

2 Aircraft Design Sequence

The sequence of activities during the project phase (see **Fig. 1.3**) can be divided in two steps:

- 1.) **preliminary sizing**
- 2.) **conceptual design.**

Beyond this, there is not much agreement in the literature about which systematic way should be followed in aircraft design. Many authors do not make much of an attempt to provide the reader with a design sequence at all. This Section proposes one design strategy. Please note: It is only one of many possible ways. Those who are new to aircraft design should stick to the given sequence. With growing design experience deviation from the set path becomes feasible. This Section builds on ideas from **Loftin 1980** and **Roskam I**.

2.1 Preliminary Sizing

Preliminary sizing of an aircraft is possible without knowledge of an aircraft geometry. In preliminary sizing the aircraft is more or less reduced to a point mass. However concrete ideas about the aircraft need to exist:

- What type of configuration will be selected?
- What aspect ratio can be expected?
- What cruise Mach number and type of propulsion system will be selected?

With these first considerations, requirements can be formulated. These **requirements** will enter the preliminary sizing phase:

- Payload m_{PL} ,
- Range R ,
- Mach number M_{CR}
- Take-off field length s_{TOFL} ,
- Landing field length s_{LFL} ,
- Climb gradient γ during second segment,
- Climb gradient γ during missed approach .

Preliminary sizing will be done in **these steps**:

Step 1: Define all requirements, sort and evaluating the requirements according to their significance! Which requirements may substantially drive the design?

Examples of requirements that might have a significant impact on the design are:

- Extremely short take-off or landing fields
- Take-off or landing fields with soft ground
- Heavy or huge payload
- Large range or endurance.

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| Step 2: | Perform trade-off studies with aircraft designed to comparable requirements! |
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Sources that can be used for these comparative studies:

- "*Jane's all the World's Aircraft*" (see **Lambert 1993**),
- Aeronautical literature,
- Information of manufacturers,
- Internet
- *Flight International* (UK, weekly),
- *Aviation Week and Space Technology* (USA, weekly)

Learn from strength and weaknesses of other successful or unsuccessful designs!

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| Step 3: | Choose an aircraft configuration! | (Section 4) |
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| Step 4: | Choose a propulsion system! | (Section 4) |
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| Step 5: | Execute the preliminary sizing method! | (Section 5) |
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These assumptions will need to be made during Step 5:

- Maximum lift coefficient (take-off), $C_{L,max,TO}$
- Maximum lift coefficient (landing), $C_{L,max,L}$
- Maximum glide ratio: $(L/D)_{max,CR}$, $(L/D)_{max,TO}$, $(L/D)_{max,L}$
during cruise flight, take off and landing.

Tables, figures und approximate equations are given in Section 5 to make an "intelligent guess" towards these parameters. Only feasible or manageable values may be selected, otherwise later design steps run into problems. Pre-select:

- Wing aspect ratio, A_w
- Wing sweep (quarter chord line), $\Phi_{25,W}$

Loftin 1980 was chosen as baseline text for this sizing process. These flight phases are considered together with their required aircraft performance: take-off, 2nd segment climb, cruise, landing and missed approach. Everything will be considered simultaneously in a matching chart. The matching chart helps to perform a two-dimensional optimization algorithm. Optimization variables are:

- Thrust-to-weight ratio, $T_{TO} / (m_{TO} \cdot g)$
- Wing loading, m_{MTO} / S_w .

The optimization has to assure:

- 1. *Preference*: Low thrust-to-weight ratio,
- 2. *Preference*: Suitable (high?) wing loading.

Using these optimized values the design parameters can be calculated:

- Take-off mass m_{MTO} ,
- Fuel mass m_F ,
- Operating empty mass m_{OE} ,
- Wing area S_W ,
- Take-off thrust T_{TO} .

Additionally the sizing process defines the cruise altitude h_{CR} .

The preliminary sizing process generates results without iteration. Applying "trial & error" and "playing around" with the spreadsheet-based method however is very helpful and revealing. The next step is the conceptual design and builds on these results from preliminary sizing.

2.2 Conceptual Design

The design process can be performed on different detail levels. The accuracy but also the amount of time necessary to do the calculations determines the "Class". A **Class I** method is an easy but less accurate method. A **Class II** method requires a lot of input but will hopefully produce more accurate results. Results from a Class I method can be improved by using a Class II method that builds on the Class I answers. The conceptual design described here may be rated Class I and requires an involvement that can be handled by one person (in a project or thesis). These further steps should be followed:

Step 6: a) Draw a **fuselage cross section!** **(Section 6)**
 b) Define a **cabin layout!**
 c) Make a drawing of the **fuselage** to scale!

