Progettazione di veicoli aerospaziali (AA-LZ)

INTRODUZIONE ALLE ESERCITAZIONI

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ESERCITAZIONI 2024-2025

E1 DESIGN PRELIMINARE DI UN VELIVOLO COMMERCIALE TRADIZIONALE

E2 DESIGN PRELIMINARE DI UN VELIVOLO COMMERCIALE A PROPULSIONE IBRIDA

E3 DESIGN PRELIMINARE DI UN ROVER MANNED PER ESPOLRAZIONE SPAZIALE

Table of Contents

Main Goals

1. To understand the importance of Conceptual Design among the design and development phases of an aircraft.
2. To acquire knowledge about the most up-to-date methodologies for Conceptual Design of aircraft
3. To understand the most influential factors on the Conceptual Design of a modern commercial aircraft
4. To be able to perform a Conceptual Design of a modern commercial aircraft
5. To be familiar with the main aspect of the manned space exploration
6. To understand the most influential factors on the Conceptual Design of exploration vehicles.

Exam

<u>Individual</u> Summary Report on the application of the conceptual design methodology for commercial airplanes taught throughout this Lecture Series to a case study.

The content of the Report will be specified all along the Lectures, with specific requests marked as “Homework”

The individual report shall be delivered as a .pdf containing as hyperlinks, all supplementary materials (Excel files, Matlab codes, CAD models, etc…)

Politecnico di Torino

Progettazione di veicoli aerospaziali (AA-LZ)

E1. Conceptual Design of subsonic commercial aircraft

E1.1. INTRODUCTION TO CONCEPTUAL DESIGN AND INITIAL GUESS ESTIMATION

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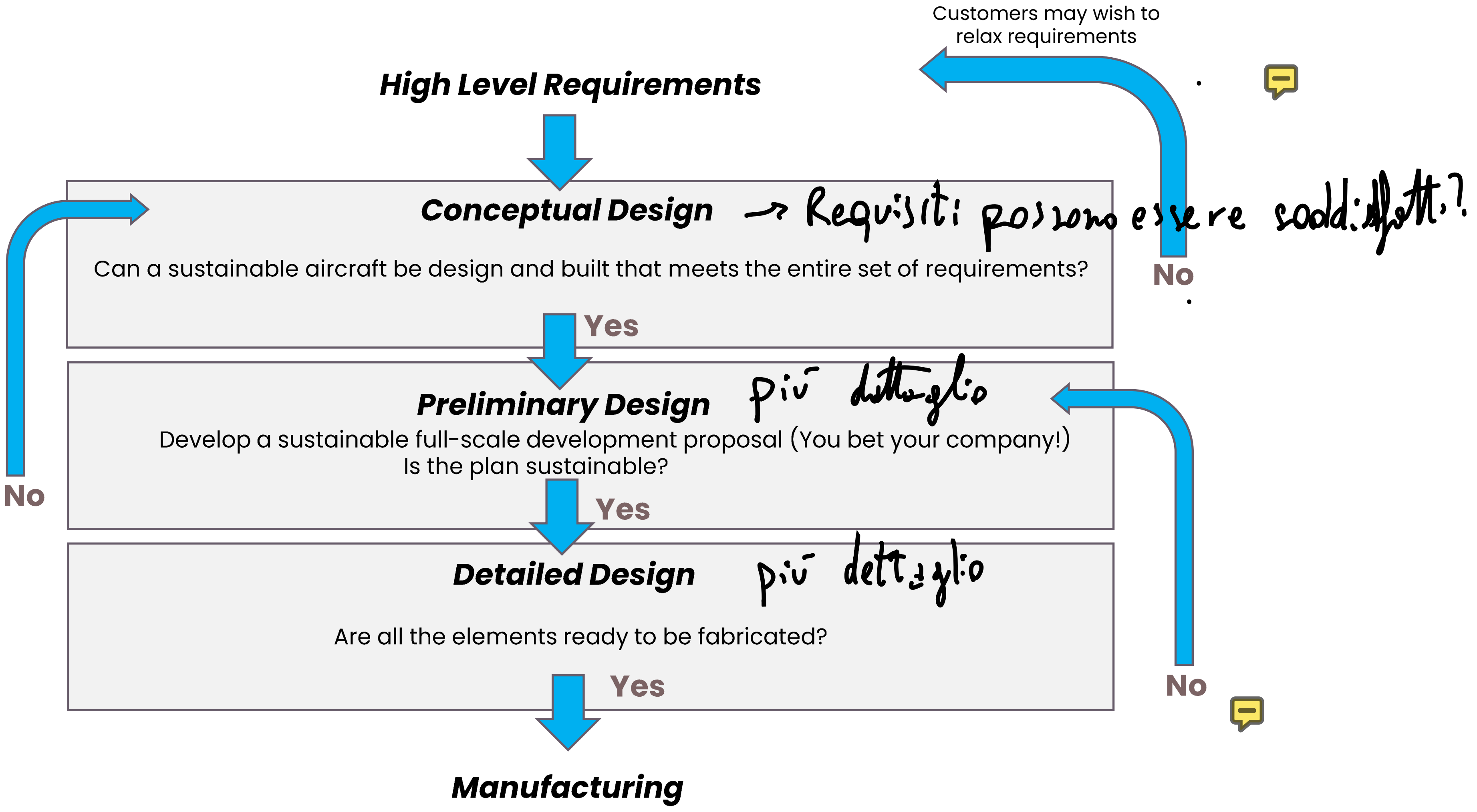
Conceptual Design among the Aircraft Design phases



Aircraft design results to be iterative and highly multidisciplinary process!

Conceptual Design Phase

During the Conceptual Design Phase, conventional and novel configurations are considered to suggest **aircraft concepts which shall be technically feasible and commercially viable**.

