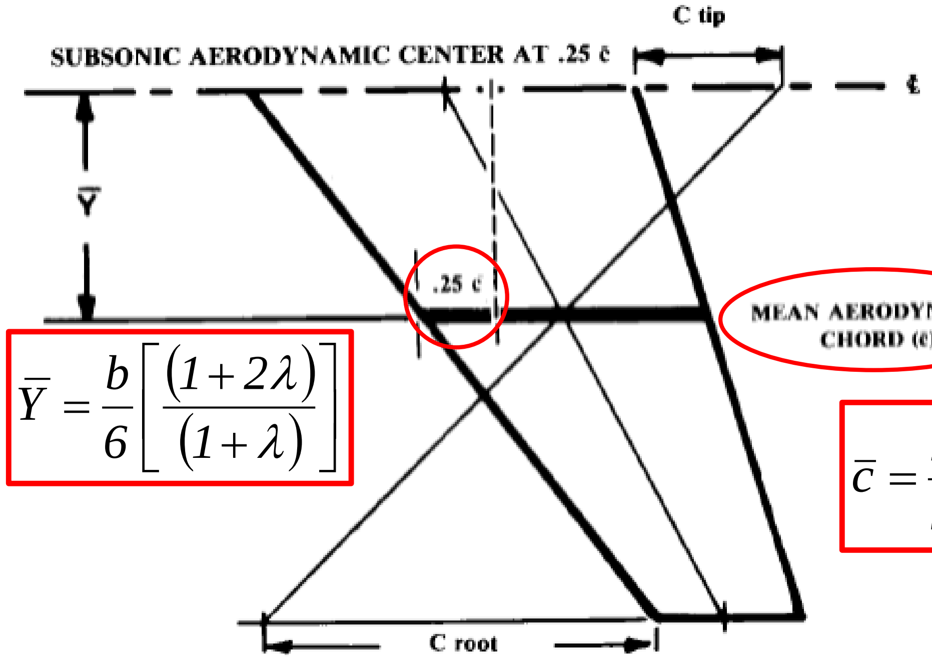
The required reference area S can be determined once the Take-Off Gross Weight (W_{TO}) is determined by:

$$S = \frac{W_{TO}}{W_{TO}/S}$$

The shape of the reference wing is determined by its aspect ratio (AR), taper ratio (λ), and swept (Λ)

Typical, wing aerodynamic centre:

- $= 0.25\ \bar{c}$ for subsonic
- $= 0.40\ \bar{c}$ for supersonic



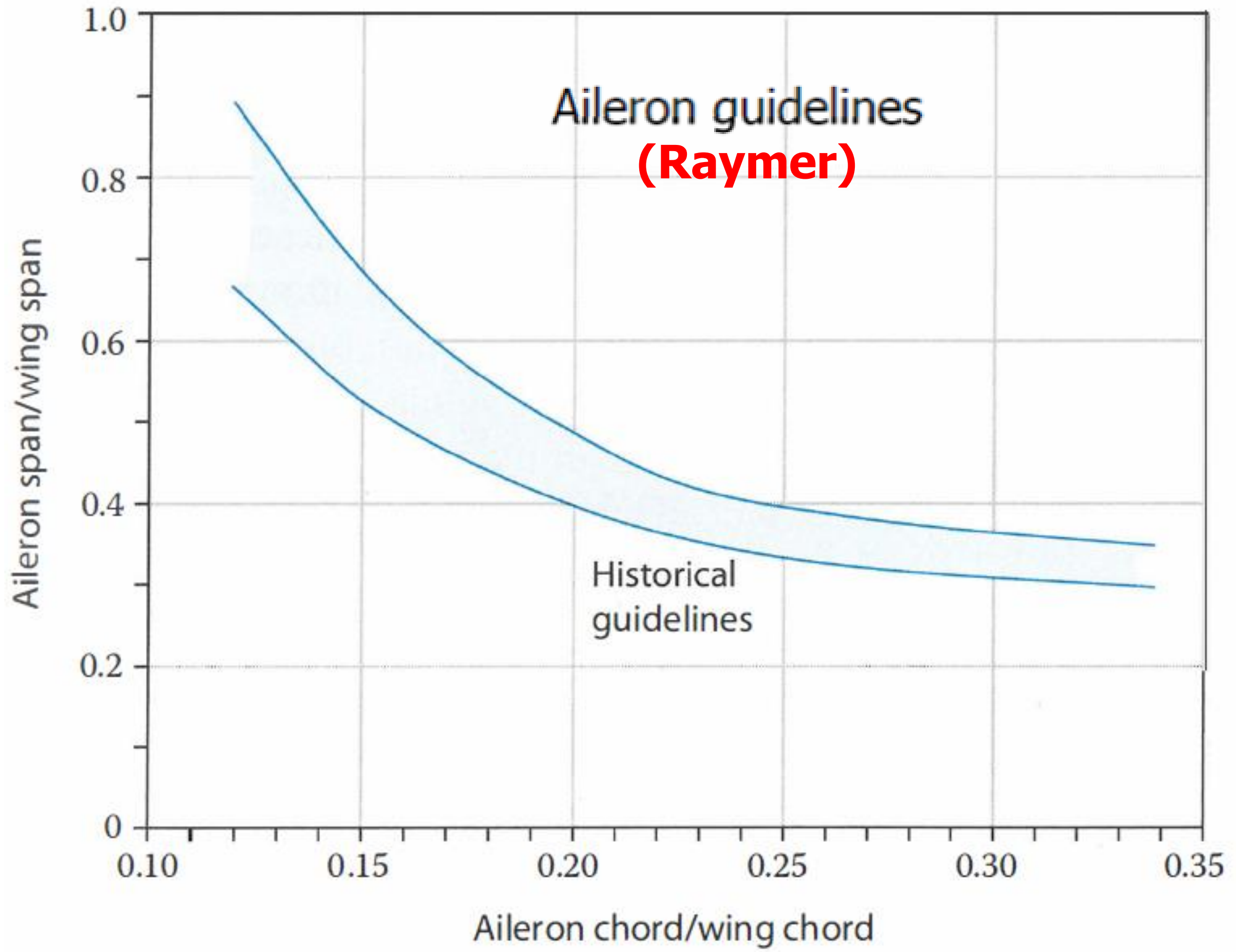
$$\bar{Y} = \frac{b}{6}\left[\frac{(1+2\lambda)}{(1+\lambda)}\right]$$

$$\bar{c} = \frac{2}{3} C_{root} \frac{(1+\lambda+\lambda^2)}{(1+\lambda)}$$

LATERAL CONTROL SURFACES SIZING AND LOCATION

Decide on the type, size and location of lateral control devices and high-lift devices

For initial design of the ailerons, the following guidelines are offered: **The required aileron area can be estimated from the "Aileron guidelines" figure**



LATERAL CONTROL SURFACES SIZING AND LOCATION

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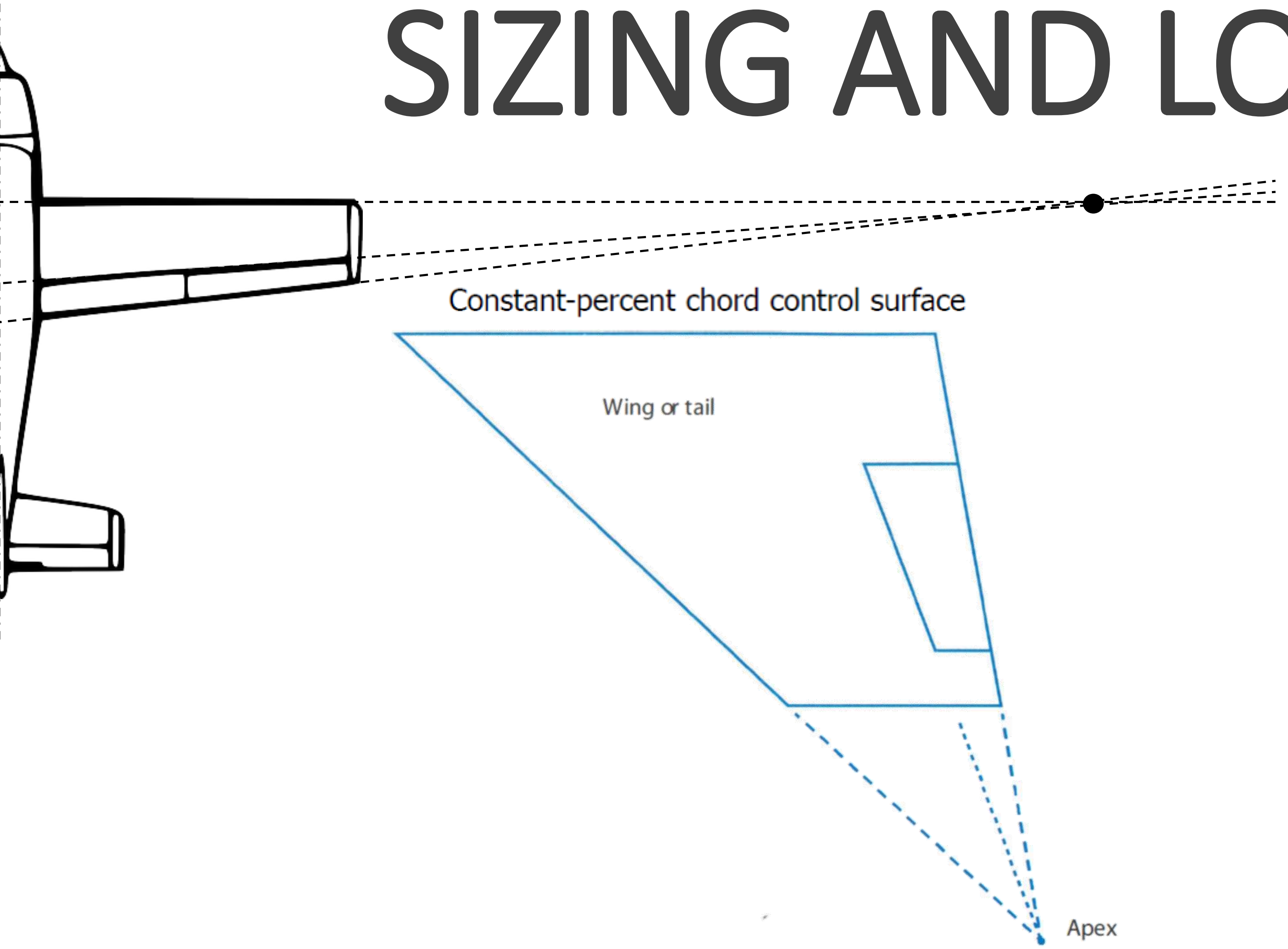

In span, the ailerons typically extend from about **50%** to **90%** **of the span**. In some aircraft, the ailerons extend all the way out to the wing tips, the extra **10%** provides little control effectiveness due to vortex flow at the wingtips, but can provide a location for an aileron mass balance

Control surfaces are usually tapered in the chord by the same ratio as the wing or tail surface so that the control surface maintains a constant percent chord

This allows spars to be straight-tapered rather than curved

Ailerons and flaps are typically **15-25% of the wing local chord**

FUSELAGE LAYOUT

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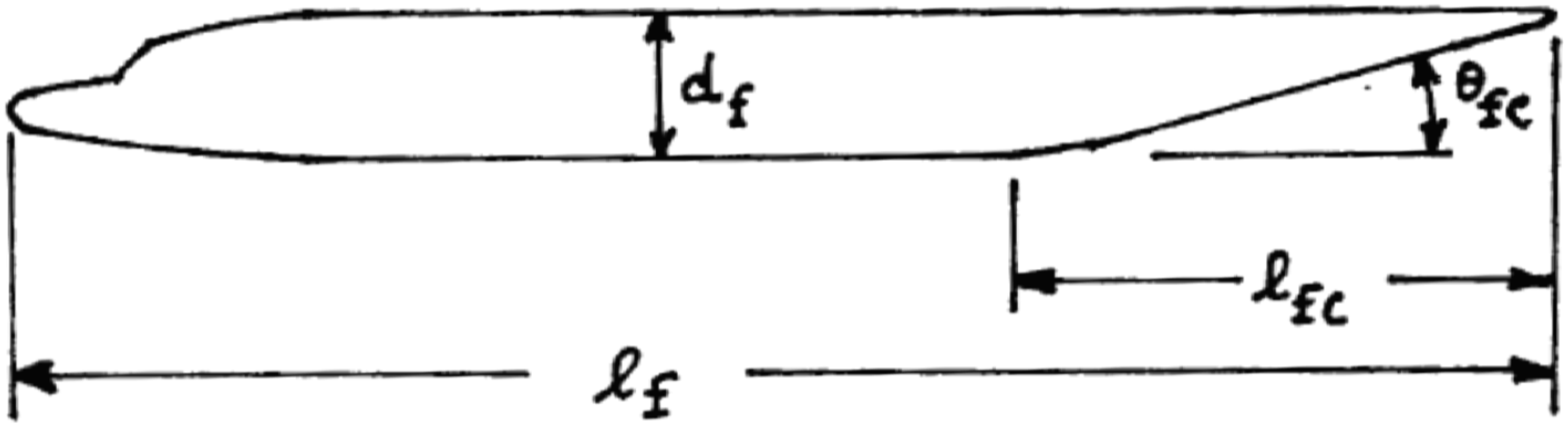
Fuselage length



- For initial guidance during fuselage layout, **table 6.3 provides statistical equations for fuselage length**. These are based solely upon Take-Off gross weight, and give remarkably good correlations to most existing aircrafts

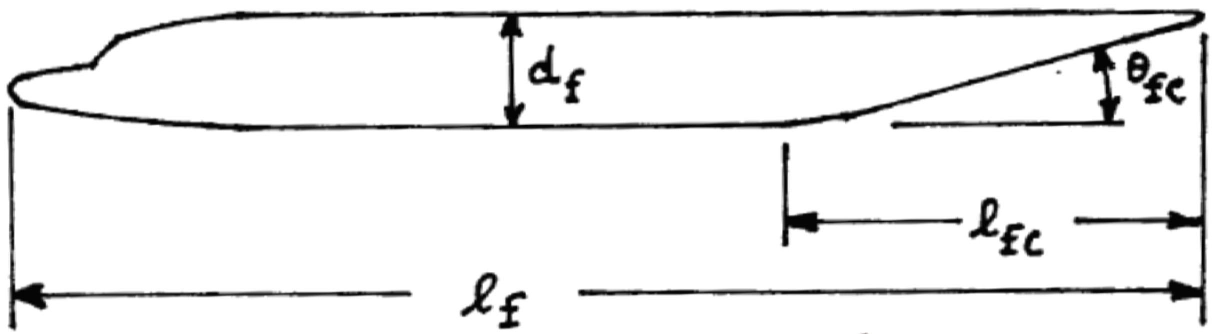
- ***Fuselage fineness ratio*** in the ratio between the fuselage length and its maximum diameter (l_f/d_f). **If the fuselage cross section is not a circle type, an equivalent diameter is calculated from the cross sectional area**

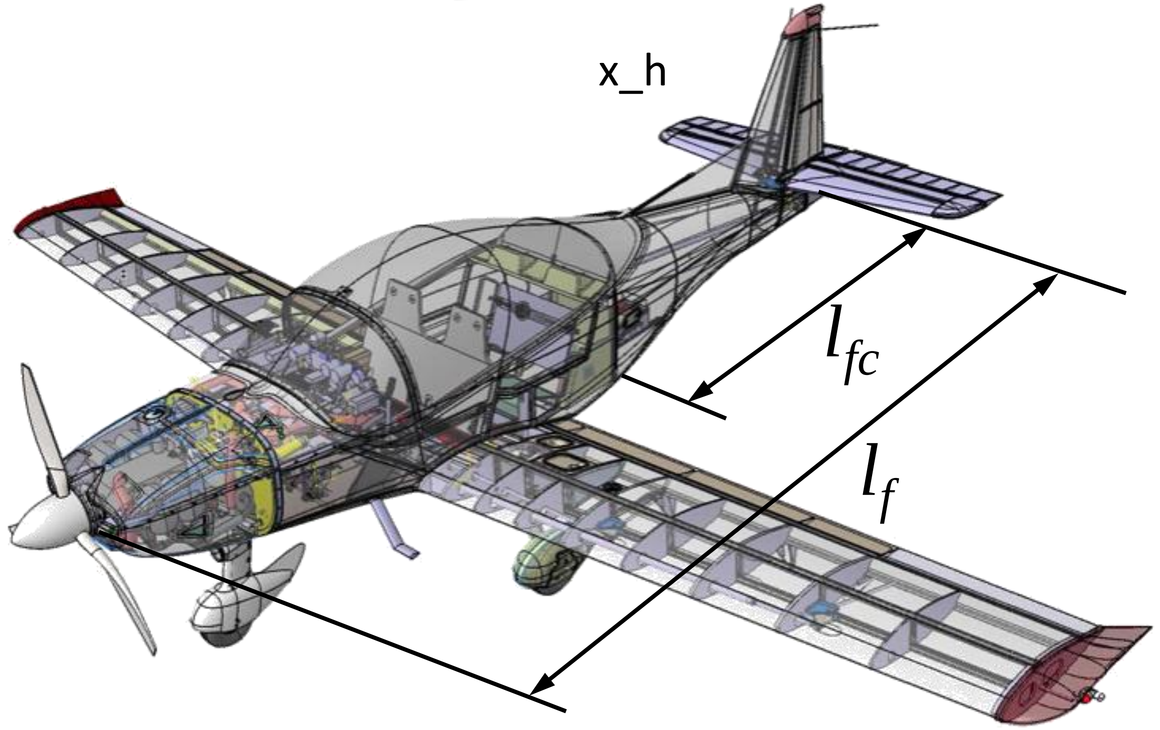
- Theoretically, for a fixed internal volume the subsonic drag is minimized by l_f/d_f of about 3.0 while supersonic drag is minimized by a l_f/d_f of about 14.0. most aircrafts fall between this ratios

- **For most design efforts the realties of packaging the internal components will establish the fuselage length and diameter**

FUSELAGE LAYOUT

Fuselage length





(Raymer)

Table 6.3 Fuselage Length vs W_0 (lb or {kg})

Length = aW_0^C (ft or {m})	a	C
Sailplane—unpowered	0.86 {0.383}	0.48
Sailplane—powered	0.71 {0.316}	0.48
Homebuilt—metal/wood	3.68 {1.35}	0.23
Homebuilt—composite	3.50 {1.28}	0.23
General aviation—single engine	4.37 {1.6}	0.23
General aviation—twin engine	0.86 {0.366}	0.42
Agricultural aircraft	4.04 {1.48}	0.23
Twin turboprop	0.37 {0.169}	0.51
Flying boat	1.05 {0.439}	0.40
Jet trainer	0.79 {0.333}	0.41
Jet fighter	0.93 {0.389}	0.39
Military cargo/bomber	0.23 {0.104}	0.50
Jet transport	0.67 {0.287}	0.43

(Roskam)

FUSELAGE LAYOUT

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Fuselage length

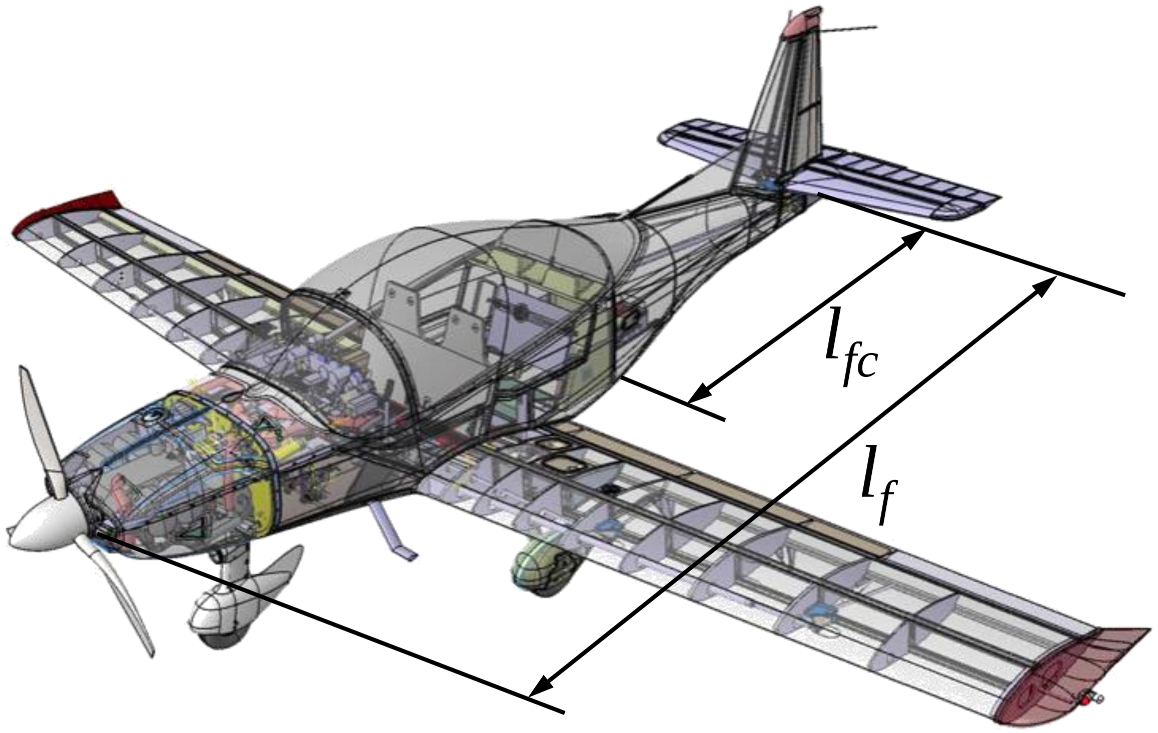
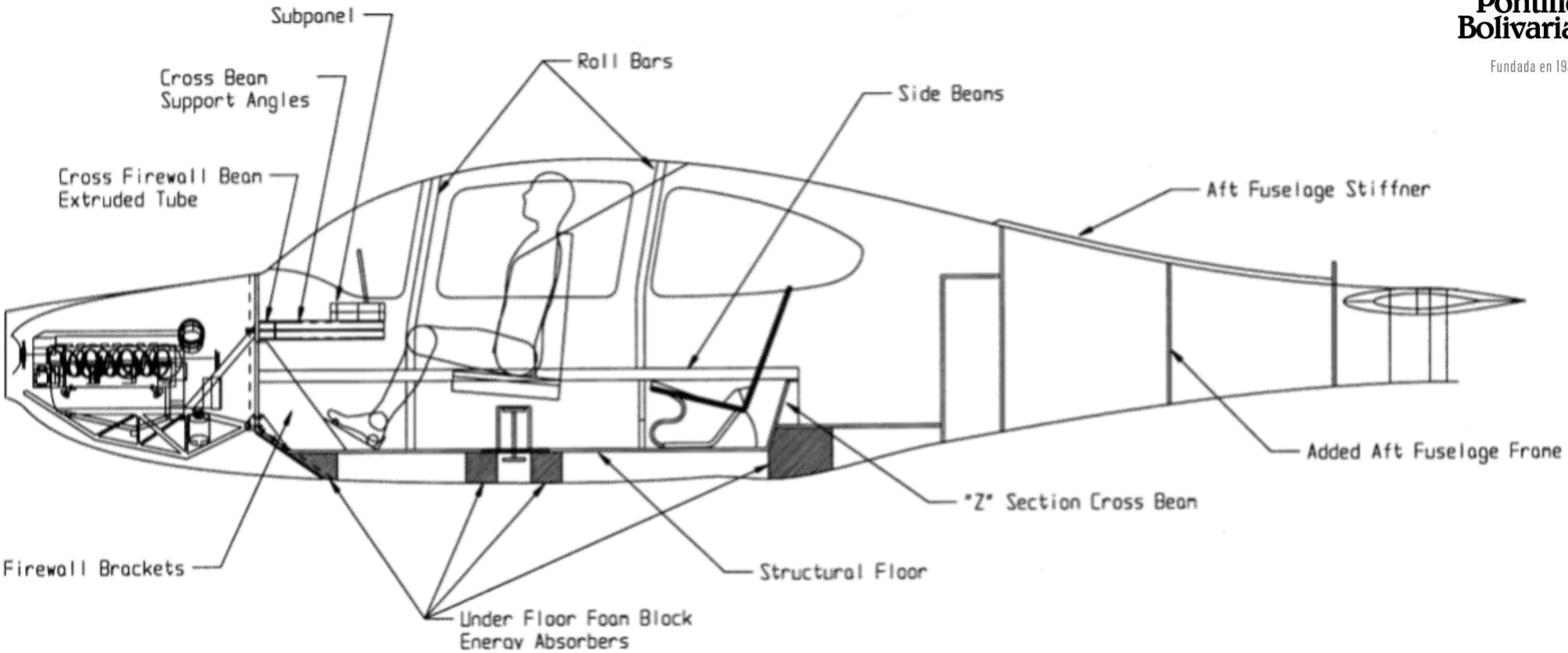


Table 4.1 Currently Used Geometric Fuselage Parameters

Airplane Type	l_f/d_f	l_{fc}/d_f	θ_{fc} (deg)
Homebuilts	4 - 8	3*	2 - 9
Single Engine	5 - 8	3 - 4	3 - 9
Twins	3.6** - 8	2.6 - 4	6 - 13
Agricultural	5 - 8	3 - 4	1 - 7
Business Jets	7 - 9.5	2.5 - 5	6 - 11
Regionals	5.6 - 10	2 - 4	15 - 19***
Jet Transports	6.8 - 11.5	2.6 - 4	11 - 16
Mil. Trainers	5.4 - 7.5	3*	up to 14
Fighters	7 - 11	3 - 5*	0 - 8
Mil. Transports, Bombers and Patrol Airplanes	6 - 13	2.5 - 6	7 - 25****
Flying Boats	6 - 11	3 - 6	8 - 14
Supersonics	12 - 25	6 - 8	2 - 9

*Tailcone as defined by Figure 4.1 not easily defined
**Cessna 336 (Fig.3.9c) ***Embraer Brasilia (Fig.3.16d)
****Lockheed Hercules (Fig.3.29d)

FUSELAGE LAYOUT



FUSELAGE LAYOUT

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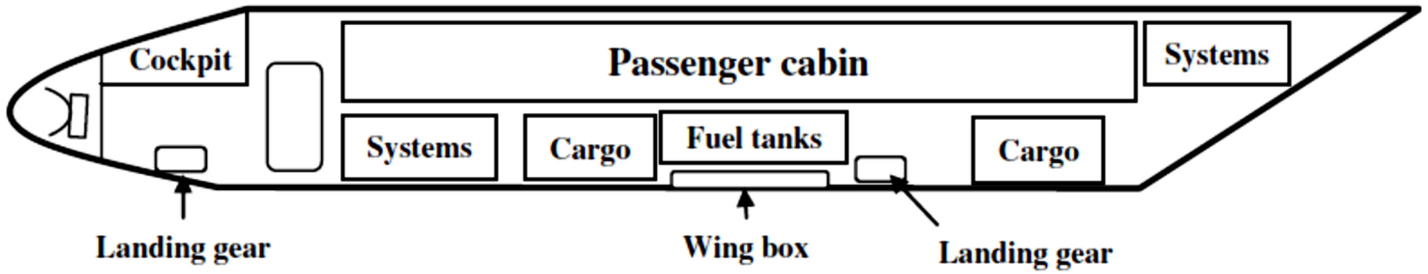

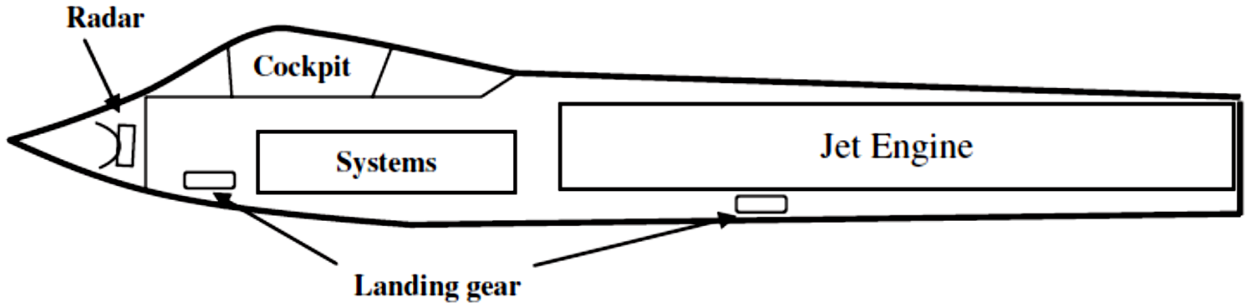

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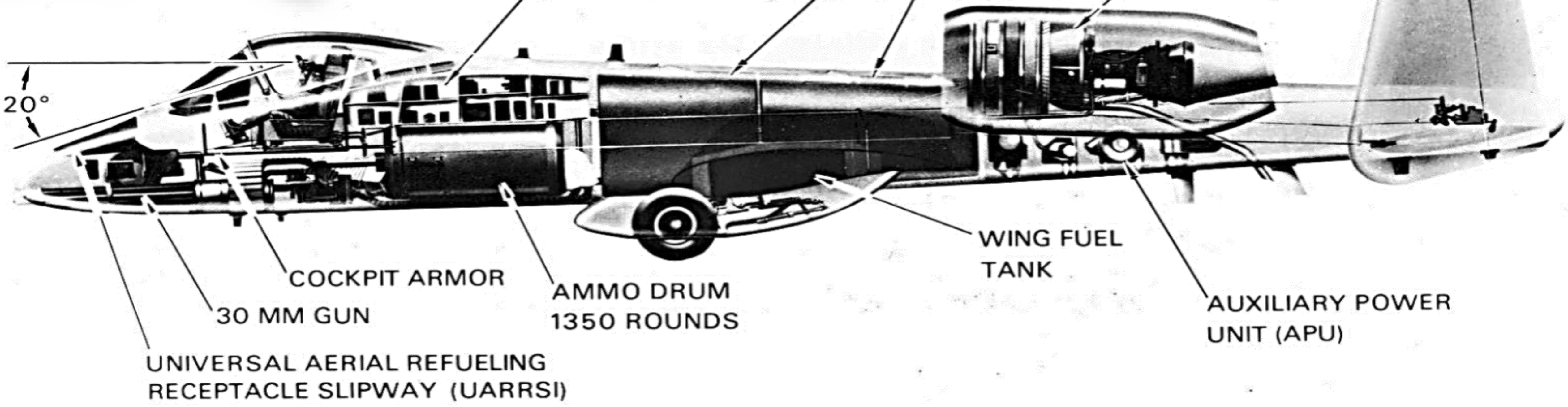

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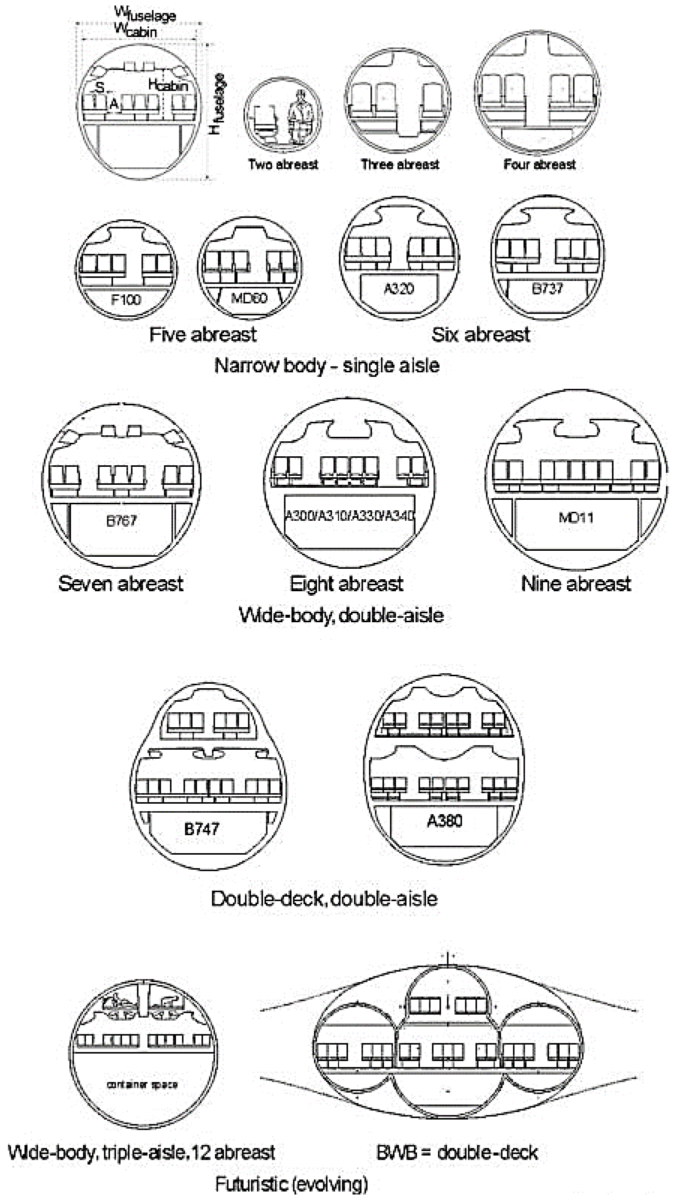

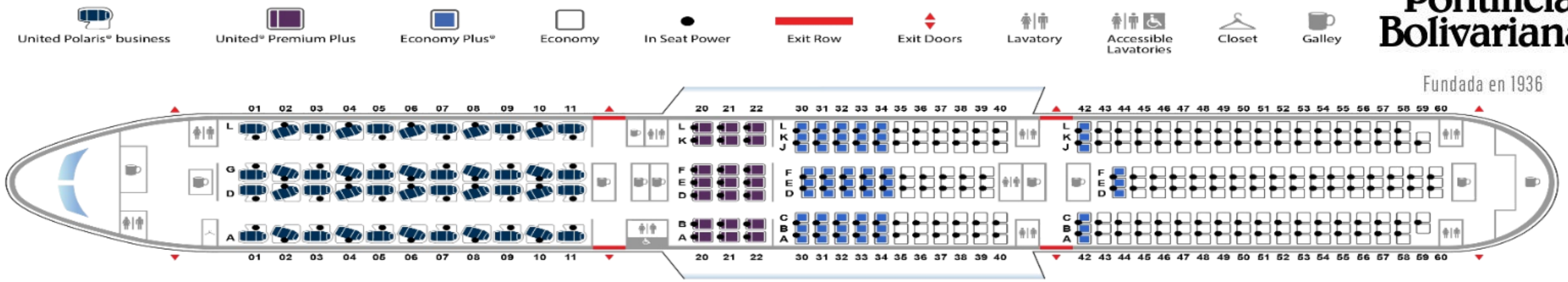

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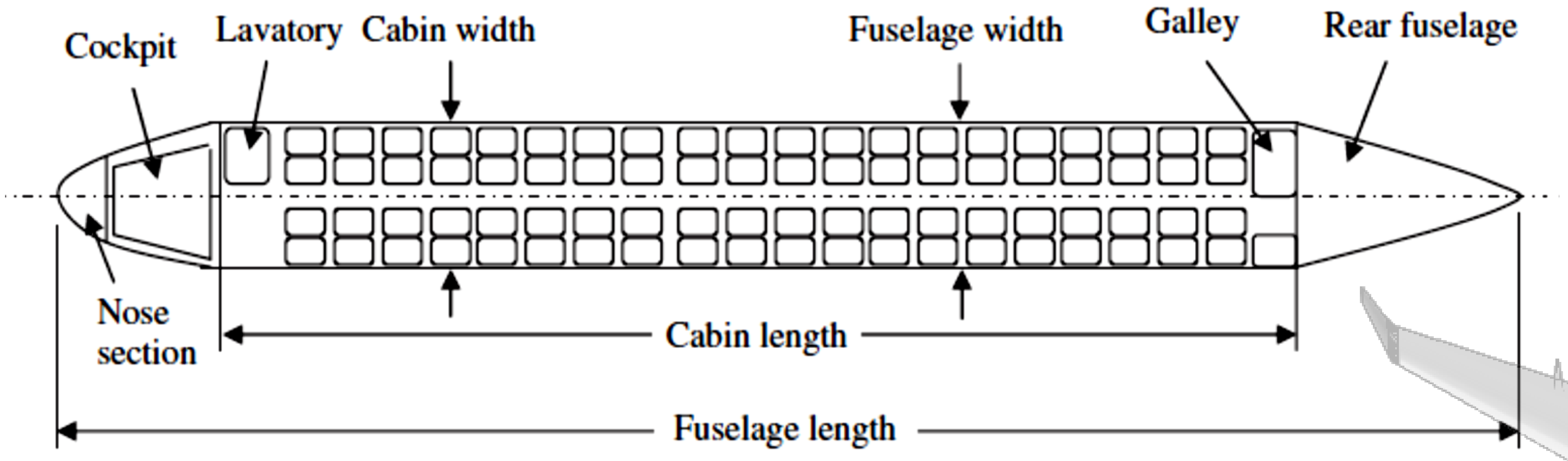
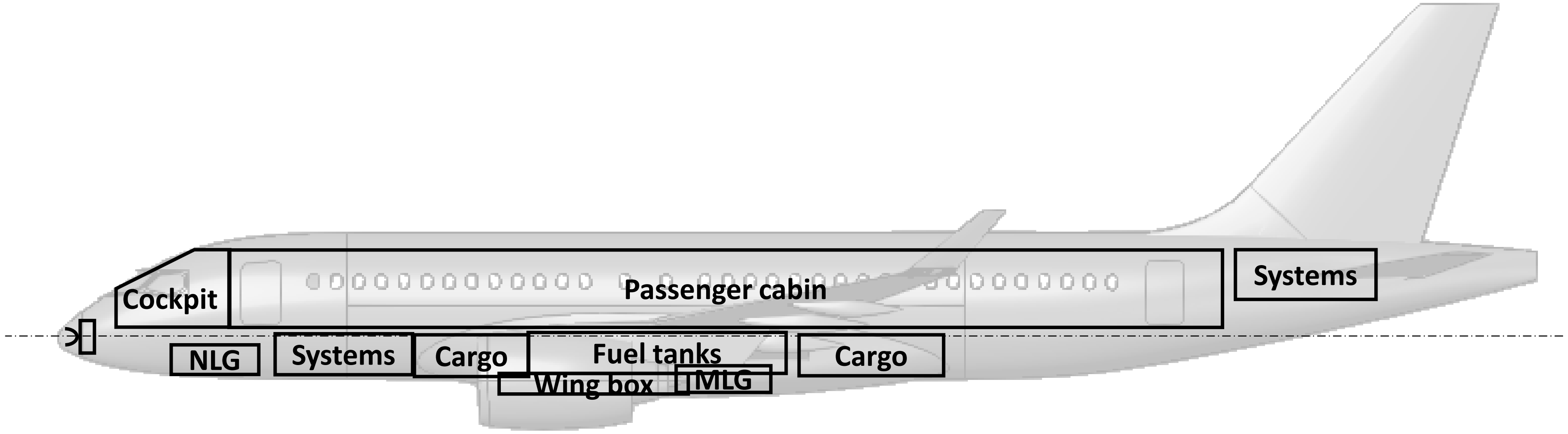
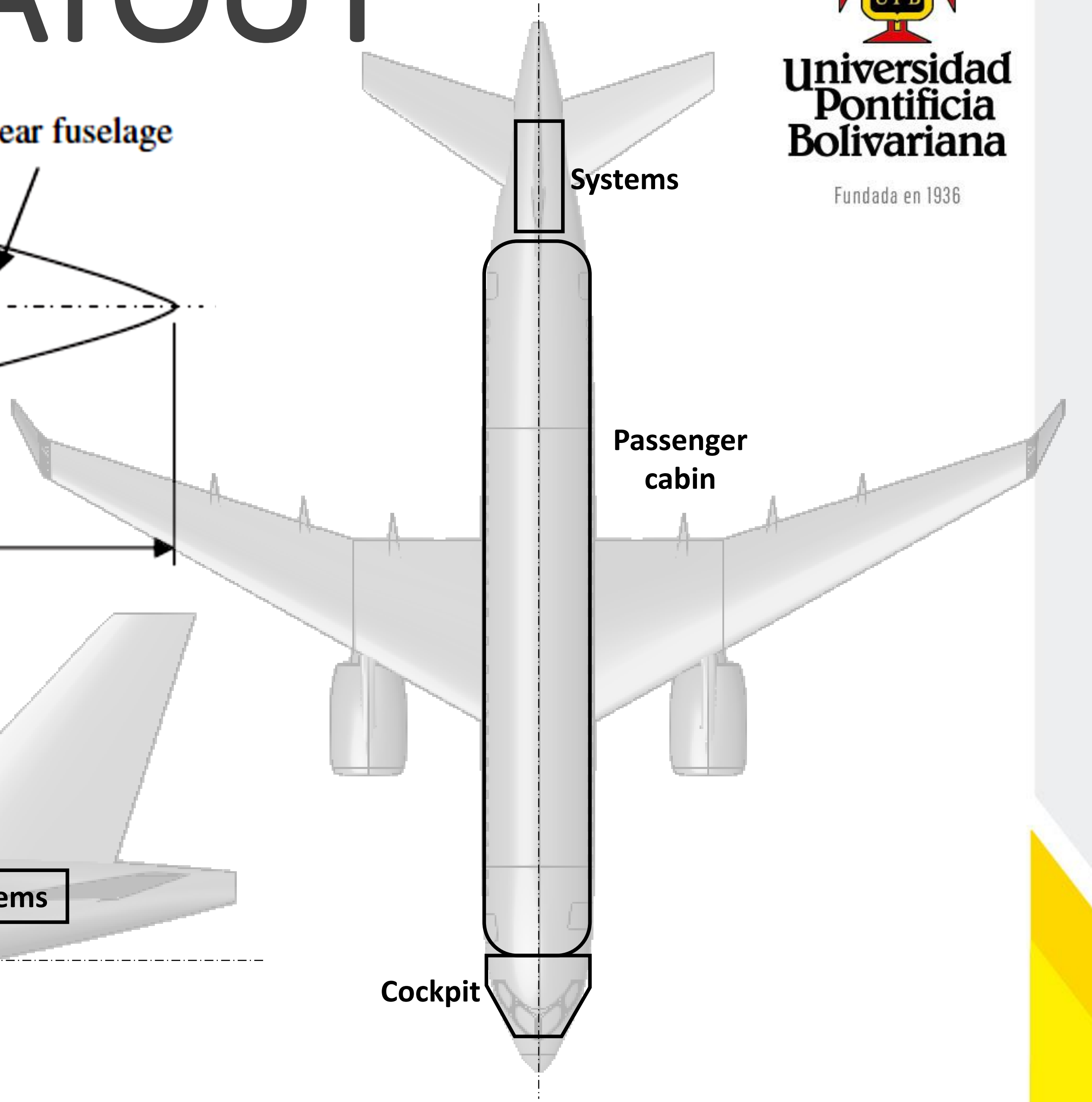
FUSELAGE LAYOUT







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METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

1. Decide on the overall empennage configuration to be used

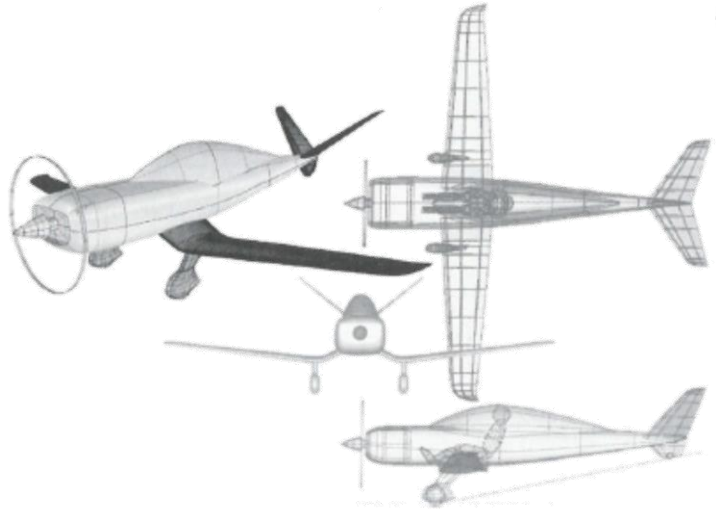
As a general rule, the horizontal tail should **NOT be placed** directly in the propeller slipstream

