1 Introduction

1.1 Requirements, Parameters, Constraints and Objectives

The task of aircraft design in the practical sense is to supply the "geometrical description of a new flight vehicle". To do this, the new aircraft is described by a *three-view drawing, a fuselage cross-section, a cabin layout* and a *list of aircraft parameters*.

The parameters of aircraft design can be subdivided into **requirements and design parameters** (**Table 1.1**).

Table 1.1 Parameter grouped into "requirements" and "design parameter"

requirements; also called	**design parameters**; also called
known parameters	unknown parameters
independent parameters	dependent parameters
given parameters	free parameters

The design of an aircraft is based on **requirements** which have to be met by the aircraft being designed. These requirements are determined by the planned use. The list of requirements is also called a performance or contract specification. Many requirements arise from the *flight mission*. The mission specification is produced from market surveys and contact with potential customers. The design engineer cannot rely on market researchers placing finished specifications on her[1] desk. Therefore, it is crucial that the design department offers economically attractive designs. These initial designs and trade-off studies then serve as a basis for discussions with market researchers and customers (**Fig. 1.1**).

The following requirements, at least, should be met when aircraft design begins:

- Cruise performance:
  - Payload m_{PL} ,
  - Range R ,
  - Mach number M_{CR}

Note: The cruise Mach number M_{CR} is not actually a requirement, but rather arises from the economic optimization of the aircraft. In order to start iteration of the design parameters, the cruise Mach number is, however, treated as a requirement to begin with.

1 The female form is used here to refer to both male and female persons.

- Airport performance:
    - Take-off field length s_{TO};
    - Landing field length s_L;
    - Climb gradient γ_{CLB} (2nd segment);
    - Missed approach climb gradient γ_{MA}.

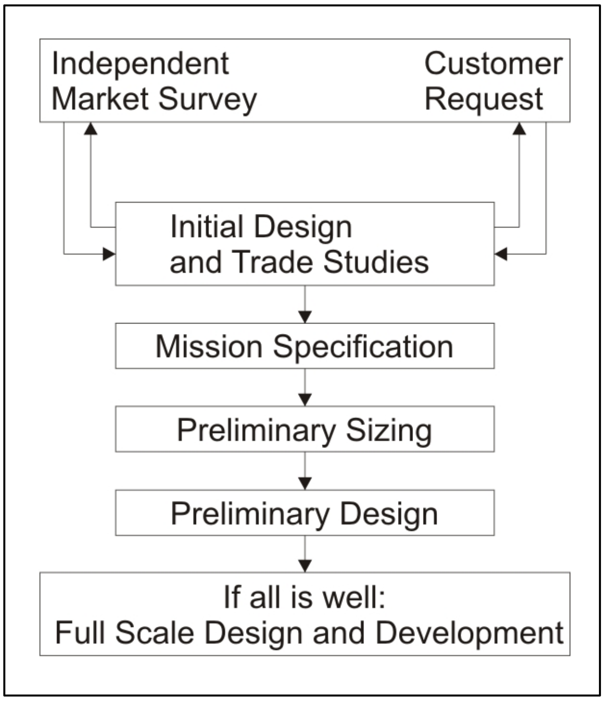

Fig. 1.1 The mission specification in civil aviation follows from joint work of the aircraft design department, market research and customer requests. Requirements for the aircraft depend on the mission specification.

The key **design parameters** are:

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

These parameters are initially determined when conducting the preliminary sizing of the aircraft. The configuration and geometry of the aircraft are defined more closely in the conceptual design. Thus, additional design parameters are determined in the conceptual design.

A distinction must then be made between *continuous design parameters* and *discrete design parameters*. Continuous design parameters can take on a *real number* as a value. The discrete design parameters describe *alternative aircraft configurations*. **Table 1.2** lists examples of both types of design parameters.

Table 1.2 Examples of discrete and continuous design parameters

discrete design parameters	continuous design parameter
wing position	wing area
tail configuration	wing aspect ratio
number of engines	wing taper ratio
engine configuration	wing thickness
fuselage cross-section	wing sweep
...	tail area (and geometry as for the wing)
	(if not given as a requirement:)
	cruise speed
	...