At the end of the Conceptual Design Phase, a knowledge of the feasibility for a certain number of concepts is expected, supported by a first estimates in terms of **size** and **performance**. These first estimates are important to support the selection process, performed through "trade-off" studies, having as **final goal the identification of the most suitable configuration**.

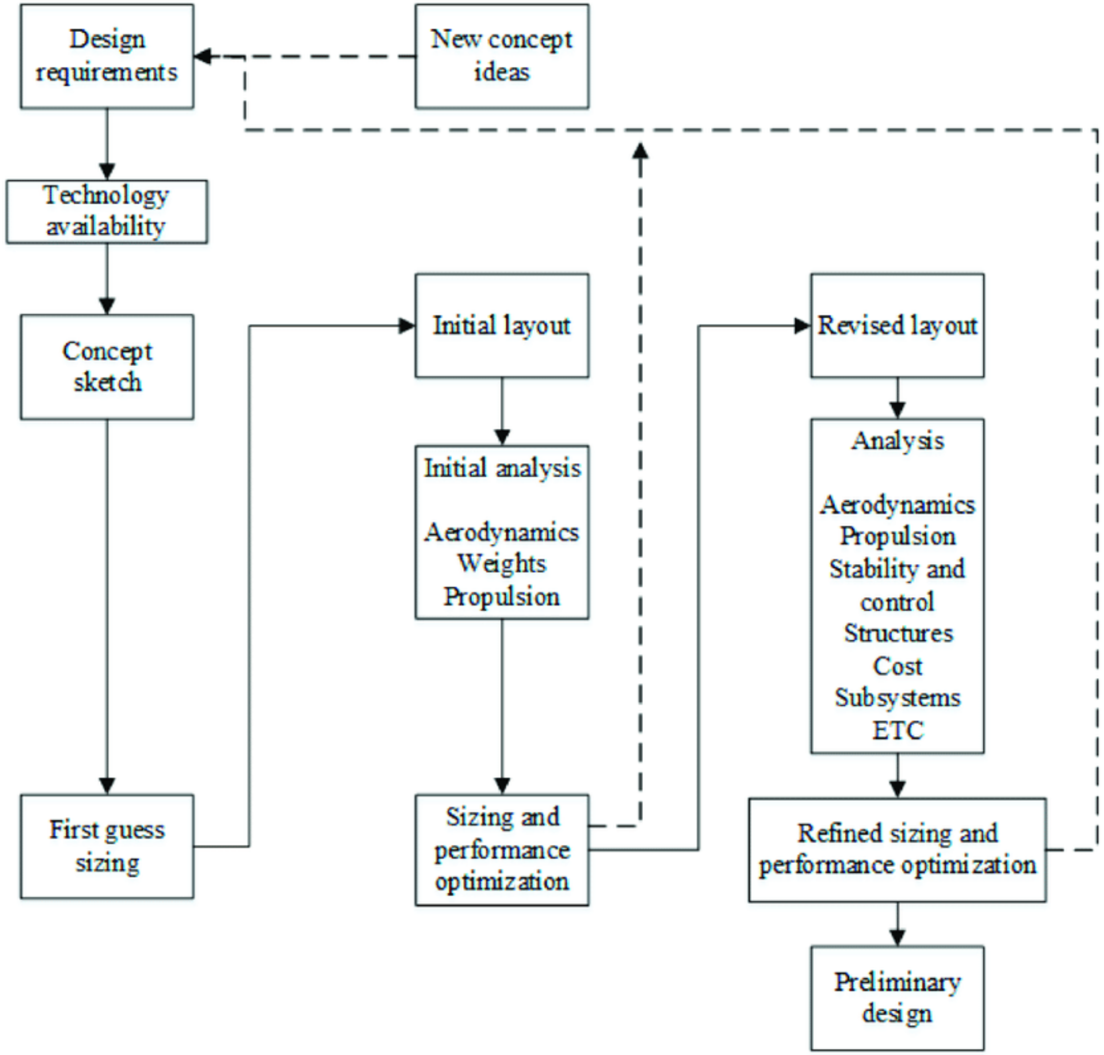
For **conventional layouts** (e.g. development of an evolution of an already existing aircraft or development of a classical layout aircraft), the analysis of reference aircraft and experience from previous design cycles may shorten the conceptual design stage, reducing the number of iterations necessary to converge towards a feasible solution.

E1

For **novel layouts**, statistical analysis and other methods based on already existing aircraft data can only be used to derive first guess data estimation. Novel methodologies and tools shall be developed to support the design of these novel concepts, leading to longer Conceptual Design Phases. Technical, technological and commercial risks have to be duly taken into account.