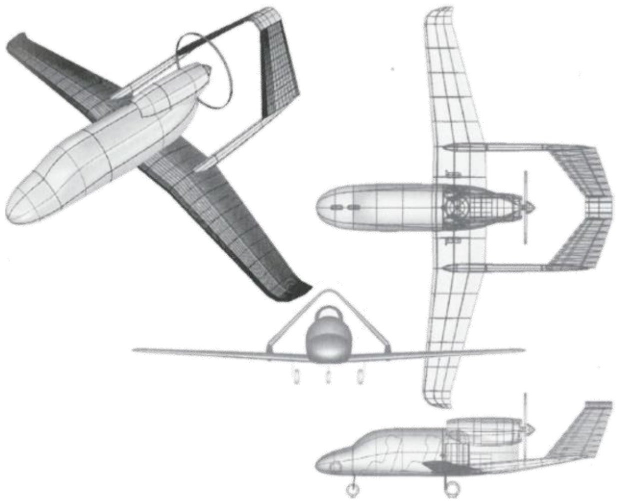
The reasons against this arrangement are:

a. The slipstream will usually cause the **tail to buffet which leads to structure-borne cabin noise**. Tail buffet can also lead to early structural fatigue
b. Rapid power increase or decreased called for the pilot can result in **undesirably large trim changes**

These comments also apply to canards

There is not usually a problem with a vertical tail mounted in the slipstream at the aft end of a fuselage



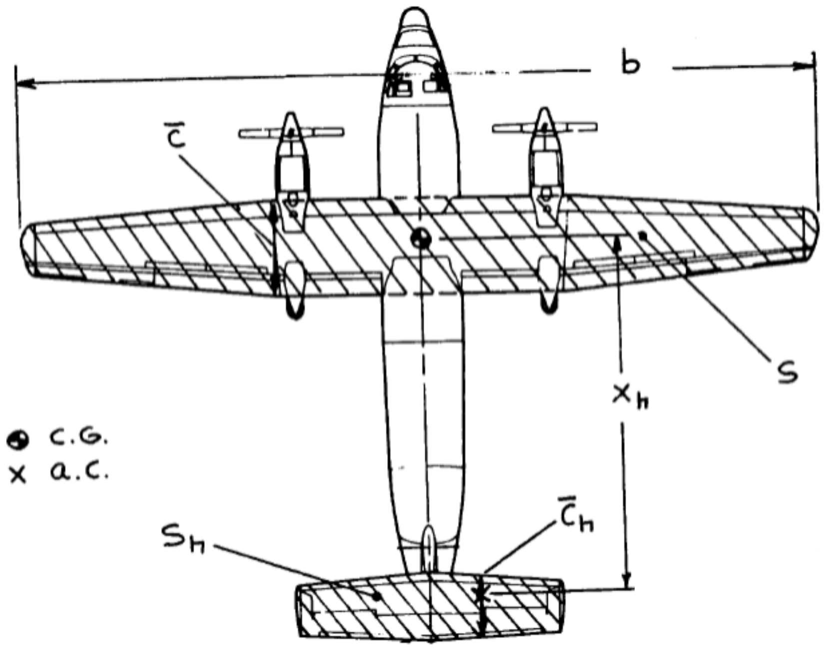


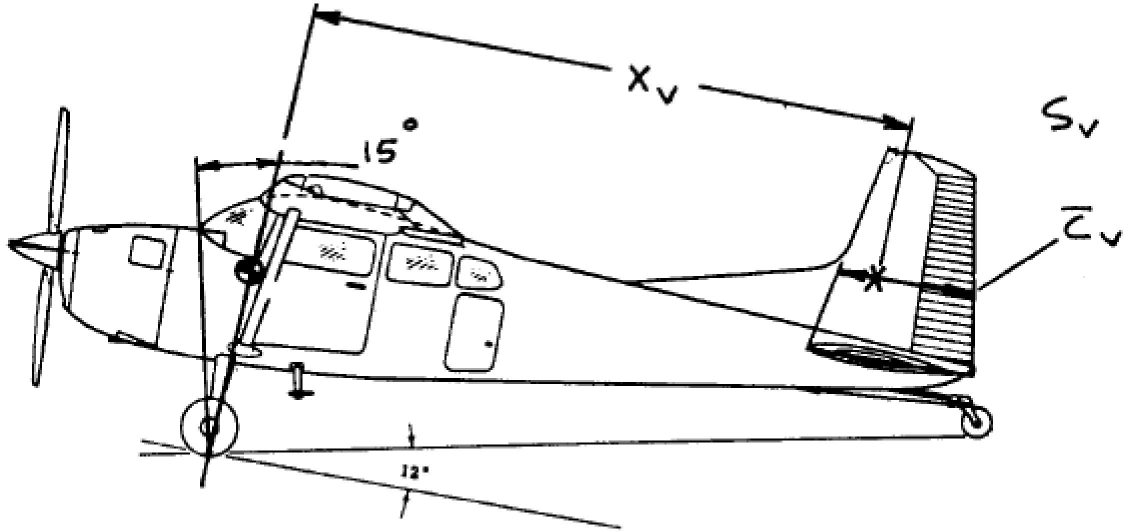
METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

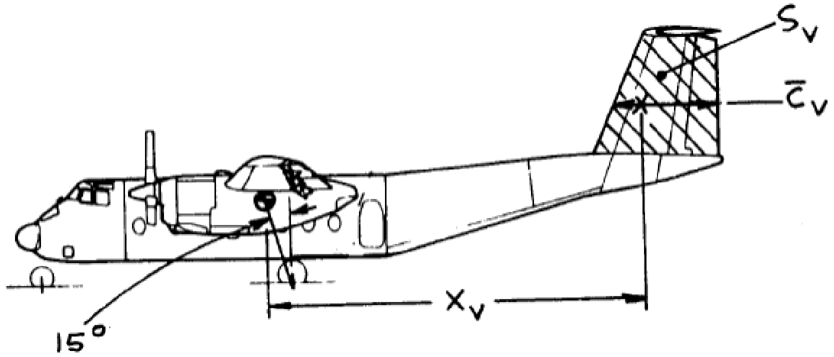
2. Determine the disposition of the empennage

Having decided on the overall empennage configuration, the location of the components on the aircraft should be decided

This amounts to deciding on the empennage moment arms x_h, x_v and x_c in accordance to the following figure







METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

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To keep the aircraft weight and drag down as much as possible it is obviously desirable to keep the empennage area as small as possible

This in turn can be achieved by locating the empennage components at as large a moment arm as possible relative to the critical centre of gravity

3. Determine the size of the empennage

    Four types of configurations are consider:
    a. Conventional configurations
    b. Canard configuration
    c. Three-surface configuration
    d. Butterfly configuration

METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

Conventional configurations

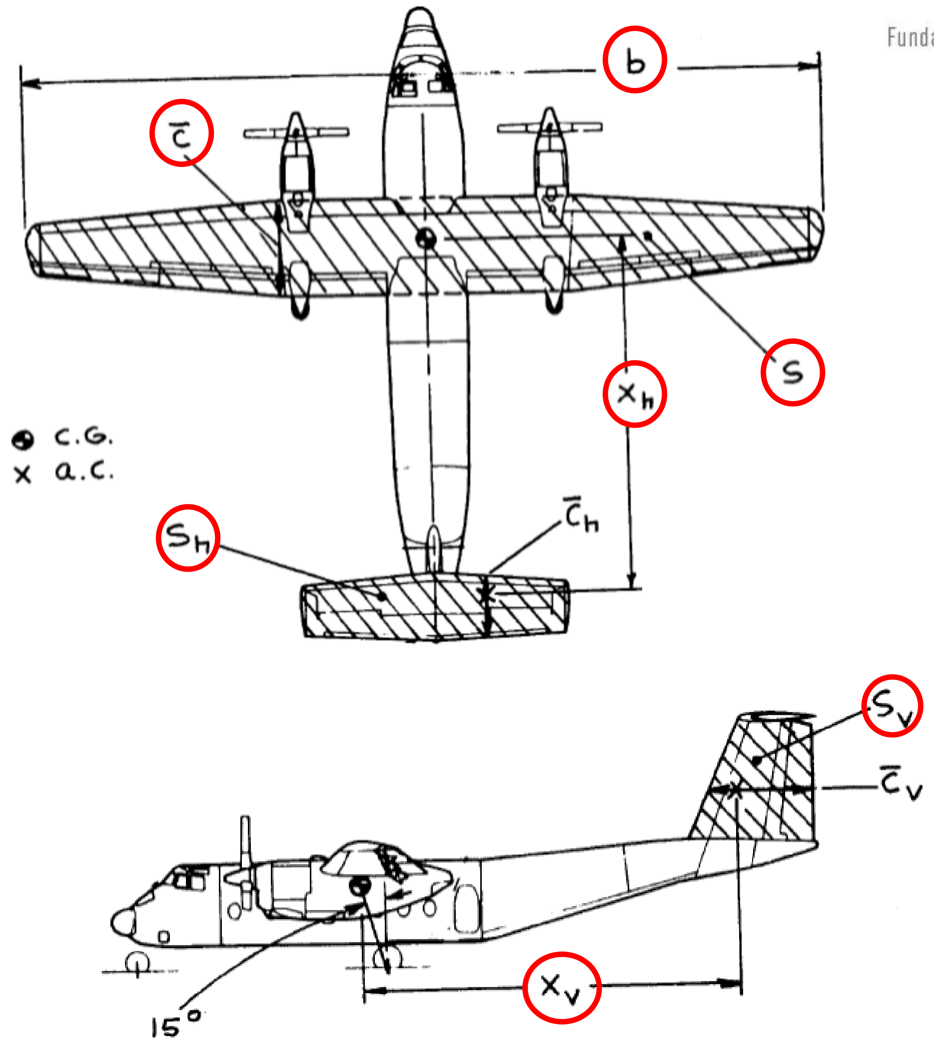
Sizing the empennage for a conventional configuration means deciding on the magnitude on S_h and S_v

For a first "cut" at the size of either the vertical or the horizontal tail, the so-called ***Tail Volume Coefficient*** method is often used

The tail volume coefficients are defined as follows

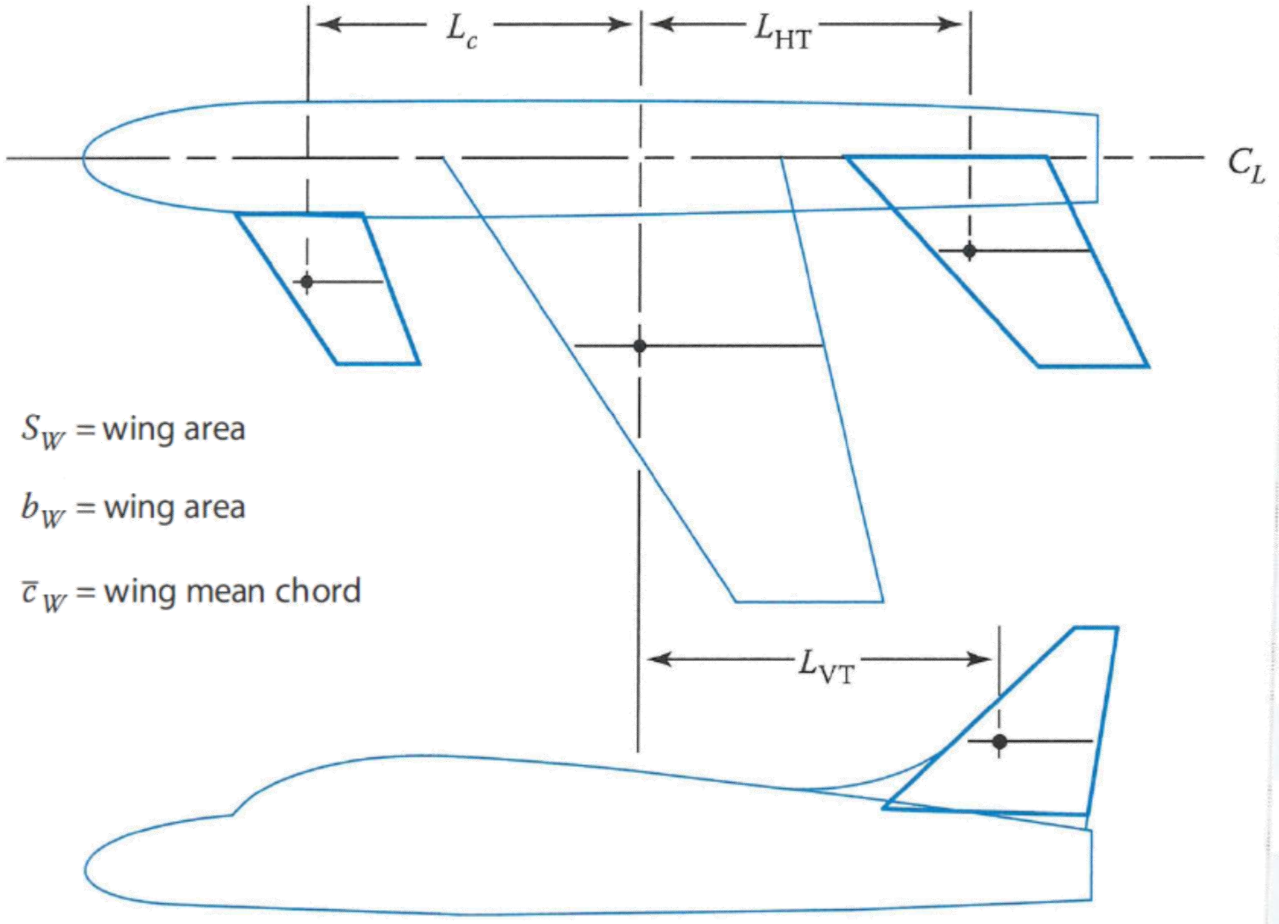
$$\bar{V}_h = \frac{x_h \cdot S_h}{S \cdot \bar{c}} \qquad \bar{V}_v = \frac{x_v \cdot S_v}{S \cdot b}$$

The values for horizontal and vertical tail volume coefficients can be found from table 6.4



METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

Tail volume coefficient method



S_W = wing area

b_W = wing area

$\bar{c}_W$ = wing mean chord

Table 6.4 Tail Volume Coefficient

	Typical Values	
	Horizontal $\overline{V}_h$	Vertical $\overline{V}_v$
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
General aviation—single engine	0.70	0.04
General aviation—twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07–0.12*
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

*Long fuselage with high wing loading needs larger value.

METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

For aircrafts with a **front-mounted propeller engine**, $x_h = x_v \approx 60\%\ l_f$

For aircrafts with the **engines mounted on the wings**, $x_h = x_v \approx 50\text{-}55\%\ l_f$

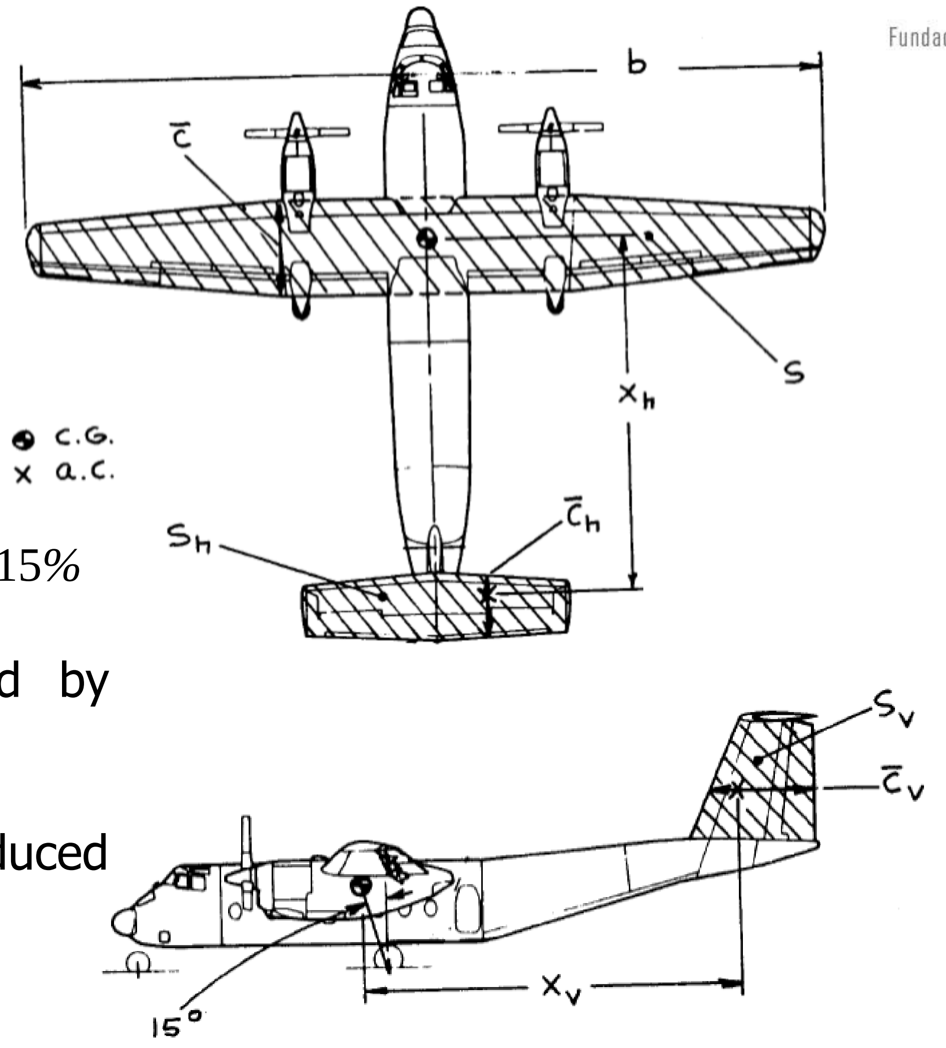
For **aft-mounted engines**, $x_h = x_v \approx 45\text{-}50\%\ l_f$

A **sailplane** has a $x_h = x_v \approx 65\%\ l_f$

For an **all-moving tail**, the volume coefficient can be reduced by about 10-15%

For a **T-tail**, the **vertical-tail volume coefficient** can be reduced by approximately 5% due to clean air seen by the horizontal

Similarly, the **horizontal tail volume coefficient** for an **H-tail** can be reduced by about 5%



METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

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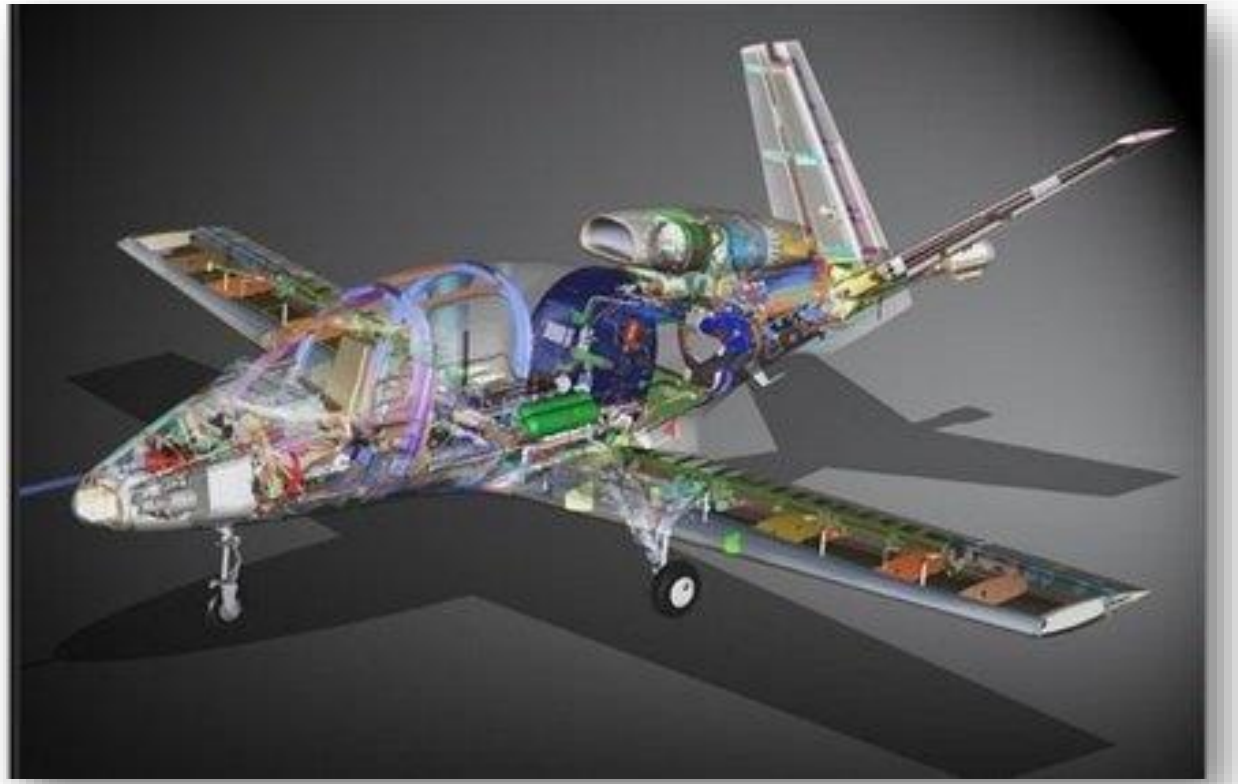
For an aircraft which uses V-tail arrangement, the required horizontal and vertical tail sizes should be estimated as the conventional arrangement

Then the V surfaces should be sized to provide the same total surface area as required for conventional tails

The tail dihedral angle should be set as: $\Gamma_h = \arctan\left(\frac{S_v}{S_h}\right)$

This should be near to $45°$



METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

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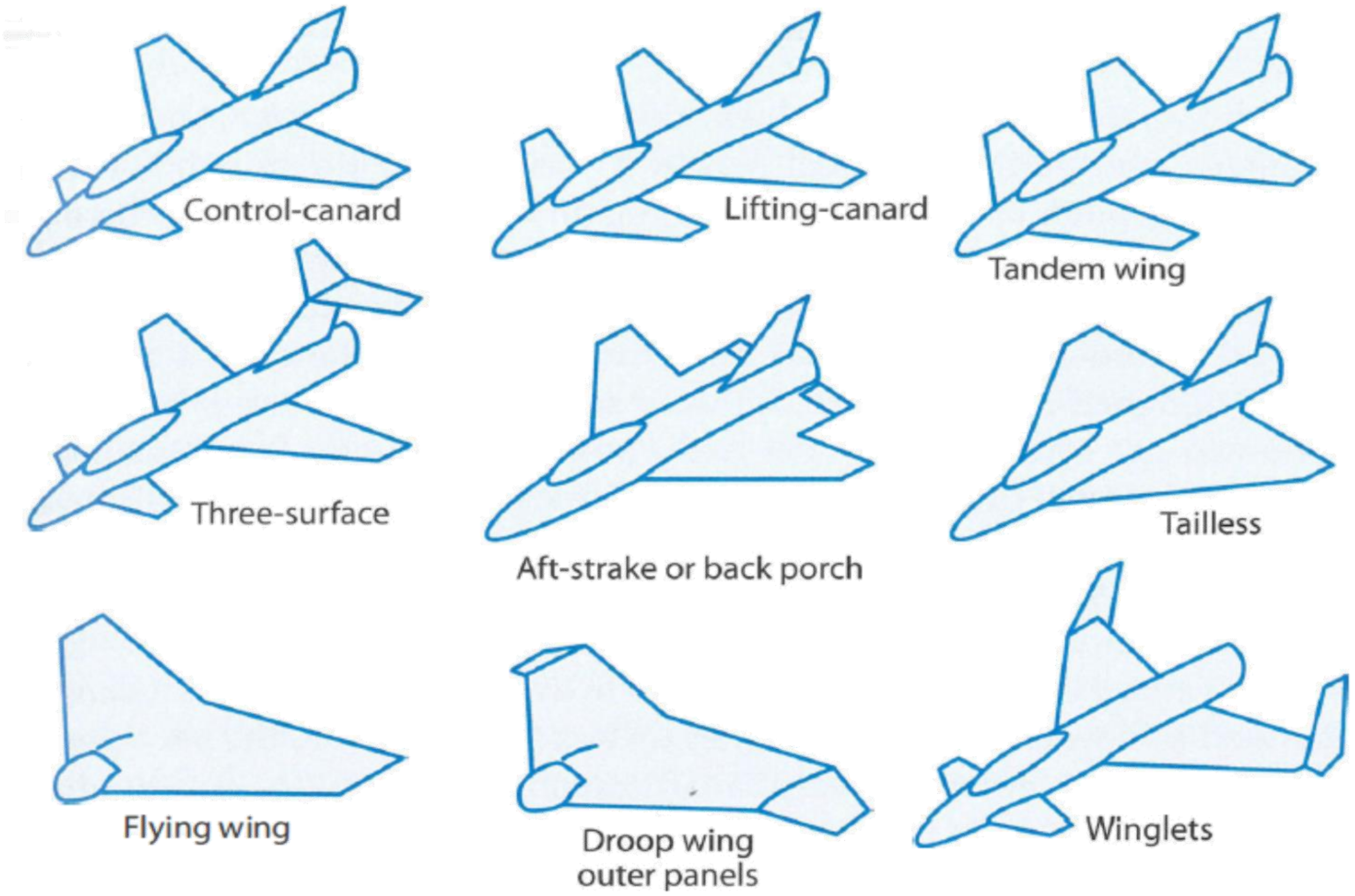
The horizontal tail volume coefficient for an aircraft with a control-type canard is approximately 0.1, based upon the relatively few aircraft of this type that have flown

For canard aircraft there is a much wider variation in the tail moment arm. **Typically, the canard aircraft will have** $x_h = x_v \approx 30\text{-}50\%\ l_f$

For a lifting-canard aircraft, the volume coefficient method is not applicable. Instead an area split must be selected by the designer

The required total wing area is then allocated accordingly. Typically, the area split allocates about 25% to the canard and 75% to the wing, although there can be wide variation

A split of around $50\text{-}50\%$ produces a tandem-wing aircraft



METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

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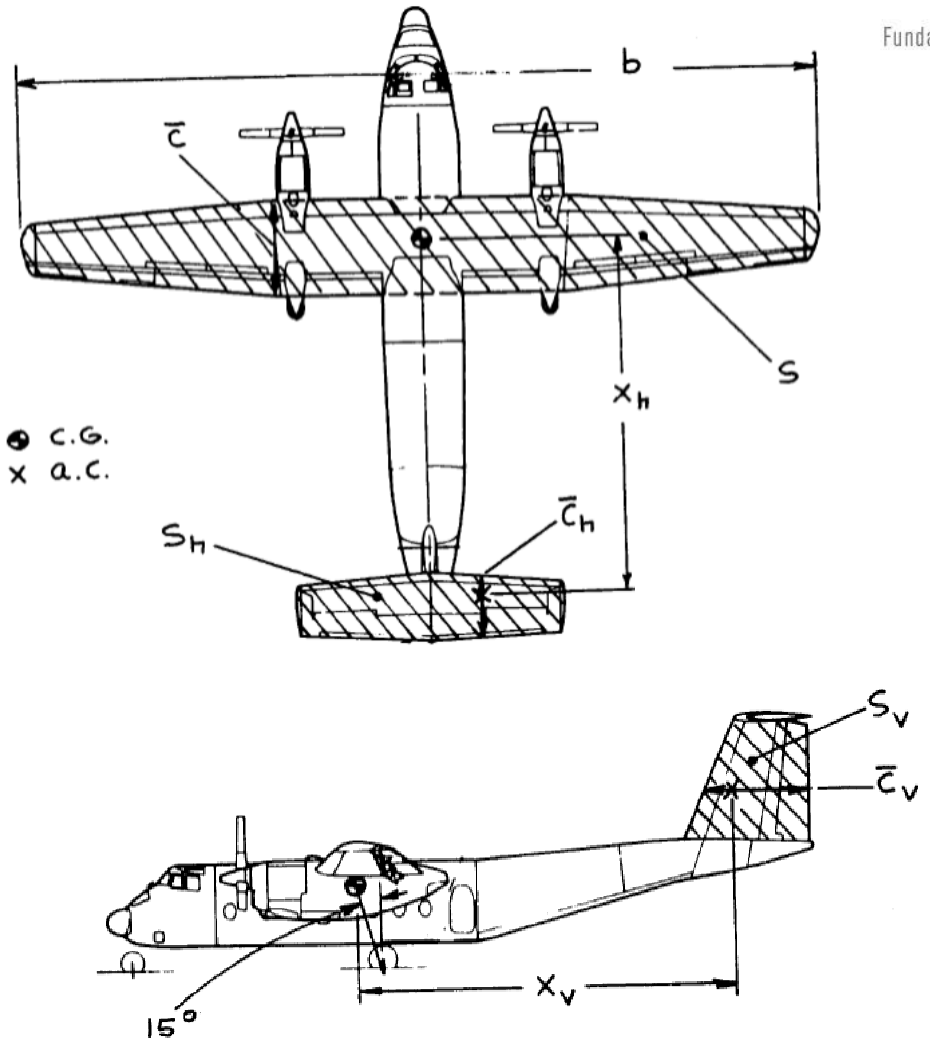
Having selected the volume coefficients, and having determined the arms x_h and x_v from the fuselage arrangement sketches, then the tail areas can be computed from:

$$S_h = \frac{\overline{V}_h \cdot S \cdot \overline{c}}{x_h} \qquad S_v = \frac{\overline{V}_v \cdot S \cdot b}{x_v}$$

4. Decide on the planform geometry of the empennage

   This involves making the following choices:
   a. Aspect Ratio
   b. Sweep angle
   c. Taper Ratio
   ~~d. Thickness ratio~~
   ~~e. Aerofoil~~
   f. Dihedral
   g. Incidence angle



METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

Tables 8.13 and 8.14 provide some guidance in making choices form a to g. The selection of these items follow some of the reasoning used in selecting the same items for the wing

In selecting sweep angle/thickness ratio combinations for tail aft configurations it is important to ensure that the critical *Mach* number for the tails is higher than that of the wing

An increment of $\Delta M = 0.05$ is usually sufficient

For most horizontal and vertical tails *NACA* symmetrical aerofoils are in use – typical *NACA* 0009 / 0018

For canards the choice of aerofoil is particularly critical. The required maximum lift coefficient capability at the canard *Reynold's* number must be determined so that the canard always stall first

Table 8.13 Planform Design Parameters for Horizontal Tails

Type	Dihedral Angle, Γ_h deg.	Incidence Angle, i_h deg.	Aspect Ratio, A_h	Sweep Angle, $\Lambda_{c/4_h}$ deg.	Taper Ratio, λ_h
Homebuilts	+5 - -10	0 fixed to variable	1.8 - 4.5	0 - 20	0.29 - 1.0
Single Engine Prop. Driven	0	-5 - 0 or variable	4.0 - 6.3	0 - 10	0.45 - 1.0
Twin Engine Prop Driven	0 - +12	0 fixed to variable	3.7 - 7.7	0 - 17	0.48 - 1.0
Agricultural	0 - +3	0	2.7 - 5.4	0 - 10	0.59 - 1.0
Business Jets	-4 - +9	-3.5 fixed	3.2 - 6.3	0 - 35	0.32 - 0.57
Regional Turbo-Props.	0 - +12	0 - 3 fixed to variable	3.4 - 7.7	0 - 35	0.39 - 1.0
Jet Transports	0 - +11	variable	3.4 - 6.1	18 - 37	0.27 - 0.62
Military Trainers	-11 - +6	0 fixed to	3.0 - 5.1	0 - 30	0.36 - 1.0
Fighters	-23 - +5	0 fixed to variable	2.3 - 5.8	0 - 55	0.16 - 1.0
Mil. Patrol, Bomb and Transports	-5 - +11	0 fixed to variable	1.3 - 6.9	5 - 35	0.31 - 0.8
Flying Boats, Amph. and Float Airplanes	0 - +25	0 fixed	2.2 - 5.1	0 - 17	0.33 - 1.0
Supersonic Cruise Airplanes	-15 - 0	0 fixed to variable	1.8 - 2.6	32 - 60	0.14 - 0.39

METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

Tables 8.13 and 8.14 provide some guidance in making choices form a to g. The selection of these items follow some of the reasoning used in selecting the same items for the wing

In selecting sweep angle/thickness ratio combinations for tail aft configurations it is important to ensure that the critical *Mach* number for the tails is higher than that of the wing

An increment of $\Delta M = 0.05$ is usually sufficient

For most horizontal and vertical tails *NACA* symmetrical aerofoils are in use – typical *NACA* 0009 / 0018

For canards the choice of aerofoil is particularly critical. The required maximum lift coefficient capability at the canard *Reynold's* number must be determined so that the canard always stall first

Table 8.14 Planform Design Parameters for Vertical Tails

Type	Dihedral Angle, Γ_v deg.	Incidence Angle, i_v deg.	Aspect Ratio, A_v	Sweep Angle, $\Lambda_{c/4_v}$ deg.	Taper Ratio, λ_v
Homebuilts	90	0	0.4 - 1.4	0 - 47	0.26 - 0.71
Single Engine Prop. Driven	90	0	0.9 - 2.2	12 - 42	0.32 - 0.58
Twin Engine Prop Driven	90	0	0.7 - 1.8	18 - 45	0.33 - 0.74
Agricultural	90	0	0.6 - 1.4	0 - 32	0.43 - 0.74
Business Jets	90	0	0.8 - 1.6	28 - 55	0.30 - 0.74
Regional Turbo-Props.	90	0	0.8 - 1.7	0 - 45	0.32 - 1.0
Jet Transports	90	0	0.7 - 2.0	33 - 53	0.26 - 0.73
Military Trainers	90	0	1.0 - 2.9	0 - 45	0.32 - 0.74
Fighters	75 - 90	0	0.4 - 2.0	9 - 60	0.19 - 0.57
Mil. Patrol, Bomb and Transports	90	0	0.9 - 1.9	0 - 37	0.28 - 1.0
Flying Boats, Amph. and Float Airplanes	90	0	1.2 - 2.4	0 - 32	0.37 - 1.0
Supersonic Cruise Airplanes	75 - 90	0	0.5 - 1.8	37 - 65	0.20 - 0.43

METHOD FOR EMPENNAGE AND CONTROL SURFACE SIZING AND DISPOSITION

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Elevators and rudders generally begin at the side of the fuselage and extend to the tip of the tail or to about 90% of the tail span

High-speed aircrafts sometimes use rudders of large chord which only extend to about 50% of the span

Rudder and elevator size are typically about 25-50% of the tail local chord

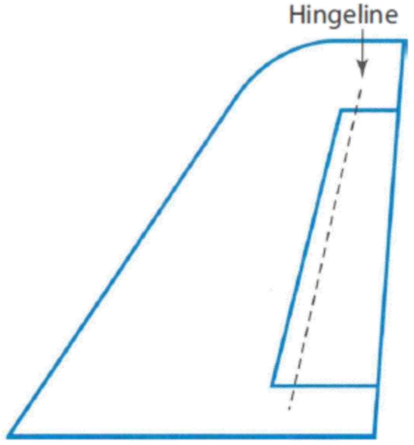
In order to avoid flutter tendencies this control surfaces uses the same balance masses as the ailerons. For this components the notched balance is the most common

The horizontal tail for a manually-controlled aircraft is almost configured such that the elevator will have a hinge line perpendicular to the aircraft centre line, this permits connecting the left and right hand elevator surfaces with a torque tube, which reduces elevator flutter tendencies

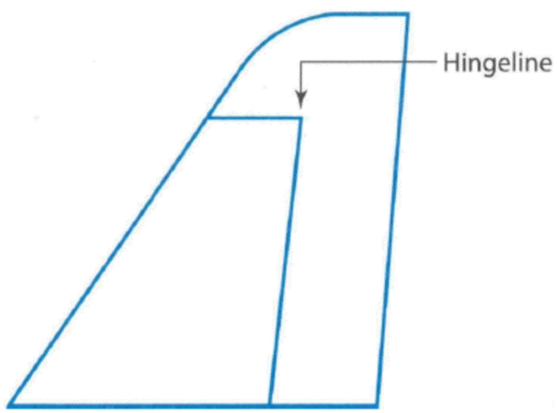
Table 6.5 Control Surface Sizing Guidelines

Aircraft	Elevator C_e/C	Rudder C_r/C
Fighter/attack	0.30*	0.30
Jet transport	0.25†	0.32
Jet trainer	0.35	0.35
Biz jet	0.32†	0.30
GA single	0.45	0.40
GA twin	0.36	0.46
Sailplane	0.43	0.40

*Supersonic usually all-moving tail without separate elevator.
†Often all-moving plus elevator.



Overhung aerodynamic balance



Notched or "horn" aerodynamic balance

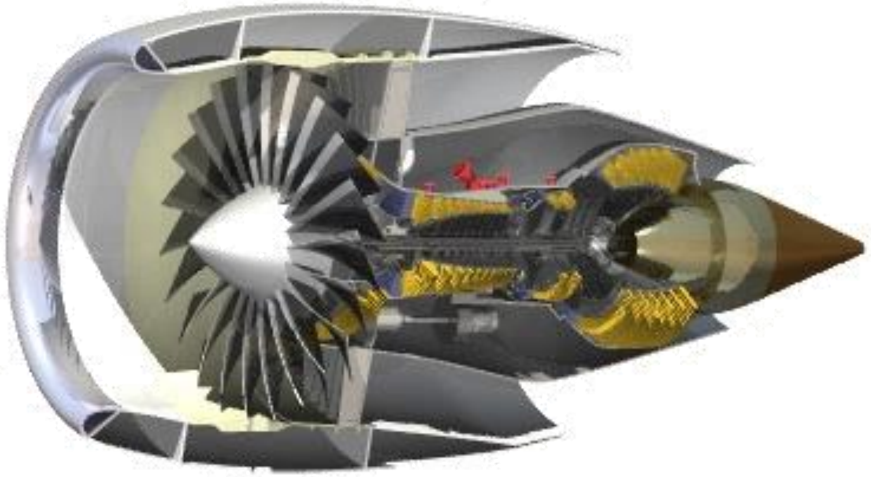
SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

Selection and integration of the propulsion system involves:

1. Selection of the propulsion system **type or types**

2. Determination of the **number of engines** to be used and the power (or thrust) level of each

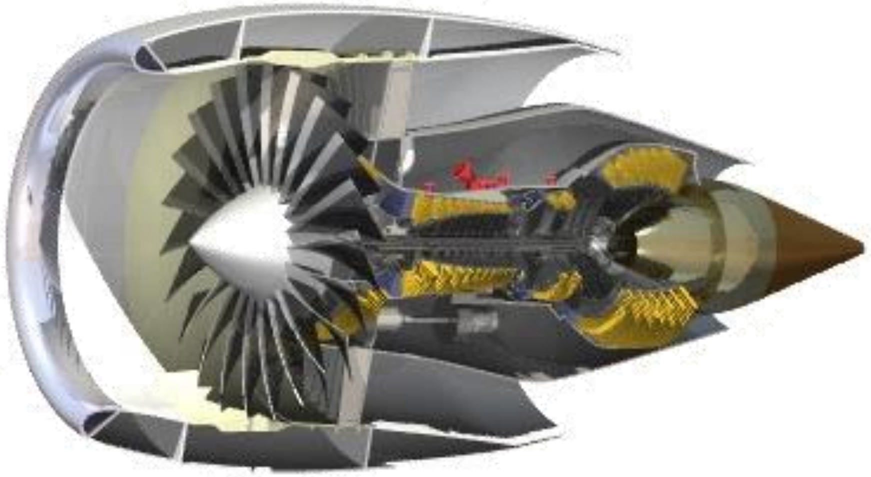
3. Disposition of these engines, i.e. **integration** of these engines into the overall design configuration



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

From a certification point of view only the following propulsion system types will be viable for application (present day):

- Electric motor/propeller (ducted-fan type)
- Piston/propeller with or without supercharging
- Turbo-propeller
- Propfan
- Unducted fan
- Turbojet
- Turbofan
- Rocket
- Ramjet
- Scramjet



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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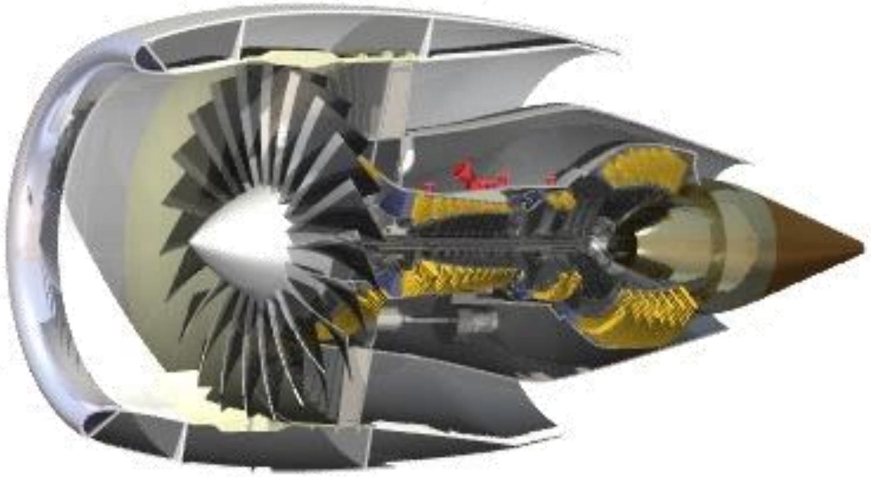
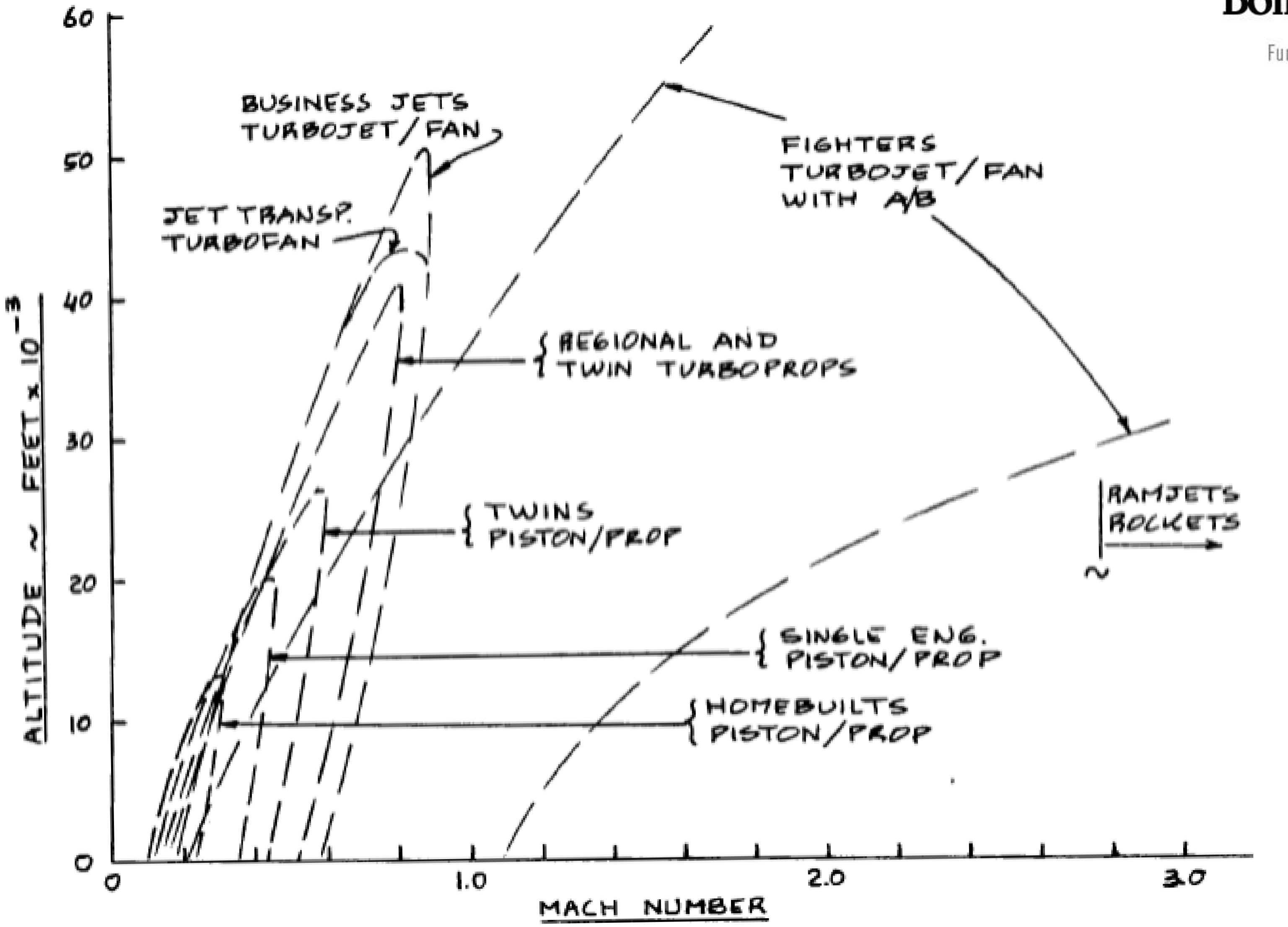
Factors that play a role in selecting the type of propulsion system:

a. Required cruise speed and/or maximum speed
b. Required maximum operating altitude
c. Required range and range economy
d. FAR 36 noise regulations (only civil aviation)
e. Installed weight
f. Reliability and maintainability
g. Fuel amount needed
h. Fuel cost
i. Fuel availability
j. Specific customer or market demands
k. Timely certification
l. Environmental issues (requirements)