Step 7: a) Definition **wing parameters!** **(Section 7)**
 b) Choose the number, the size and position of the ailerons und the spoilers!

These parameters will be known at the end of Step 7:

- Aspect ratio, A_W (already pre-selected during preliminary sizing)
- Taper ratio, λ_W
- Sweep angle, $\Phi_{25,W}$, (already pre-selected during preliminary sizing)

- Thickness ratio, $(t/c)_W$
- Airfoils
- Incidence angle, i_W
- Dihedral angle, v_W
- Wing twist, ϵ_t .

These parameters need to be assigned a value in such a way that the maximum lift coefficient during landing $C_{L,max,L}$ may be feasible with an appropriate high lift system (from Step 8).

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| <p>Step 8:</p> <p>a) Choose a high lift system!</p> <p>b) Calculate maximum lift coefficients $C_{L,max,TO}$, $C_{L,max,L}$!</p> <p>c) Compare the results with the assumptions from Step 5!</p> <p>d) <u>If</u> the maximum lift coefficient does not reach values from Step 5, <u>than</u> the high lift system and/or the wing geometry (Step 7) has to be changed.</p> | <p>(Section 7 and 8)</p> |
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| <p>Step 9:</p> <p>a) Design the horizontal tail and vertical tail!</p> <p>b) Design elevator und rudder!</p> | <p>(Section 9)</p> |
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The parameters for the empennage will be determined from statistical data and the tail volume.

These parameters will be known at the end of Step 9 for the horizontal tailplane and the vertical tailplane (fin):

- **Tail area**, S_H , S_V
- Aspect ratio, A_H , A_V
- Taper ratio, λ_H , λ_V
- Sweep angle, $\Phi_{25,H}$, $\Phi_{25,V}$
- Thickness ratio, $(t/c)_H$, $(t/c)_V$
- Airfoils
- Incidence angle, i_H
- Dihedral angle, v_H

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| <p>Step 10:</p> <p>a) Make a preliminary side- and top-view drawing of the aircraft! (Section 10)</p> <p>b) Calculate aircraft mass and position of the center of gravity (weight and balance calculation)</p> <p>c) Analyze the results from b)</p> <p>d) <u>If</u> the center of gravity is not suitably placed or within a permissible range, <u>then</u> the arrangement of the aircraft components has to be changed.</p> |
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Step 11: a) Analyze **stability & control!** (Section 11)
 b) Calculate the **empennage areas** with results from a)!
 c) Compare the empennage areas from b) with the areas from Step 9!
 d) If the derivation from c) is higher than 10%,
then Step 10 and Step 11 have to be repeated until convergence.

Step 12: Define and integrate the **landing gear!** (Section 12)

These parameters will be known at the end of Step 12:

- Landing gear type and configuration of wheels and struts
- Number, type and size of wheels and floatation details
- Principle landing gear retraction

Landing gear extension and retraction must be without conflict to other components. The landing gear attachment to the aircraft should be structurally sound. Attention: Without a defined and integrated landing gear, the overall aircraft design is not finished, because the landing gear can have a considerable impact on overall aircraft design.

Step 13: a) Calculate of the aircraft **polar** for (Section 13)
 cruise flight, take-off and landing!
 b) Calculate of the **lift-to-drag ratio** using the polar!
 c) Calculate of the **fuel mass** m_F using the lift-to-drag ratio and the equations from Step 5.
 d) Calculate the **take-off mass** $m_{TO} = m_{OE} + m_F + m_{PL}$
 Hint: m_F from c), m_{OE} from Step 10 und m_{PL} (requirement)
 e) If the derivation of m_{TO} (calculated in d) and m_{TO} (calculated in Step 5) exceeds 5 %, than Step 5 has to be repeated and the values of wing area S_W and take-off thrust T_{TO} have to be corrected.

Step 14: Make a final check on **aircraft performance!** (lecture: **flight mechanics**)

- a) Take-off field length s_{TOFL} ,
- b) Landing field length s_{LFL} ,
- c) Climb gradient γ (second segment),
- d) Climb gradient γ (missed approach).