E2
E3

Aircraft Conceptual Design Process



Conceptual Design among the Aircraft Design phases

Preliminary Design Phase

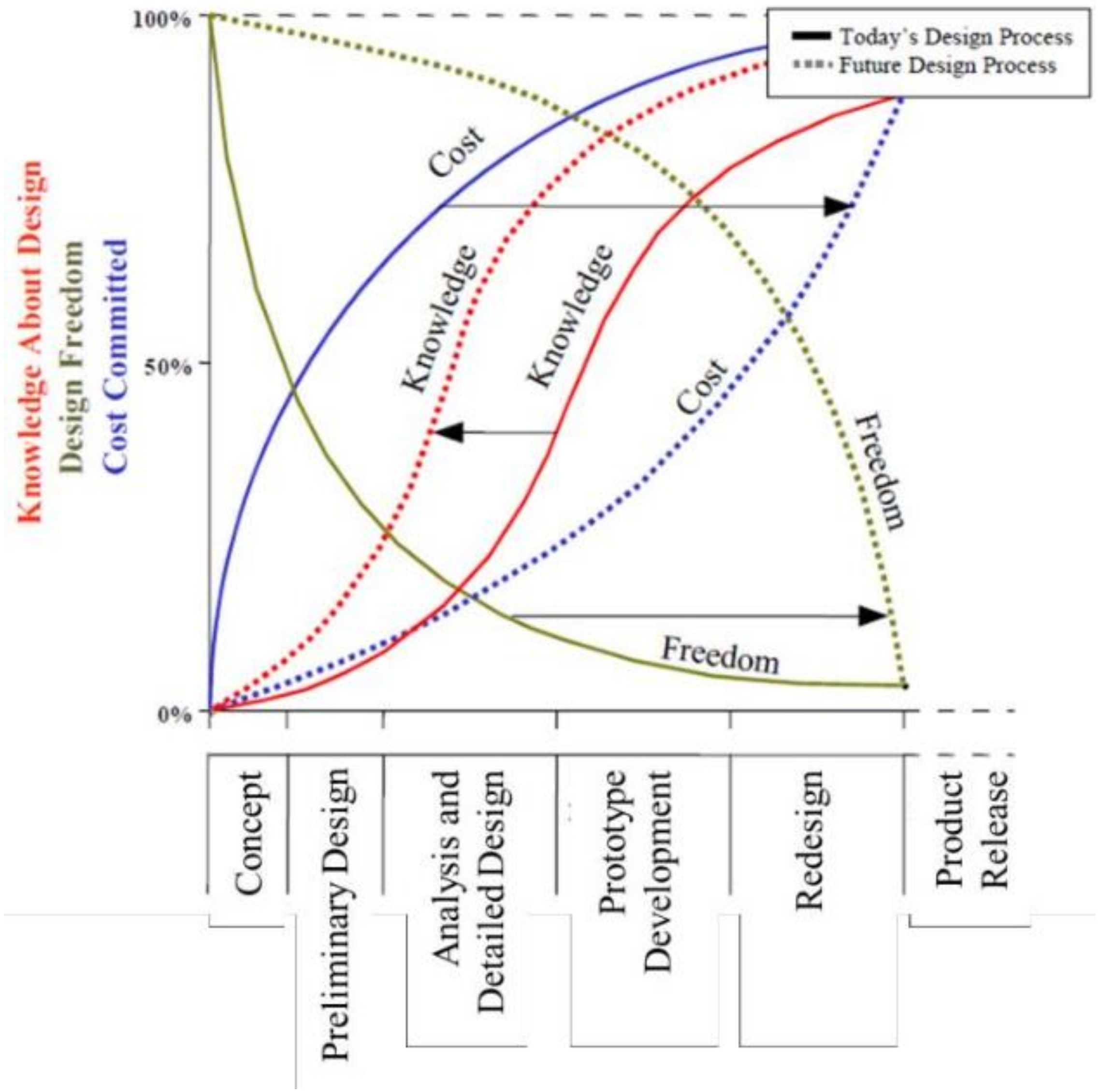
The best option(s) resulting from the Conceptual Design Phase is subjected to a more rigorous technical analysis. The objective of this phase is to find the best ('optimum') geometry for the aircraft with respect to the list of requirements.
Preliminary Design Phase begins when the major changes are over and specialists in the various disciplines have a sufficient number of elements to start the detailed analysis. During a Preliminary Design Phase, sensitivity analyses are carried out and testing is initiated with the need to develop mock-ups.

Detailed Design Phase

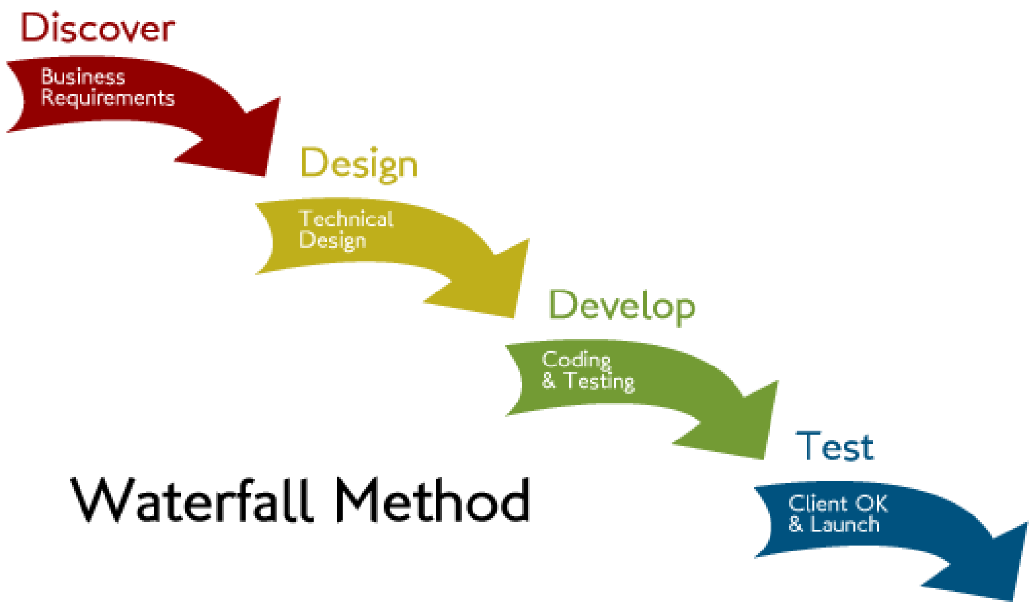
During the Detailed Design Phase, the layout is refined to a greater level of detail. With the external shape fixed, the structural framework is defined. In areas of doubt, finer calculations are performed and validated by component tests. Throughout this phase the aircraft weight and performance estimates are continuously updated as more details of the aircraft layout become available. At the end of this phase the aircraft is 'released for production'

The Paradigm Shift in Aircraft Conceptual Design

From the industrial standpoint, an urgent need to **reduce the costs committed during the very early design stages** and to **increase the resilience** of the aircraft project, moving as forward as possible the design points.