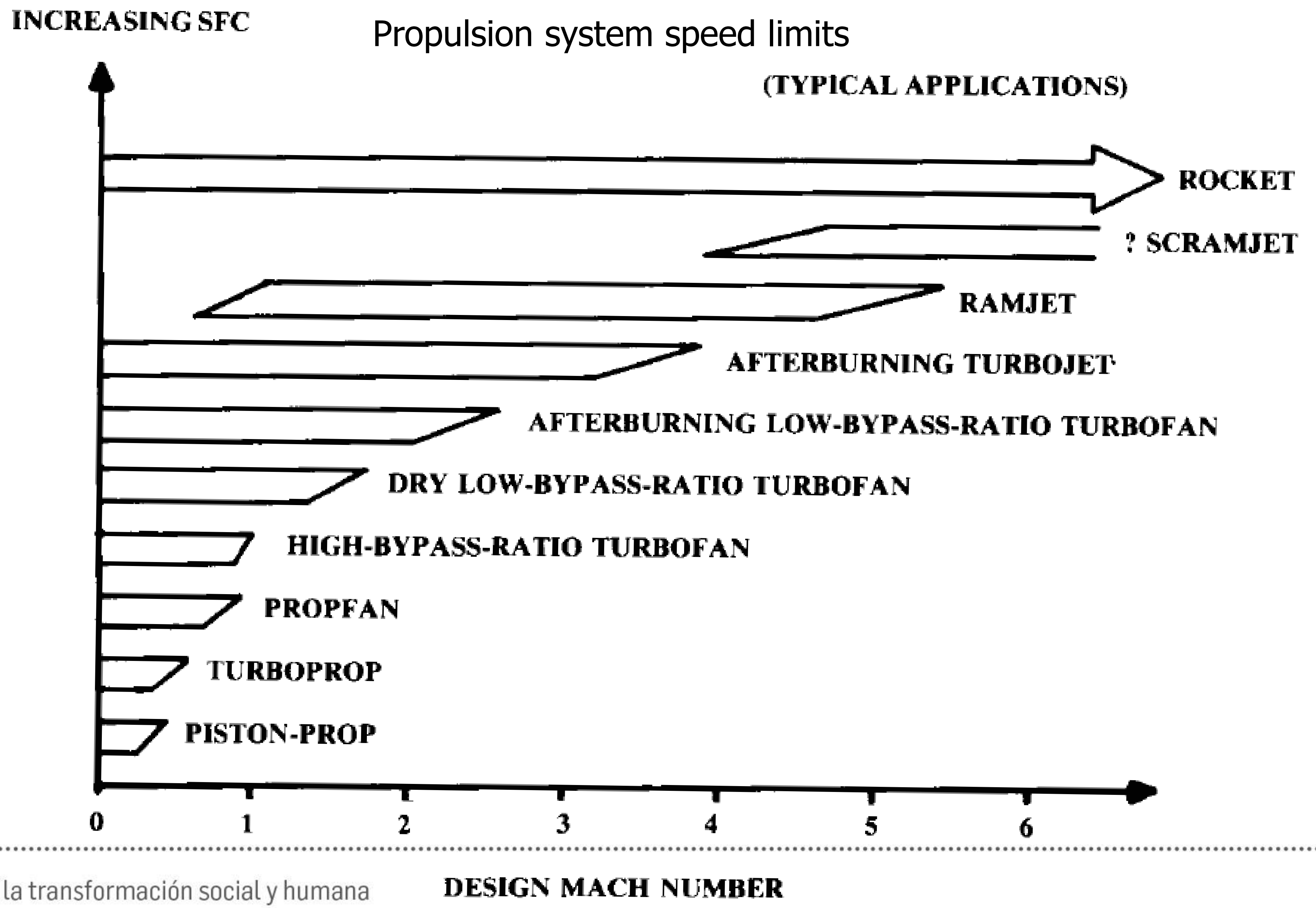
SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

This figure provides an overview of trends in propulsion system application as it relates to the flight envelope of aircrafts



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

Propulsion system speed limits



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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The following step-by-step procedure is suggested to arrive at a decision on the type(s) of propulsion system to be use on your design:

1. Check the mission specification for any definition of the type of **powerplant required**

2. Compare the aircraft speed-altitude envelope with those of figure "**trends in propulsion system application as it relates to the flight envelope of aircrafts**" and decide which type of powerplant provides the best overall match

Experience has shown that it is undesirable to mix different types of powerplants in one aircraft configuration, because:

- Different types of propulsion system call for different operating procedures
- Increasing of the crew workload which is not desirable
- Maintenance will become more costly

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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Selection of the number of engines and the power or thrust level per engine

There are two possibilities:

a. A new engine will be developed for the proposed design (**rubberized-engine**):

The engine(s) can be tailored to the existing design. This requires higher cost and longer times (7-10 years)

b. An existing engine must be used (**fixed engine**):

This is the most typical way of design procedure. Because the power or thrust level of existing engines is basically “frozen”, the number of engines is determined by dividing the required Take-Off power or thrust level by an integer: 1, 2, 3 or 4

Special design have been employed more than four engines – this causes problems in maintenance, rigging and failure probabilities

Selection of the number of engines and the power or thrust level per engine

Rubber engine methods

The dimensions for the engine must be obtained by scaling from some nominal engine size by whatever scale factor is required to provide the desired thrust

In major aircraft companies, designers can obtain estimated data for hypothetical "rubber" engines from the engines companies. This data is presented for a nominal engine size, and precise scaling laws are provided

Sometimes engine companies provide a "**parametric deck**", a computer software that will provide performance and dimensional data for an arbitrary advanced-technology engine based upon inputs such as by-pass ratio, pressure ratio, and turbine-inlet temperatures

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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Selection of the number of engines and the power or thrust level per engine

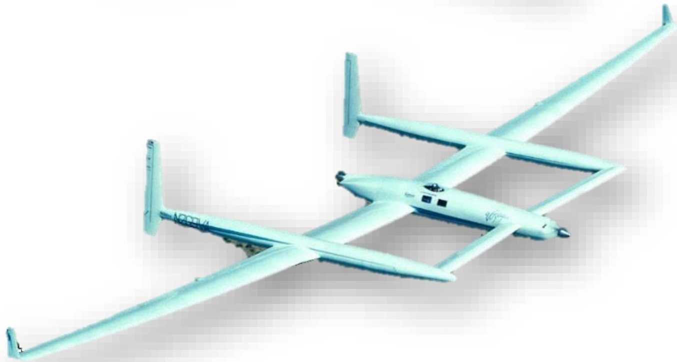
Experience has shown that is not desirable to use engines of different power (or thrust) levels in one aircraft

There have been several instances of successful deviations from this rule as well

Examples are:

- The *Dehavilland 121 Trident IIIE* uses four jet engines, three large, one small. The fourth engine was added to allow for higher T.O. weights and to do so with minimum development and production cost

- *Rutan's Voyager*, which uses two piston/propeller engines of different power output. Because of the extreme range requirements placed on this aircraft, it was important to match best fuel consumption to power required. In this application, the solution of two different power levels was a sensible one



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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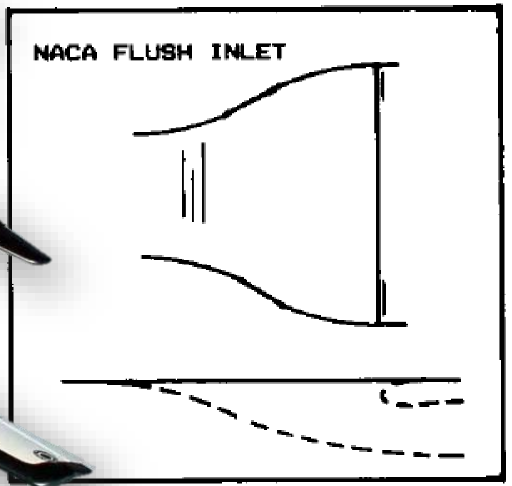
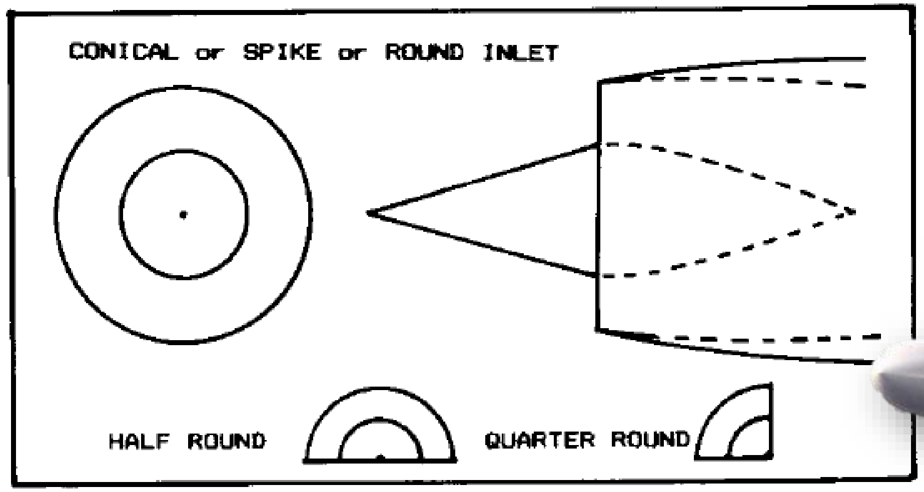
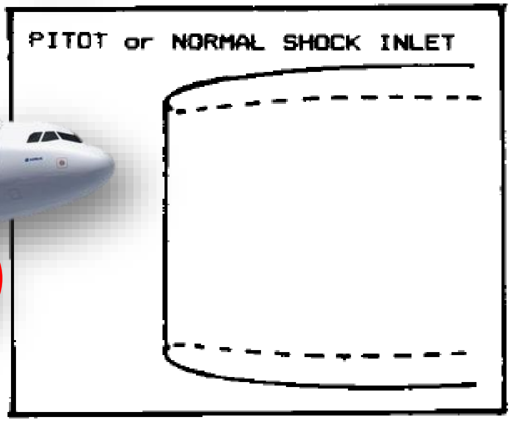
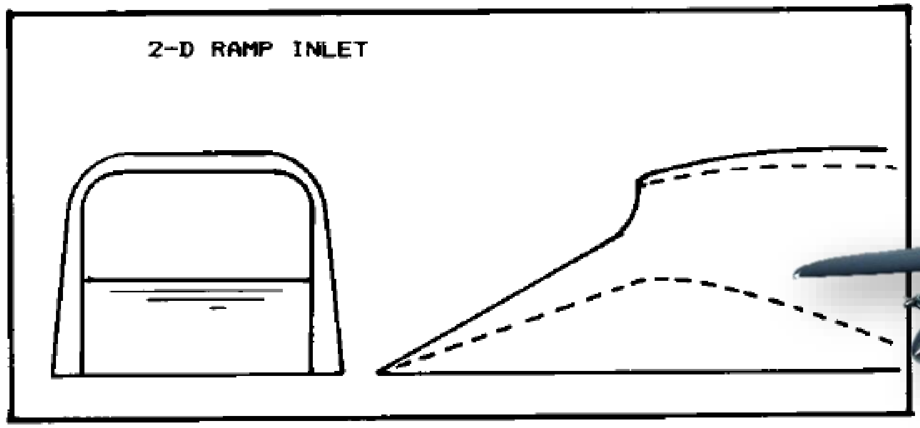
Inlet types









SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

Flush inlet geometry

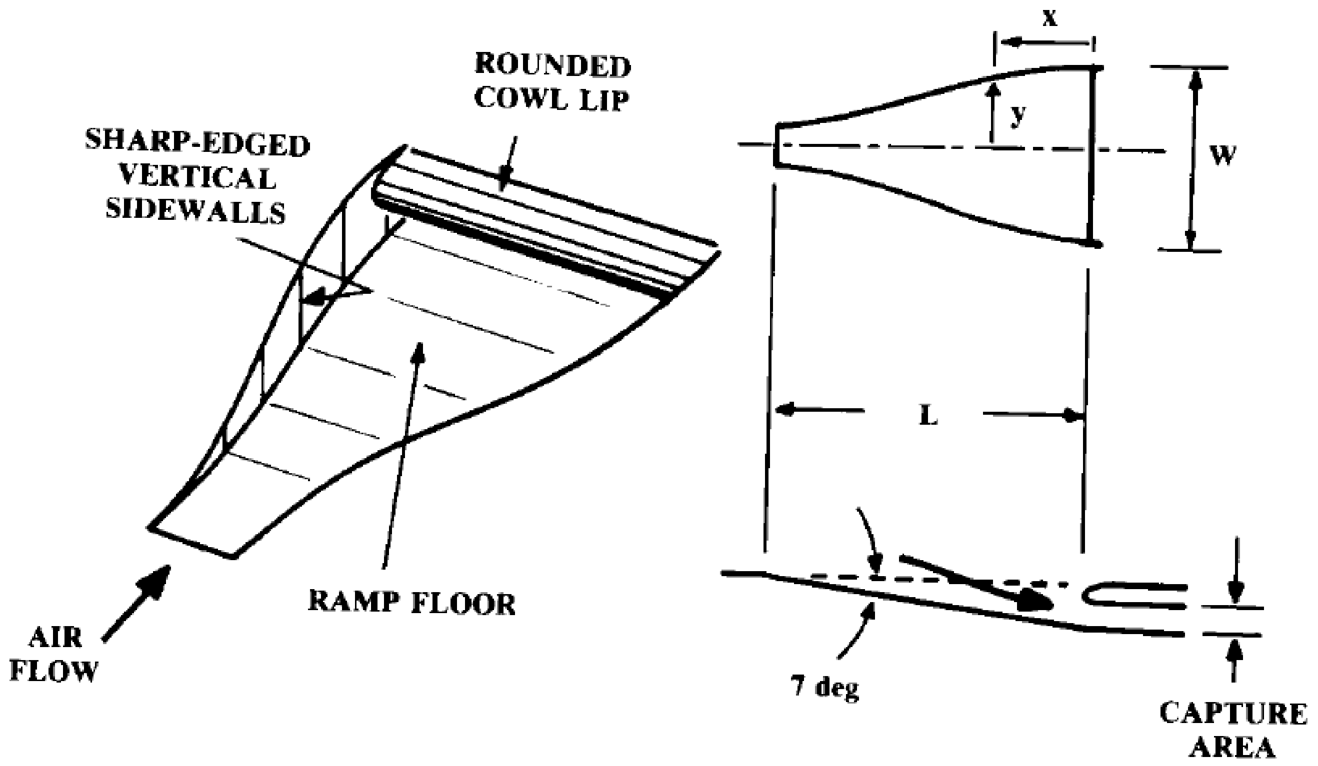


Table 10.1 Flush inlet wall geometry

x/L	$\frac{y}{W/2}$
1.0	0.083
0.9	0.160
0.8	0.236
0.7	0.313
0.6	0.389
0.5	0.466
0.4	0.614
0.3	0.766
0.2	0.916
0.1	0.996
0.0	1.000

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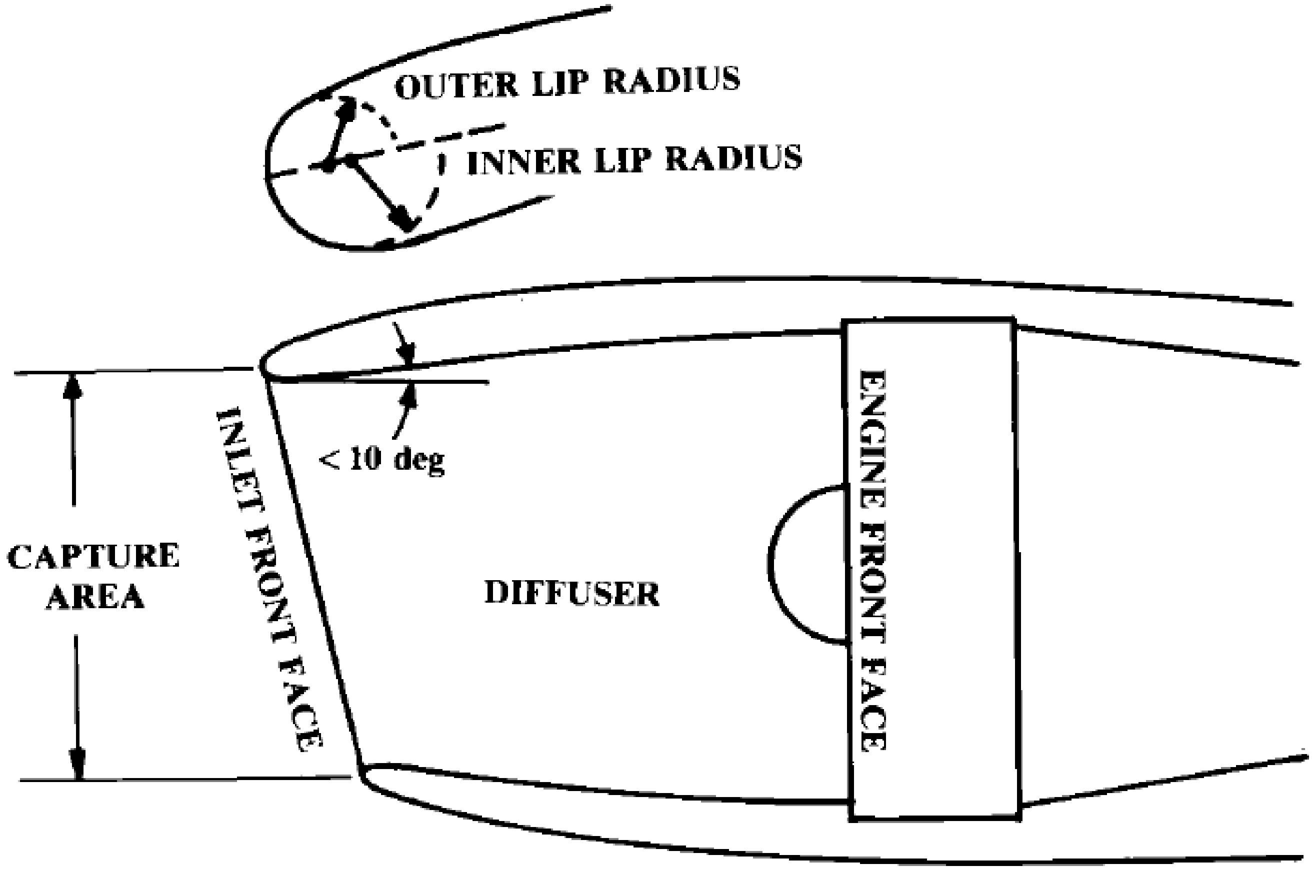
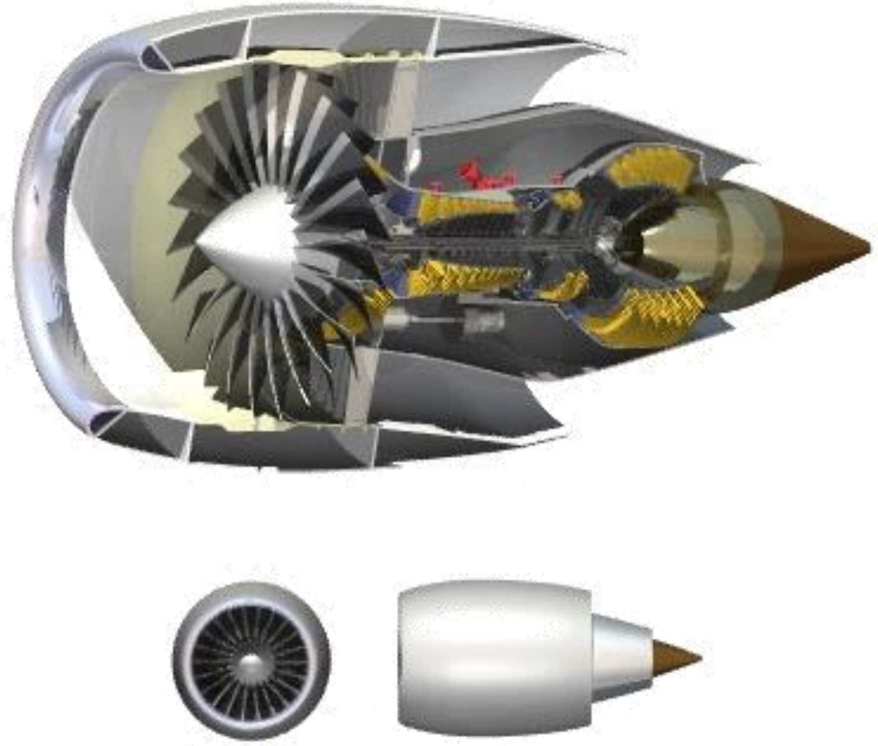
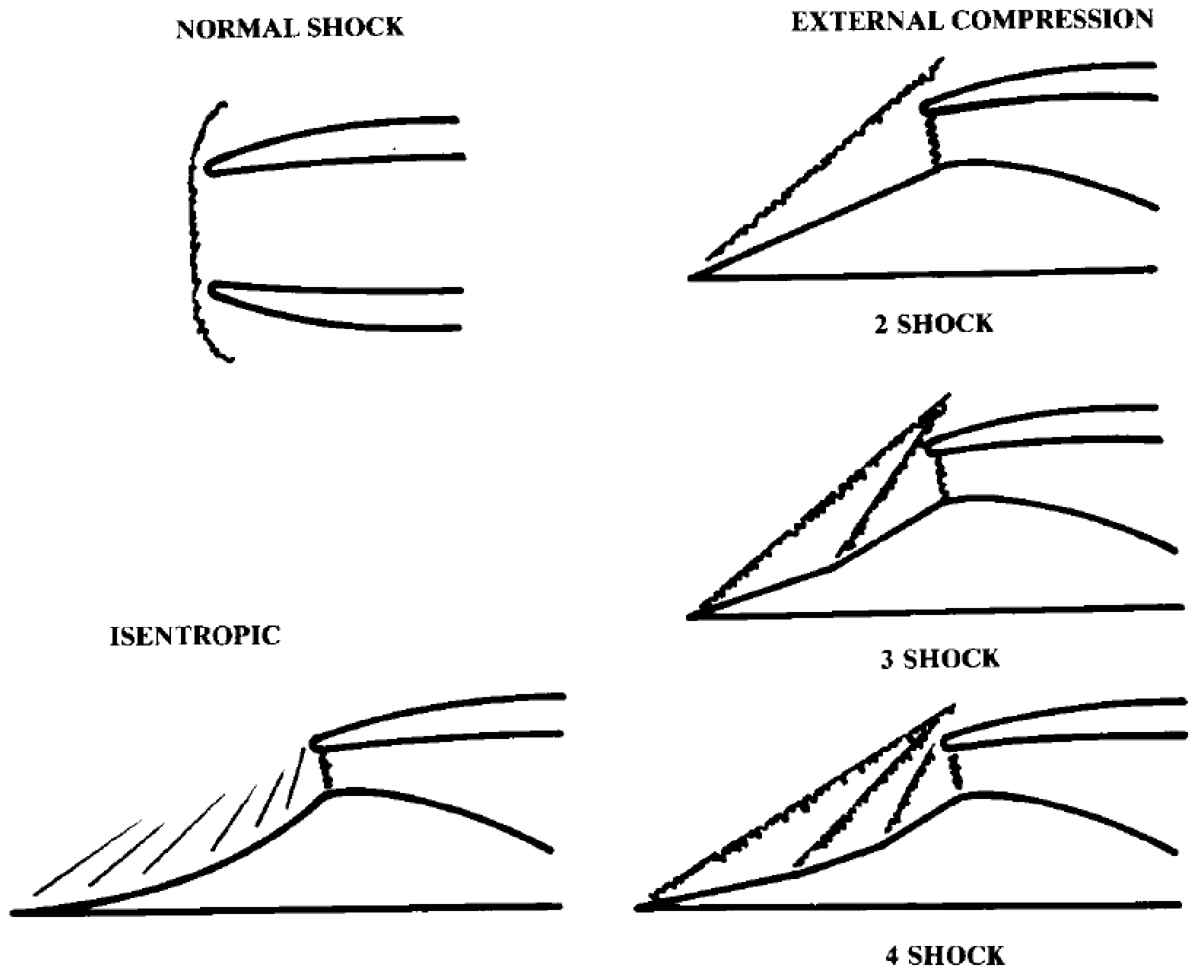
Pitot (normal shock) inlet layout

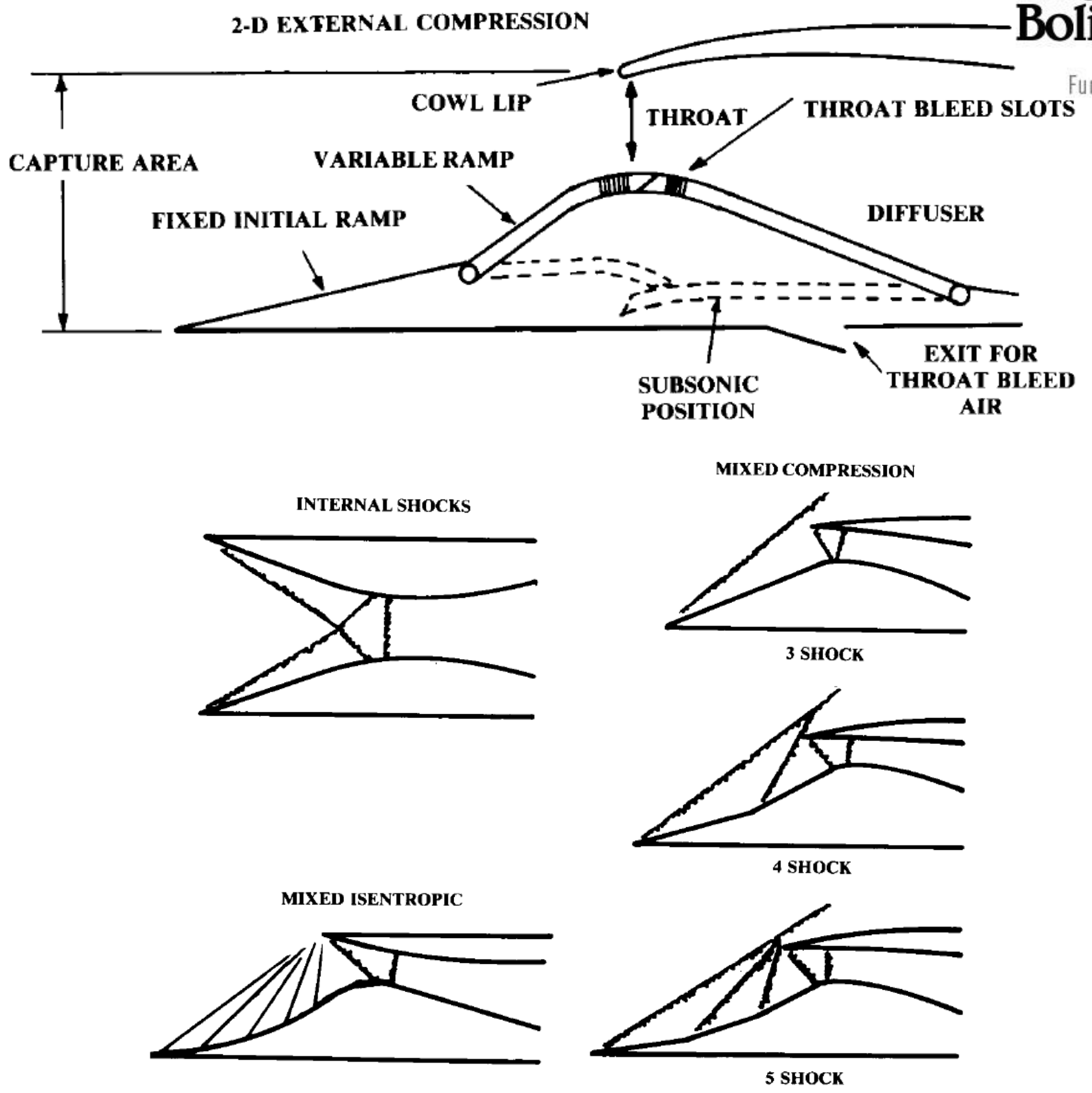




SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

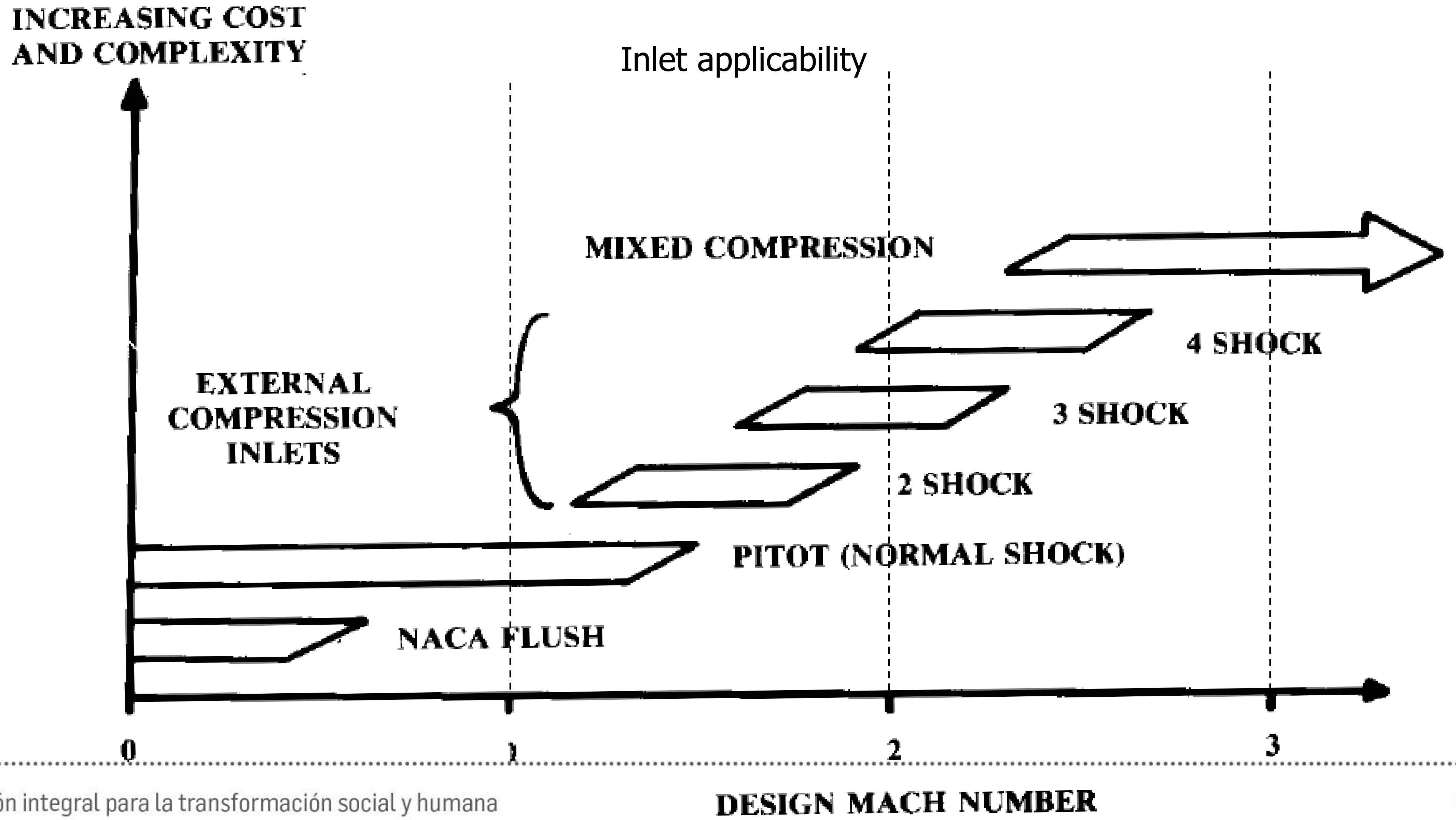
Supersonic inlet – external and internal shocks





SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

Inlet applicability



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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3. Determine the maximum power (or thrust) requirement for the aircraft

   The requirements of maximum power, P_{TO} (or thrust, T_{TO}) were already established from the preliminary sizing work (**constrain diagram**)

4. Decide on the number of engines and on the specific engine model to be used

   The number of engines to be used in an aircraft is often specified in the mission specifications. If this is not the case, make a list of candidate engines which are available in the market

   <u>This information can be found in brochures from engine manufacturers</u>

   The power (or thrust) levels of the candidate engine should be as possible to the Take-Off power (or thrust) levels divided by an integer. The accuracy of this calculations must be of $+/- 10\%$

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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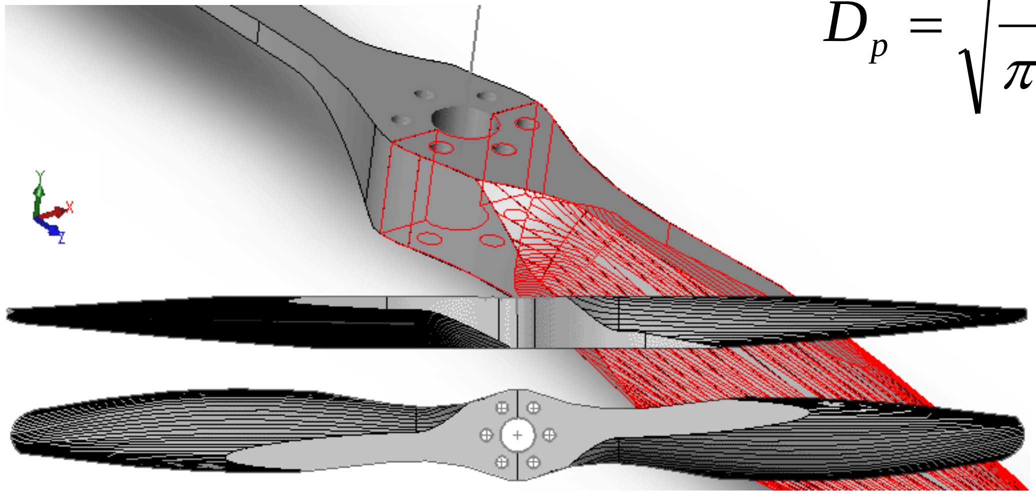
5. If the aircraft being designed/selected is a propeller driven aircraft, determine the required propeller diameter and the number of propeller blades

Tables 5.2, 5.3 and 5.4 list a typical Take-Off power and propeller data for six aircraft types

With the help of these tables, the propeller diameter could be compute by the use of the following equation:

$$D_p = \sqrt{\frac{4 \cdot P_{\max}}{\pi \cdot n_p \cdot P_{bl}}}$$



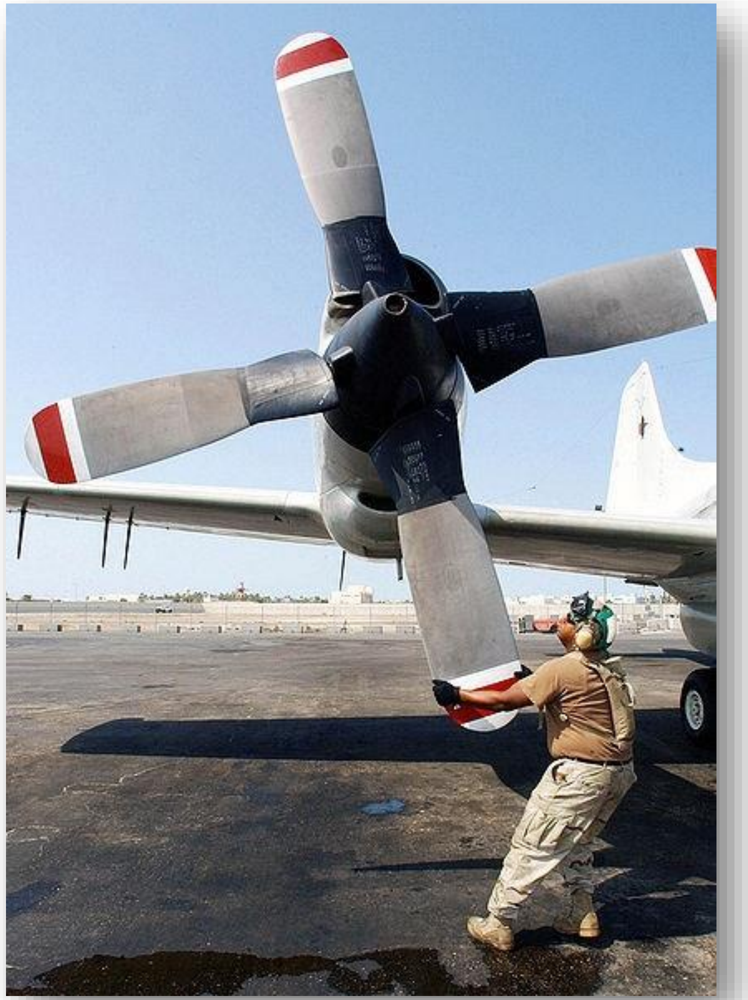


Table 5.2 Relation Between Max. Engine Power, Propeller Diameter and Number of Propeller Blades for Homebuilts and for Single Engine FAR23 Certified Airplanes

Airplane Type	Prop. Pitch	Max. Power per Engine, P_{max}, hp	Prop. Diam., D_p, ft	Number of Prop. Blades, n_p,	Power Loading per Blade, P_{bl}, hp/ft^2
Homebuilts					
Jurca MJ5	Fixed	115	6.1	2	2.0
Piel CP1320	Fixed	160	5.9	2	2.9
Piel CP80	Fixed	90	5.0	2	2.3
Pottier P70S	Fixed	60	4.3	2	2.1
Pazmany PL4A	Fixed	50	5.7	2	1.0
Variviggen	Fixed	150	5.8	2	2.8
Rand/R KR-1	2-pos.	90	4.4	2	3.0
Van's RV-3	Fixed	125	5.7	2	2.5
Sequoia F8L	Fixed	135	6.2	2	2.2
Per. Osprey II	Fixed	150	5.5	2	3.2
			P_{bl} range: 1.0-3.2		
Single Engine FAR23 Certified					
CESSNA					
152	Fixed	108	5.8	2	2.0
Skyhawk	Fixed	160	6.3	2	2.6
Skylane	C.Spd	230	6.8	2	3.2
Skywagon (185)	C.Spd	300	6.7	3	2.8
Caravan I	C.Spd	600	8.3	3	3.7
BEECH					
V35B Bonanza	C.Spd	285	7.0	2	3.7
38P Lightning	C.Spd	550	7.7	3	3.9
PIPER					
PA28 Warrior II	Fixed	160	6.2	2	2.6
Mooney 201	C.Spd	200	6.2	2	3.3
Mooney 301	C.Spd	360	6.5	3	3.6
			P_{bl} range: 2.0-3.9		

Note: $P_{bl} = 4P_{max}/\pi n_p D_p^2$

Table 5.3 Relation Between Max. Engine Power, Propeller Diameter and Number of Propeller Blades for Agricultural Airplanes and for Military Propeller Driven Trainers

Airplane Type	Prop. Pitch	Max. Power per Engine, P_{max}, hp	Prop. Diam., D_p, ft	Number of Prop. Blades, n_p,	Power Loading per Blade, P_{bl}, hp/ft^2
Agricultural Airplanes					
Schweiz. AgCat	C.Spd	750	9.0	2	5.9
Airtruk PL12	C.Spd	300	7.3	2	3.6
EMB 201A	C.Spd	300	7.0	2	3.9
PZL-104	C.Spd	260	8.7	2	2.2
PZL-106A	C.Spd	592	8.6	4	2.5
PZL-M18A	C.Spd	1,000	10.8	4	2.7
NDN Fieldmaster	C.Spd	750	8.8	3	4.1
Cessna AgTruck	C.Spd	300	7.2	2	3.7
Air Tr. AT-301A	C.Spd	600	9.1	2	4.6
Ayr. Thrush S2R	C.Spd	600	9.0	2	4.7
			P_{bl} range: 2.2-5.9		
Military Propeller Driven Trainers					
EMB 312 Tucano	C.Spd	750	7.8	3	5.2
Indaer Pillan	C.Spd	300	6.3	3	3.2
Aerosp. Epsilon	C.Spd	300	6.5	2	4.5
RFB 600 Fantr.	C.Spd	420	4.0	5*	6.7
SM SF-260	C.Spd	260	6.3	2	4.2
FFA AS32T	C.Spd	420	7.2	3	3.4
Pilatus PC-7	C.Spd	650	7.8	3	4.5
NDN-1 Firecr.	C.Spd	260	6.3	3	2.8
NDN-1T Firecr.	C.Spd	715	7.0	3	6.2
Beech T34C	C.Spd	715	7.5	3	5.4
			P_{bl} range: 2.8-6.7		

Note: $P_{bl} = 4P_{max}/\pi n_p D_p^2$

*This airplane has a ducted fan instead of a propeller

Table 5.4 Relation Between Max. Engine Power, Propeller Diameter and Number of Propeller Blades for Twin Engine FAR23 and for Regional Turbopropeller Driven Airplanes

Airplane Type	Prop. Pitch	Max. Power per Engine, P_{max}, hp	Prop. Diam., D_p, ft	Number of Prop. Blades, n_p,	Power Loading per Blade, P_{bl}, hp/ft^2
Twin Engine FAR23 Certified Airplanes					
PIPER					
PA-31 Navajo	C.Spd	325	6.7	3	3.1
PA-31T Chey. II	C.Spd	620	7.8	3	4.3
CESSNA					
T303	C.Spd	250	6.2	3	2.8
340A	C.Spd	310	6.4	3	3.2
Conquest I	C.Spd	450	7.8	3	3.1
Conquest II	C.Spd	636	7.5	3	4.8
BEECH					
Baron 95-B55	C.Spd	260	6.5	2	3.9
Duke B60	C.Spd	380	6.2	3	4.2
King Air C90-1	C.Spd	550	7.8	3	3.8
BN2B Islander	C.Spd	260	6.5	2	3.9
				P_{bl} range: 2.8-4.8	
Regional Turbopropeller Driven Airplanes					
EMB-110 Bandar.	C.Spd	750	7.8	3	5.2
EMB-120 Brasil.	C.Spd	1,500	10.5	4	4.3
SF-340	C.Spd	1,630	10.5	4	4.7
Fokker F27-200	C.Spd	2,140	11.5	4	5.2
Brit.Aer. 748	C.Spd	2,280	12.0	4	5.0
Casa Nurt. 235	C.Spd	1,700	10.8	4	4.6
Beech C99	C.Spd	715	7.8	3	5.0
Beech 1900	C.Spd	1,100	9.1	4	4.2
ATR-42	C.Spd	1,800	13.0	4	3.4
IAI Arava 201	C.Spd	750	8.5	3	4.4
				P_{bl} range: 3.4-5.2	