In aircraft design, continuous and discrete *design parameters* are expediently *determined in two steps*:

Step 1: The discrete design parameters are chosen.
(Thus, an aircraft configuration is selected.)

Step 2: The continuous design parameters are varied for each aircraft configuration received.

In addition to the requirements, **constraints** must be taken into account. The following three examples are intended to explain the principle of constraints.

- A wing must be built so as to ensure that sufficient fuel can be accommodated in it. This gives a lower limit for the design parameter *wing area*.
- The wing aspect ratio of a passenger aircraft cannot be chosen arbitrarily for reasons of material strength and weight. This gives an upper limit for the parameter *wing aspect ratio*.
- An aircraft that is designed for subsonic speeds experiences a limit to the achievable Mach number. This gives an upper limit for the parameter *payload Mach number*.

Many constraints arise from the certification regulations, limits of technology or the existing airport infrastructure.

The aircraft design aims to meet one or more **objectives** optimally. In this process of *optimization,* the free parameters of the aircraft design are varied (while, naturally, always meeting the requirements and constraints).

As a rule, the **design objective in civil aircraft manufacture** is to generate a *profit* with the aircraft. Profit is generated if the *revenues* are larger than the *expenses*. If a *payload* is transported over a specific *distance* at a specific *speed,* revenues are obtained within a specific fare structure. Expenses are incurred through fixed costs (irrespective of the aircraft's use, e.g. *depreciation*) and variable costs (depending on the aircraft's use, e.g. *fuel costs*). Another important factor is *maintenance costs*, which contain both fixed and variable elements. Profit is maximized if the ratio between the flow of revenues and the flow of expenses is maximized. The *requirements* must therefore be *met at minimum cost*.

It should be noted that there is no hard and fast rule for deciding what constitutes a *requirement*, *free parameter*, *constraint* or *design objective*. Thus, for example, the *requirement*: "take-off distance = 1000m" (under given conditions) can also be interpreted as:

- *constraint* take-off distance = 1000m or
- *design objective* take-off distance $\leq$ 1000 m or
- *design parameter* take-off distance = ?

if the optimization of the design objective is not to be unnecessarily restricted initially and the parameter *take-off distance* is only to arise from the optimization.

The task of aircraft design in an abstract sense is to determine the design parameters so as to ensure that

1. the requirements and constraints are met
   (then we have a permissible design) and, furthermore,

2. the design objectives are optimally met
   (then we have an optimum design).

1.2 Aircraft Design: Part of Aircraft Development

In the literature and in practice, aircraft development has been repeatedly broken down into different elements with different technical terms. In **Table 1.3** an attempt has been made to summarize frequently recurring terms in an orderly fashion. Examples of the work carried out in the respective phases are intended to create a link with actual practice. **Fig. 1.3** shows the time-based sequence of the phases of aircraft development combined with key *milestones*, taking the development of large civil aircraft as an example. The *aircraft design* lecture only deals with the project phase. The project phase comprises the preliminary sizing and the conceptual design.

Table 1.3 Phases during aircraft development

Phase	Project Phase	Definition Phase	Development Phase
Activity	• Preliminary Sizing • Conceptual Design	• Preliminary design	• Detail Design
Example Deliverables	• Market Analysis • Configuration • Engine Selection	• Preliminary Development Structure o Design, Manufactering Process • Definition System • Flight-mechanical Simulation	• Construction • System Development • Engine Integration • Test Structure and System • Flight Test