Traditional Conceptual Design Methodologies



There are five phases of the Waterfall methodology: Requirements, Design, Implementation, Verification and Maintenance. Below, we discuss each phase and the purpose for each one.

Requirements. During this phase, you outline the big picture of your project's requirements.

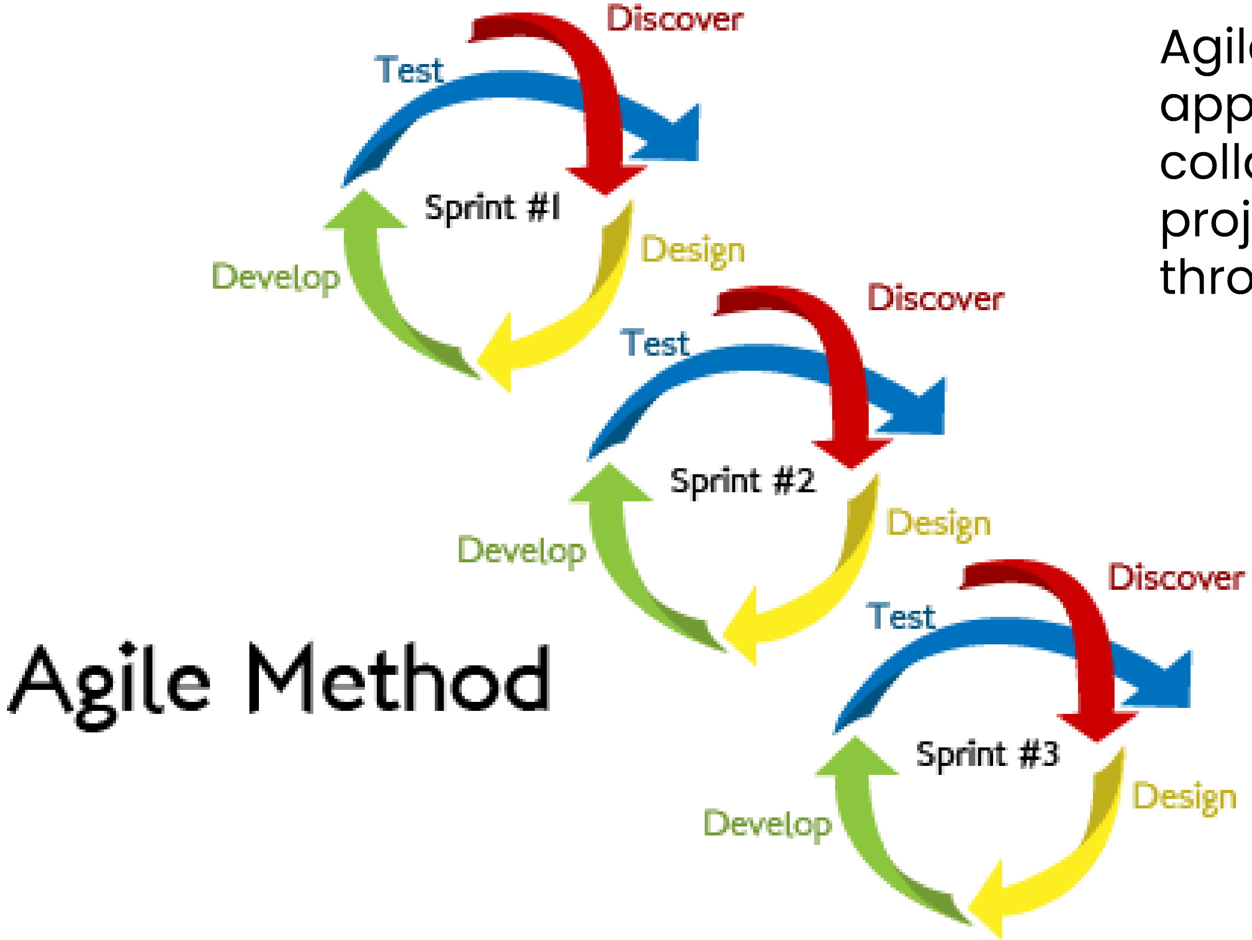
Design. Once you understand the project requirements, the next step is to come up with ways to design solutions that meet them.

Implementation. During this phase, you select one of your candidate designs and use technology to implement them. This could involve collecting data and inspecting whether the design is able to support the requirements.

Verification. During this phase, you take the implementation you created in phase four and test whether it validates your requirements.

Maintenance. The project isn't over once it has gone through validation and verification. The system still needs to be maintained.

Innovative Conceptual Design Methodologies



Agile methodology is a project management approach that prioritizes cross-functional collaboration and continuous improvement. It divides projects into smaller phases and guides teams through cycles of planning, execution, and evaluation.

The Conceptual Design Problem: How does it start?