Note: $P_{bl} = 4P_{max}/\pi n_p D_p^2$

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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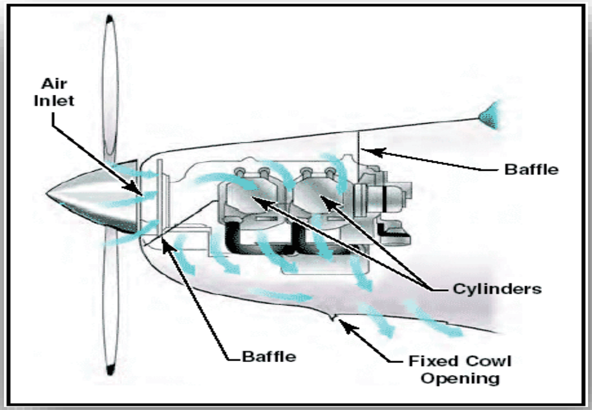
6. Decide on a pusher, a tractor or a mixed installation

When the propeller or inlet plane is forward of the $c.g.$ the installation is referred to as a tractor installation

When the propeller or the inlet plane is located behind the $c.g.$ the installation is referred to as a pusher installation

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

6. Decide on a pusher, a tractor or a mixed installation



Cooling is a major concern, up to 10% of the engine's horsepower can be wasted by the drag associated with taking in cooling air, passing it over the engine, and exiting it

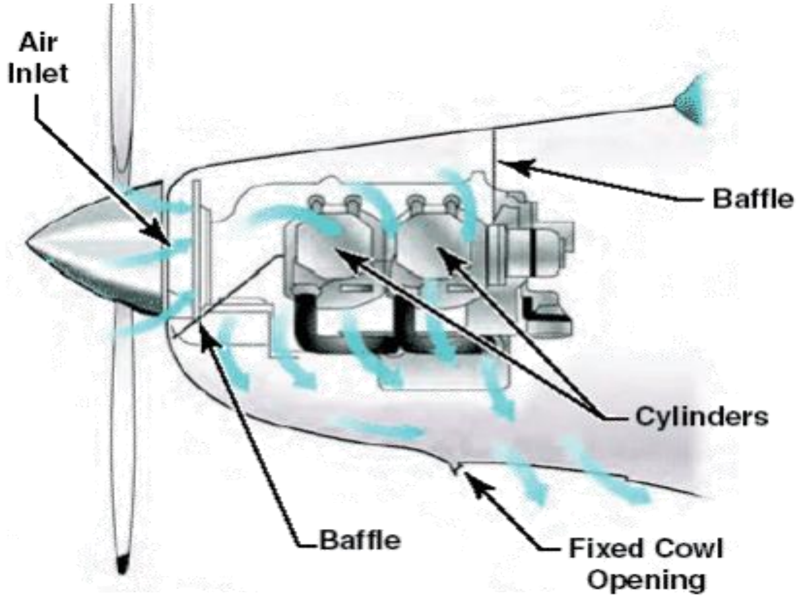
To minimize this cooling drag, the cooling-air mass flow should be kept as small as possible and used as efficiently as possible

As a rule, the cooling – air intake should be about 30-50% of the engine frontal area. The exit should be about 30% larger, and may be variable in area ("cowl flaps") to better control cooling airflow

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

6. Decide on a pusher, a tractor or a mixed installation

For the tractor engines, the cooling air intake is usually located directly in front of engine cylinders. The air is diverted over the top of the engine by "baffles", which are flat sheets of metal that direct the airflow within the engine compartment

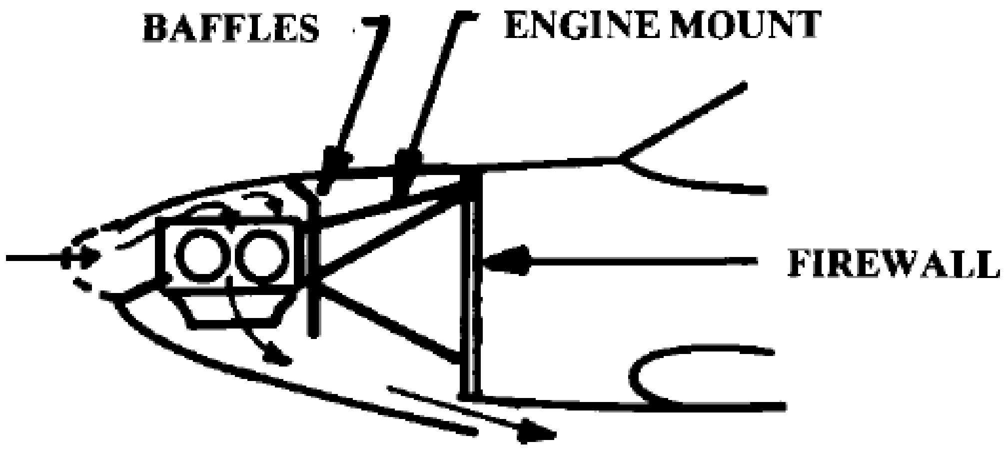


The air then flows down through and around the cylinders into the area beneath the engine, and then exits through an aft facing hole below the fuselage referred as "down-draft" cooling

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

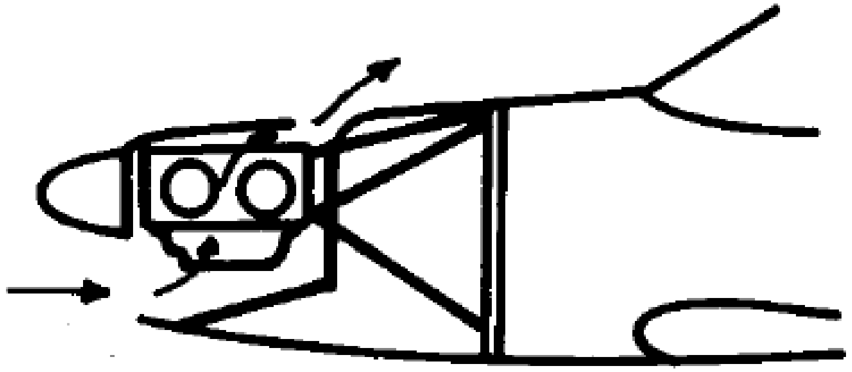
6. Decide on a pusher, a tractor or a mixed installation

Down-draft cooling exits the air beneath the fuselage, which is a high-pressure area, therefore, a poor place to exit air



DOWNDRAFT COOLING

For pusher engines, cooling is much more difficult. On the ground a front-mounted propeller blows the air into the cooling intakes, which is not the case for a pusher engine



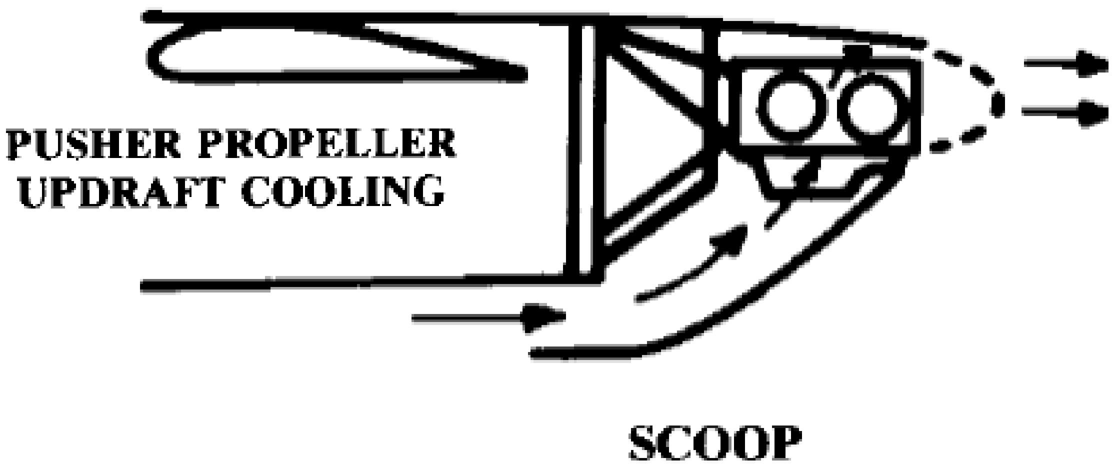
UPDRAFT COOLING

The cooling air intakes for a pusher engine are at the rear of the fuselage where the boundary layer is thick and slow-moving. For these reason virtually all piston-pushers are updraft cooling with a large scoop mounted below the fuselage. Also, internal fans are sometimes used to improve cooling on pusher configurations

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

6. Decide on a pusher, a tractor or a mixed installation

For pusher engines, cooling is much more difficult. On the ground a front-mounted propeller blows the air into the cooling intakes, which is not the case for a pusher engine



The cooling air intakes for a pusher engine are at the rear of the fuselage where the boundary layer is thick and slow-moving. For these reason virtually all piston-pushers are updraft cooling with a large scoop mounted below the fuselage. Also, internal fans are sometimes used to improve cooling on pusher configurations

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

6. Decide on a pusher, a tractor or a mixed installation

If it is decided to go with a pusher propeller installation with the propeller behind the trailing edge of the wing, make certain that the distance between the wing trailing edge and the propeller plane is at least one half of the local wing chord

This is to alleviate dynamic excitation of the propeller blades by the wing vortex system

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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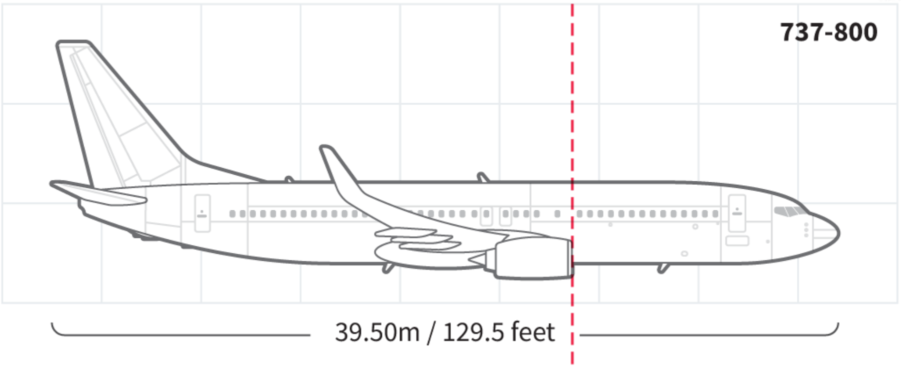
Integration of the propulsion system

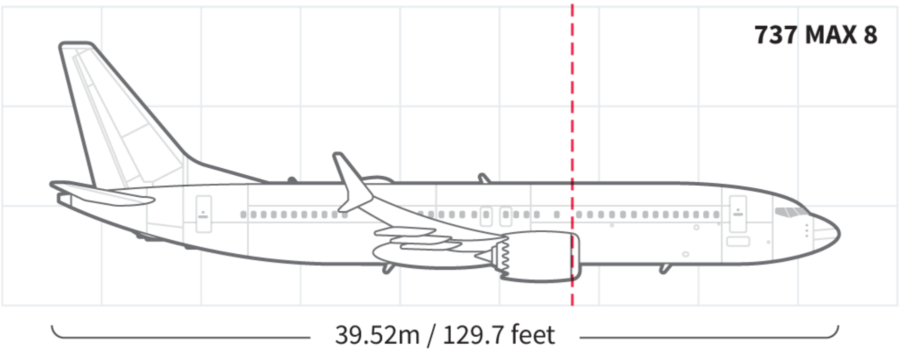
Having decided on the type and the number of engines to be employed, the next decision is the location of the engines

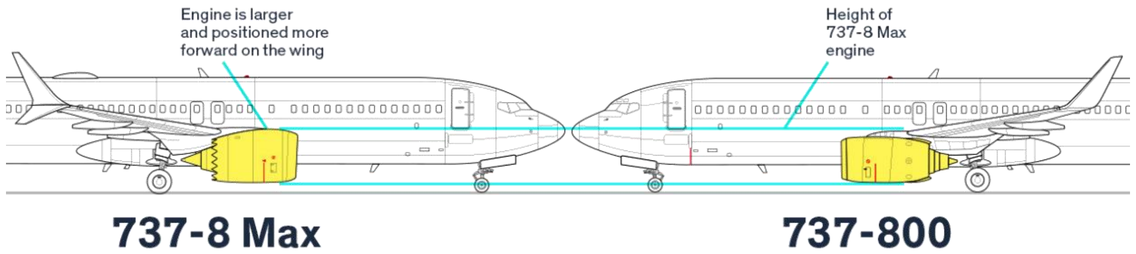
The number of possible arrangements is very large

The following factors play a role in deciding on the engine disposition:

a. Effect of power changes or power failures on stability and control: longitudinal, lateral and directional. The vertical and/or lateral location of the thrust line(s) are critically important in this respect
b. Drag of the proposed installation
c. Inlet requirements and resulting effect on "installed" power and efficiency
d. Accessibility and maintainability







SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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7. Decide on mounting the engines on:
    a. The wing
    b. The fuselage
    c. The empennage
    d. Any combination of a. through c.

In the case of propeller installations it is highly desirable to maintain **clearance between the propeller tips and the fuselage of $20-40\ in$**, depending on the blade power loading and on the propeller tip-speed

This clearance is necessary to avoid acoustic fatigue of the adjacent structure and to avoid excessive noise entering the cabin

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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7. Decide on mounting the engines on:

In the case of jet engines, make sure that **no primary structure is placed too close to exhaust gases**

SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

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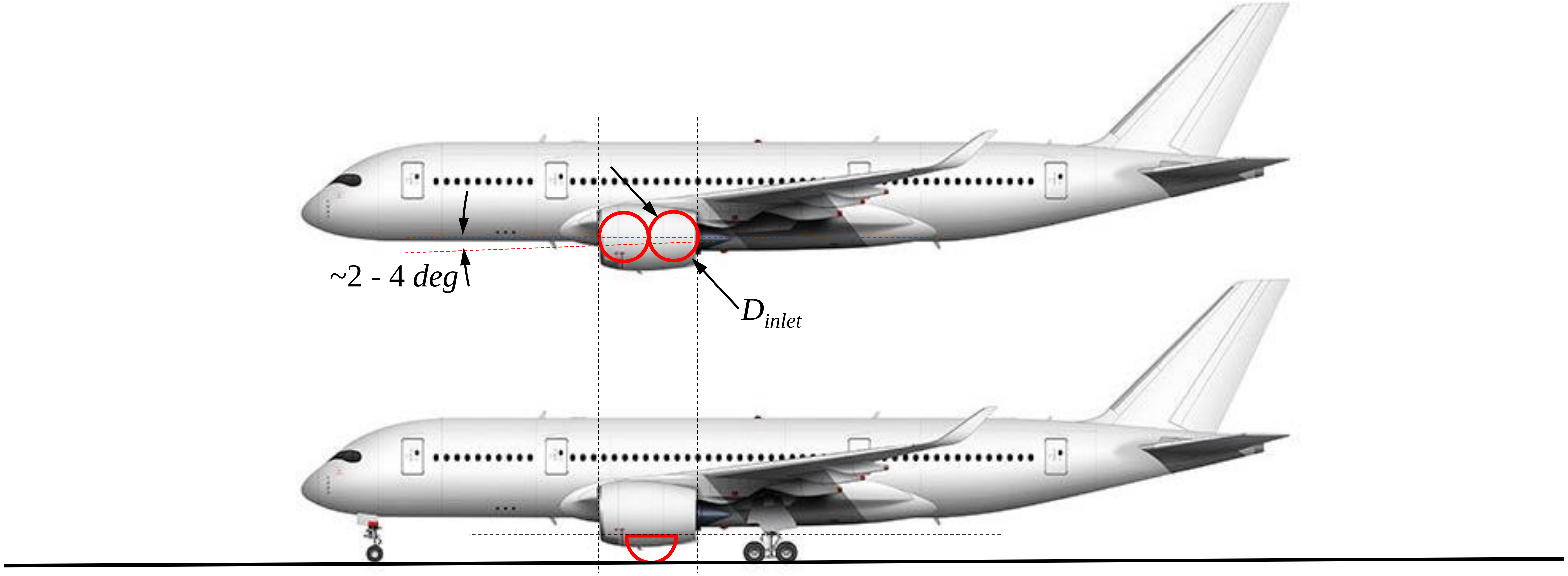
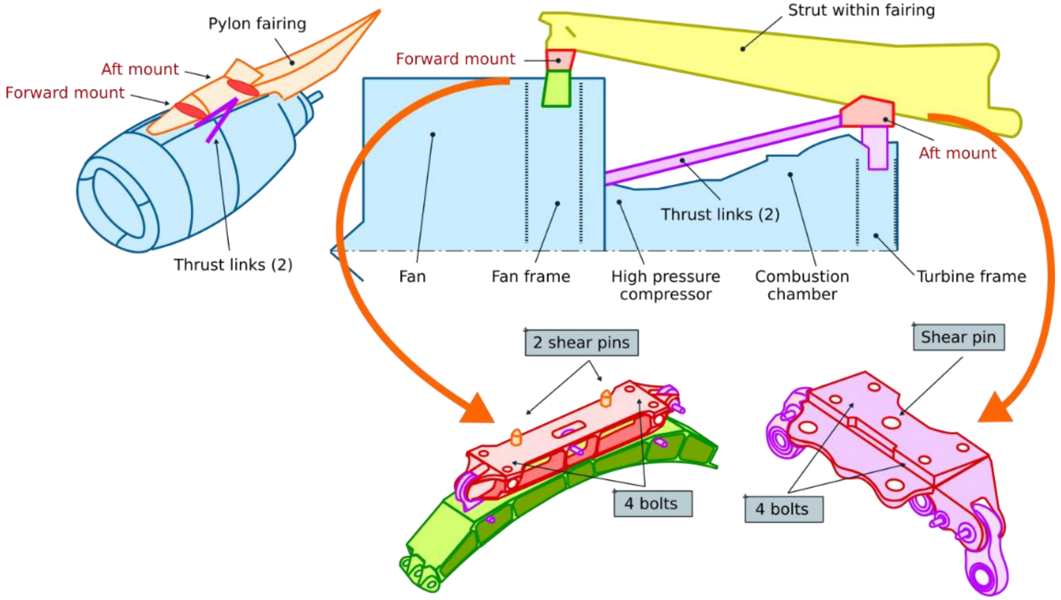


SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

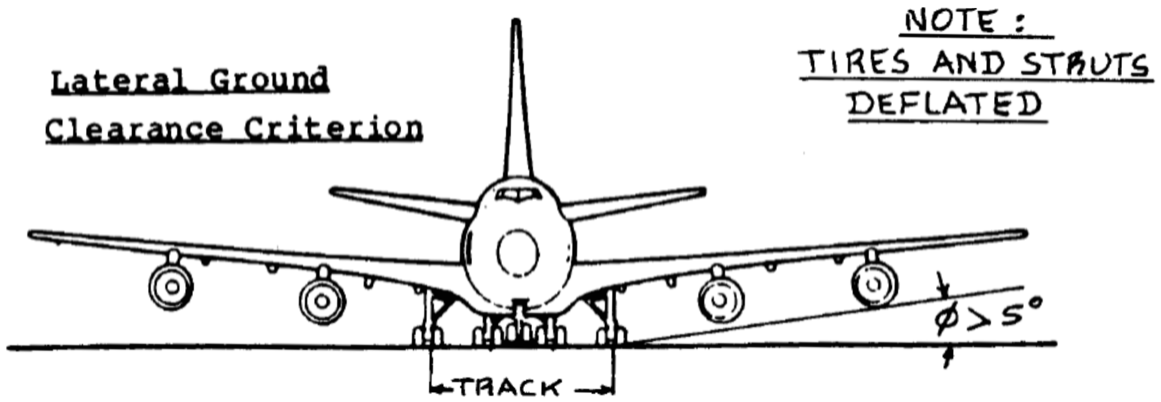
8. Obtain the necessary information on:
    a. Engine geometry and clearance envelope
    b. Engine mounting (attachment) points
    c. Engine air-ducting requirements
    d. Engine thrust reversing requirements
    e. Engine exhaust system requirements
    f. Engine accessory requirements
    g. Engine $c.g.$ location
    h. Engine firewall requirements
    i. In the case of a propeller/pusher installation, verify that the propeller thrust bearings are suitable for a pusher installation
    j. Engine inlet requirements can play a major role in the layout of those jet engine installations where long inlets are needed. This is the case in many "buried" installations
    k. For supersonic aircrafts a variable geometry inlet duct is often required



SELECTION AND INTEGRATION OF THE PROPULSION SYSTEM

9. Make certain that the proposed engine installations are compatible with such requirements as:

   a. Acceptable FOD characteristics
   b. Geometric clearance when static on the ramp: no nacelle or propeller tip may touch the ground with deflated landing gear struts and tires
   c. Geometric clearance during Take-Off rotation: no scraping of nacelles or of propeller tips is allowed, with deflated landing gear struts and tires
   d. Geometric clearance during a low speed approach with a $5°$ bank angle
   e. No gun exhaust gasses may enter the inlet a jet engine. Such gun gasses are highly corrosive to fan, compressor and turbine blades



WEIGHT & BALANCE – PRELIMINARY STUDIES

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Estimation of the weight of a conceptual aircraft is a critical part of the design process

Most weights engineers work in detail design and production and are essentially referees and accountants keeping track of the weight design, which **in preliminary and detail design phases is mostly estimated by multiplying material density by the volume of the part as seen on the drawing or CAD file**

WEIGHT & BALANCE – PRELIMINARY STUDIES

Weights reporting and cg estimation – preliminary method

$$W_{Empty} = W_{Structure} + W_{Propulsion} + W_{Fixed\ equipment}$$

(often add an empty weight allowance of $3–15\%$ at this point to allow for future weight growth and requirements creep)

$$W_{TO} = W_E + W_{useful\ load} = W_E + W_{crew} + W_{Fuel} + W_{Payload}$$

Table 15.1 Group Weight Statement Format

	Weight lbs	Loc ft	Moment ft-lbs		Weight lbs	Loc ft	Moment ft-lbs
Structures	**4526**		**106,879**	**Equipment**	**4067**		**80,646**
Wing	1459.4	23.3	34,004	Flight controls	655.7	21.7	14,229
Horizontal tail	280.4	39.2	10,992	APU		0.0	0
Vertical tail		0	0	Instruments	122.8	10.0	1228
Ventral tail		0.0	0	Hydraulics	171.7	21.7	3726
Fuselage	1574	21.7	34,156	Pneumatics		21.7	0
Main landing gear	631.5	23.8	15,030	Electrical	713.2	21.7	15,476
Nose landing gear	171.1	13.0	2224	Avionics	989.8	10.0	9898
Other landing gear		0.0	0	Armament		0.0	0
Engine mounts	39.1	33.0	1290	Furnishings	217.6	6.2	1349
Firewall	58.8	33.0	1940	Air conditioning	190.7	15.0	2860.5
Engine section	21	33.0	693	Anti-icing			0
Air induction	291.1	22.5	6550	Photographic			0
			0	Load & handling	5.3	15.0	79.5
			0	Misc equipment & W_e	1000	31.8	31,800
			0	**Empty weight allowance**	**547**	**23.6**	**12,923**
Propulsion	**2354**		**70,931**	**Total weight empty**	**11,495**	**23.6**	**271,379**
Engine(s)—installed	1517	33.0	50,061				
Accessory drive			0	**Useful load**	**4985**		
Exhaust system			0	Crew	220	15.0	3300
Engine cooling	172	33.0	5676	Fuel—usable	3836	22.3	85,551
Oil cooling	37.8	33.0	1247	Fuel—trapped	39	22.3	864
Engine controls	20	33.0	660	Oil	50	33.0	1650
Starter	39.5	15.7	620	Passengers			0
Fuel system/tanks	568	22.3	12,666	Cargo/payload	840	21.7	18,228
			0	Guns			0
			0	Ammunition	0	21.7	0
			0	Misc useful load			
			0	**Takeoff gross weight**	**16,480**	**22.0**	**362,744**

WEIGHT & BALANCE – PRELIMINARY STUDIES

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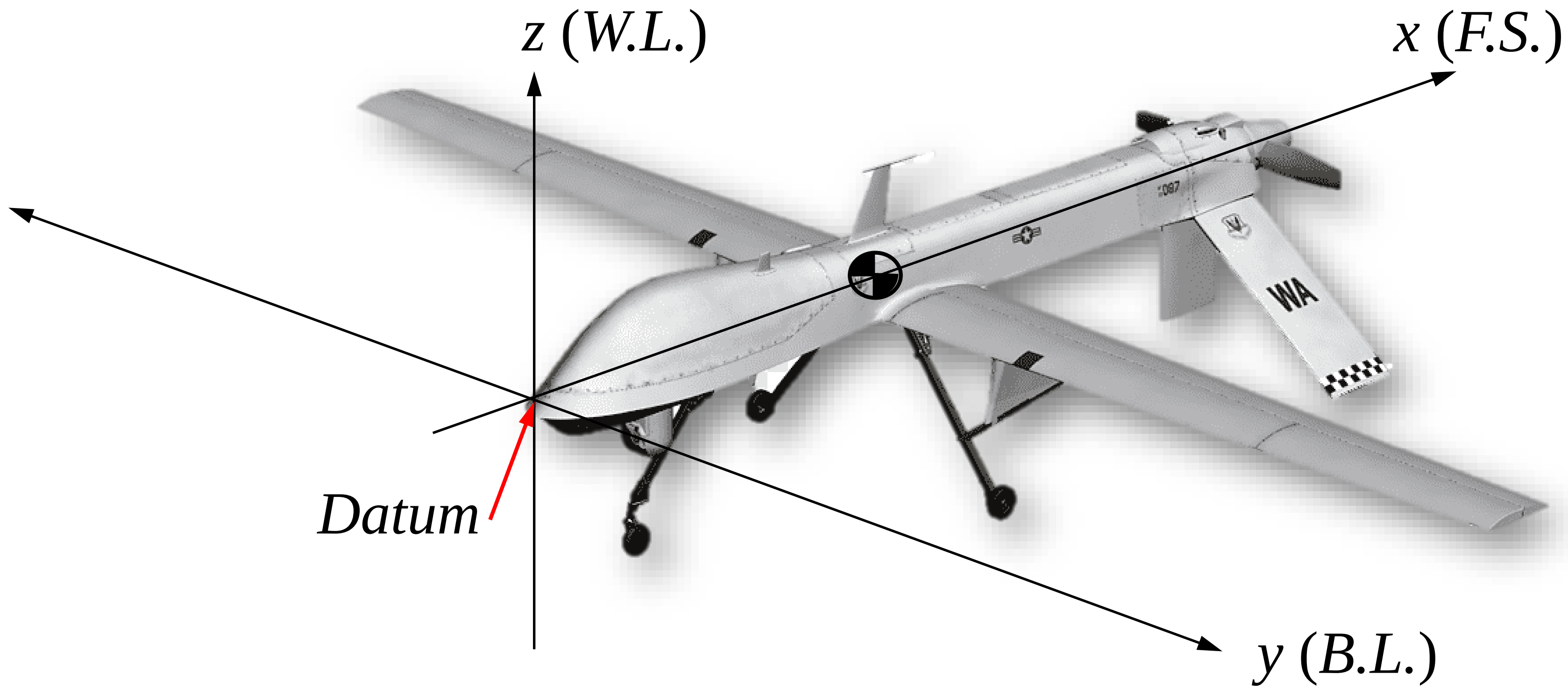

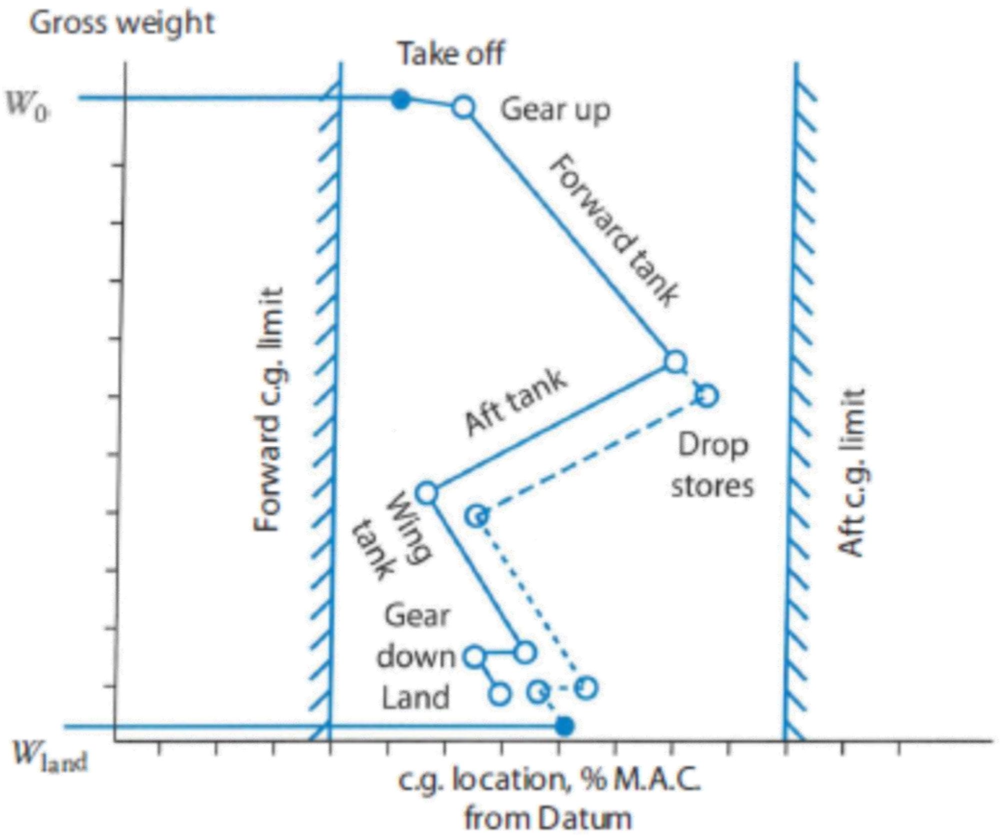

WEIGHT & BALANCE – PRELIMINARY STUDIES

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Approximate W_E build-up method – multiplier factor

Table 15.2 Approximate Empty Weight Buildup

	Fighters		Transport & Bomber		General Aviation		Multiplier	Approximate Location
	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2		
Wing	9	44	10	49	2.5	12	$S_{\text{exposed planform}}$	40% MAC
Horizontal tail	4	20	5.5	27	2	10	$S_{\text{exposed planform}}$	40% MAC
Vertical tail	5.3	26	5.5	27	2	10	$S_{\text{exposed planform}}$	40% MAC
Fuselage	4.8	23	5	24	1.4	7	$S_{\text{wetted area}}$	40–50% length
	Weight Ratio		Weight Ratio		Weight Ratio			
Landing gear*	0.033		0.043		0.057		TOGW	centroid
Landing gear—Navy	0.045		—		—		TOGW	centroid
Installed engine	1.3		1.3		1.4		Engine weight	centroid
"All-else empty"	0.17		0.17		0.1		TOGW	40–50% length

*15% to nose gear, 85% to main gear; reduce gear weight by 0.014 W_0 if fixed gear.

WEIGHT & BALANCE – PRELIMINARY STUDIES

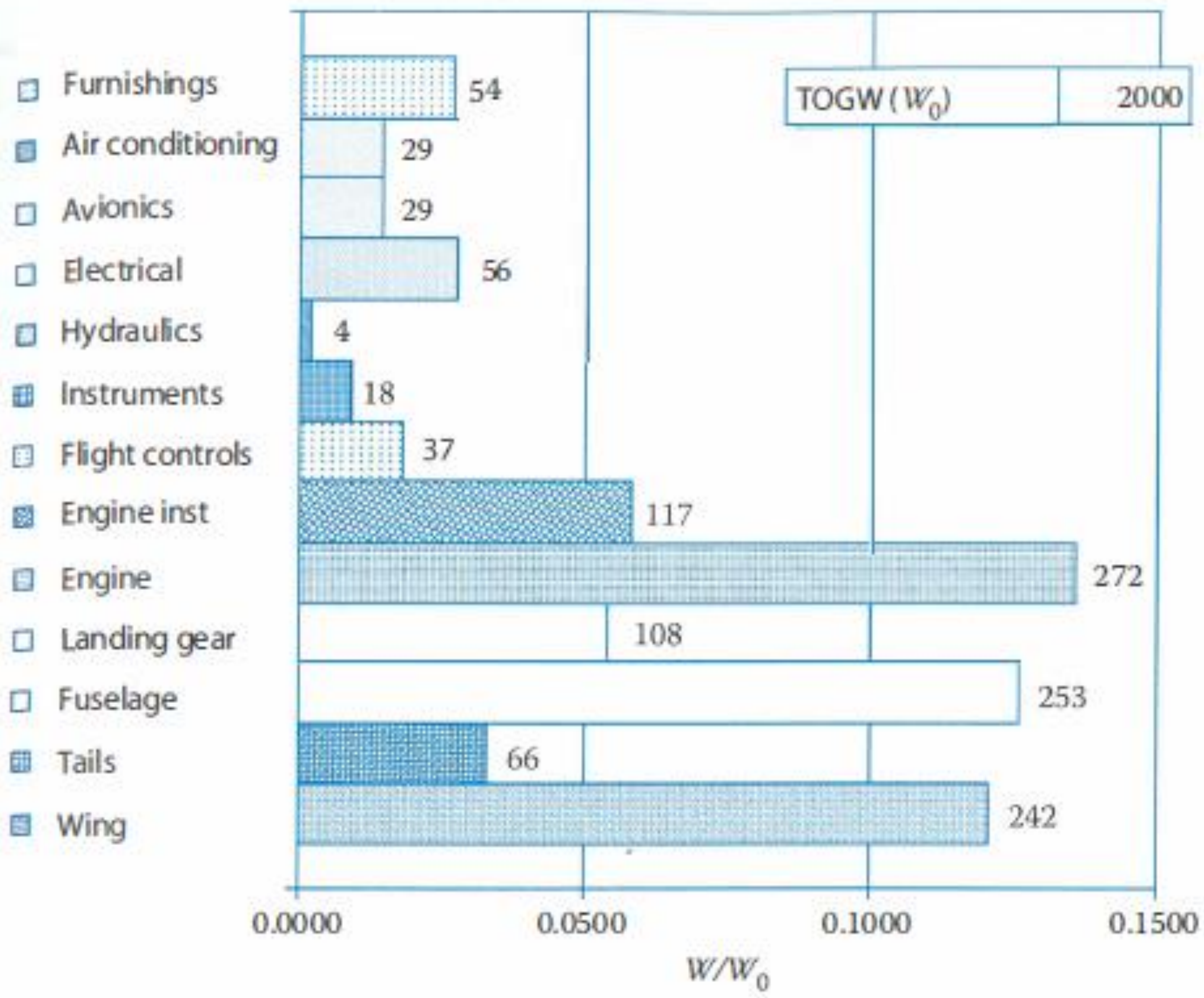
Listing of the major components of the aircraft, with rough estimates of their weight based on statistical ratios for typical aircraft in that class

Approximate W_E build-up method – weight budget

The ratios in this sample were taken from several GA and homebuilt airplanes including the *BD*-5, *Cessna* 172, and *T*-34*C*

A weight budget is NOT a target!!!, if the wing weighs less than the budget implies, don't add rocks until the budget is met!, it merely acts as a guide and a reality check while the detailed calculations described below are being performed

Example for a new GA aircraft



LANDING GEAR SIZING AND DISPOSITION

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1. Decide which landing gear system to use

The choices here are:

- Fixed or non-retractable
- Retractable

As a general rule: **if the cruise speed of the aircraft is above $150\ kts$, a fixed landing gear imposes an unacceptably drag penalty**

Gear type / Characteristics	Fixed	Retractable
Aerodynamic drag	High	Minimal
Weight	Low	High
Complexity and cost	Low	High
Maintenance cost	Insignificant	Significant

LANDING GEAR SIZING AND DISPOSITION

2. Decide on the overall landing gear configuration

   Depends strongly on the aircraft mission

   The choices are as follows:
   - Single main
   - Tail-wheel or tail-dragger (conventional)
   - Tandem (bicycle or quadricycle – with Outrigger)
   - Tricycle
   - Multi-bogey
   - Beaching gear (for flying boats)

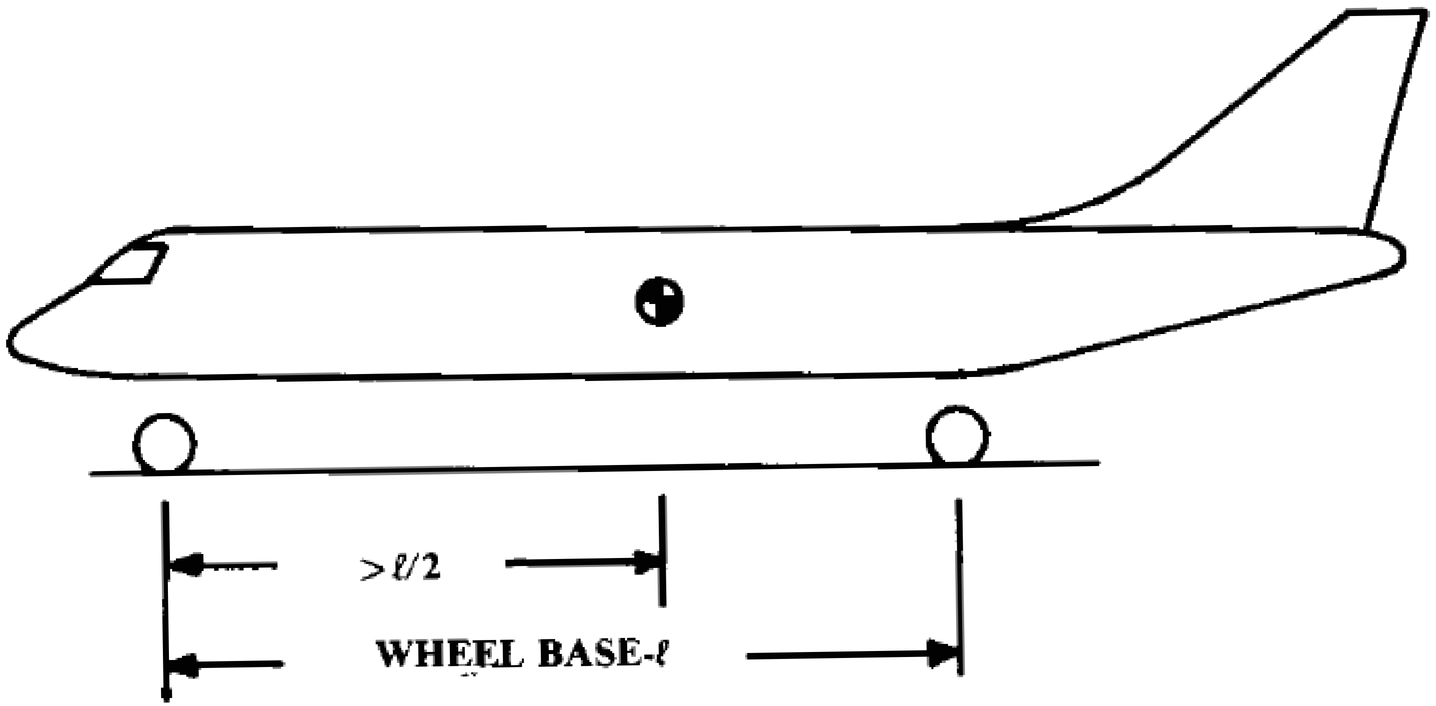
LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition

   There are **two geometric criteria that must be consider** in deciding the disposition of the landing gear struts:

   a. Tip-over criteria
   b. Ground clearance criteria

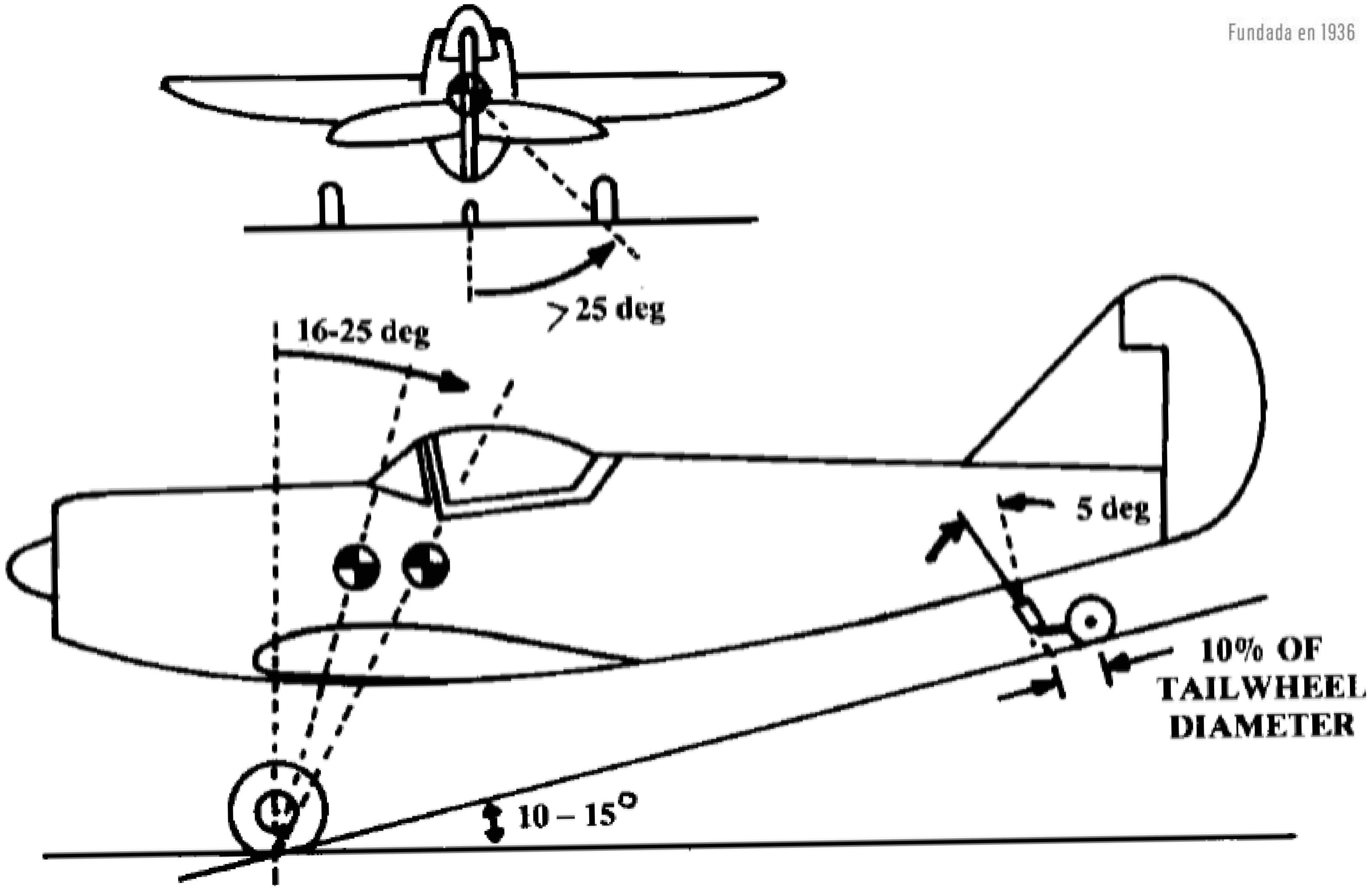
   As a special arrangement the guidelines for layout of a bicycle landing gear said that the *c.g.* should be aft of the midpoint between the two wheels



LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition - Tip-over criteria

Longitudinal tip-over criterion
For tail-draggers: **the main landing gear must be forward of the aft *c.g.* location**