Step 15: a) Calculate the **operation costs!** (Abschnitt 14)

- b) Optimize the aircraft with respect to the **operation costs!**
 An adequate iteration loop has to be defined. Iteration steps could include:
 Step 7 \leftrightarrow Step 6 \leftrightarrow Step 3 \leftrightarrow requirements.
 Also the cruise Mach number has to be adjusted.

- Step 16:**
- Prepare a **3-view drawing** of the aircraft to scale based on the calculated parameters.
 - Prepare a final cabin **cross section** and **seat layout!**
 - Prepare a **table with all aircraft parameters** that have been generated!

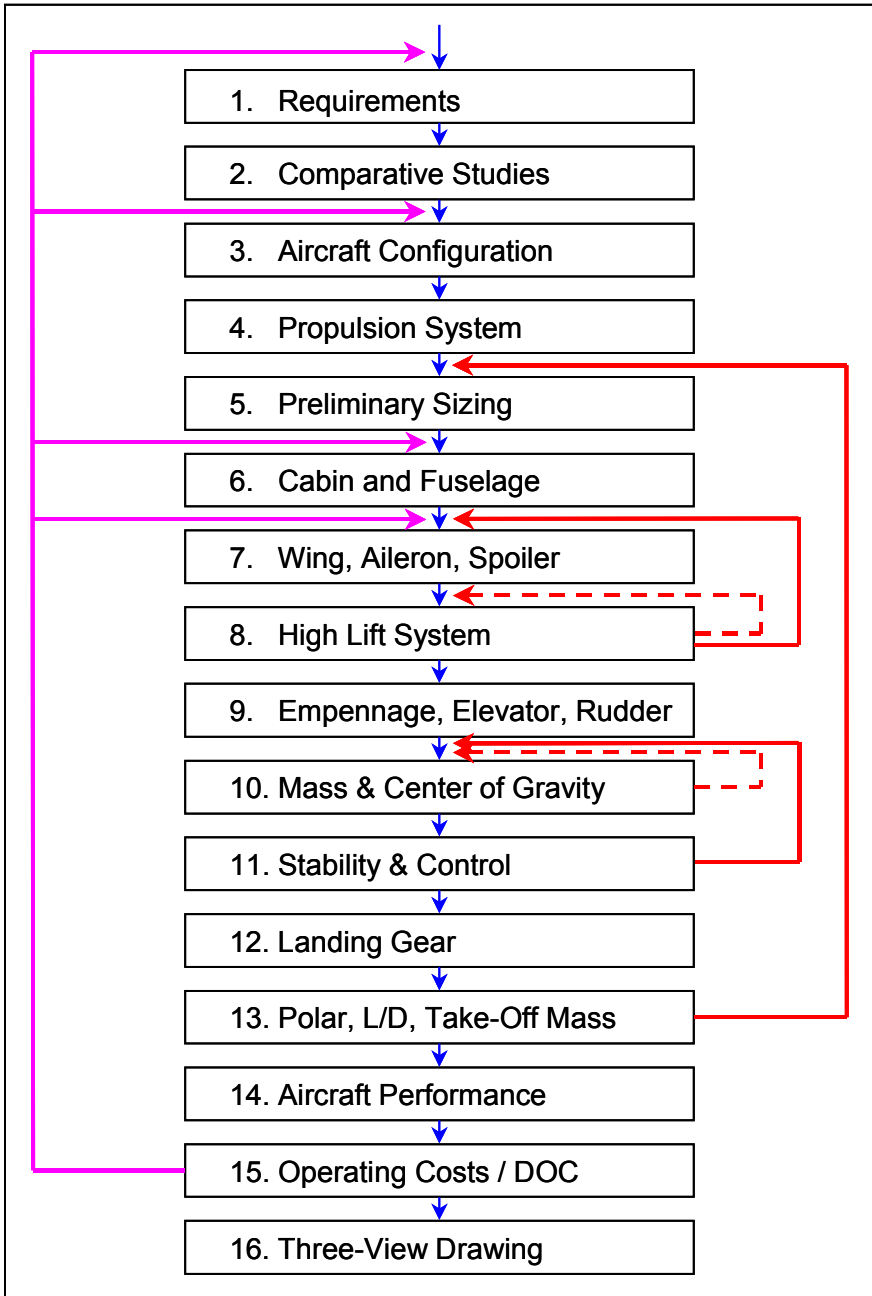


Fig. 2.1 The proposed aircraft design sequence including preliminary sizing and conceptual design and iteration loops