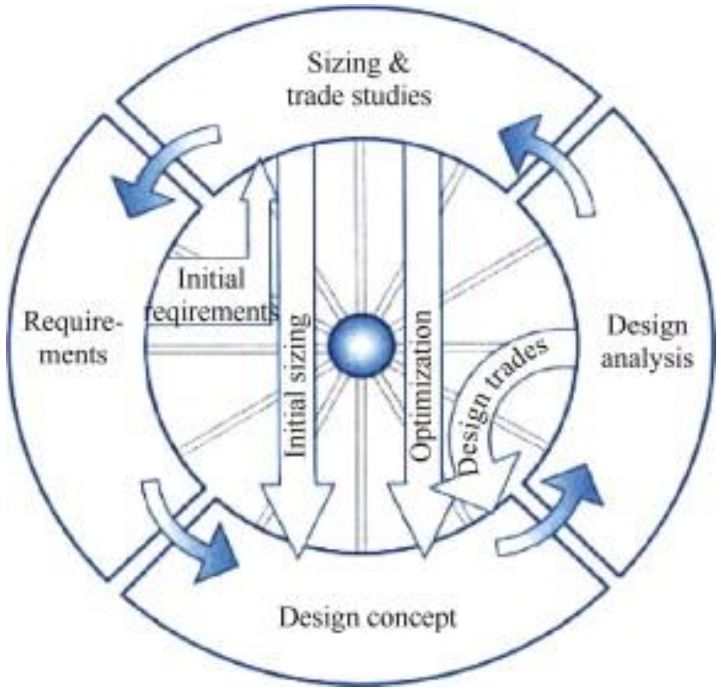
Experts involved into an aircraft design process can never quite agree on which is the entry point of the Design Wheel.

> **Designer**: "the conceptual design starts with a new airplane concept, i.e., with a sketch!"
>
> **Sizing Specialists**: "Nothing can begin until first guess data are made, and especially, before MTOM is estimated "

But ... Who does really stand at the beginning of the design process? Neither Designers, nor specialists, but *stakeholders!*

> **Stakeholders**: "The design of a new product of a re-design of an existing one generates from requirements"

Civilian and Military Markets have very different approaches, which can be simplified as "make money" and "win the war" respectively.



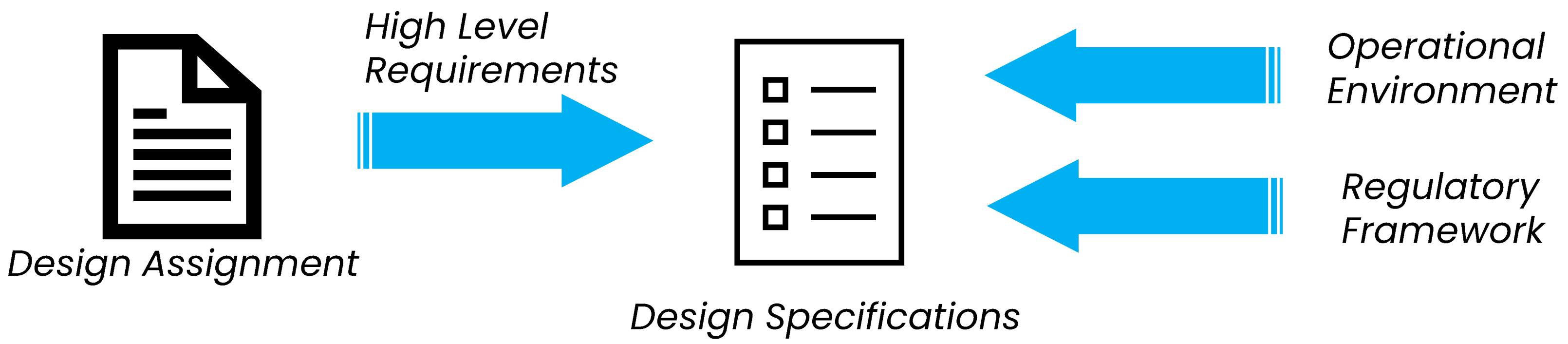
Design Wheel [1]

[1] Raymer, Daniel. Aircraft design: a conceptual approach. American Institute of Aeronautics and Astronautics, Inc., 2012.

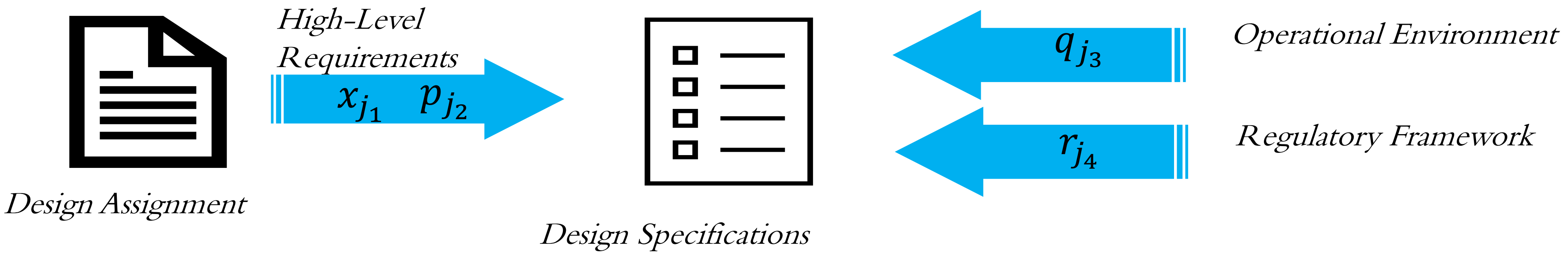
Origin of the Conceptual Design Problem

A Conceptual Design Problem always originates from a *Design Topic* (or assignment), which can be duly expressed through a set of ***High Level Requirements***. The set of High Level Requirements usually consists of a list of aircraft performance (e.g. maximum speed, kilometric range, etc…) and a list of aircraft characteristics (e.g. payload mass, fuselage length, wingspan, etc…).

This preliminary list of requirements shall be complemented by a set of requirements and constraints coming from the analysis of the foreseen *operational environment* and of the applicable *regulatory and certification framework*.