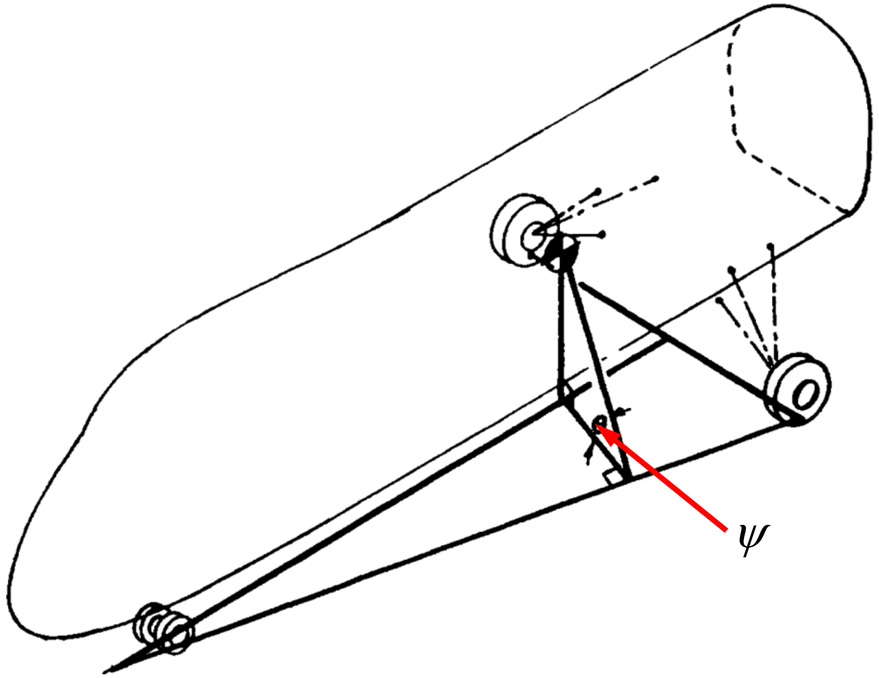


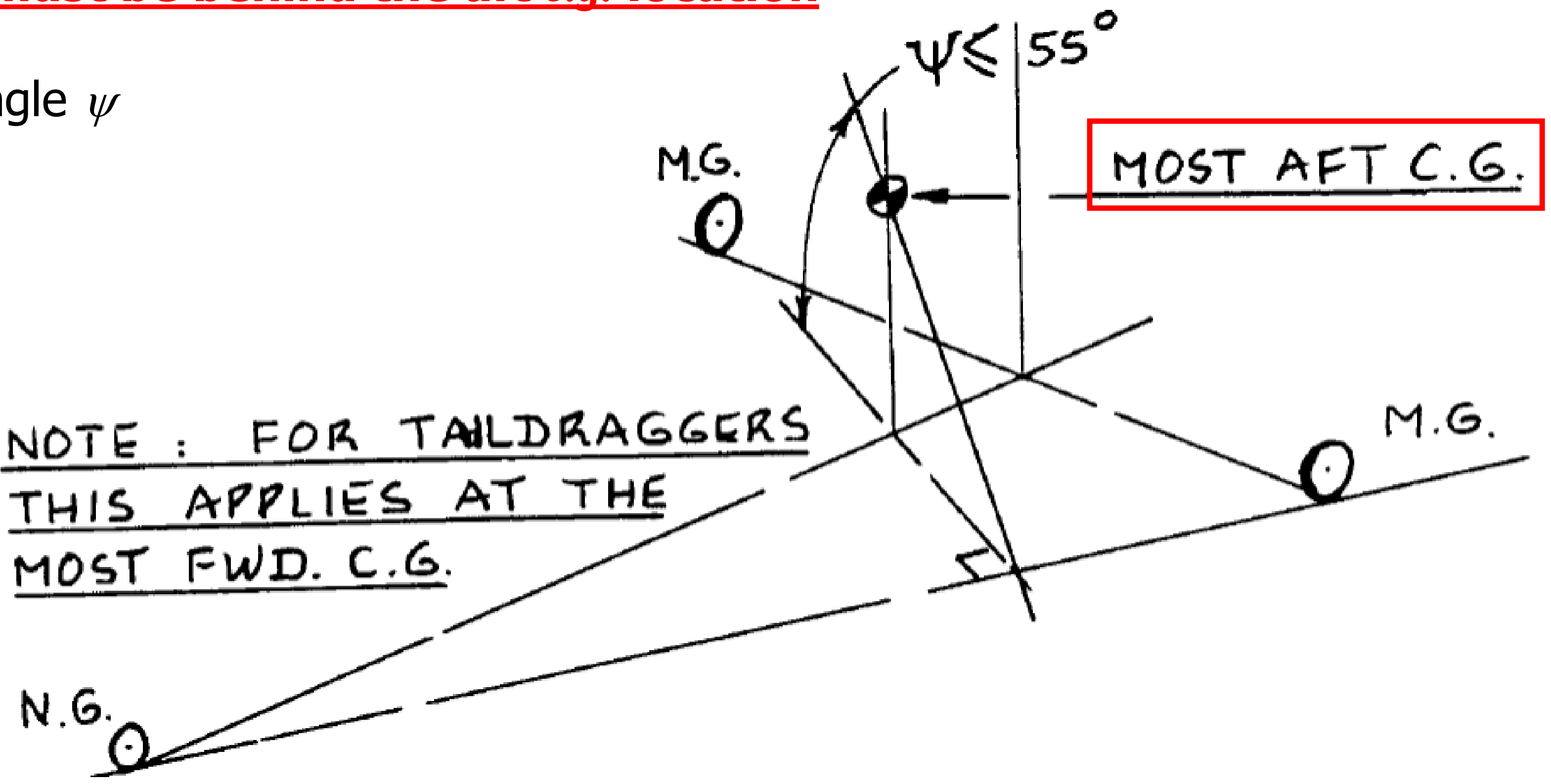
LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition - Tip-over criteria

Longitudinal tip-over criterion
For tricycle gears: **the main landing gear must be behind the aft $c.g.$ location**

Lateral tip-over criterion is dictated by the angle ψ





LANDING GEAR SIZING AND DISPOSITION

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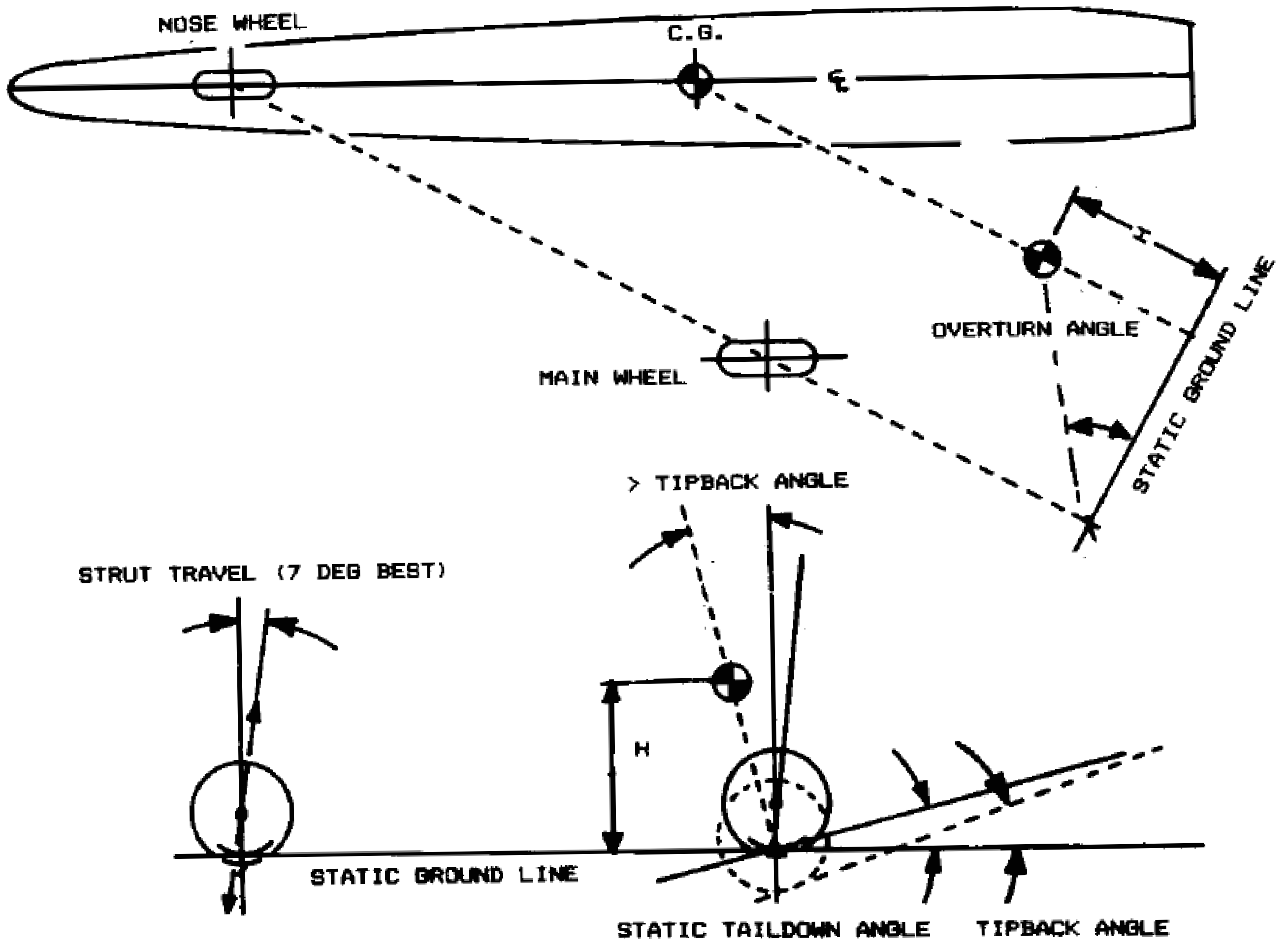
3. Decide the preliminary landing gear strut disposition

The length of the landing gear must be set so that the tail does not hit the ground on landing

This is measured from the wheel in the static position assuming an aircraft angle of attack for landing which gives 90% of the maximum lift. This ranges from about $10°$-$15°$ for most types of aircraft

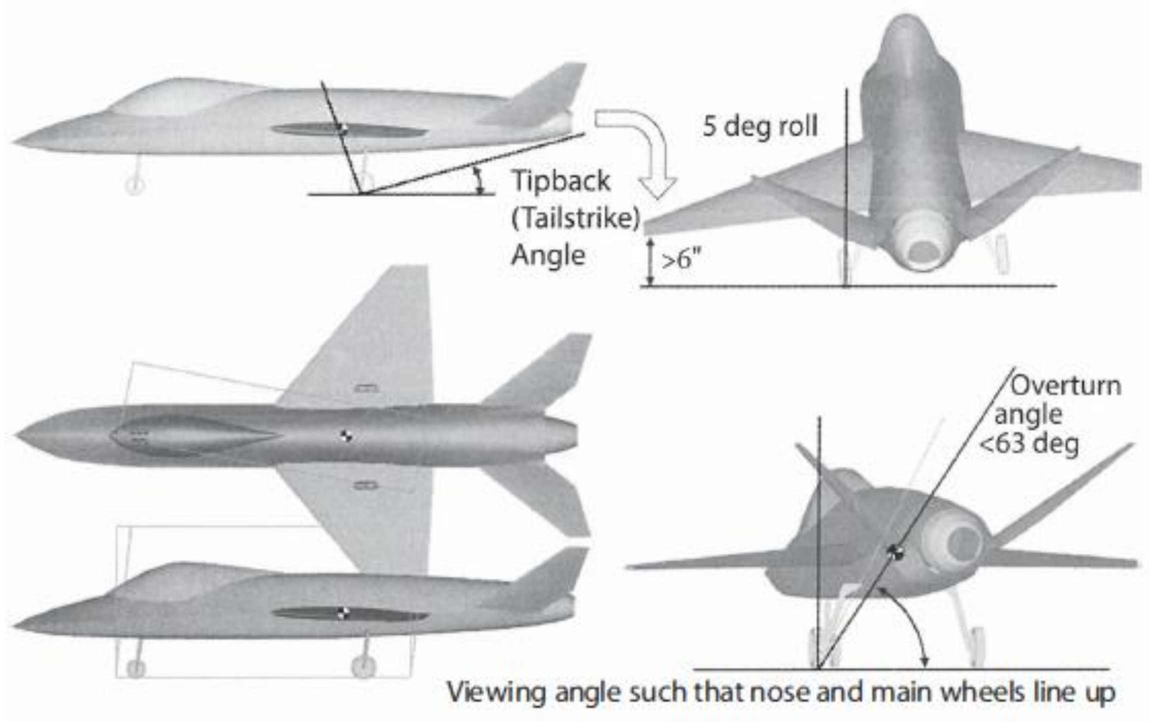
The "**Tip-back**" angle is the maximum aircraft nose-up attitude with the tail touching the ground and the strut fully extended. To prevent the aircraft from tipping back on its tail, **the angle of the vertical from the main wheel position to the *c.g.* should be greater than the tip-back angle or $15°$, which ever is larger**

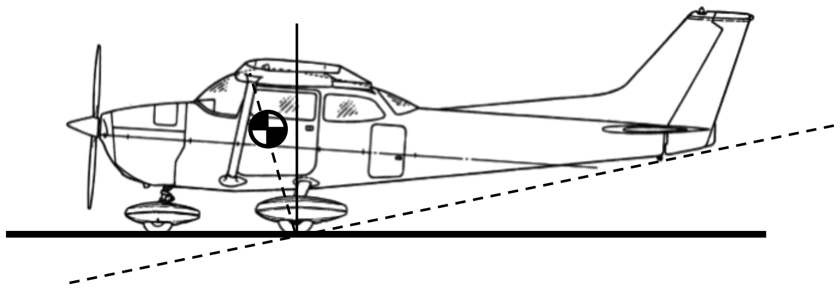
The "**over-turn**" angle is a measure of the aircraft's tendency to overturn when taxied around a sharp corner. **For most aircrafts this angle should be no greater than $63°$**

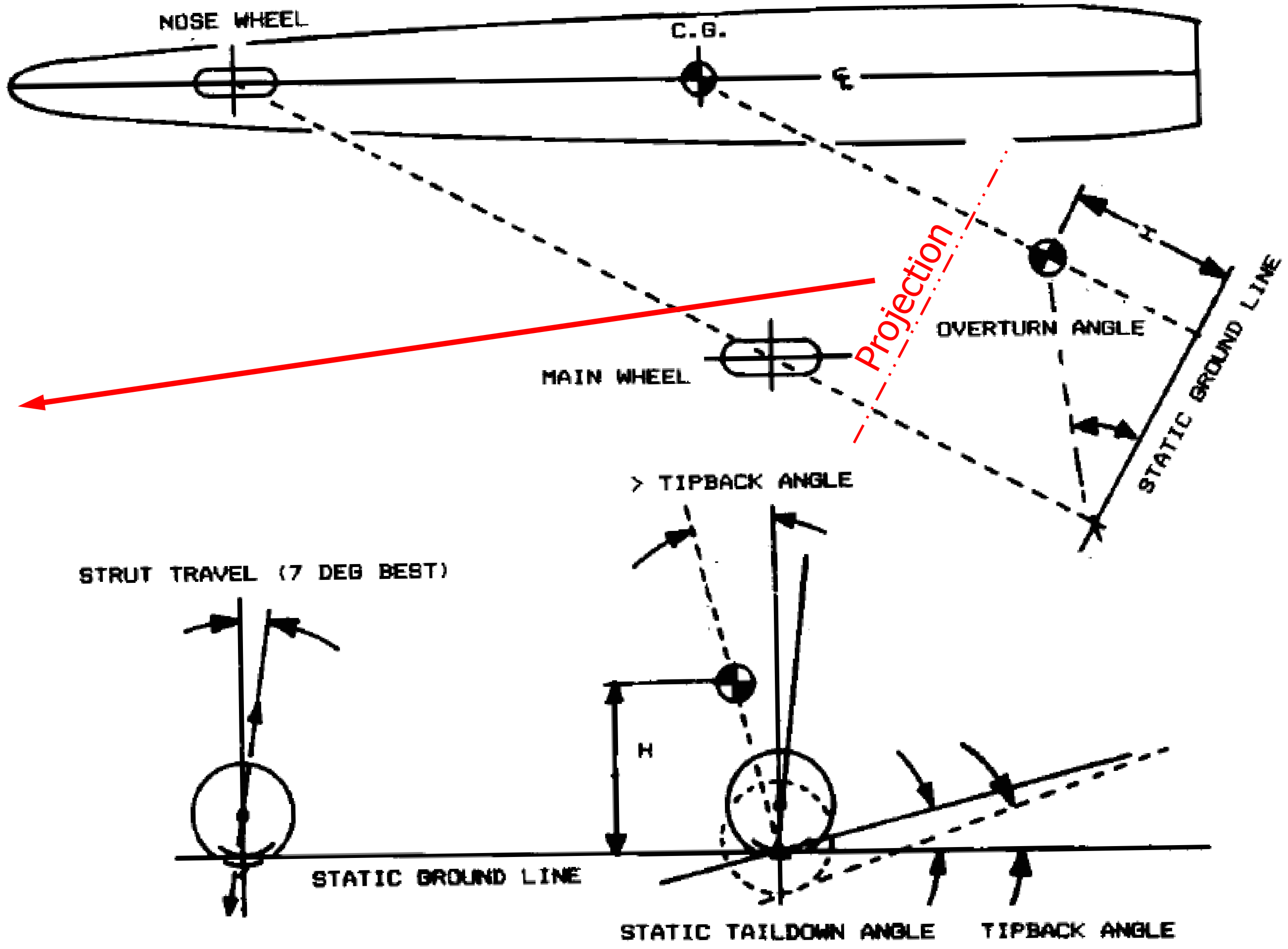


LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition - Tip-over criteria



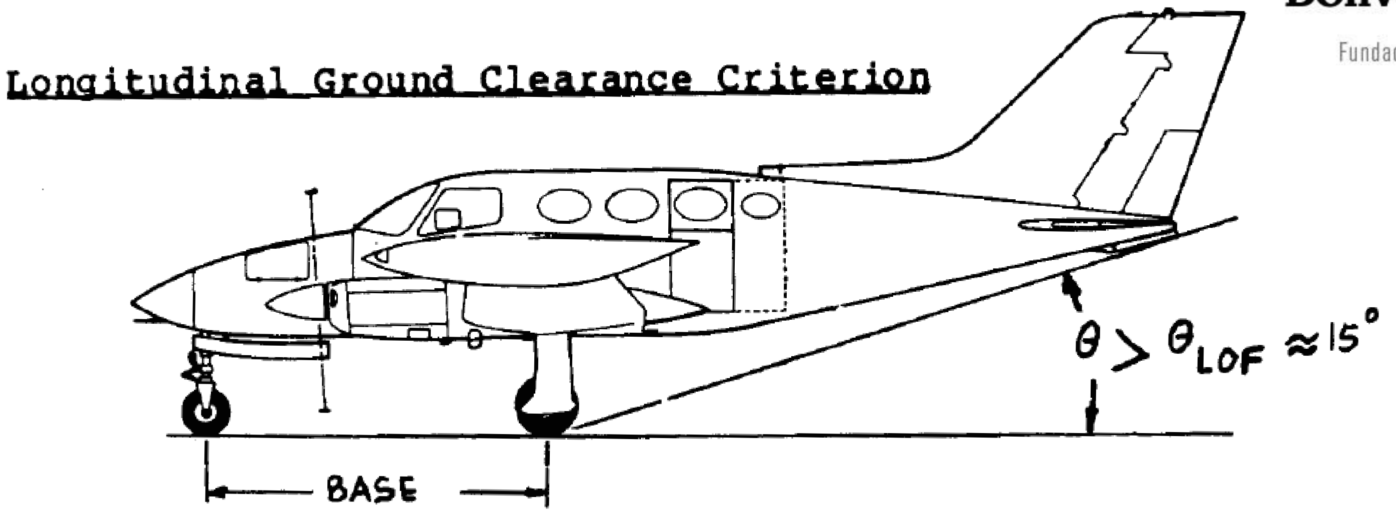


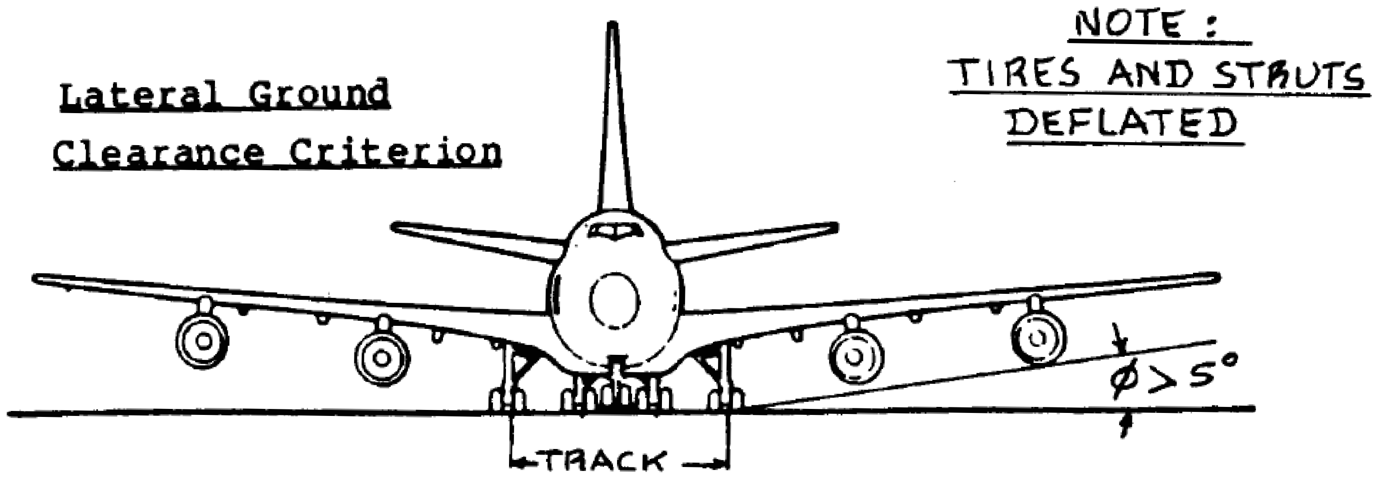


LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition – Ground clearance criteria

The lateral ground clearance angle applies to tricycles and to tail draggers. The longitudinal ground clearance angles applies to tricycle only





LANDING GEAR SIZING AND DISPOSITION

3. Decide the preliminary landing gear strut disposition

   Keeping in mind the geometric criteria, the following decisions must now be made:

   a. Number, location and length of main gear struts
      i. Under the wing
      ii. Under the fuselage
      iii. Both

   b. Number, location and length of nose gear struts
      Usually only one strut, located at the forward end of the fuselage

   To summarize, the selection of strut length has a major impact on:

   - The weight of the landing gear
   - The ground clearance of the aircraft with deflated tires and struts
   - The tip-over characteristics
   - Overall aircraft stability during ground operation

LANDING GEAR SIZING AND DISPOSITION

4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

For that it is useful to know about gear-retraction geometries available. this in order to find the "home for the gear" in the retracted position

A poor location for the retracted gear can ruin an otherwise good design concept. A bad choice for the retracted position can chop up the aircraft structure (increasing weight), reduce the internal fuel volume, or create additional aerodynamic drag

The typical options for main-landing gear retracted positions are:

- In the wing
- Wing podded
- In the fuselage
- Fuselage podded
- Wing/fuselage junction
- In the nacelle

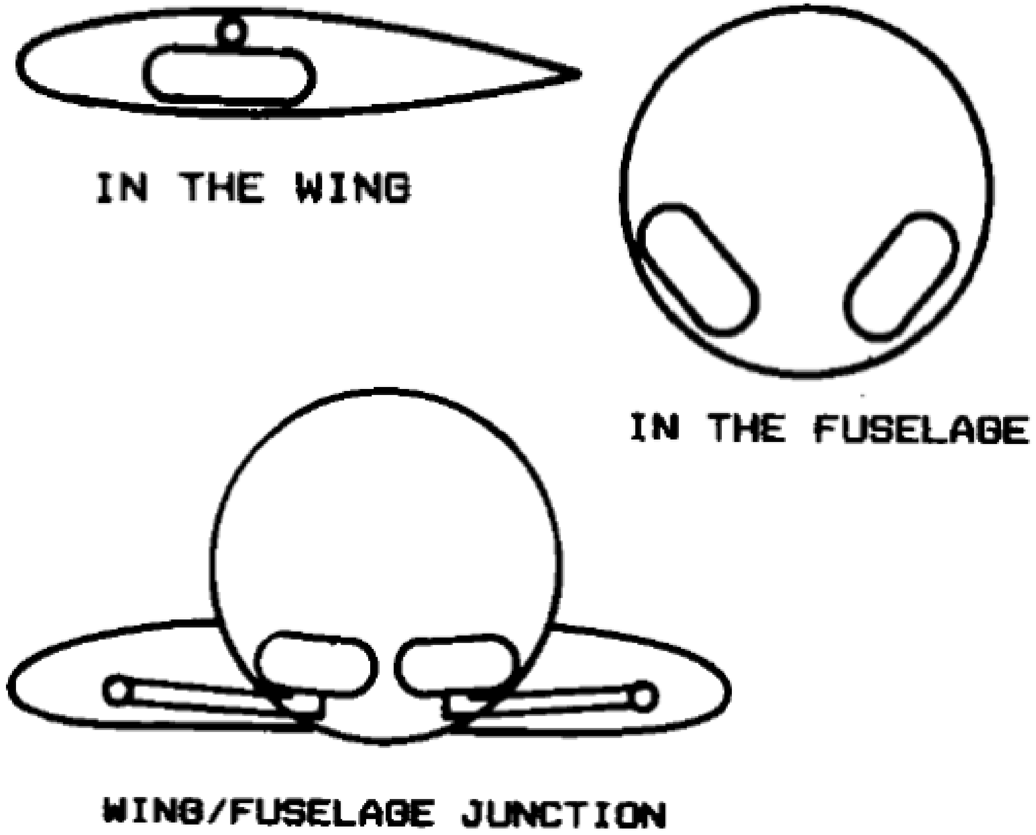
LANDING GEAR SIZING AND DISPOSITION

4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

Locating the gear in the wing, in the fuselage, or in the wing fuselage junction **produces the smallest aerodynamic penalty but tends to chop up the structure**

Gear in the wing reduces the size of the wing box, which increases weight and may reduce fuel volume. Gear in the fuselage or wing-fuselage junction may interfere with the longerons

Virtually all civilian jet transports retract the gear into the wing-fuselage junction. Most low-wing fighters retract the gear into the wing or wing-fuselage junction, while mid and high-wing fighters retract the gear into the fuselage



LANDING GEAR SIZING AND DISPOSITION

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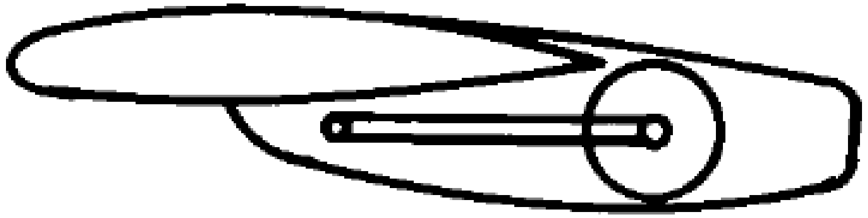
4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

While some slower aircraft retract the gear into the wing, fuselage, or wing-fuselage junction, many retract the gear into the nacelles or a separate gear pod

This reduces weight significantly because the wing and fuselage structure is not interrupted

The wing-podded arrangement is rarely seen, but is used in some designs even for jet transports and bombers



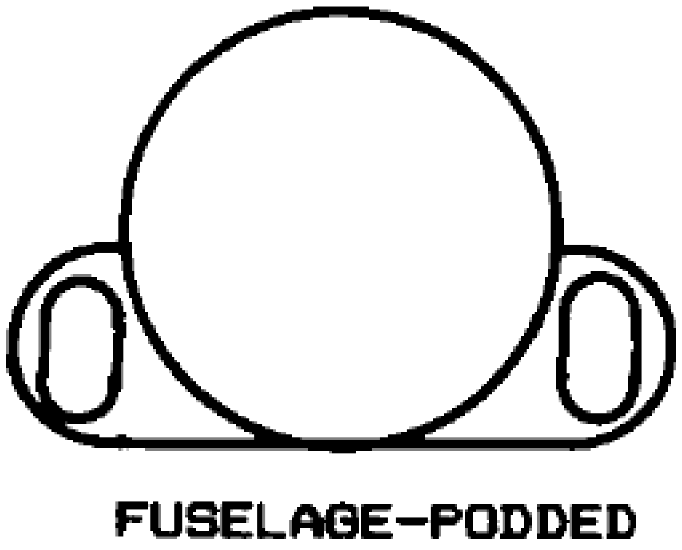
WING-PODDED

LANDING GEAR SIZING AND DISPOSITION

4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

The fuselage-podded arrangement is common for high-wing military transports where the fuselage must remain open for cargo

The drag penalty of the pods can be substantial

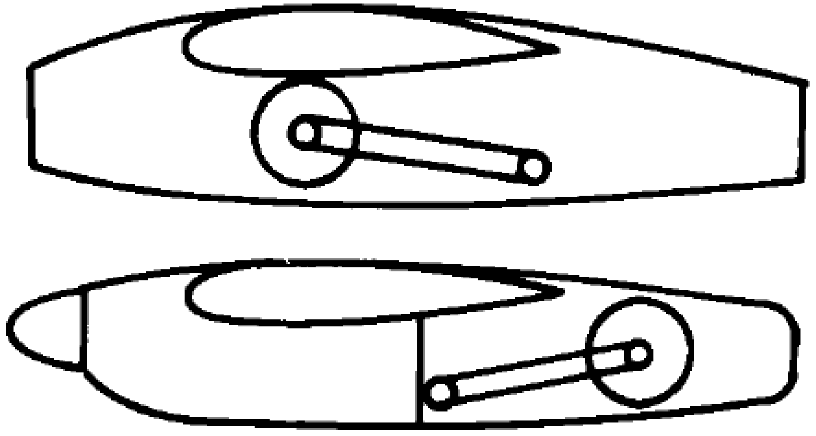


LANDING GEAR SIZING AND DISPOSITION

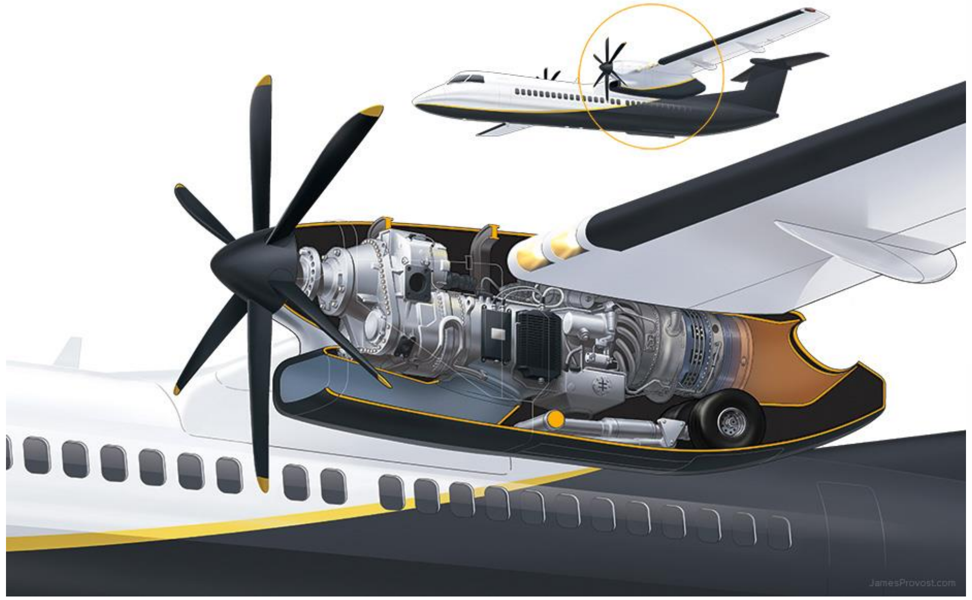
4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

Retraction of the gear into the nacelles behind the engine is typically for propeller-driven aircraft

For jet-engine aircraft, nacelle mounted landing gear must go alongside the engine, which widens the nacelle, increasing the drag



IN THE NACELLE



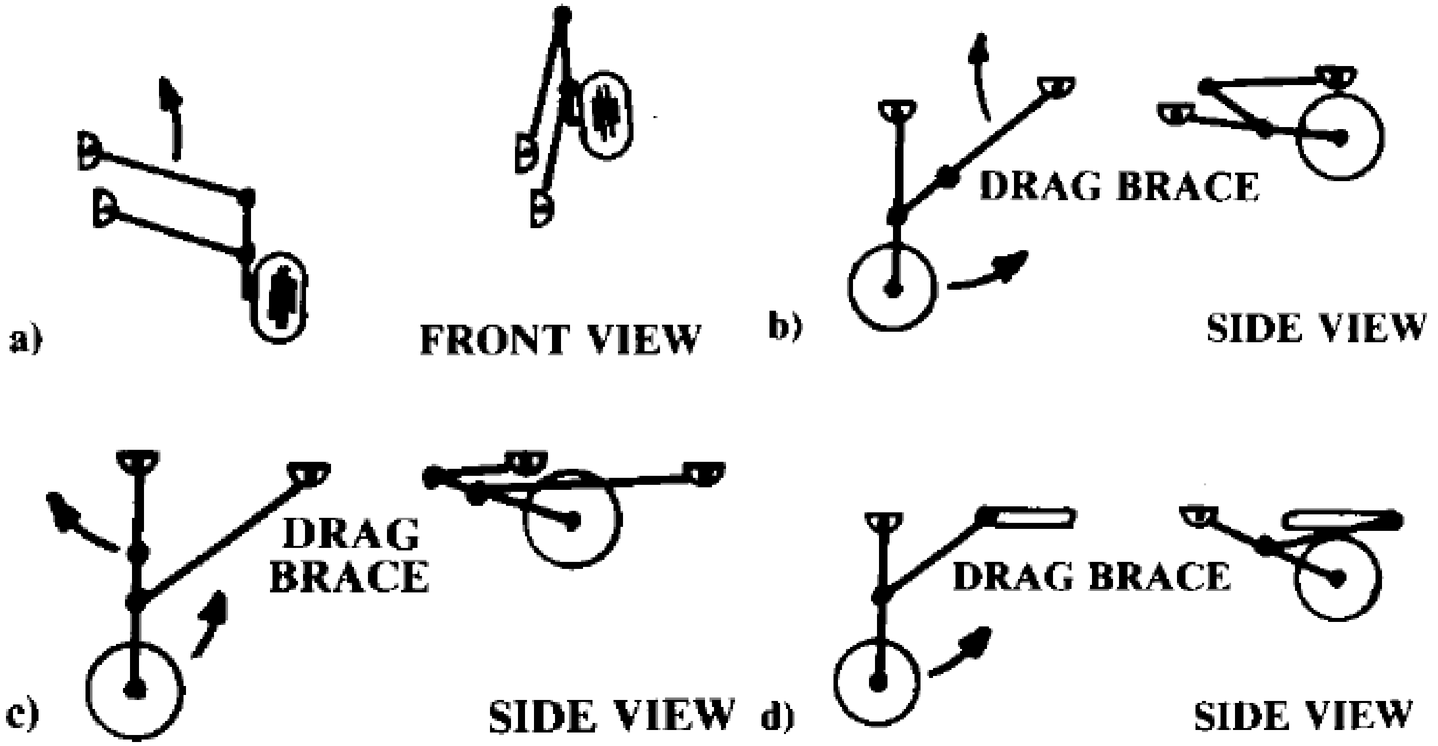
LANDING GEAR SIZING AND DISPOSITION

4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

Most mechanisms for the landing-gear retraction are based upon the "**four-bar linkage**"

This uses three members (the fourth bar being the aircraft structure) connected by pivots

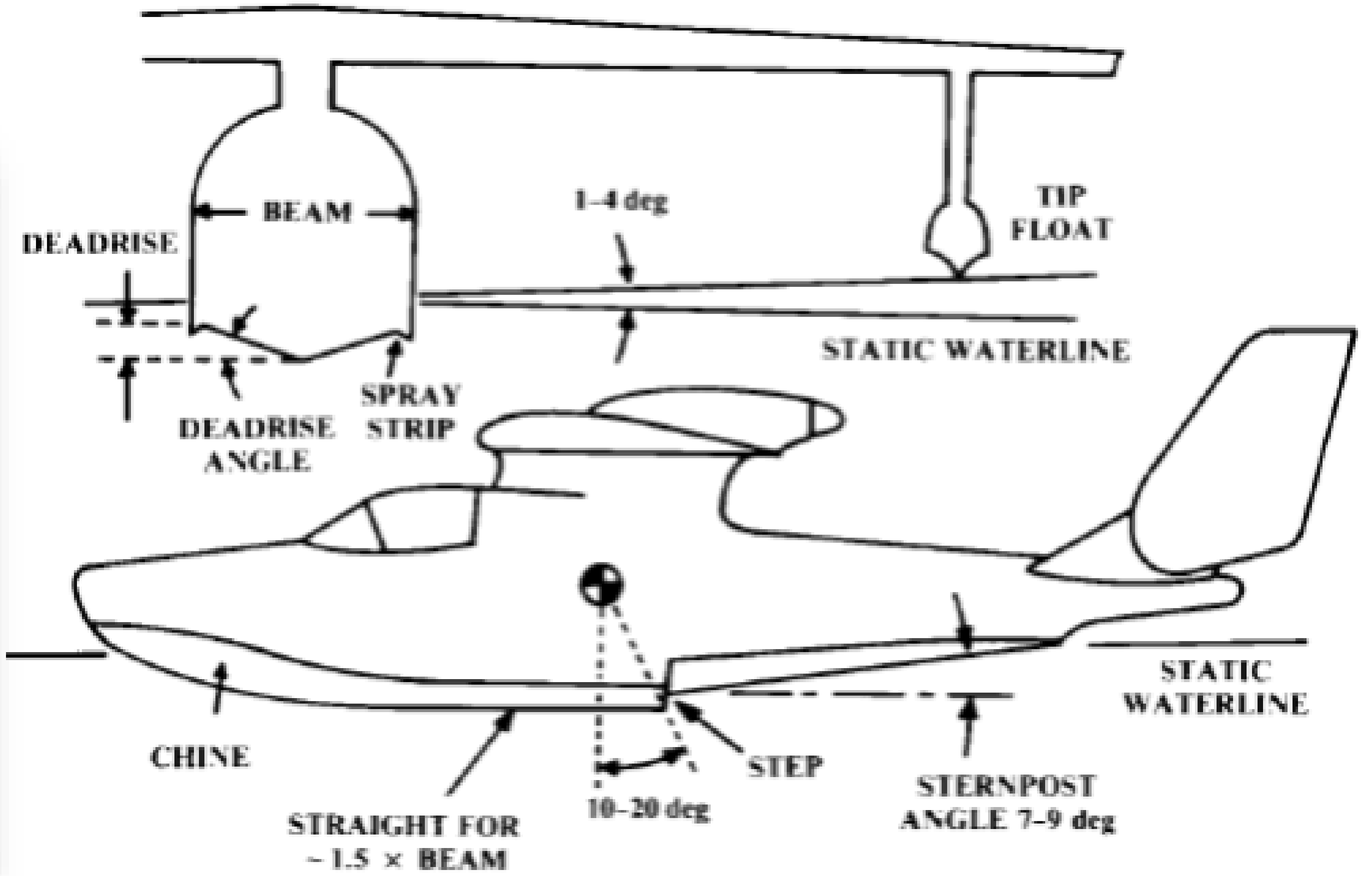
The four-bar linkage provides a simple and light-weight gear because the loads pass through rigid members and simple pivots



LANDING GEAR SIZING AND DISPOSITION

4. Make sure that the gear as now configured can be retracted into the designated retraction volume(s)

Special case – Sea planes



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

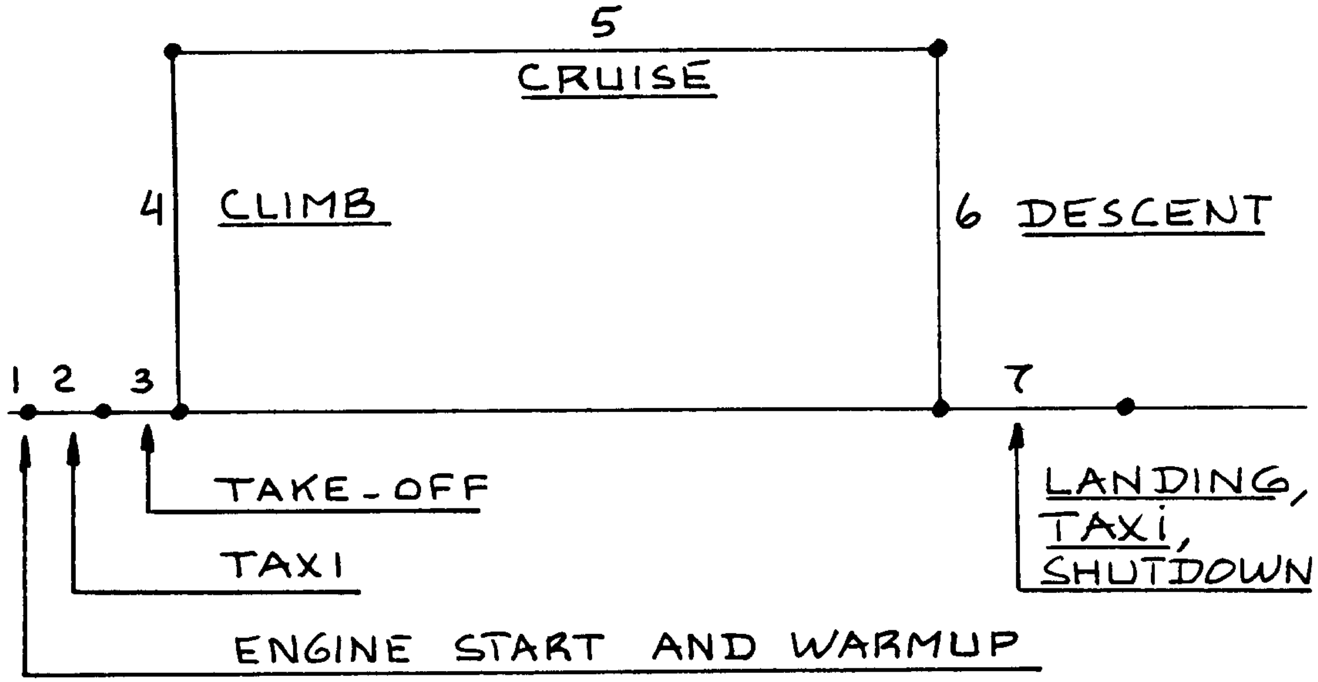
Universidad Pontificia Bolivariana

Fundada en 1936

Twin engine propeller driven airplane

Payload:	Six passengers at 175 lbs each (this includes the pilot) and 200 lbs total baggage.
Range:	1,000 sm with max. payload. Reserves equal to 25% of required mission fuel.
Altitude:	10,000 ft (for the design range).
Cruise Speed:	250 kts at 75% power at 10,000 ft.
Climb:	10 minutes to 10,000 feet at max. W_{TO}.
Take-off and Landing:	1,500 ft groundrun at sealevel, std. day. Landing performance at $W_L = 0.95 W_{TO}$.
Powerplants:	Piston/Propeller
Pressurization:	None
Certification Base:	FAR 23

Mission Profile:



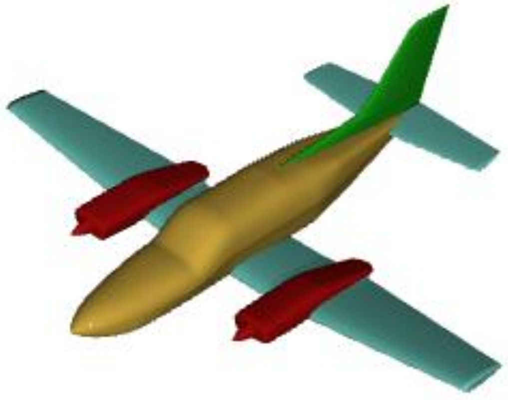
AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Weight sizing results:

$W_{PL} = 6x175 + 200 = 1,250$ lbs

Take-off weight: 7,900 lbs
Empty weight: 4,900 lbs
Fuel weight: 1,706 lbs



Matching chart results:

Take-off wing loading: 46 psf
Power loading at take-off: 8.8 lbs/hp

Maximum lift coefficients:

Clean: $C_{L_{max}} = 1.7$

Take-off: $C_{L_{max_{TO}}} = 1.85$

Landing: $C_{L_{max_L}} = 2.3$

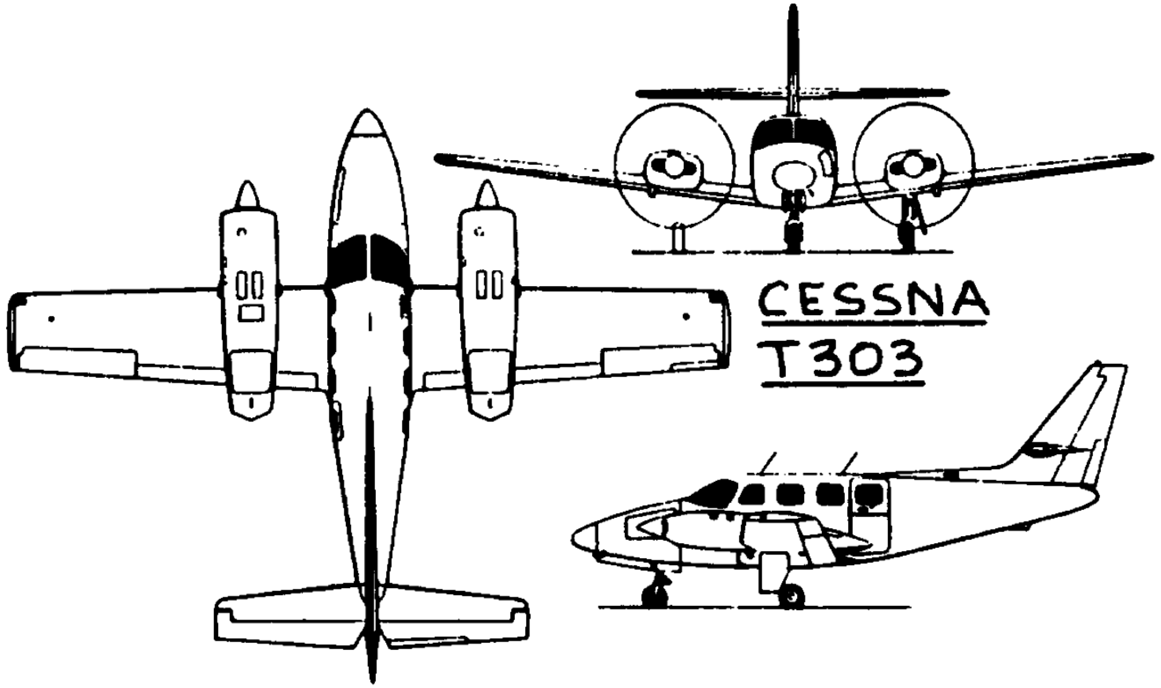
Aspect ratio: $A = 8$

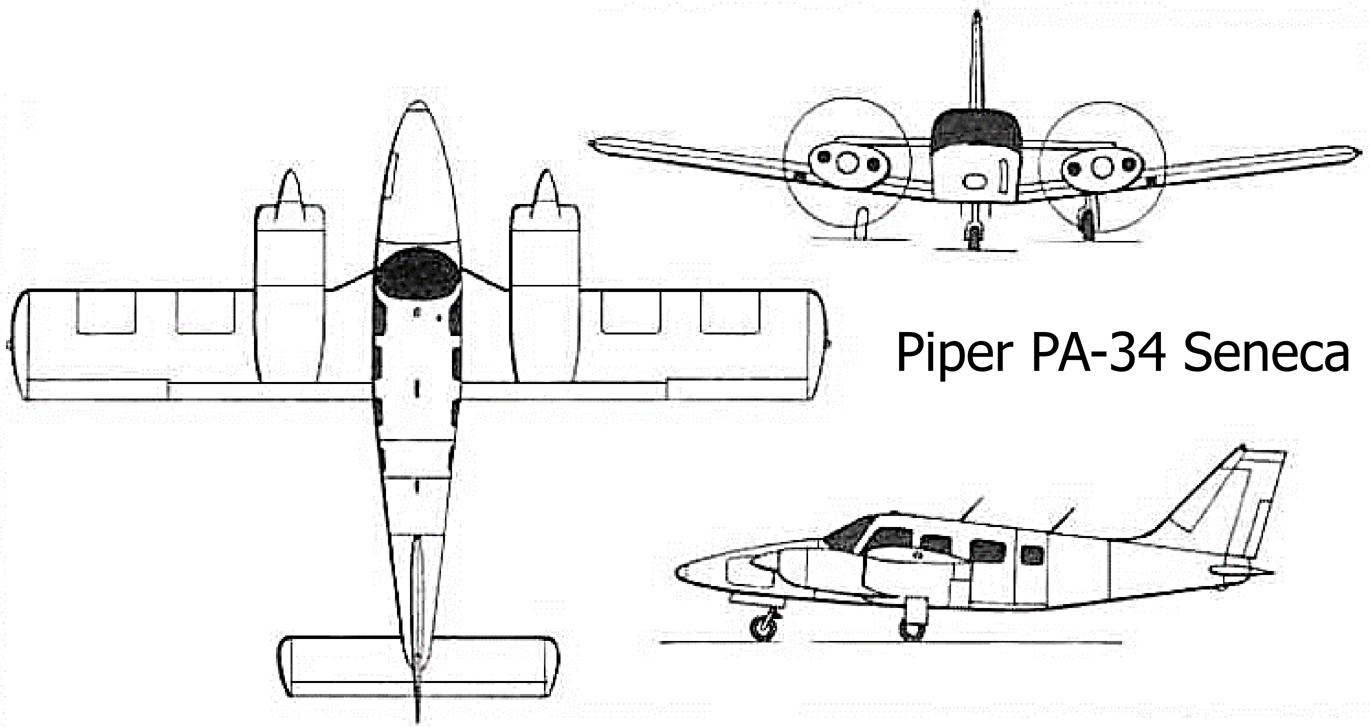
AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

With the previous information, determine the airplane preliminary geometry (measures)

Reference airplanes:





Piper PA-34 Seneca

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

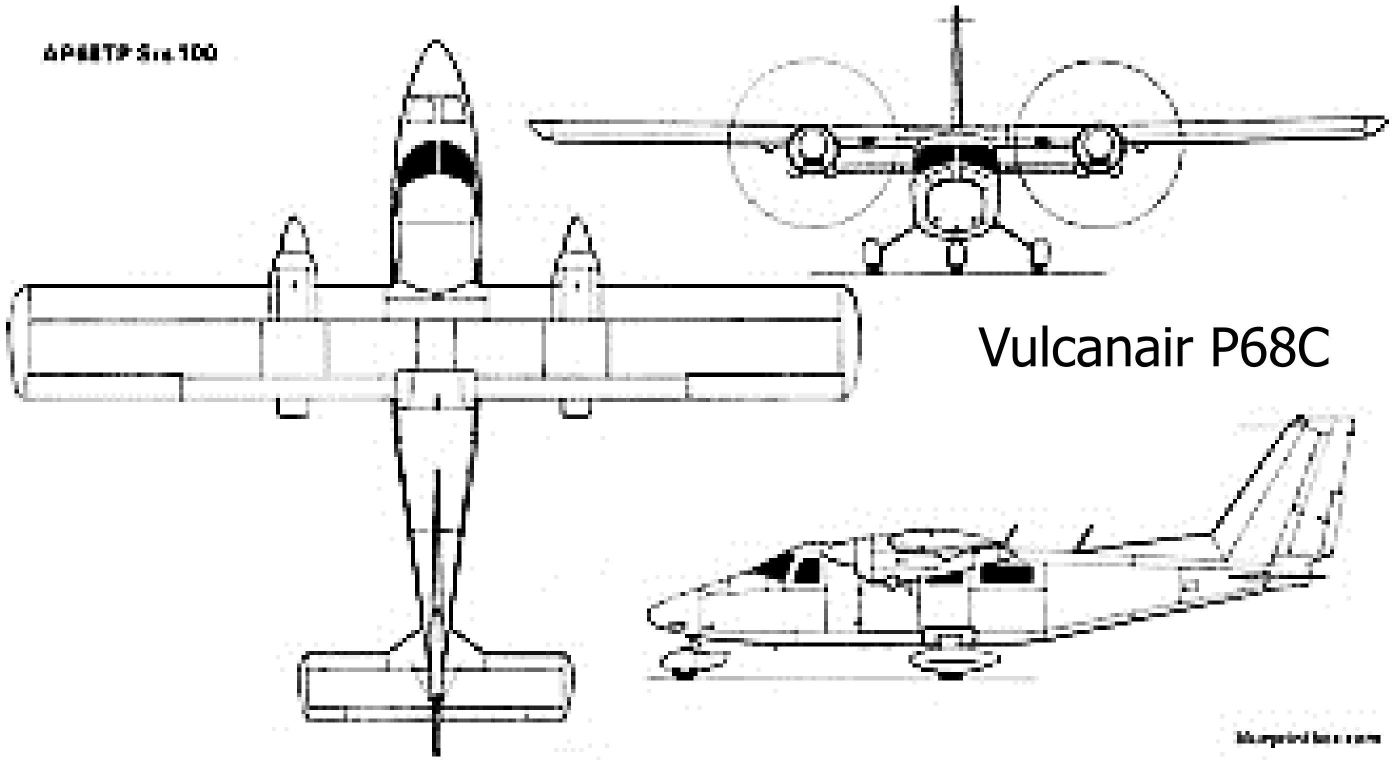
Universidad Pontificia Bolivariana

Fundada en 1936

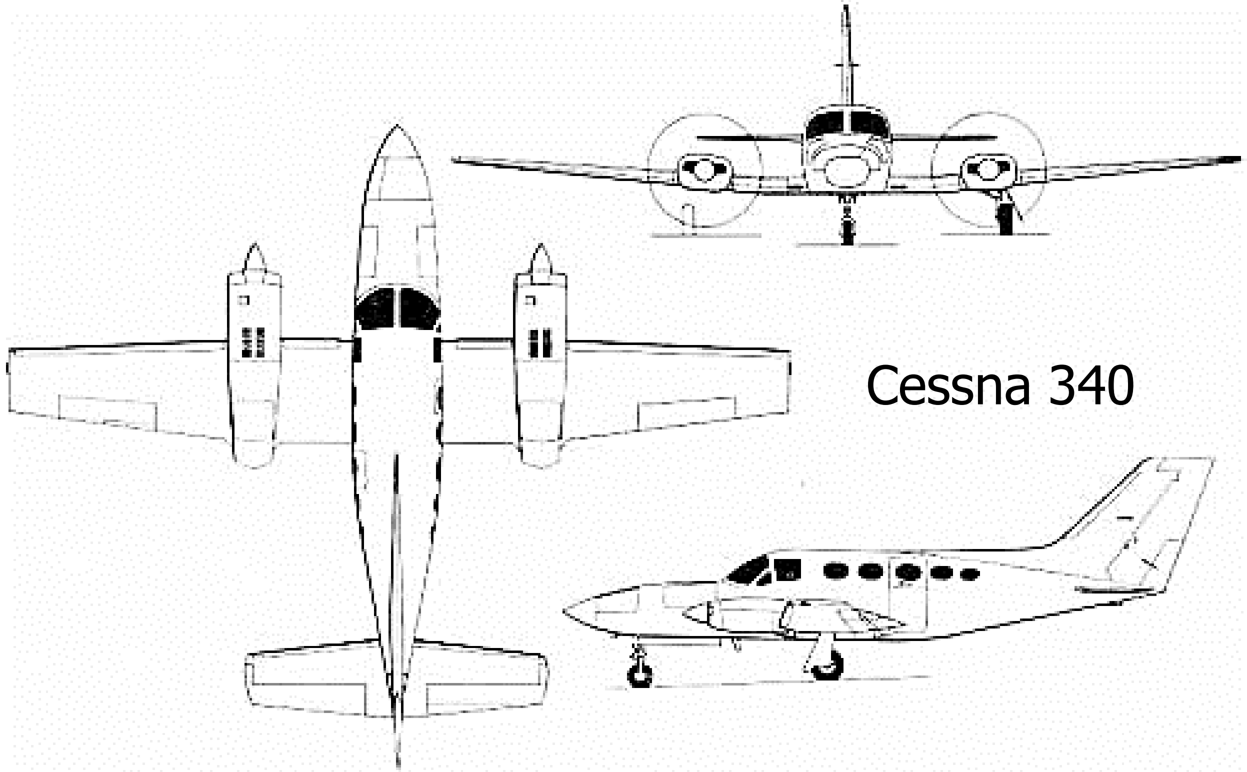
Twin engine propeller driven airplane

With the previous information, determine the airplane preliminary geometry (measures)

Reference airplanes:



Vulcanair P68C

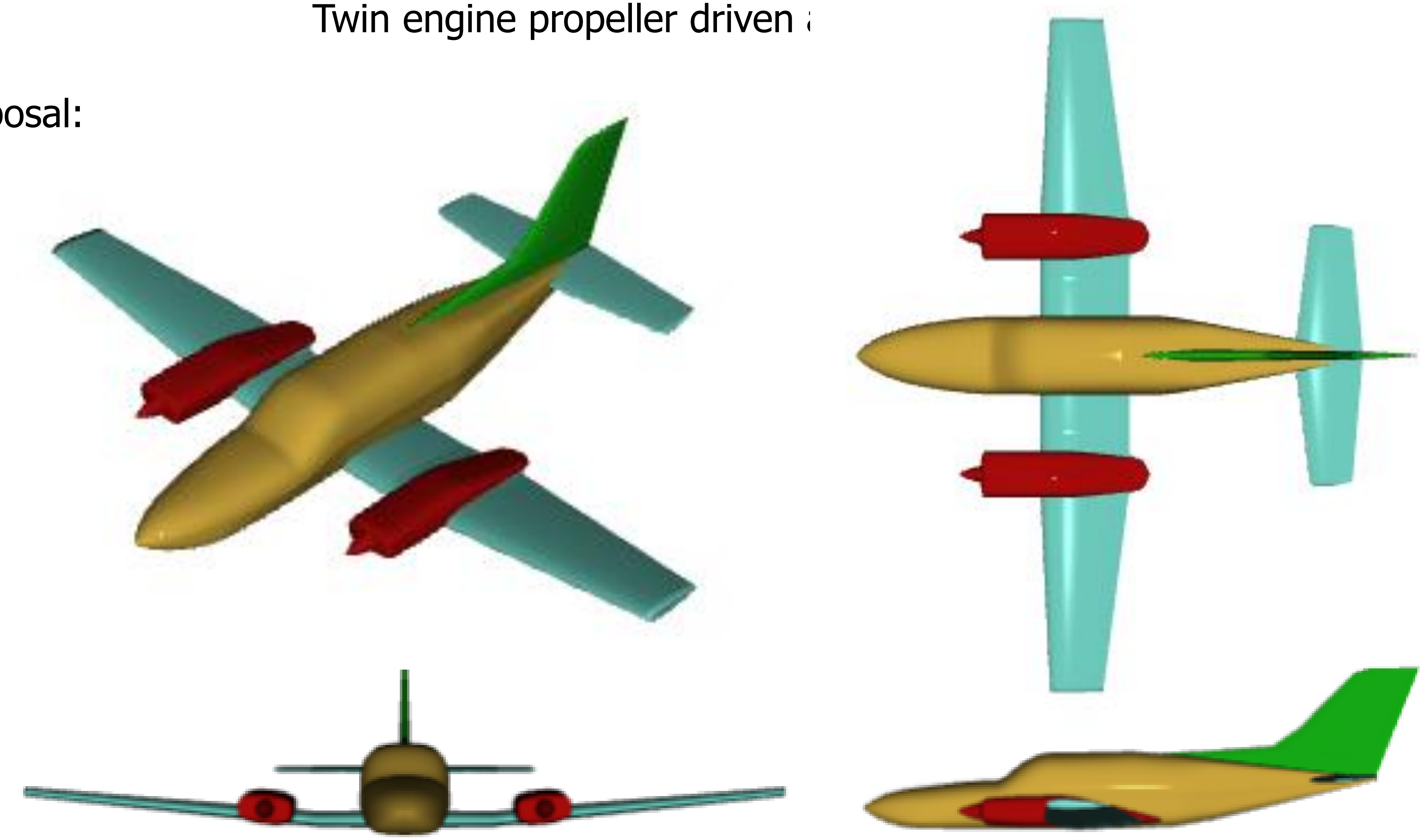


Cessna 340

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven a

Initial proposal:

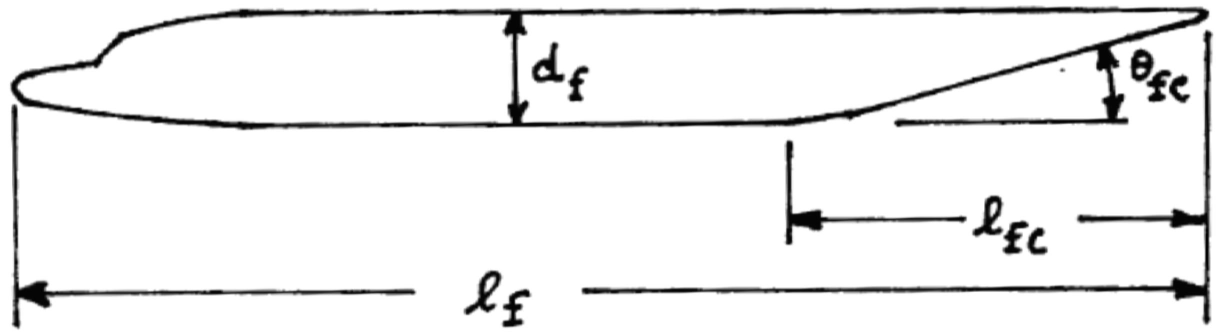


AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Universidad Pontificia Bolivariana
Fundada en 1936

Twin engine propeller driven airplane

Fuselage sizing:



$$l_f = aW_{TO}^C = 0.366(7900 \times 0.453592)^{0.42} = 11.38\,m$$

Checking with baseline fuselage length is smaller, It is decided to adjust this measure:

$$\boxed{l_f = 9.5\,m}$$

Table 6.3 Fuselage Length vs W_0 (lb or {kg})

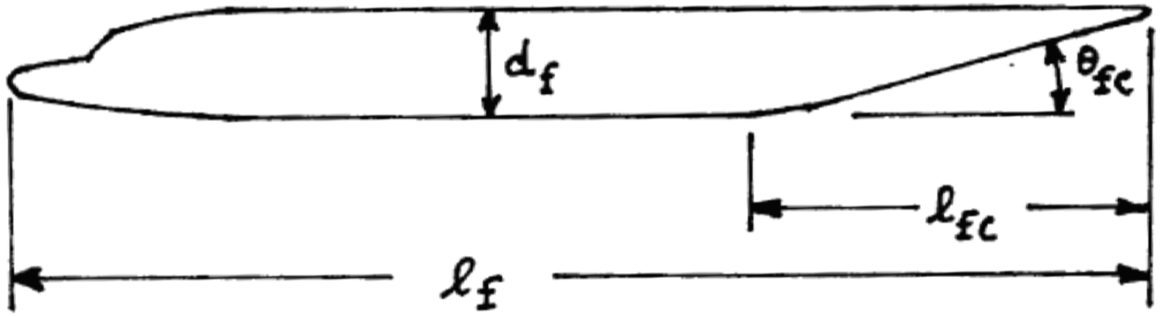
Length $= aW_0^C$ (ft or {m})	a	C
Sailplane—unpowered	0.86 {0.383}	0.48
Sailplane—powered	0.71 {0.316}	0.48
Homebuilt—metal/wood	3.68 {1.35}	0.23
Homebuilt—composite	3.50 {1.28}	0.23
General aviation—single engine	4.37 {1.6}	0.23
General aviation—twin engine	0.86 {0.366}	0.42
Agricultural aircraft	4.04 {1.48}	0.23
Twin turboprop	0.37 {0.169}	0.51
Flying boat	1.05 {0.439}	0.40
Jet trainer	0.79 {0.333}	0.41
Jet fighter	0.93 {0.389}	0.39
Military cargo/bomber	0.23 {0.104}	0.50
Jet transport	0.67 {0.287}	0.43

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Fuselage sizing:

$$l_f = 9.5\,m$$



Assuming:

$$\frac{l_f}{d_f} \approx 6.5 \longrightarrow d_f = \frac{l_f}{6.5} = \frac{9.5}{6.5} = \boxed{1.46\,m}$$

$$\frac{l_{fc}}{d_f} \approx 4.0 \longrightarrow l_{fc} = d_f\,3.5 = 1.46 \times 3.5 = \boxed{5.12\,m}$$

$$\theta_{fc} \approx 12\,deg$$

Table 4.1 Currently Used Geometric Fuselage Parameters

Airplane Type	l_f/d_f	l_{fc}/d_f	θ_{fc} (deg)
Homebuilts	4 - 8	3*	2 - 9
Single Engine	5 - 8	3 - 4	3 - 9
Twins	3.6** - 8	2.6 - 4	6 - 13
Agricultural	5 - 8	3 - 4	1 - 7
Business Jets	7 - 9.5	2.5 - 5	6 - 11
Regionals	5.6 - 10	2 - 4	15 - 19***
Jet Transports	6.8 - 11.5	2.6 - 4	11 - 16
Mil. Trainers	5.4 - 7.5	3*	up to 14
Fighters	7 - 11	3 - 5*	0 - 8
Mil. Transports, Bombers and Patrol Airplanes	6 - 13	2.5 - 6	7 - 25****
Flying Boats	6 - 11	3 - 6	8 - 14
Supersonics	12 - 25	6 - 8	2 - 9

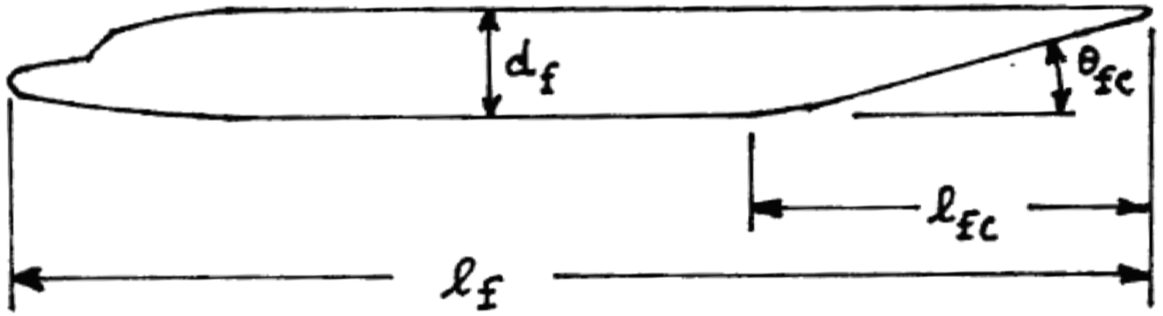
*Tailcone as defined by Figure 4.1 not easily defined
**Cessna 336 (Fig.3.9c) ***Embraer Brasilia (Fig.3.16d)
****Lockheed Hercules (Fig.3.29d)

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Fuselage sizing:

$$d_f = 1.46\, m$$



Fuselage fineness assumes that the cross-section is rounded. For this case, the airplane is not pressurized and checking the baselines cross-section is usually square type in order to accommodate the interior and reduce as much area (cross section) as possible, then:

$$A_{equivalent} = \pi \left(\frac{d_f}{2}\right)^2 = w_f h_f = \boxed{1.68\, m^2}$$

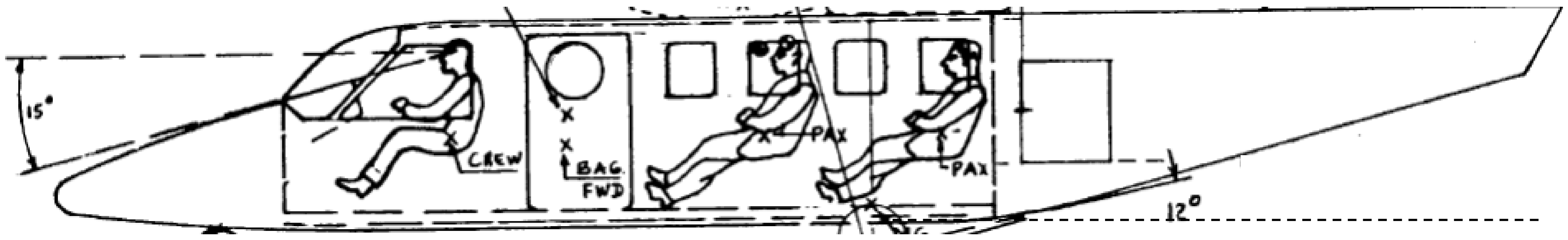
Where:
w_f – fuselage width
h_f – fuselage height

Assuming $w_f = 1.25\, m$, then: $h_f = \dfrac{A_{equivalent}}{w_f} = \dfrac{1.68}{1.25} = \boxed{1.34\, m}$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Fuselage interior arrangement



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Wing sizing:

From **matching chart** result:

$$\begin{cases} \dfrac{W_{TO}}{S_w} = 46\,psf \longrightarrow S_w = \dfrac{W_{TO}}{W_{TO}/S_w} = \dfrac{(7900)(0.453592)}{(46)\left(\dfrac{0.453592}{0.3048^2}\right)} = \boxed{15.96\ m^2} \\ AR = 8.0 \end{cases}$$

$$AR = \frac{b^2}{S_w} \longrightarrow b = \sqrt{AR \times S_w} = \sqrt{(8.0)(15.96)} = \boxed{11.3\ m}$$

Assuming: $\boxed{\lambda_w = \dfrac{c_{tip}}{c_{root}} = 1.0} \longrightarrow c_{root} = \dfrac{2 \cdot S_w}{b(1+\lambda_w)} = \dfrac{2(15.96)}{11.3(1+1)} = \boxed{1.41\ m} \longrightarrow c_{tip} = c_{root}\lambda_w = (1.41)(1.0) = \boxed{1.41\ m}$

$$\bar{c} = \frac{2}{3}c_{root}\frac{(1+\lambda_w+\lambda_w^2)}{(1+\lambda_w)} = \frac{2}{3}(1.41)\frac{(1+(1.0)+(1.0)^2)}{(1+(1.0))} = \boxed{1.41\ m}$$

$$\bar{Y} = \frac{b}{6}\left[\frac{(1+2\lambda_w)}{(1+\lambda_w)}\right] = \frac{11.3}{6}\left[\frac{1+(2)(1.0)}{1+(1.0)}\right] = \boxed{2.82\ m}$$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

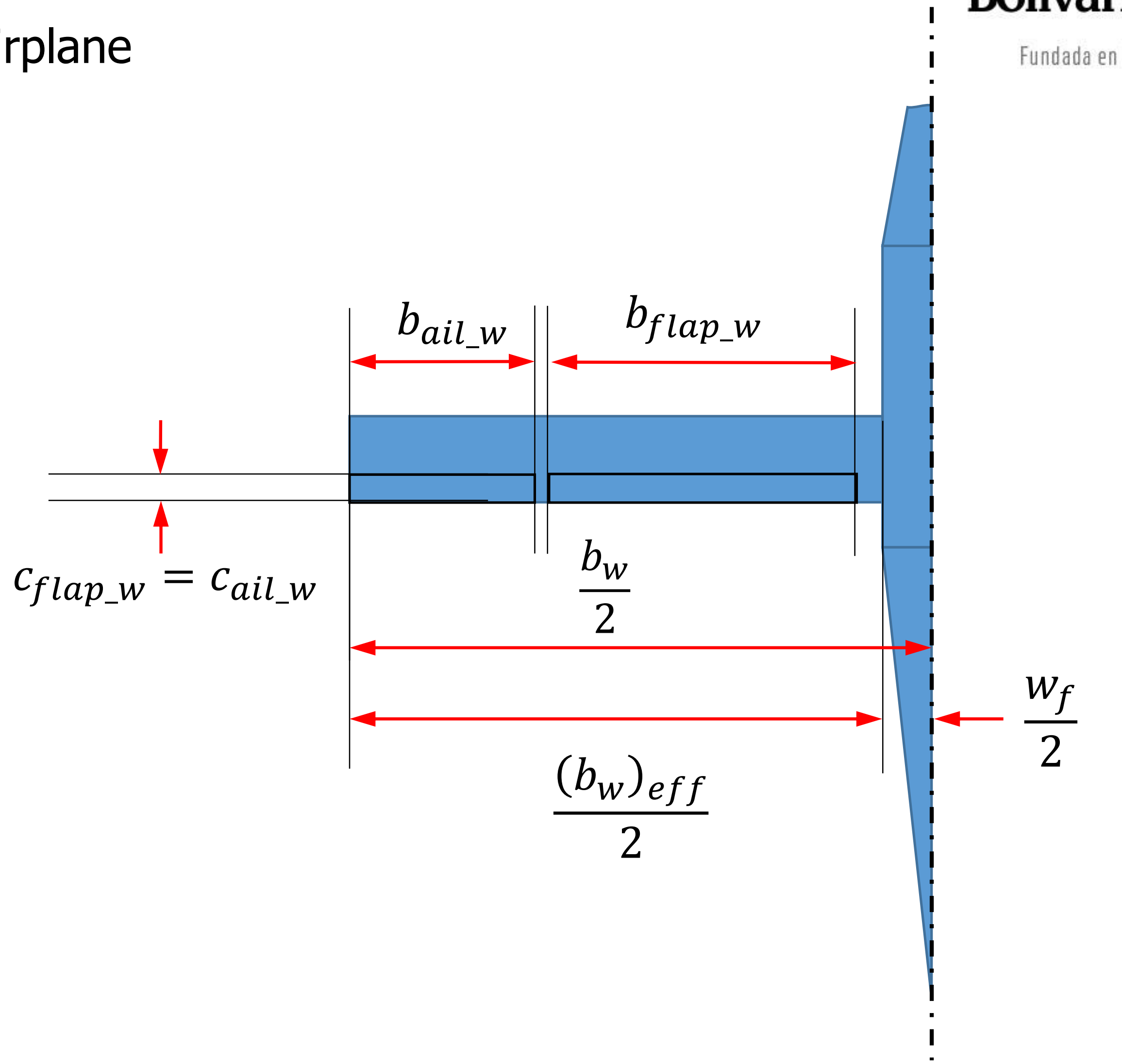
Twin engine propeller driven airplane

Wing sizing:

Assuming: $\begin{cases} \Gamma_w = 5.0\ deg \\ i_w = 2.0\ deg \\ \beta_w = 0.0 \end{cases}$

Table 4.2 Dihedral guidelines

	Wing position		
	Low	Mid	High
Unswept (civil)	5 to 7	2 to 4	0 to 2
Subsonic swept wing	3 to 7	−2 to 2	−5 to −2
Supersonic swept wing	0 to 5	−5 to 0	−5 to 0



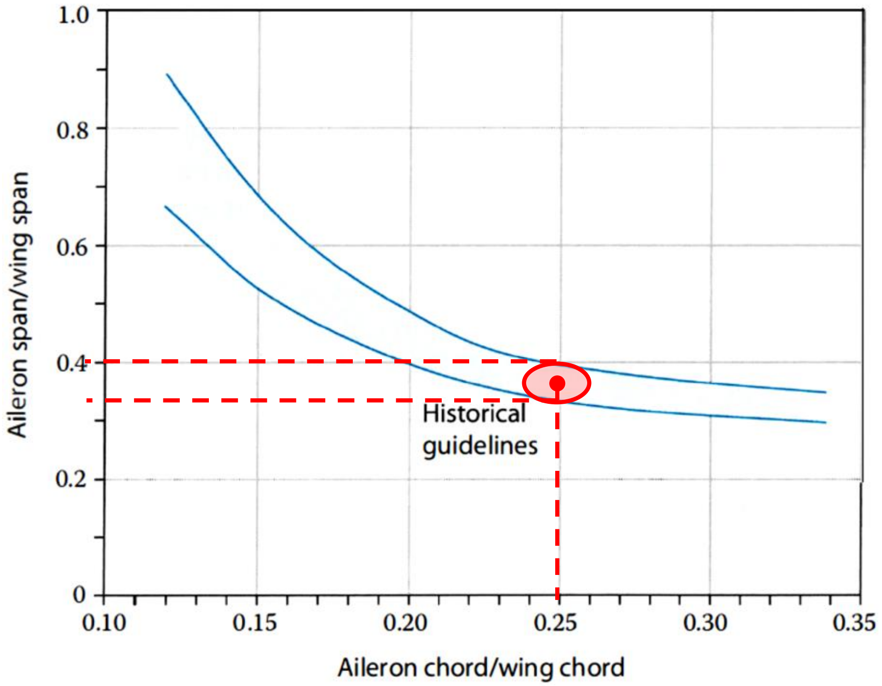
AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Universidad Pontificia Bolivariana
Fundada en 1936

Twin engine propeller driven airplane

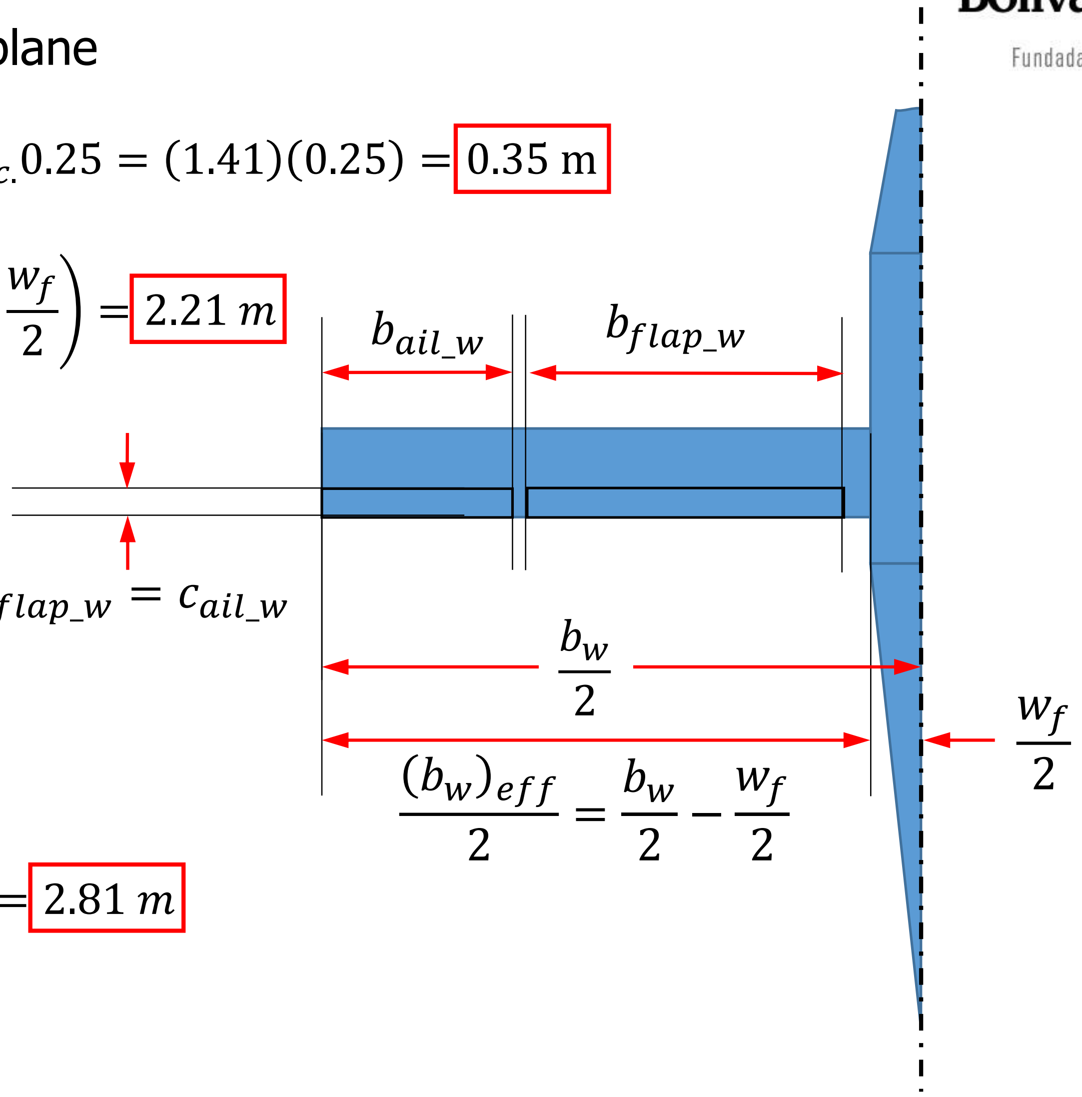
Wing sizing: $\boxed{\dfrac{c_{ail}}{c_{loc.}} = \dfrac{c_{flap}}{c_{loc.}} = 0.25}$ $\rightarrow$ $c_{ail} = c_{flap} = c_{loc.}0.25 = (1.41)(0.25) = \boxed{0.35\ \text{m}}$

Assuming: $\boxed{\dfrac{b_{ail\_w}}{\dfrac{b_w}{2} - \dfrac{w_f}{2}} = 0.44}$ $\rightarrow$ $b_{ail\_w} = 0.44\left(\dfrac{b_w}{2} - \dfrac{w_f}{2}\right) = \boxed{2.21\ m}$



$$\boxed{\dfrac{b_{flap\_w}}{\dfrac{b_w}{2} - \dfrac{w_f}{2}} = 0.56}$$

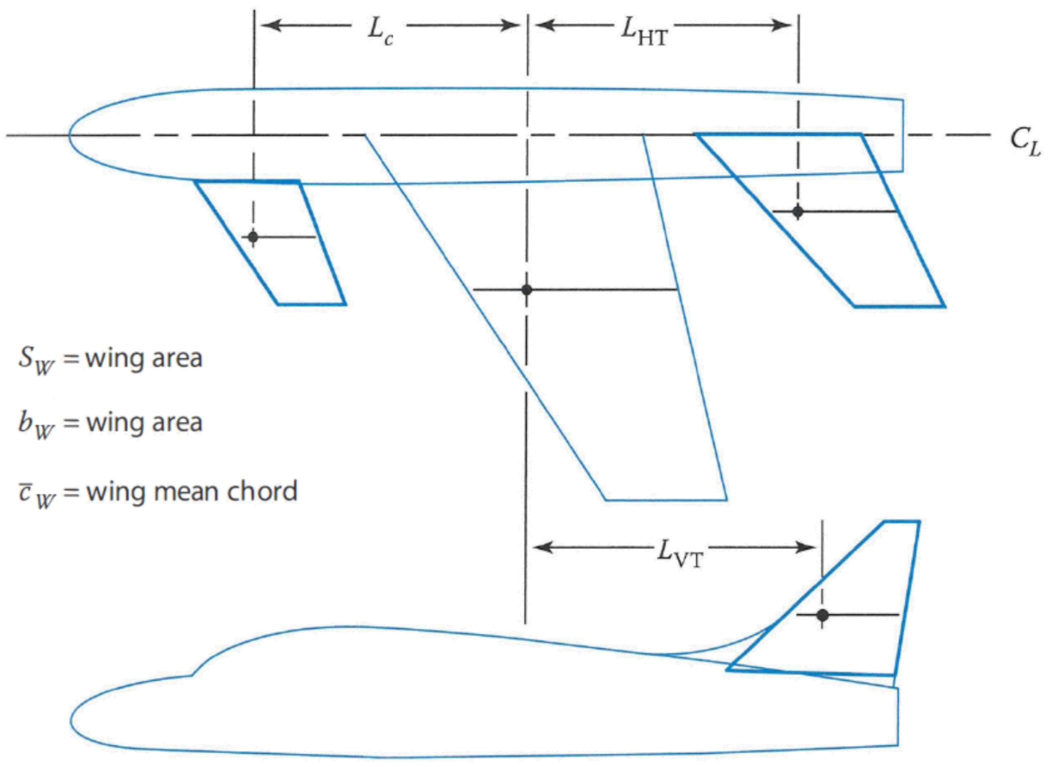
$$b_{flap\_w} = 0.56\left(\dfrac{b_w}{2} - \dfrac{w_f}{2}\right) = \boxed{2.81\ m}$$



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Empennage sizing:



$$\bar{V}_h = \frac{x_h \cdot S_h}{S \cdot \bar{c}}$$

$$\bar{V}_v = \frac{x_v \cdot S_v}{S \cdot b}$$

Table 6.4 Tail Volume Coefficient

	Typical Values	
	Horizontal $\overline{V}_h$	Vertical $\overline{V}_v$
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
General aviation—single engine	0.70	0.04
General aviation—twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07–0.12*
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

*Long fuselage with high wing loading needs larger value.