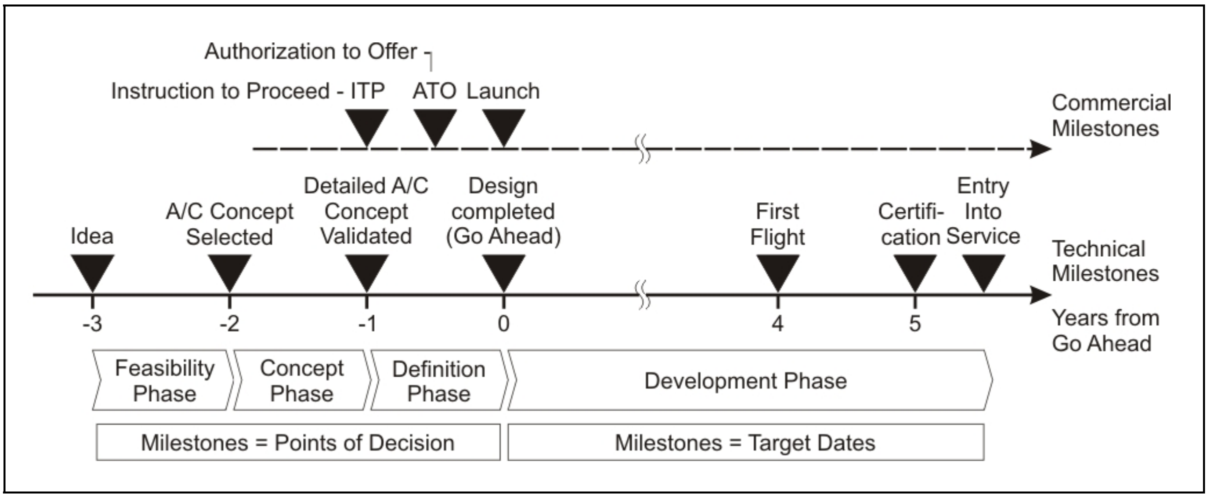

Fig. 1.3 Phases of aircraft development

1.3 General Approach to Aircraft Design

In principle, the aim of aircraft design is to create something new through *synthesis*. This contrasts with the *analysis* of the aircraft by a large number of specialized disciplines in aircraft construction. Flight mechanics, as an example of one of the disciplines, focuses on aircraft geometry and uses this to determine flight performance and flight characteristics.

In aircraft design various approaches are adopted:

- *Statistics* and experience are applied.
- The design of aircraft takes place in a large number of *iterations*.
- *Inverse methods* of analytically precedent specialized disciplines are used.

  Example: Flight mechanics calculates the take-off distance from wing loading m/S and thrust-to-weight ratio $T/(m \cdot g)$. Conversely a function $T/(m \cdot g) = f(m/S)$ can be

calculated from a required take-off distance. Therefore, the thrust T can be expressed as a function of wing area S.
- Formal *optimization algorithms* provide a purely mathematical approach to solving problems of aircraft design. In practice this approach is gaining more and more in importance.

The engineer in aircraft design must always remind herself that she is not actually building the aircraft. Rather, the situation is as follows: **aircraft design must try to supply the best possible specifications for the specialized disciplines** and to predefine the best possible framework for the detailed work. This framework and these specifications must
- be realistic, on the one hand,
- but, on the other hand, they should also serve to get the best out of, for example, the aerodynamics or lightweight construction.

Specifications may only diverge from empirical values if new technologies justify these new specifications. In this case, it must be possible for the new technologies to be incorporated in the development of the new aircraft without taking too great a risk. If an aircraft design cannot be implemented at a later stage of aircraft development, it is often due not to the inadequacies of the specialized departments, but rather to over-optimistic specifications stemming from the aircraft design.

The mark of **a good design** is that detailed studies by specialists do not require any changes to be made to the design, or only minor changes which do not have a retroactive effect on the work of other specialists. At the end of the day, optimum results from aircraft development are based on multidisciplinary cooperation. This optimum result can, however, only be achieved if all the experts involved have an equal say in the design process and the joint work is characterized by mutual understanding and consideration.

Unfortunately, practice has shown that the battle for money, influence and recognition between nations, companies, departments and people often prevents an optimum design being achieved – or, at least, makes a smooth and efficient work flow impossible. **Fig. 1.4** gives a (somewhat exaggerated) impression of what happens if one discipline dominates in the development process and is not sufficiently aware of the problems of other specialized departments.