The Conceptual Design Problem



$$HR = (x_{j_1}) \cup (p_{j_2}) \cup (q_{j_3}) \cup (r_{j_4})$$

Where

- HR is the entire set of Design Specifications;
- x_{j_1} (j_1 = 1:n_1) is the set of target performance to be reached
- p_{j_2} (j_2 = 1:n_2) is the set of design parameters initially set by customers
- q_{j_3} (j_3 = 1:n_3) is the set of operational requirements
- q_{j_4} (j_3 = 1:n_4) is the set of constraints superimposed by the applicable regulatory framework

Reference Material:
[1] Antona, E. "Fondamenti teorici dell'avamprogetto degli aeromobili." Memorie della Accademia delle Scienze di Torino, Classe di Scienze Fisiche Matematiche e Naturali 31 (2007): 147-170.
[2] NASA systems Engineering Handbook

Origin of the Design Topic and of the Design Spec

Stakeholders

High-level performance and design parameters

Competitors

Mission Analysis

Operational Requirements

Concept of Operations

Analysis of Applicable Regulations

Constraints from Regulatory Framework

Sustainable aviation!

High Level Requirements for Passenger Aircraft

$$HR = (x_{j_1}) \cup (p_{j_2}) \cup (q_{j_3}) \cup (r_{j_4})$$

Where
- ✓ HR is the entire set of Design Specifications;
- ✓ x_{j_1} (j_1 = 1:n_1) is the set of target performance to be reached
- ✓ p_{j_2} (j_2 = 1:n_2) is the set of design parameters initially set by customers
- ✓ q_{j_3} (j_3 = 1:n_3) is the set of operational requirements
- ✓ q_{j_4} (j_3 = 1:n_4) is the set of constraints superimposed by the applicable regulatory framework

Set of Performance
$$\begin{cases} Cruise\ Mach\ Number:\ x_1 \geq 0.85 \\ Range: x_2 \geq 5000\ km \\ \ldots \end{cases}$$

Set of Design Parameters
$$\begin{cases} Payload\ Mass: p_1 \geq 10\ t \\ Fuselage\ Length: p_2 \leq 40\ m \\ Wing\ span: p_3 \leq 35\ m \\ \ldots \end{cases}$$

Set of Operational Requirements
$$\begin{cases} Cruise\ Altitude: 11\ k \leq q_1 \leq 12\ km \\ Turn\ Around\ Time\ q_2 \leq 2h \end{cases}$$

Set of constraints from Regulatory Framework
$$\begin{cases} n_{exits} = f(n_{pax} g[m_{pay}]) \\ Balance\ field\ Length \\ \ldots \end{cases}$$

New Requirements for new aircraft configurations

Task 1.1

To write down an initial list of requirements for an aircraft that shall replace A320, with an entry into service in 2035. Please, while listing the requirements, refer to the categories reported in the previous slides

leggero
avanzamento
tecnologico

Design Problem

$$\boxed{HR = \left(x_{j_1}\right) \cup \left(p_{j_2}\right) \cup \left(q_{j_3}\right) \cup \left(r_{j_4}\right)}$$

Origin of the design process

$$\Downarrow$$

$f_n(y_k, HR) = 0$ → funzione da ottimizzare

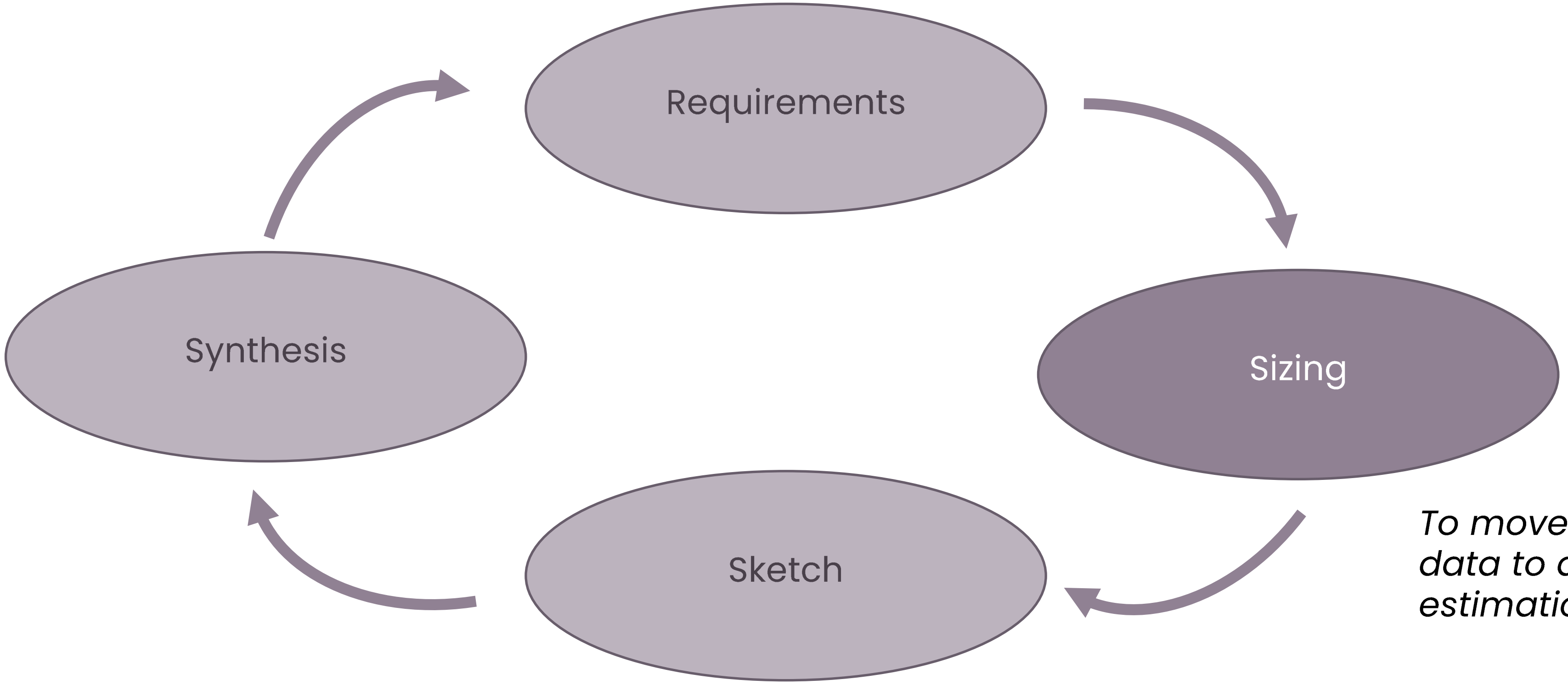
$$\boxed{Unknown\ variables\ y_k}$$

Goal of the design process

The design problem can be formalized through a set of equations f_n. The problem is properly structured only if the number of equations is equal or higher than the number of unknown variables.