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Universidad Pontificia Bolivariana

Fundada en 1936

Twin engine propeller driven airplane

Empennage sizing:

Having: $\begin{cases} \bar{V}_h = 0.8 \\ \bar{V}_v = 0.07 \end{cases}$

$$\boxed{\bar{V}_h = \frac{x_h \cdot S_h}{S_w \cdot \bar{c}}} \qquad \boxed{\bar{V}_v = \frac{x_v \cdot S_v}{S_w \cdot b_w}}$$

For aircrafts with the engines mounted on the wings, $x_h = x_v \approx 50\text{-}55\%\ l_f$ $\longrightarrow$ $x_h = x_v = 0.55\ l_f = (0.55)(9.5)$

Knowing: $\boxed{x_h = x_v = 6.26\ m}$

$S_w = 15.96\ m^2$

$b_w = 11.3\ m^2$

$\bar{c} = 1.41\ m$

$$S_h = \frac{\bar{V}_h \cdot S_w \cdot \bar{c}}{x_h} = \frac{(0.8)(15.96)(1.41)}{6.26} = \boxed{2.88\ m^2}$$

$$S_v = \frac{\bar{V}_v \cdot S_w \cdot b_w}{x_v} = \frac{(0.07)(15.96)(11.3)}{6.26} = \boxed{2.02\ m^2}$$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Universidad Pontificia Bolivariana
Fundada en 1936

Twin engine propeller driven airplane

Empennage sizing: Horizontal stabilizer

Table 8.13 Planform Design Parameters for Horizontal Tails

Type	Dihedral Angle, Γ_h deg.	Incidence Angle, i_h deg.	Aspect Ratio, A_h	Sweep Angle, $\Lambda_{c/4_h}$ deg.	Taper Ratio, λ_h
Homebuilts	+5 - -10	0 fixed to variable	1.8 - 4.5	0 - 20	0.29 - 1.0
Single Engine Prop. Driven	0	-5 - 0 or variable	4.0 - 6.3	0 - 10	0.45 - 1.0
Twin Engine Prop Driven	0 - +12	0 fixed to variable	3.7 - 7.7	0 - 17	0.48 - 1.0
Agricultural	0 - +3	0	2.7 - 5.4	0 - 10	0.59 - 1.0
Business Jets	-4 - +9	-3.5 fixed	3.2 - 6.3	0 - 35	0.32 - 0.57
Regional Turbo-Props.	0 - +12	0 - 3 fixed to variable	3.4 - 7.7	0 - 35	0.39 - 1.0
Jet Transports	0 - +11	variable	3.4 - 6.1	18 - 37	0.27 - 0.62
Military Trainers	-11 - +6	0 fixed to	3.0 - 5.1	0 - 30	0.36 - 1.0
Fighters	-23 - +5	0 fixed to variable	2.3 - 5.8	0 - 55	0.16 - 1.0
Mil. Patrol, Bomb and Transports	-5 - +11	0 fixed to variable	1.3 - 6.9	5 - 35	0.31 - 0.8
Flying Boats, Amph. and Float Airplanes	0 - +25	0 fixed	2.2 - 5.1	0 - 17	0.33 - 1.0
Supersonic Cruise Airplanes	-15 - 0	0 fixed to variable	1.8 - 2.6	32 - 60	0.14 - 0.39

$$\boxed{\begin{aligned}\Gamma_h &= 0.0\\ i_h &= 0.0\\ AR_h &= 6.5\\ \lambda_h &= 1.0\end{aligned}}$$

$$AR_h = \frac{b_h^2}{S_h} \rightarrow b_h = \sqrt{AR_h \times S_h} = \sqrt{(6.5)(2.88)} = \boxed{4.33\ m}$$

$$\lambda_h = \frac{c_{tip}}{c_{root}} \rightarrow c_{root} = c_{tip} = \frac{2 \cdot S_h}{b_h(1+\lambda_h)} = \frac{2(2.88)}{4.33(1+1)} = \boxed{0.67\ m}$$

Table 6.5 Control Surface Sizing Guidelines

Aircraft	Elevator C_e/C	Rudder C_r/C
Fighter/attack	0.30*	0.30
Jet transport	0.25†	0.32
Jet trainer	0.35	0.35
Biz jet	0.32†	0.30
GA single	0.45	0.40
GA twin	0.36	0.46
Sailplane	0.43	0.40

*Supersonic usually all-moving tail without separate elevator.
†Often all-moving plus elevator.

$$\frac{c_{elev}}{c_{loc.}} = 0.36 \rightarrow c_{elev} = 0.36 c_{loc.} = \boxed{0.24\ m}$$

$$b_h = b_{elev} = \boxed{4.33\ m}$$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Empennage sizing: Vertical stabilizer

Table 8.14 Planform Design Parameters for Vertical Tails

Type	Dihedral Angle, Γ_v deg.	Incidence Angle, i_v deg.	Aspect Ratio, A_v	Sweep Angle, $\Lambda_{c/4_v}$ deg.	Taper Ratio, λ_v
Homebuilts	90	0	0.4 - 1.4	0 - 47	0.26 - 0.71
Single Engine Prop. Driven	90	0	0.9 - 2.2	12 - 42	0.32 - 0.58
Twin Engine Prop Driven	90	0	0.7 - 1.8	18 - 45	0.33 - 0.74
Agricultural	90	0	0.6 - 1.4	0 - 32	0.43 - 0.74
Business Jets	90	0	0.8 - 1.6	28 - 55	0.30 - 0.74
Regional Turbo-Props.	90	0	0.8 - 1.7	0 - 45	0.32 - 1.0
Jet Transports	90	0	0.7 - 2.0	33 - 53	0.26 - 0.73
Military Trainers	90	0	1.0 - 2.9	0 - 45	0.32 - 0.74
Fighters	75 - 90	0	0.4 - 2.0	9 - 60	0.19 - 0.57
Mil. Patrol, Bomb and Transports	90	0	0.9 - 1.9	0 - 37	0.28 - 1.0
Flying Boats, Amph. and Float Airplanes	90	0	1.2 - 2.4	0 - 32	0.37 - 1.0
Supersonic Cruise Airplanes	75 - 90	0	0.5 - 1.8	37 - 65	0.20 - 0.43

$$\Gamma_v = 0.0$$
$$i_v = 0.0$$
$$AR_v = 1.6$$
$$\lambda_v = 1.0$$

$$AR_v = \frac{b_v^2}{S_v} \rightarrow b_v = \sqrt{AR_v \times S_v} = \sqrt{(1.6)(2.02)} = \boxed{1.8\,m}$$

$$\lambda_v = \frac{c_{tip}}{c_{root}} \rightarrow c_{root} = c_{tip} = \frac{2 \cdot S_v}{b_v(1+\lambda_v)} = \frac{2(2.02)}{1.8(1+1)} = \boxed{1.12\,m}$$

Table 6.5 Control Surface Sizing Guidelines

Aircraft	Elevator C_e/C	Rudder C_r/C
Fighter/attack	0.30*	0.30
Jet transport	0.25†	0.32
Jet trainer	0.35	0.35
Biz jet	0.32†	0.30
GA single	0.45	0.40
GA twin	0.36	0.46
Sailplane	0.43	0.40

*Supersonic usually all-moving tail without separate elevator.
†Often all-moving plus elevator.

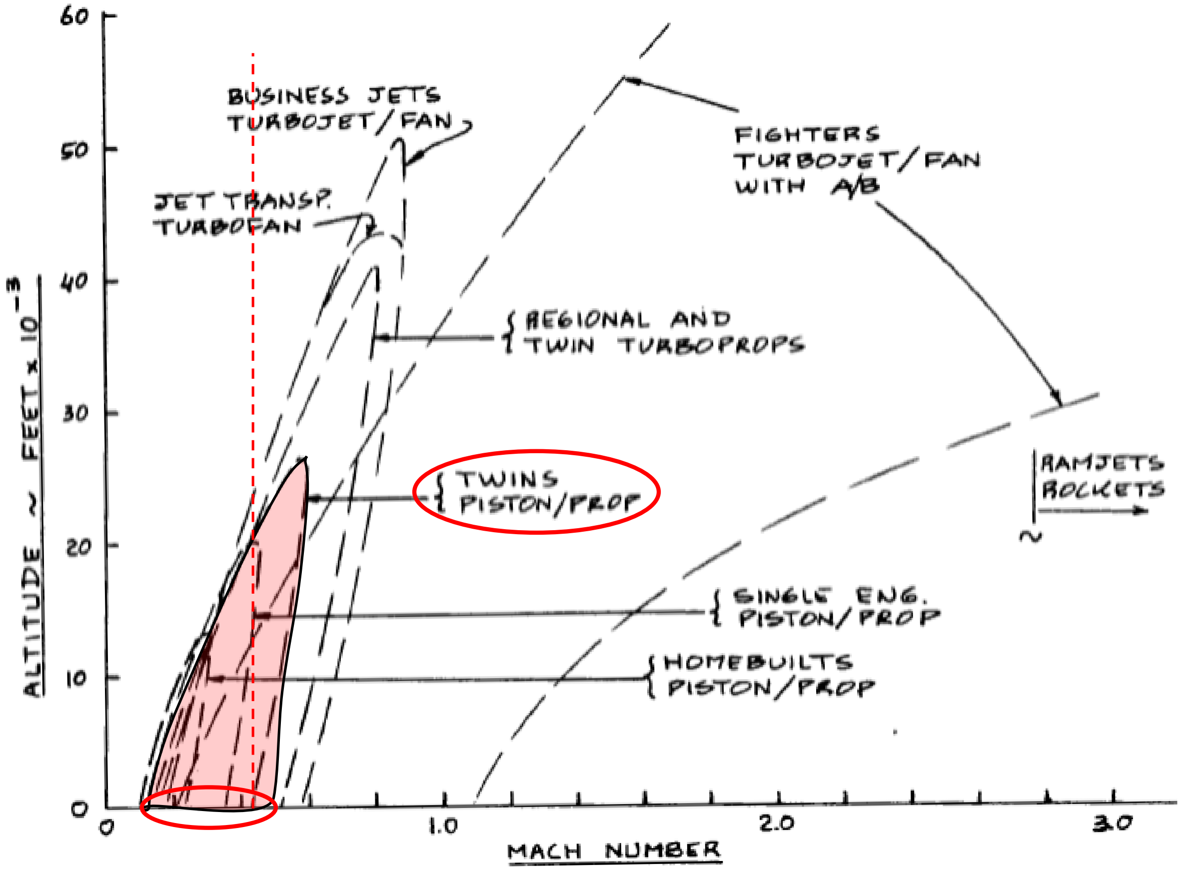
$$\frac{c_{rud.}}{c_{loc.}} = 0.46 \rightarrow c_{rud.} = 0.46 c_{loc.} = \boxed{0.516\,m}$$

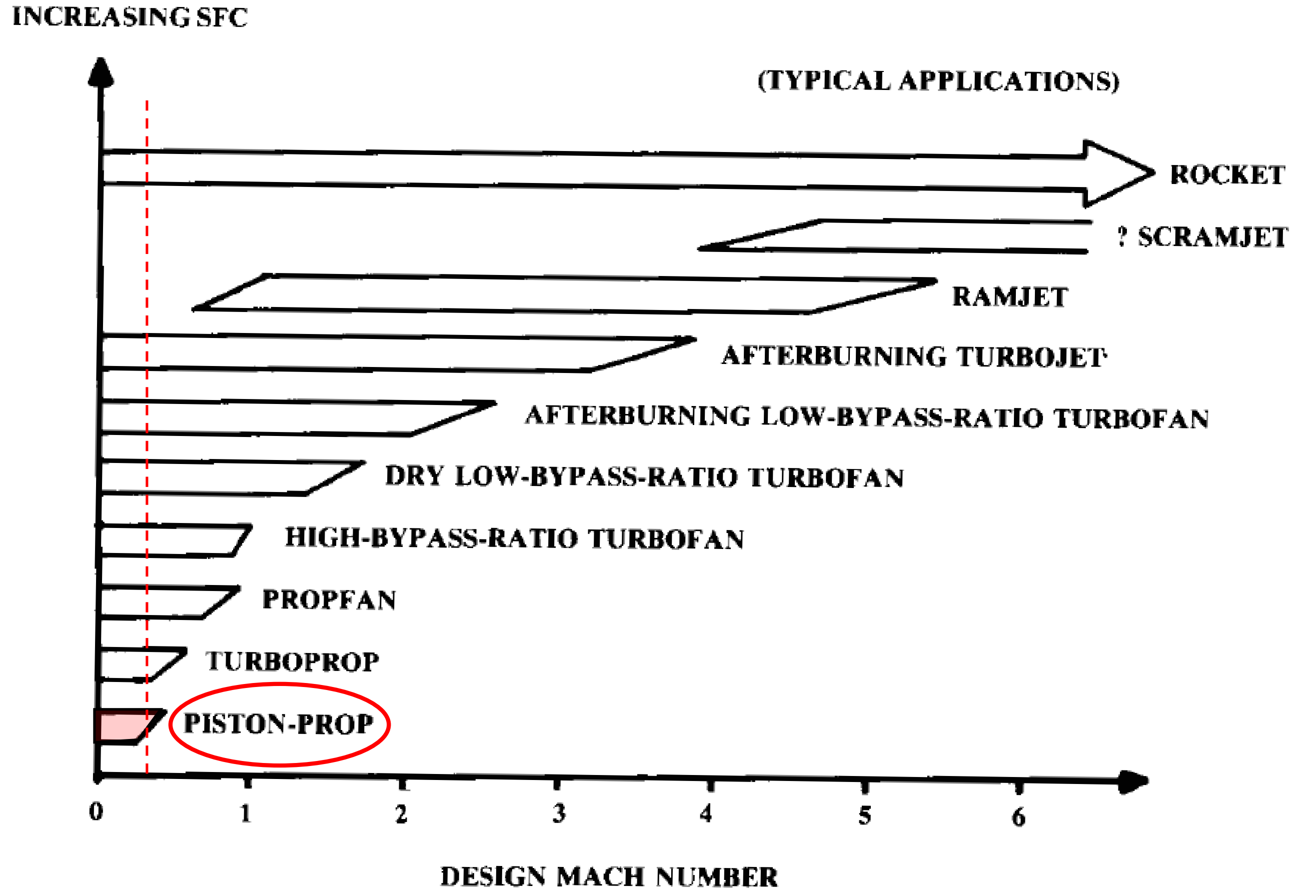
$$b_v = b_{rud.} = \boxed{1.8\,m}$$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Engine selection:





AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Engine selection:

$$D_p = \sqrt{\frac{4 \cdot P_{\max}}{\pi \cdot n_p \cdot P_{bl}}}$$

From matching chart results:

$$\frac{W_{TO}}{P_{TO}} = 8.8\ \frac{lb}{hp} \rightarrow P_{TO} = \frac{W_{TO}}{W_{TO}/P_{TO}} = \frac{7900}{8.8} = \boxed{897.73\ hp}$$

Engine selected is a Continental $TSIO$-520-$AE/LGTSIO$-520-F turbocharged air-cooled flat-six piston engine with $425.0\ hp$

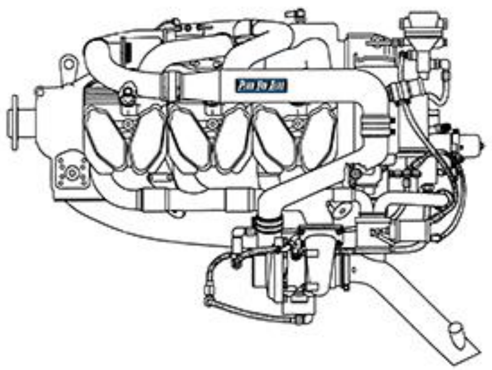


Table 5.4 Relation Between Max. Engine Power, Propeller Diameter and Number of Propeller Blades for Twin Engine FAR23 and for Regional Turbopropeller Driven Airplanes

Airplane Type	Prop. Pitch	Max. Power per Engine, P_{max}, hp	Prop. Diam., D_p, ft	Number of Prop. Blades, n_p	Power Loading per Blade, P_{bl}, hp/ft^2
Twin Engine FAR23 Certified Airplanes					
PIPER					
PA-31 Navajo	C.Spd	325	6.7	3	3.1
PA-31T Chey. II	C.Spd	620	7.8	3	4.3
CESSNA					
T303	C.Spd	250	6.2	3	2.8
340A	C.Spd	310	6.4	3	3.2
Conquest I	C.Spd	450	7.8	3	3.1
Conquest II	C.Spd	636	7.5	3	4.8
BEECH					
Baron 95-B55	C.Spd	260	6.5	2	3.9
Duke B60	C.Spd	380	6.2	3	4.2
King Air C90-1	C.Spd	550	7.8	3	3.8
BN2B Islander	C.Spd	260	6.5	2	3.9
					P_{bl} range: 2.8-4.8
Regional Turbopropeller Driven Airplanes					
EMB-110 Bandar.	C.Spd	750	7.8	3	5.2
EMB-120 Brasil.	C.Spd	1,500	10.5	4	4.3
SF-340	C.Spd	1,630	10.5	4	4.7
Fokker F27-200	C.Spd	2,140	11.5	4	5.2
Brit.Aer. 748	C.Spd	2,280	12.0	4	5.0
Casa Nurt. 235	C.Spd	1,700	10.8	4	4.6
Beech C99	C.Spd	715	7.8	3	5.0
Beech 1900	C.Spd	1,100	9.1	4	4.2
ATR-42	C.Spd	1,800	13.0	4	3.4
IAI Arava 201	C.Spd	750	8.5	3	4.4
					P_{bl} range: 3.4-5.2

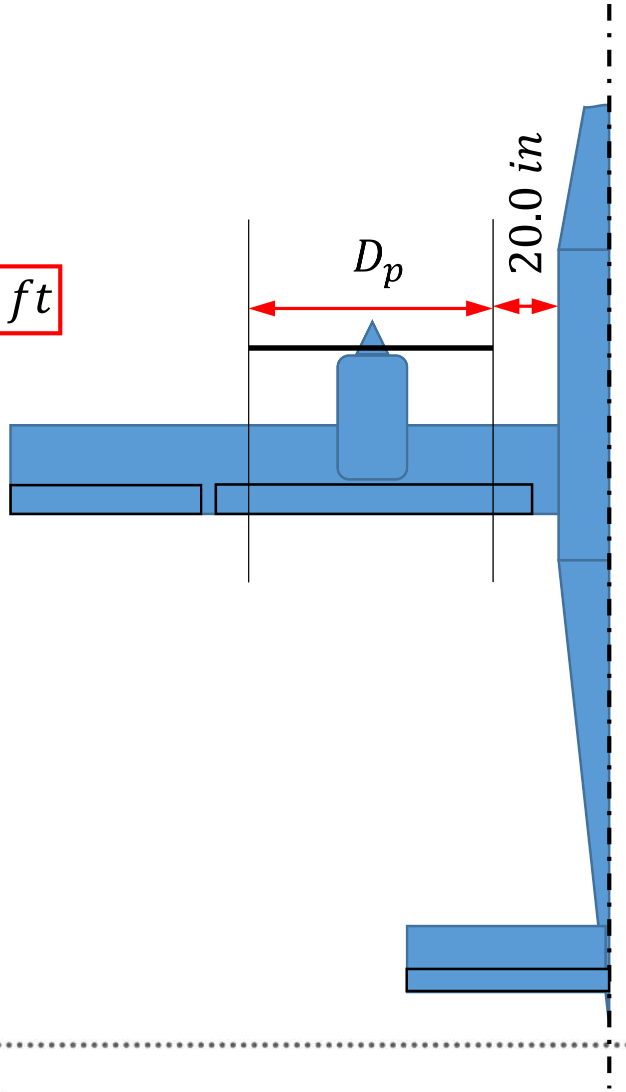
Note: $P_{bl} = 4P_{max}/\pi n_p D_p^2$

AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Engine selection:

$$D_p = \sqrt{\frac{4 \cdot P_{\max}}{\pi \cdot n_p \cdot P_{bl}}} = \sqrt{\frac{4(425)}{\pi(3)(3.2)}} = \boxed{7.51\ ft}$$



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Conquest I	C.Spd	450	7.8	3	3.1
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BEECH					
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BN2B Islander	C.Spd	260	6.5	2	3.9
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Regional Turbopropeller Driven Airplanes					
EMB-110 Bandar.	C.Spd	750	7.8	3	5.2
EMB-120 Brasil.	C.Spd	1,500	10.5	4	4.3
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			P_{bl} range: 3.4-5.2		

Note: $P_{bl} = 4P_{max}/\pi n_p D_p^2$

$\frac{W_f}{2}$

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AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

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Fundada en 1936

Twin engine propeller driven airplane

W&B:

Table 15.2 Approximate Empty Weight Buildup

	Fighters		Transport & Bomber		General Aviation		Multiplier	Approximate Location
	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2		
Wing	9	44	10	49	2.5	12	$S_{exposed\ planform}$	40% MAC
Horizontal tail	4	20	5.5	27	2	10	$S_{exposed\ planform}$	40% MAC
Vertical tail	5.3	26	5.5	27	2	10	$S_{exposed\ planform}$	40% MAC
Fuselage	4.8	23	5	24	1.4	7	$S_{wetted\ area}$	40–50% length
	Weight Ratio		Weight Ratio		Weight Ratio			
Landing gear*	0.033		0.043		0.057		TOGW	centroid
Landing gear—Navy	0.045		—		—		TOGW	centroid
Installed engine	1.3		1.3		1.4		Engine weight	centroid
"All-else empty"	0.17		0.17		0.1		TOGW	40–50% length

*15% to nose gear, 85% to main gear; reduce gear weight by 0.014 W_0 if fixed gear.

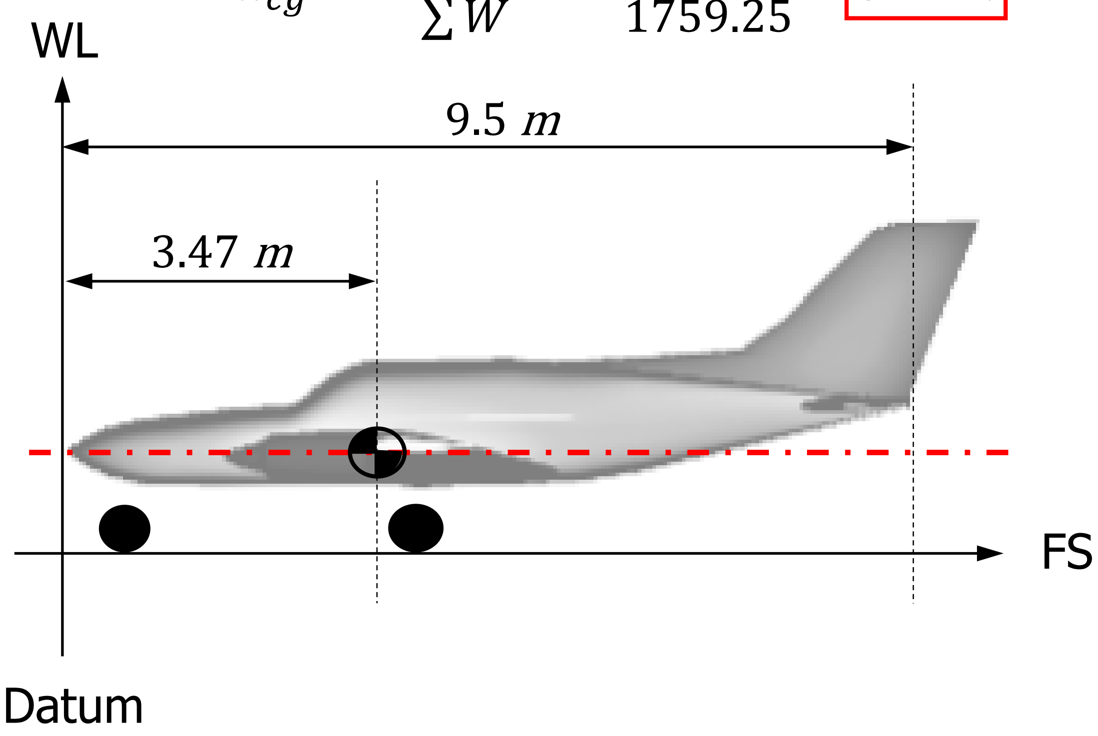
AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

W&B:

W&B Component	GA kg/m^2	Multiplier	W [kg]	FS [m]	W*FS [kg*m]
Wing	12 kg/m^2	15.96 m^2	191.46	3.54	677.25
Horizontal tail	10 kg/m^2	2.88 m^2	28.79	9.10	262.01
Vertical tail	10 kg/m^2	2.02 m^2	20.15	8.83	177.89
Fuselage	7 kg/m^2	~ 61.6 m^2	439.60	4.28	1879.29
Landing gear	5.7 %	3583.38 kg	204.25	2.50	510.63
Installed engine	1.4 %	220.0 kg	308.00	3.10	954.80
W_E	**-**	**-**	**1192.26**	**3.74**	**4461.87**
Crew	-	-	79.38 kg	1.80	142.88
Baggage	-	-	90.72 kg	3.50	317.51
Payload	-	-	396.89 kg	3.00	1190.68
		$\Sigma W =$	**1759.25**	**$\Sigma(W*FS) = 6112.94$**	

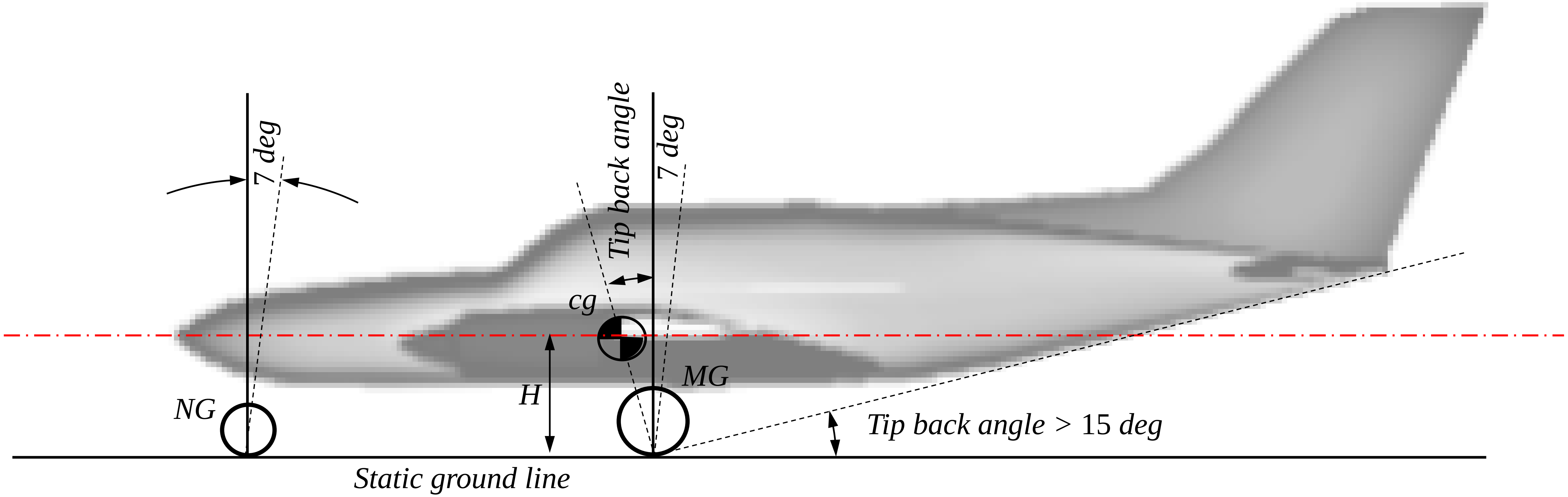
$$x_{cg} = \frac{\sum W * FS}{\sum W} = \frac{6112.94}{1759.25} = \boxed{3.47\ m}$$



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

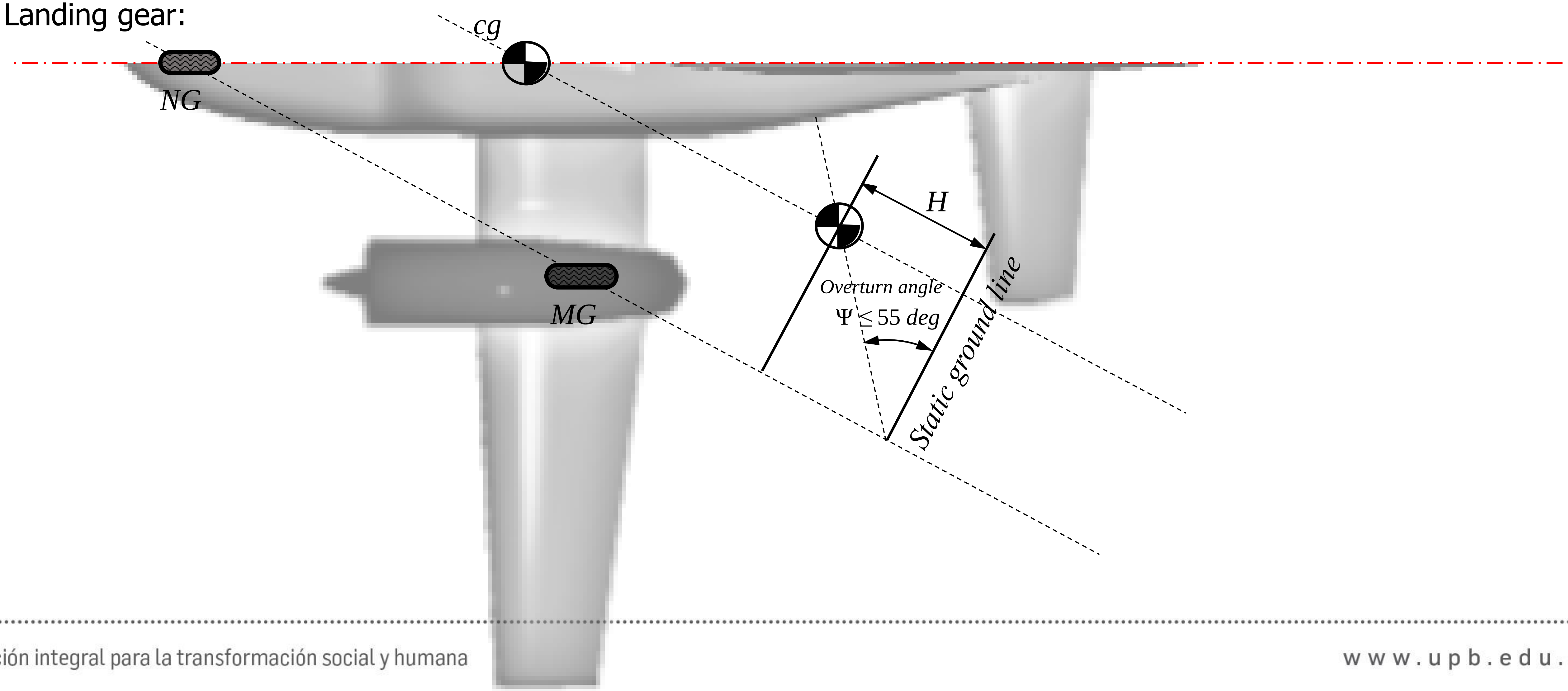
Landing gear:



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

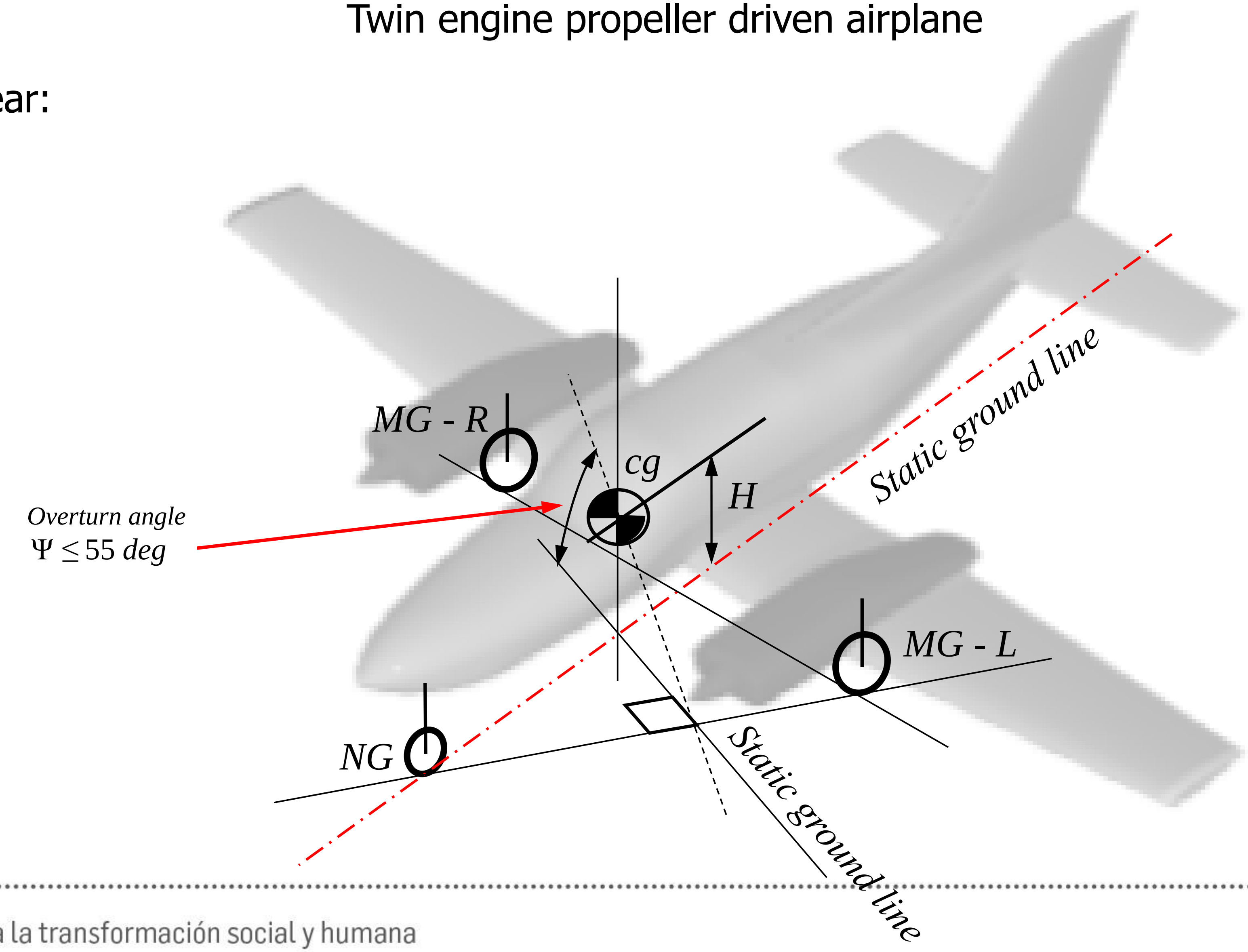
Landing gear:



AIRCRAFT INITIAL SIZING BY STATISTICS – EXAMPLE

Twin engine propeller driven airplane

Landing gear:



AIRCRAFT CHARACTERISTICS EXTRA FEATURES

As usual it must be remained that the results and configuration obtained at the end of the design process/phase will probably change as the design evolve (time)

In addition to a large number of technical considerations, configuration design is also influenced by marketing, emotional and styling considerations among others

Technical considerations that play a role in the selection of the overall configuration:

1. It is nearly always desirable to place:

$$\left.\begin{array}{l} \bullet \quad W_f \; c.g. \\ \bullet \quad W_{payload} \; c.g. \\ \bullet \quad W_E \; c.g. \end{array}\right\}$$

at the same longitudinal location – **this will limit the $c.g.$ travel**

Limiting the $c.g.$ travel results in a configuration with **less wetted area** due to less need for trim control power

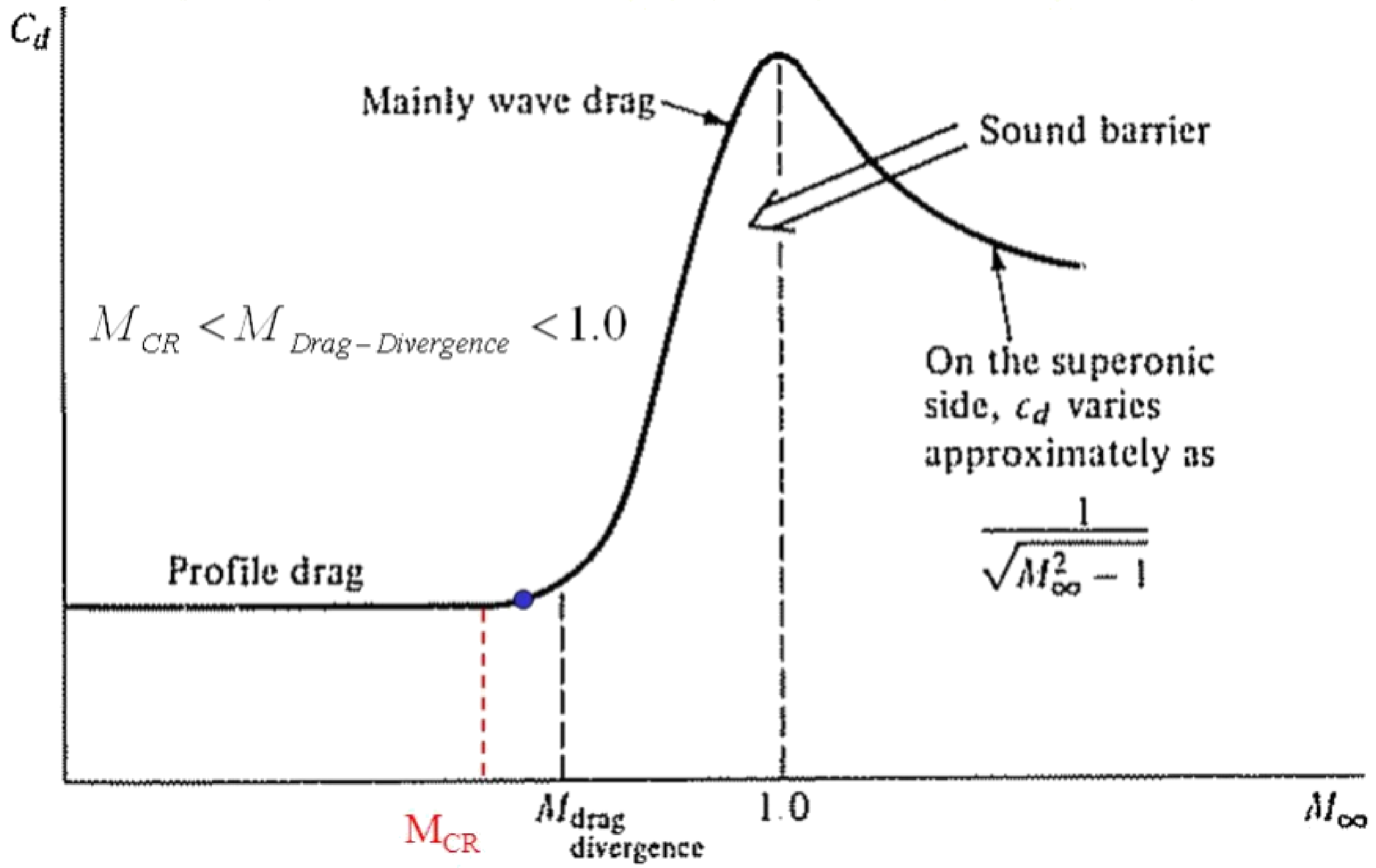
AIRCRAFT CHARACTERISTICS EXTRA FEATURES

Technical considerations that play a role in the selection of the overall configuration:

2. The critical *Mach* number of the wing of a subsonic airplane should be selected such that the airplane does not cruise too far into the drag rise

Key factors:

- Wing sweep angle
- Aerofoil type
- Aerofoil thickness (*t/c*)



AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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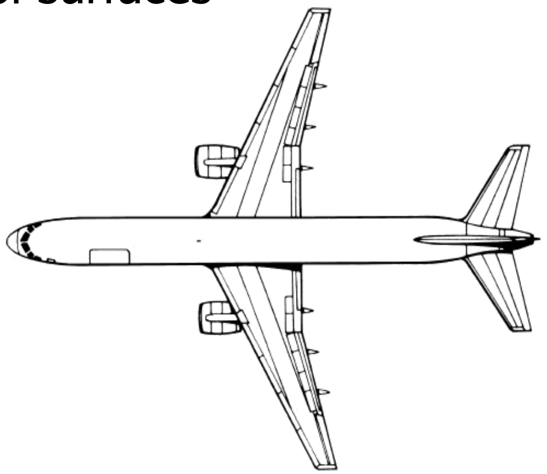
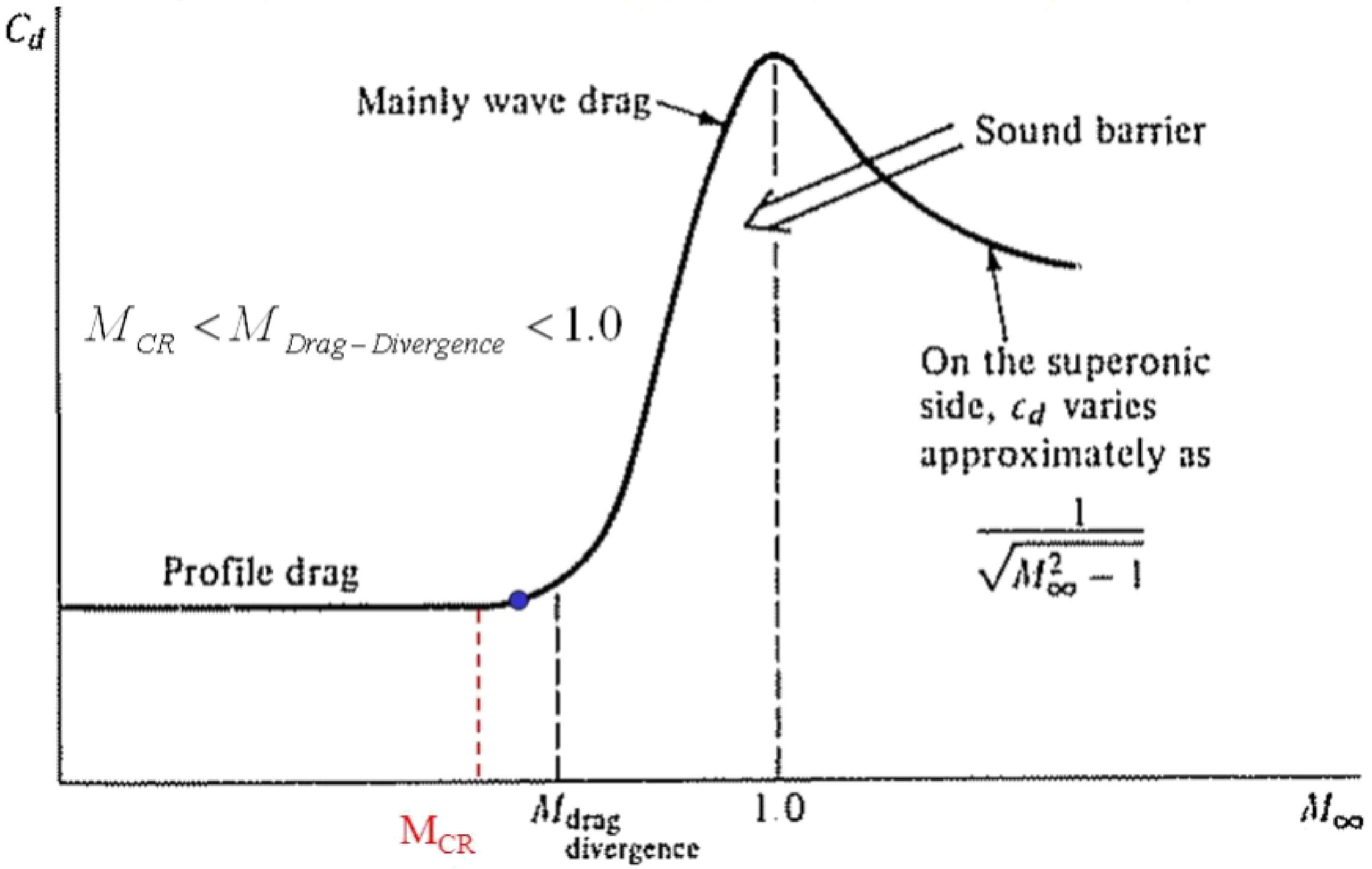
Technical considerations that play a role in the selection of the overall configuration:

3. The ***critical Mach* number of the wing should always be lower than the *critical Mach*** number of the stabilizing or control surfaces

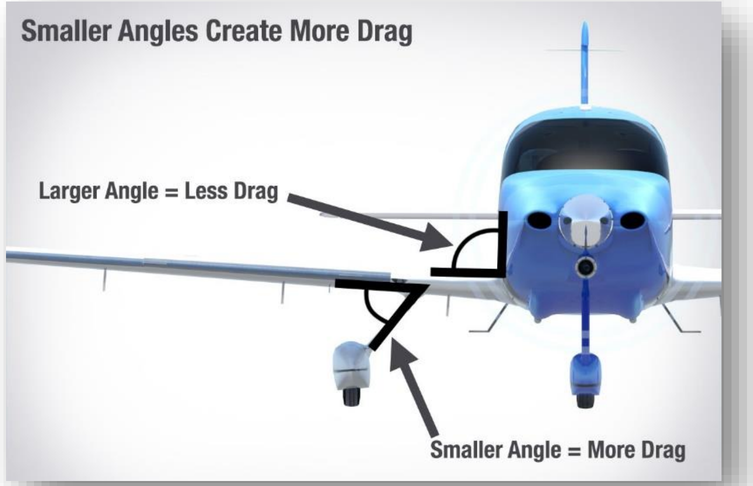


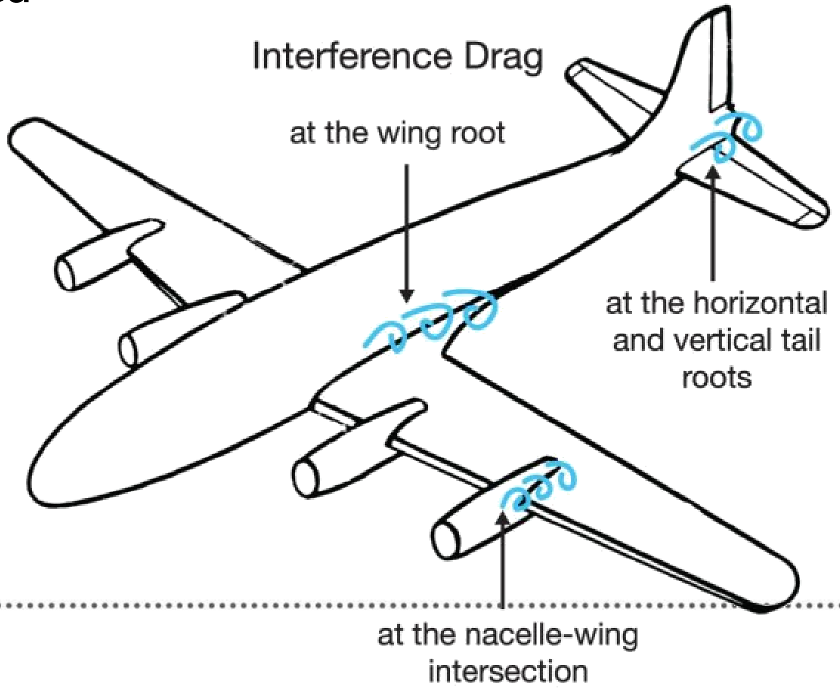


AIRCRAFT CHARACTERISTICS EXTRA FEATURES

Technical considerations that play a role in the selection of the overall configuration:

4. The integration of major components such as the nacelle on the wing, nacelle on the fuselage, wing on fuselage and so on needs to be done so that interference drag is minimized





AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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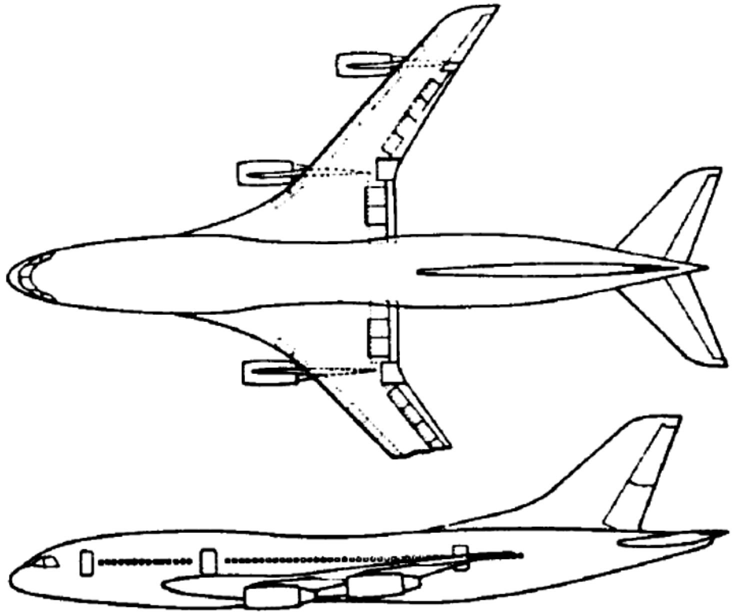
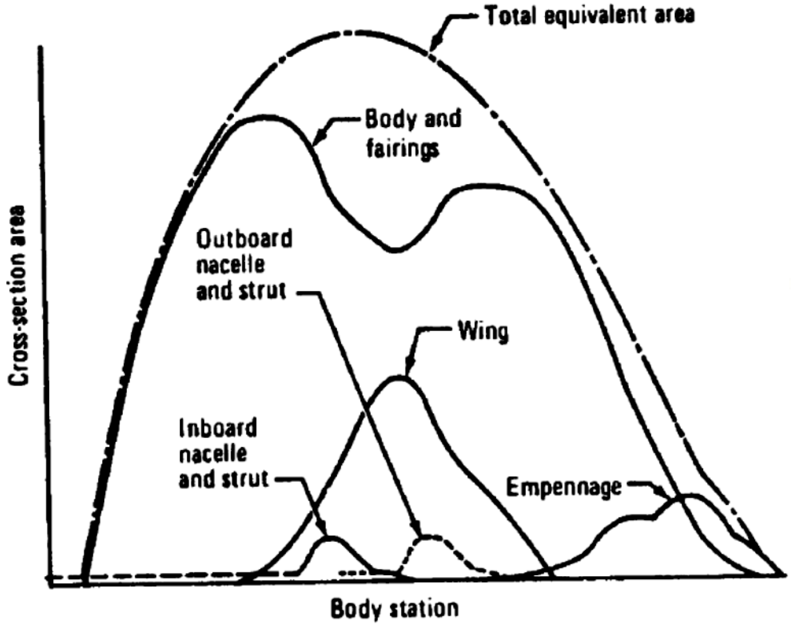
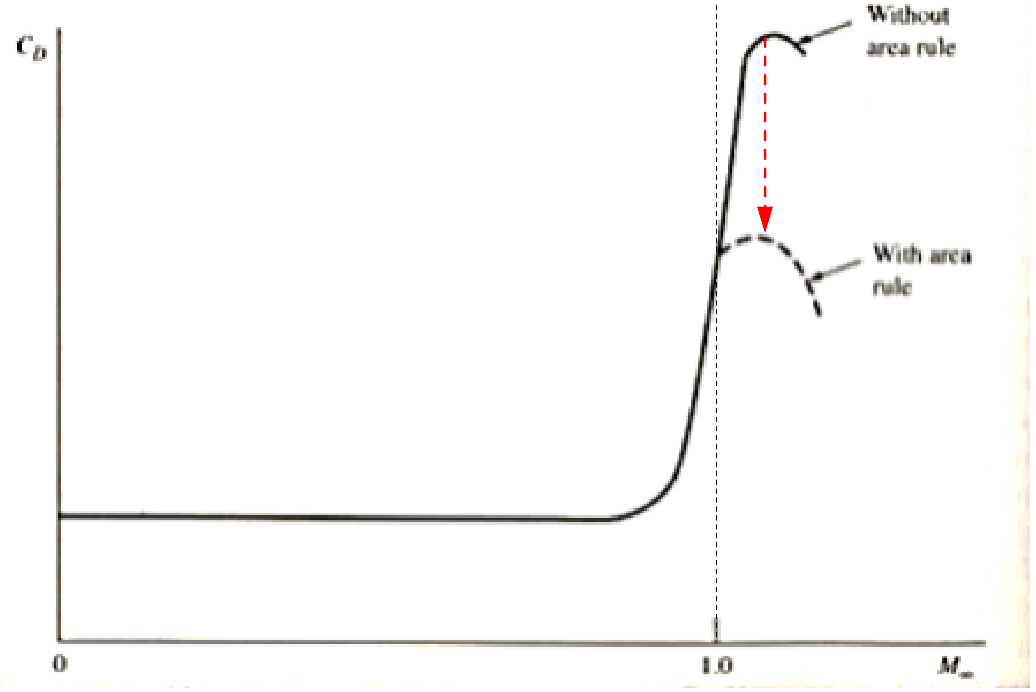




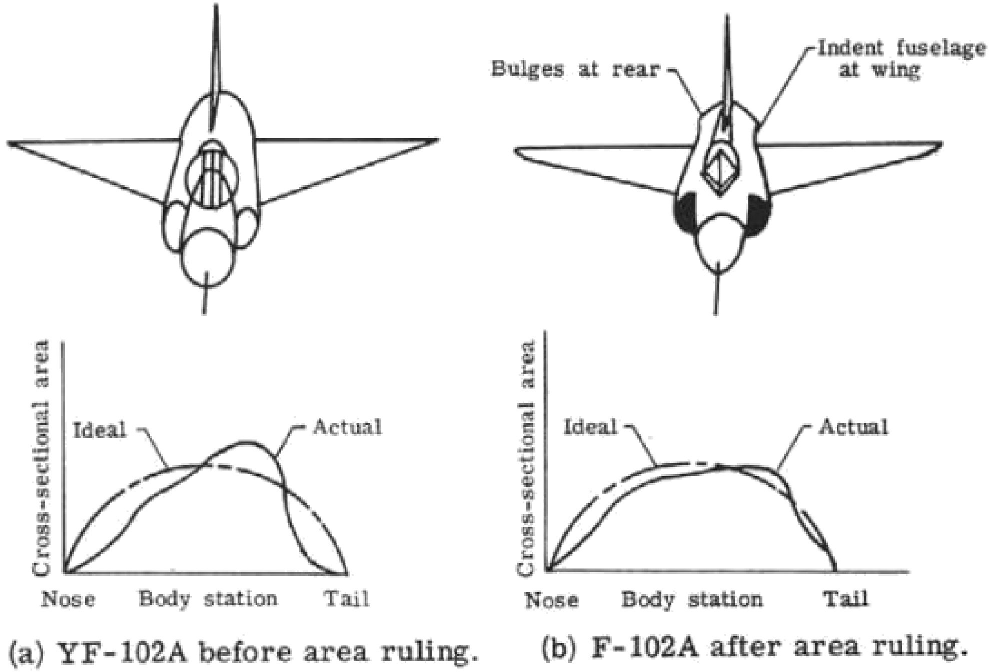


At high speeds – **area rule** (reduce subsonic wave drag)

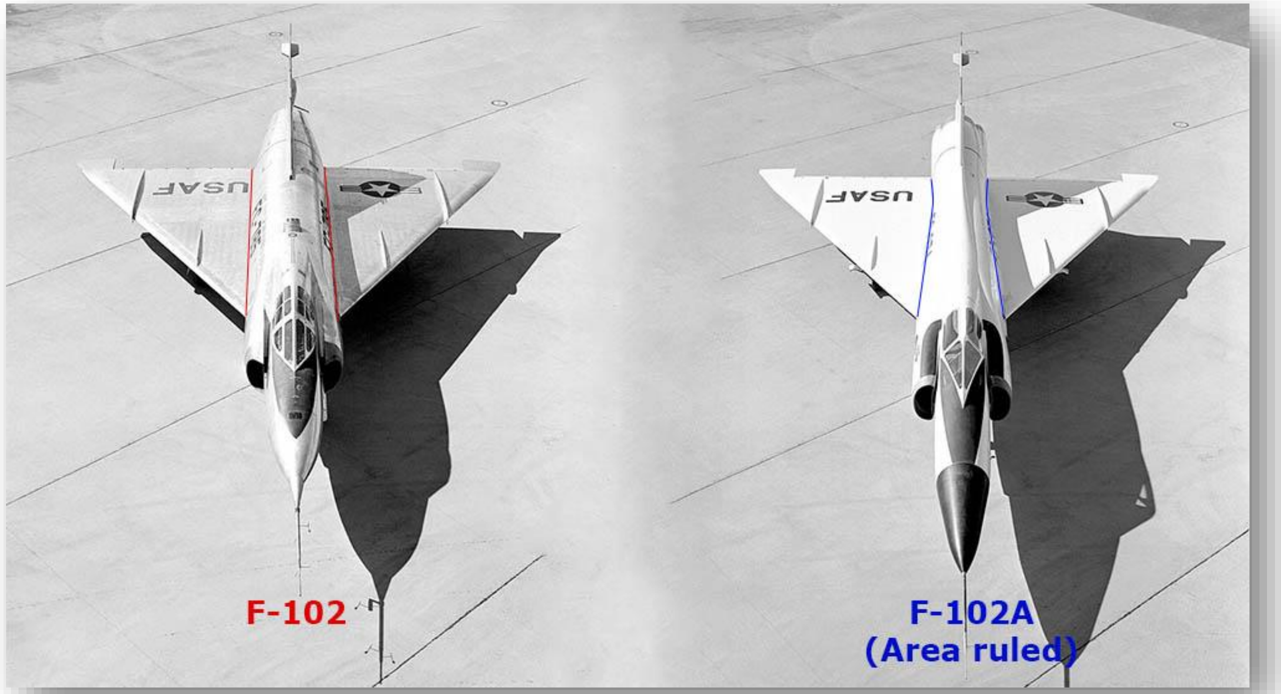
AIRCRAFT CHARACTERISTICS EXTRA FEATURES

Technical considerations that play a role in the selection of the overall configuration:

5. In fighter aircraft with requirements of supersonic cruise performance or supersonic manoeuvring performance the wave drag becomes an essential design consideration



Shape of the cross sectional area distribution



AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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Technical considerations that play a role in the selection of the overall configuration:

6. Major intersecting structural components should be arranged to avoid duplication of special heavy structure

<u>Structural synergism</u>

SYNERGISM CONSIDERATIONS

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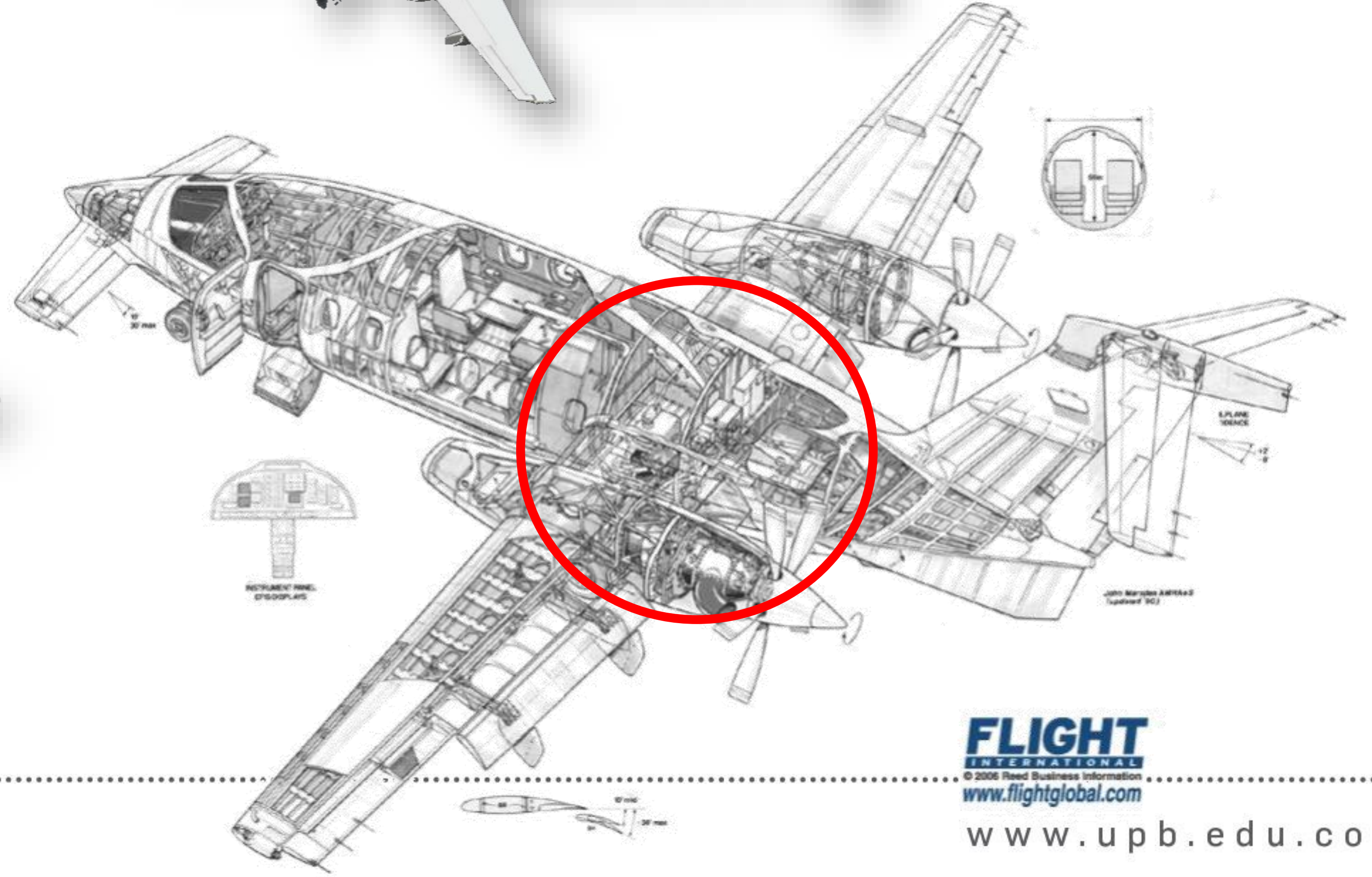
In some cases it is possible by a unique combination of structural components to achieve a particularly favourable ratio of empty weight to Take-Off weight

As an example, the *GP180* aircraft have the wing torque box, the rear pressure bulkhead and the main landing gear essentially attached to a common fuselage structure

Couple with the favourable wing/fuselage intersection (mid wing) and a significant synergism has been achieve



SYNERGISM CONSIDERATIONS

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Case study: History of the design of the *Boeing 727*

In the early stages of design study the landing gear was retracted into *Küchemann* bodies, so there was no acceptable spot for the APU and the rear cargo door was simply too small

By deciding to retract the gear into the fuselage (via a Yehudi in the wing) which resulted in the need for a local enlargement of the fuselage cross section, sufficient room was created for the APU as well as for a cargo door of acceptable size

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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Technical considerations that play a role in the selection of the overall configuration:

7. In deciding on the location of the major airplane components:

THINK LIGHT, THINK SIMPLE, THINK ACCESSIBILITY, THINK MAINTAINABILITY AND THINK COST!

Configurations are often selected as an outgrowth of an existing configuration (used for large airplane companies)

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

CRASHWORTHINESS CONSIDERATIONS

Careful design can reduce the probability of injury in a moderate crash. Some obvious suggestion can be made in relation with the placing of the propeller and with the fuel tank near the passengers deck

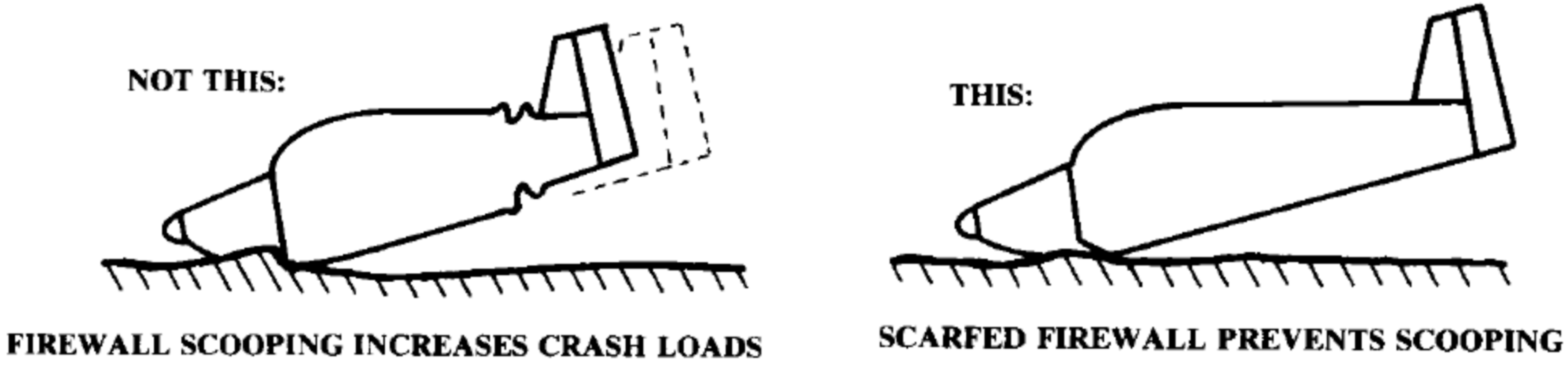
Common sense will avoid many crashworthiness problems, for example, things will break loose and fly forward during crash

It should be consider the secondary damage, for example, landing gear and engine nacelles will frequently be ripped away during a crash. If possible, they should be located so that they no rip open fuel tanks in the process

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

CRASHWORTHINESS CONSIDERATIONS

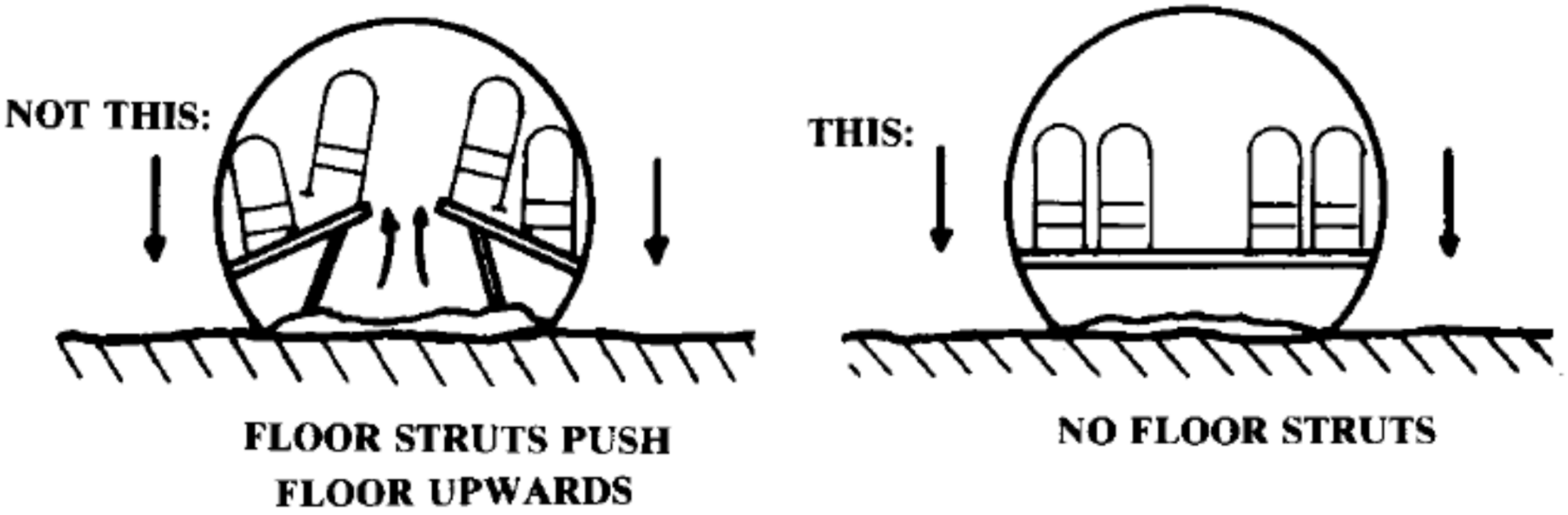
A normal, vertical firewall in a propeller aircraft has a sharp lower corner which tends to dig into the ground, stopping the aircraft dangerously in, therefore reducing the deceleration



AIRCRAFT CHARACTERISTICS EXTRA FEATURES

CRASHWORTHINESS CONSIDERATIONS

For a large passenger aircraft, the floor should not be supported by braces from the lower part of the fuselage. These braces may push upward through the floor in the event of a crash



AIRCRAFT CHARACTERISTICS EXTRA FEATURES

CRASHWORTHINESS CONSIDERATIONS

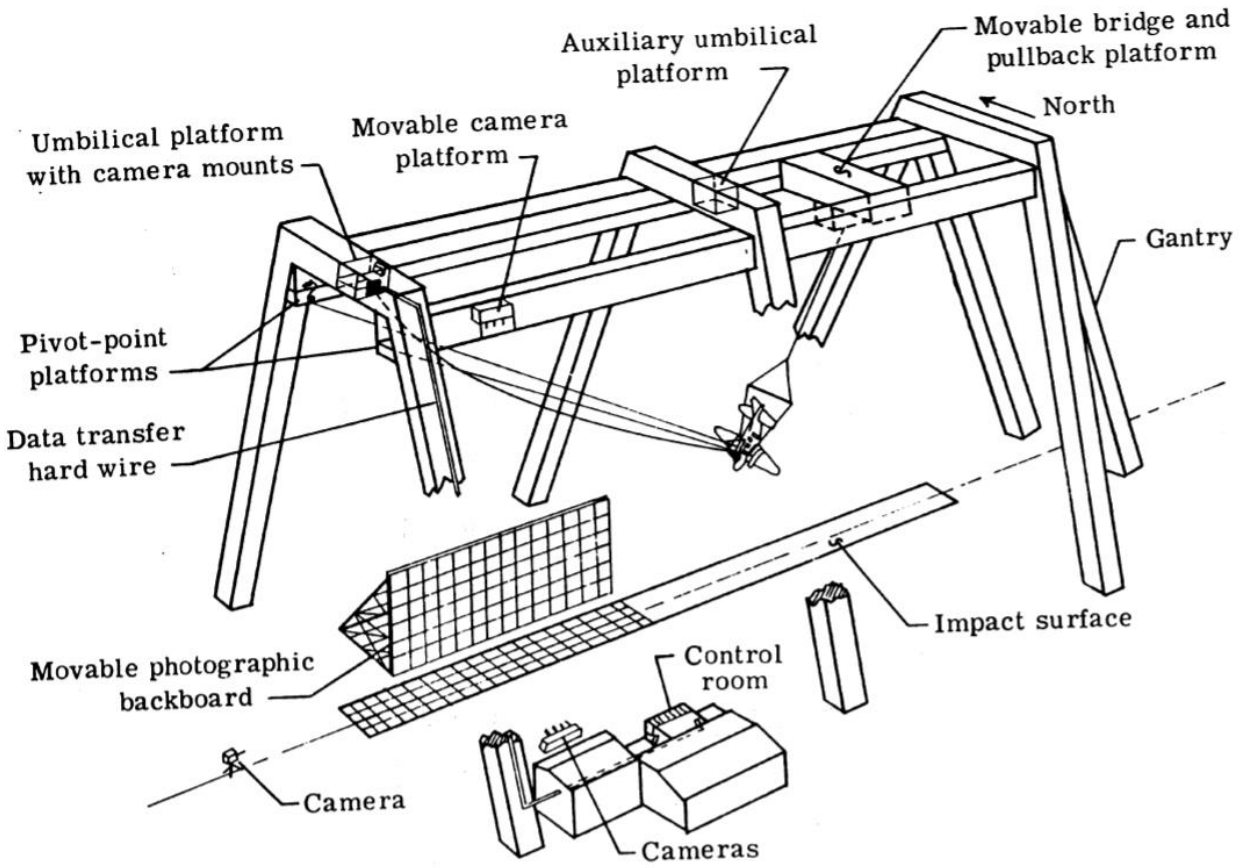
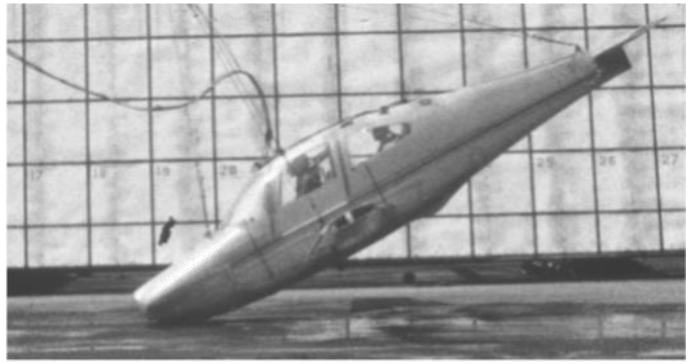
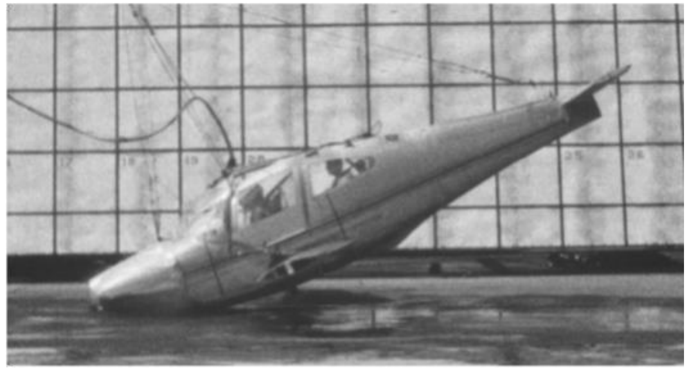


Figure 5. Diagram of NASA Impact Dynamics Research Facility

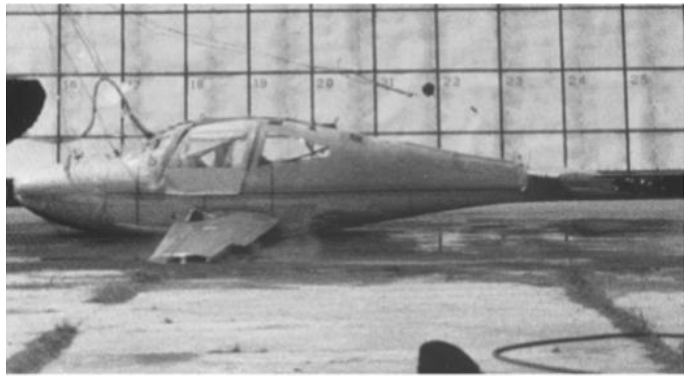


Impact



t = .040 seconds

t = .080 seconds



t - .120 seconds

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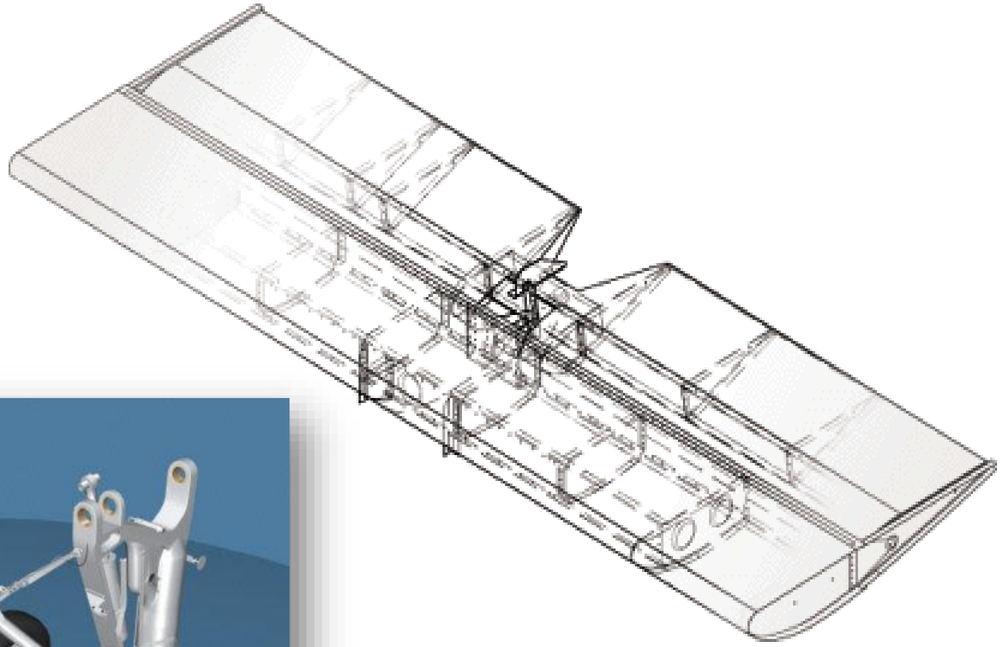

PRODUCIBILITY CONSIDERATIONS

The aircraft cost is not most directly related only to weight, but also to strong cost impact due to materials selected, the fabrication processes and tooling required and the assembly man-hours

Part commonality can also reduce production costs:
- If possible, the left and the right main landing gears should be identical
- It may be desirable to use un-cambered horizontal tails to allow left-right commonality even if a slightly aerodynamic penalty results

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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PRODUCIBILITY CONSIDERATIONS

Installation of internal components and routing of hydraulic lines, electrical wiring, and cooling ducts comprises another major production cost due to the large amount of manual labour required

Routing can be simplified through provision of a clearly defined "**routing tunnels**", this can be internal or external and non-structural fairing that typically runs along the spine of the aircraft

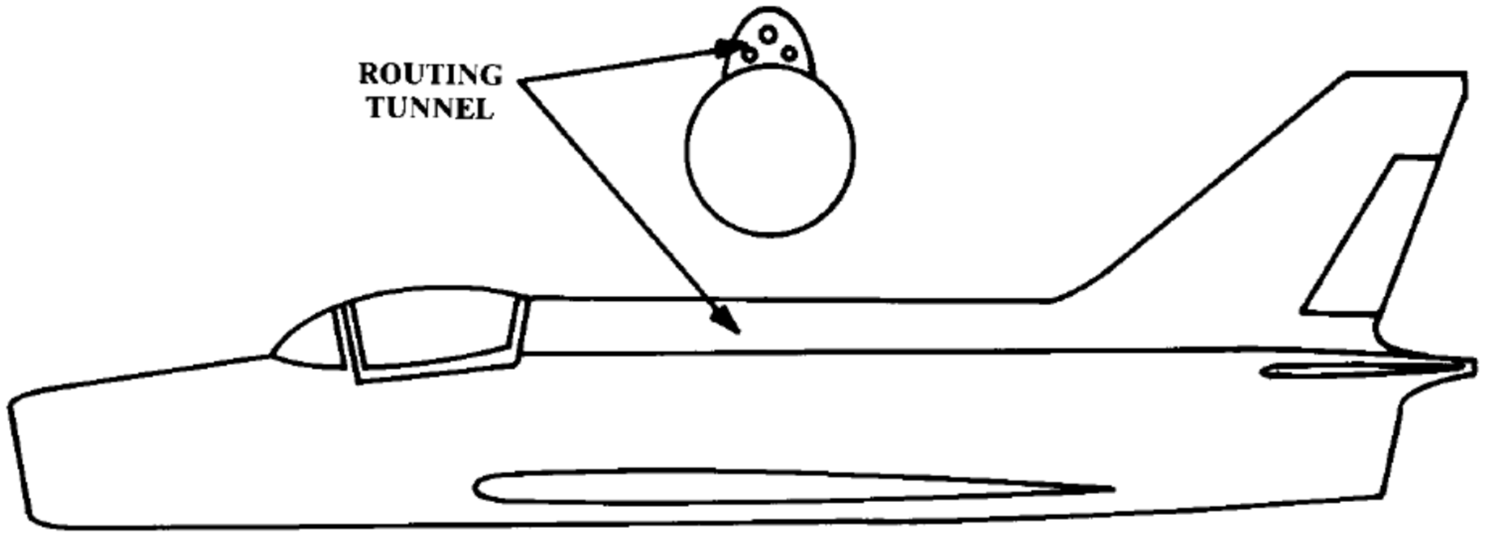

Fig. 8.16 External routing tunnel.

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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PRODUCIBILITY CONSIDERATIONS

Manufacturing breaks are another producibility factor (aircraft are built in sub-assemblies)

- A large aircraft will be built up from a cockpit, an aft-fuselage, and a number of mid-fuselage subassemblies
- A small aircraft may be built from only two or three sub-assemblies

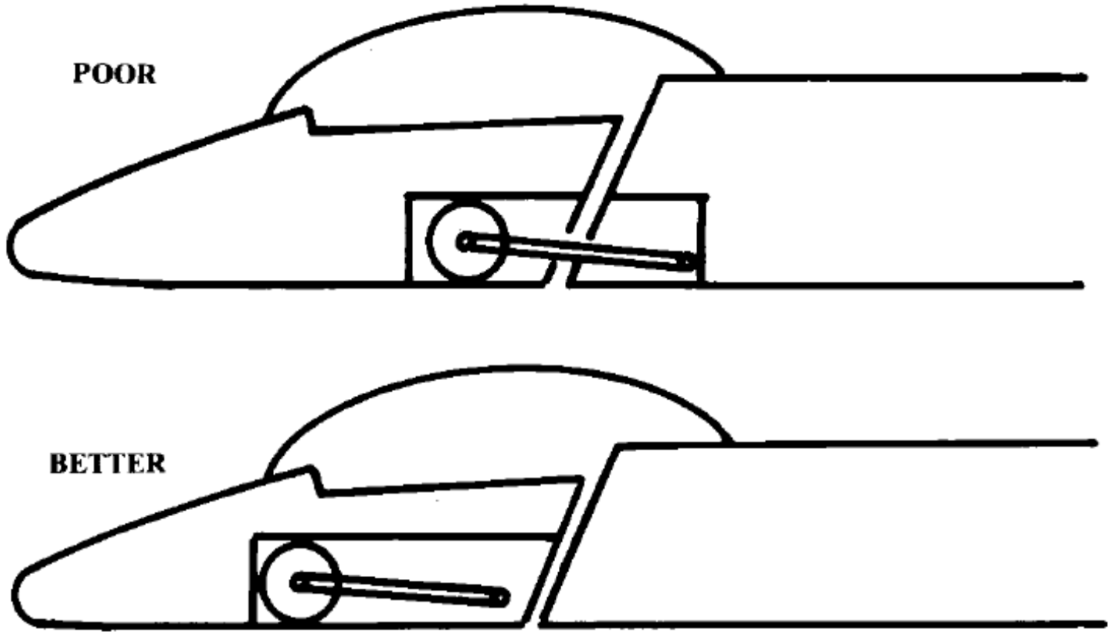
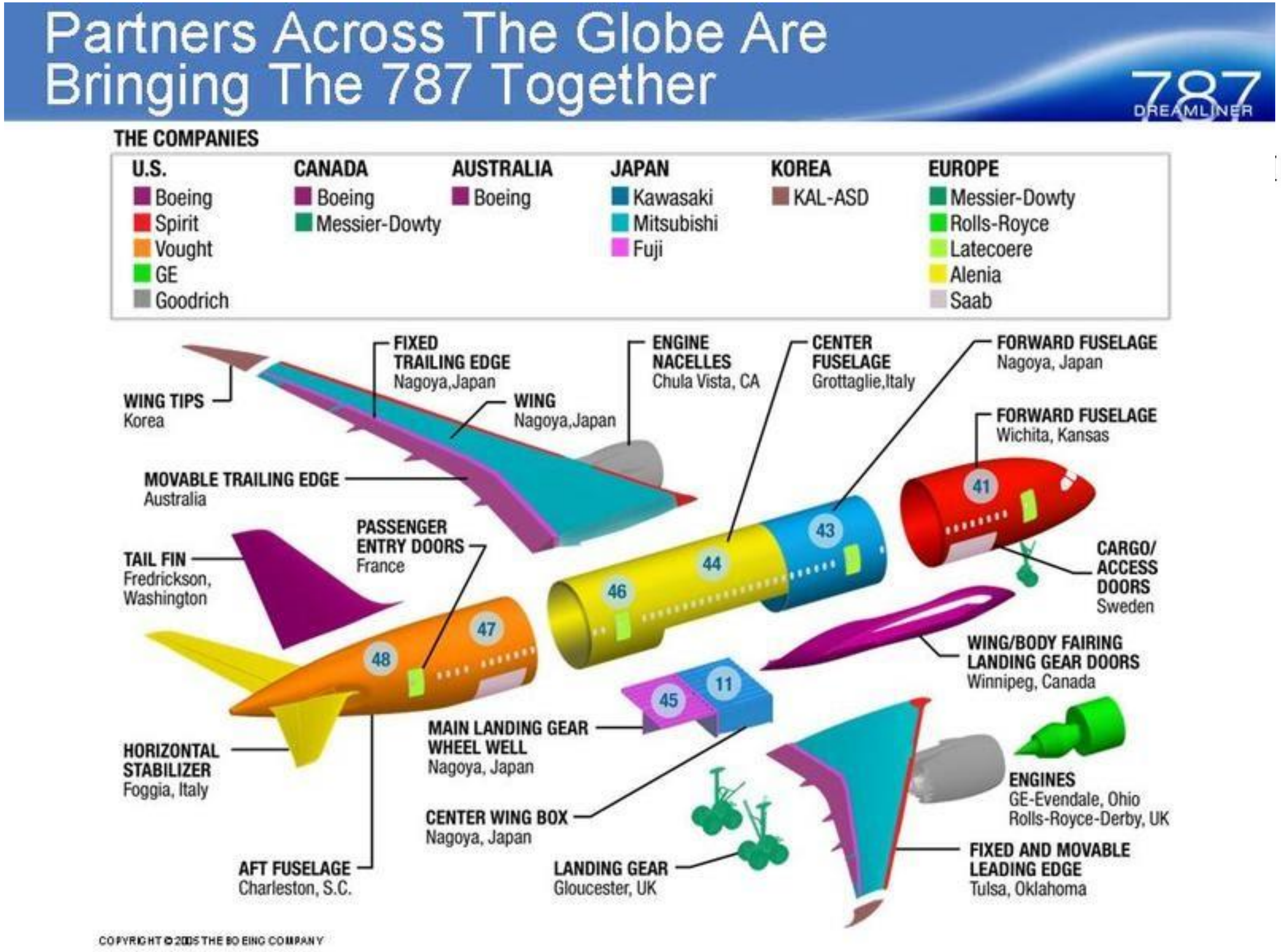


Fig. 8.17 Production breaks.

AIRCRAFT CHARACTERISTICS EXTRA FEATURES



PRODUCIBILITY CONSIDERATIONS

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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MAINTAINABILITY CONSIDERATIONS

Maintainability means simply the ease with which the aircraft can be fixed

Reliability and Maintainability (*R&M*) are frequently bundle together and measured in "*Maintenance Man Hours Per Flight Hour*" (*MMH/FH*)

MMH/FH range from less than one for a small private aircraft to well over a hundred for a sophisticated supersonic bomber or interceptor

Reliability is usually out of the hands of the conceptual designer. It depends largely upon the detail design of the avionics, engines, and other subsystems

Accessibility depends upon the package density, number and location of doors, and number of components that must be removed to get at the broken component

The designer should avoid placing internal components such that one must be removed to get another

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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MAINTAINABILITY CONSIDERATIONS

Easy of accessibility for maintenance (and operational cost) purposes

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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<u>"GOOD LOOKS" CONSIDERATION</u>

This aspect of aircraft design should not be considered as trivial

The "**<u>good looks</u>**" question is obviously a very subjective one. An aircraft designer should always consider the aesthetics of his creations

AIRCRAFT CHARACTERISTICS EXTRA FEATURES

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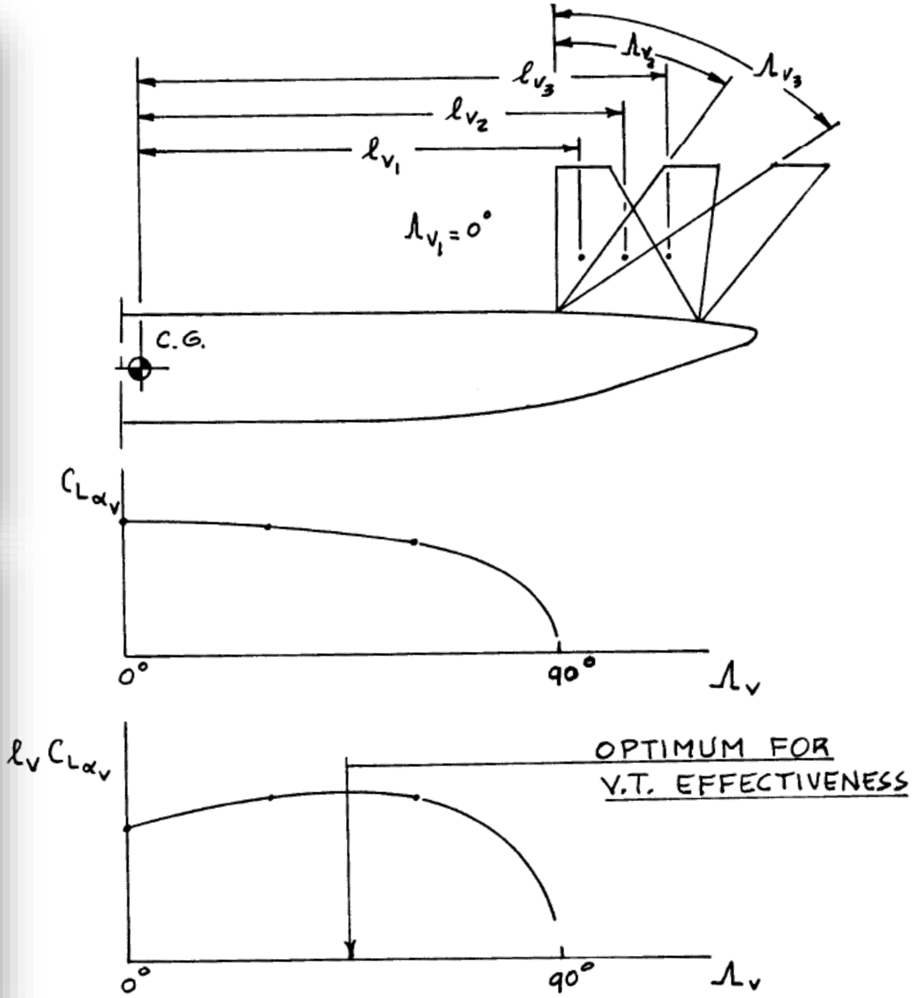
<u>"GOOD LOOKS" CONSIDERATION</u>

Case study: the sweep vertical tail on Cessna single engine aircrafts

Those sweep angles are incorporated **not for high** ***Mach*** **reasons**, but only for "good looks"

Illustration of optimization of the aerodynamic effectiveness of an empennage surface

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