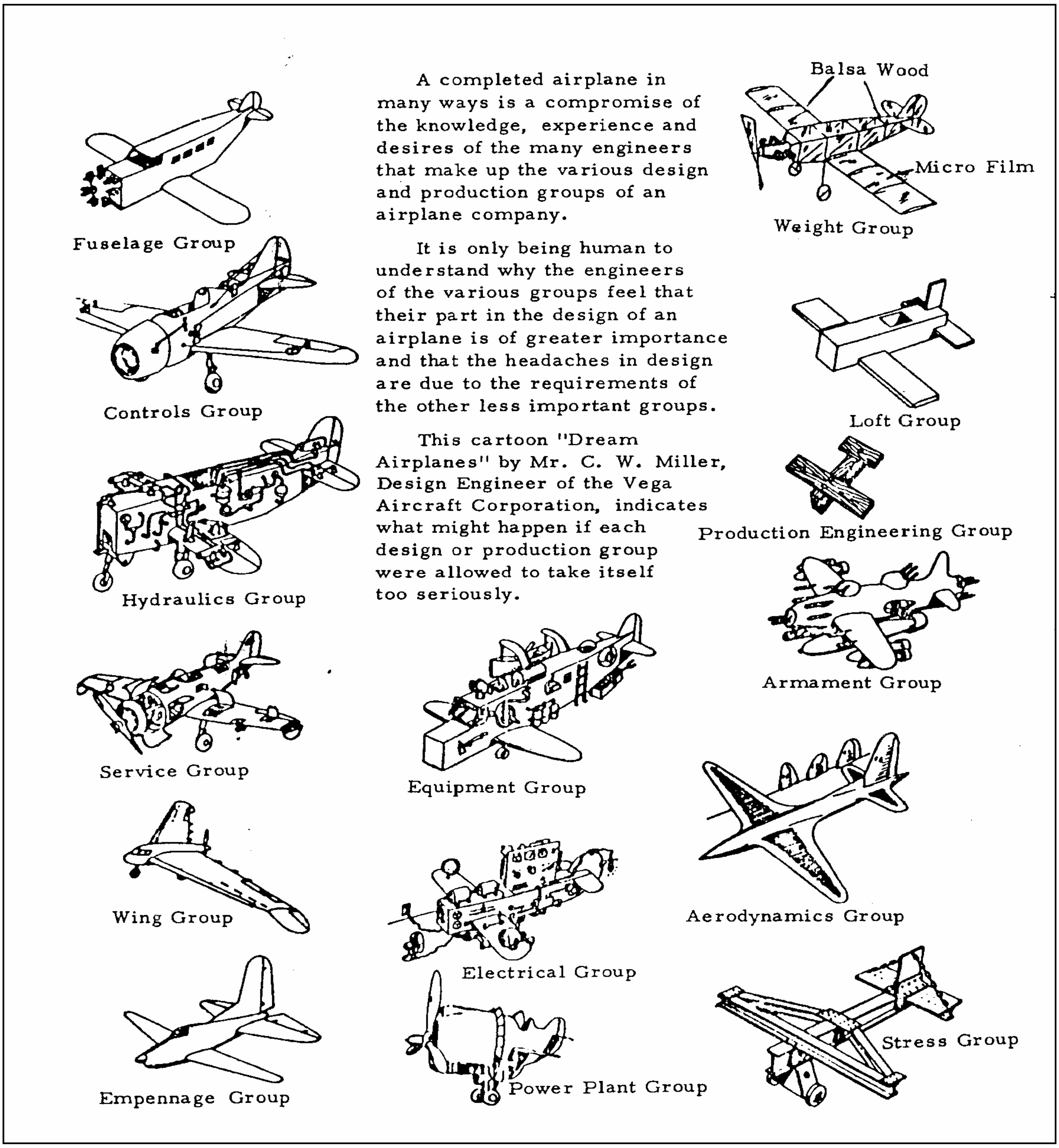

Fig. 1.4 Results of aircraft development if one technical discipline strongly dominates the others (**Nicolai 1975**)