Please, notice that during Conceptual Design, usually, there are a multiplicity of possible solutions. Therefore, the main goal of the Conceptual Design phase is to identify all possible solutions and select the bet one(s)

Design Problem



To move from qualitative data to quantitative estimations

Conceptual Design Process

Highly Iterative
Highly Multidisciplinary

Preliminary design various approaches

- Statistics and experience are applied.
- Inverse methods of analytically precedent specialized disciplines are used.
- 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

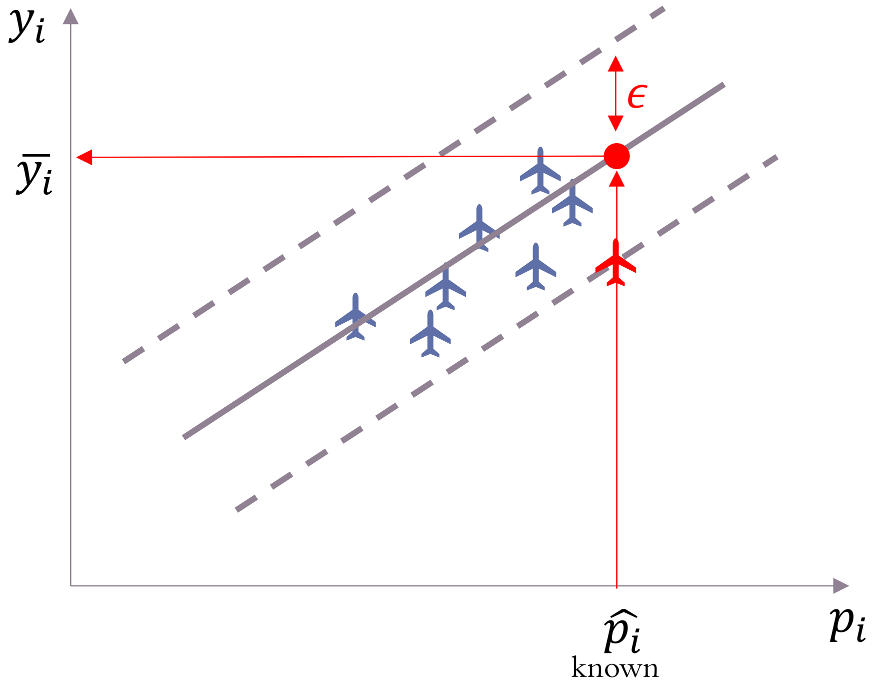
The engineer in aircraft design must always remind herself that she is not actually building the aircraft. Rather, the situation is as follows: aircraft design must try to supply the best possible specifications for the specialized disciplines and to predefine the best possible framework for the detailed 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.

Guess Data Estimation

At the very beginning of the design process, it is important to understand the limits of the design space (sizing procedure), thus it is fundamental to start estimating the main design variables, such as:

- Maximum Take-Off Mass (MTOM)
- Aircraft Level Mass Breakdown $(m_{OE}, m_{fuel}, etc \ldots)$
- Thrust (T_{req})
- Wing Loading
- Lift-over-Drag



For conventional configurations, methods for Guess Data Estimation are usually based on statistical analysis. Error margins shall be duly considered.

Guess Data Estimation: Uncertainties and Margin Philosophy

Allowable Mass is the requirement set by the customers. It is limit against which mass margins are calculated. Please notice that this requirement already contains a Margin, called "Reserve".

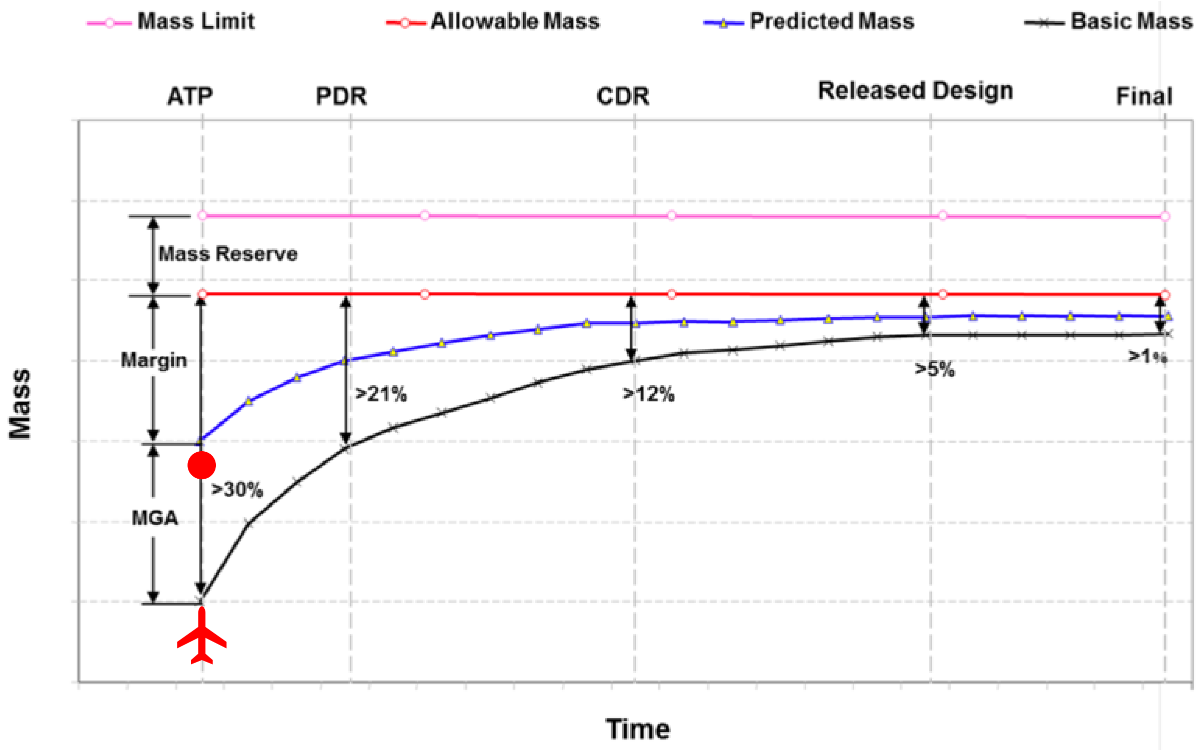
Mass Reserve: mass allowance defined and retained by the customer or program management for potential out-of-scope changes or any other unforeseen mass impacts

Mass Limit
maximum mass that can satisfy all mission performance requirements

Predicted Mass estimates the final mass according to designer's knowledge (Mass Growth Allowance) and design best practice (Design Margins)

Mass Growth Allowance
the predicted change to the basic mass of an item based on an assessment of the hardware category, design maturity, fabrication status, and an estimate of the in-scope design changes that may still occur throughout life-cycle.

$$MGA = f(\epsilon)$$



Task 1.2

On the basis of the list of Requirements elicited in the previous step, identify a good list of reference aircraft and collect data to be used as meaningful statistical population.

TO CONCLUDE….

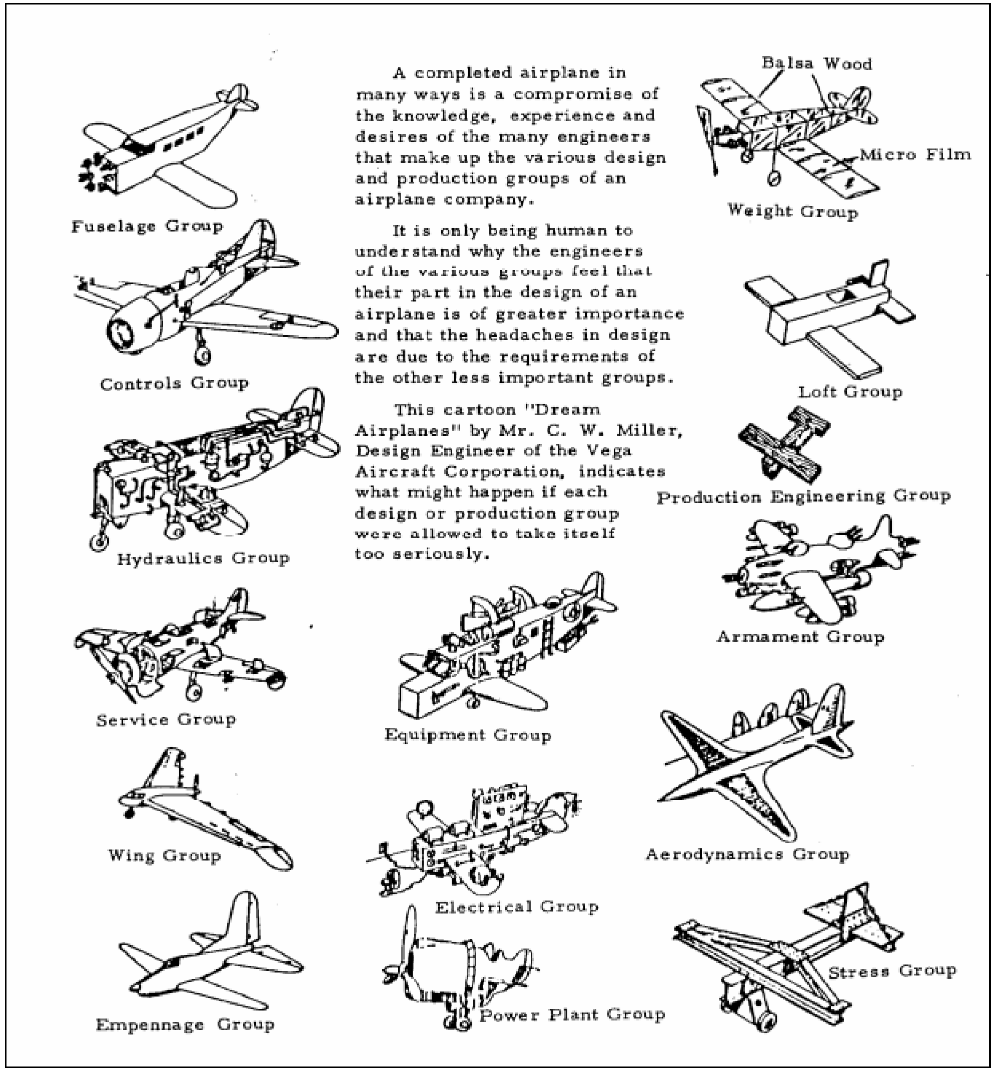


Fig. 1.4 Results of aircraft development if one technical discipline strongly dominates the others (**Nicolai 1975**)

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.