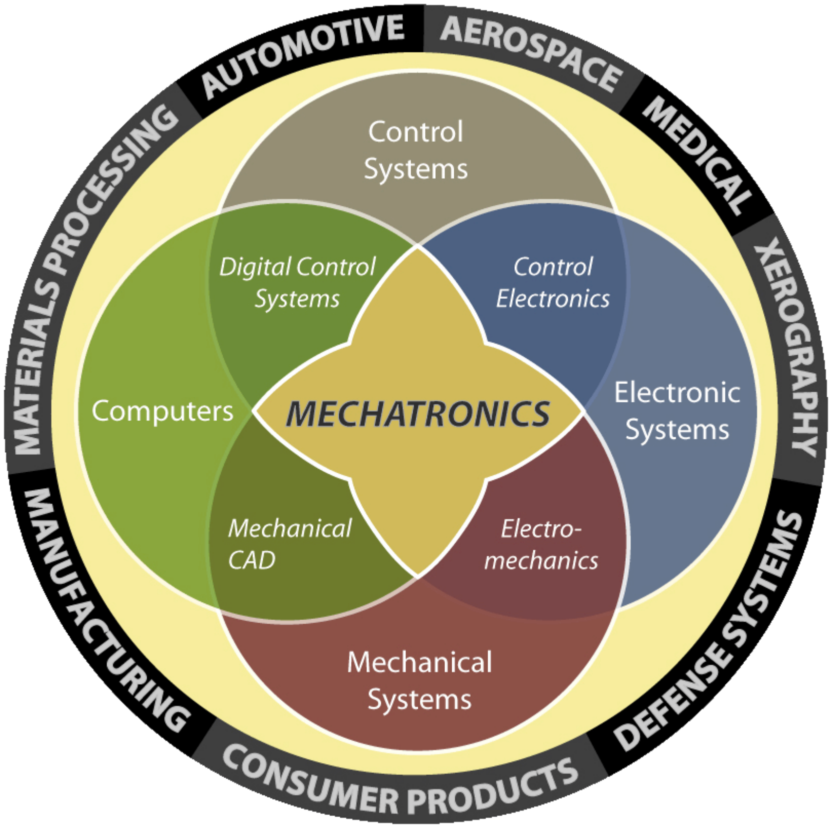
MECHATRONICS BACKGROUND

What is Mechatronics?

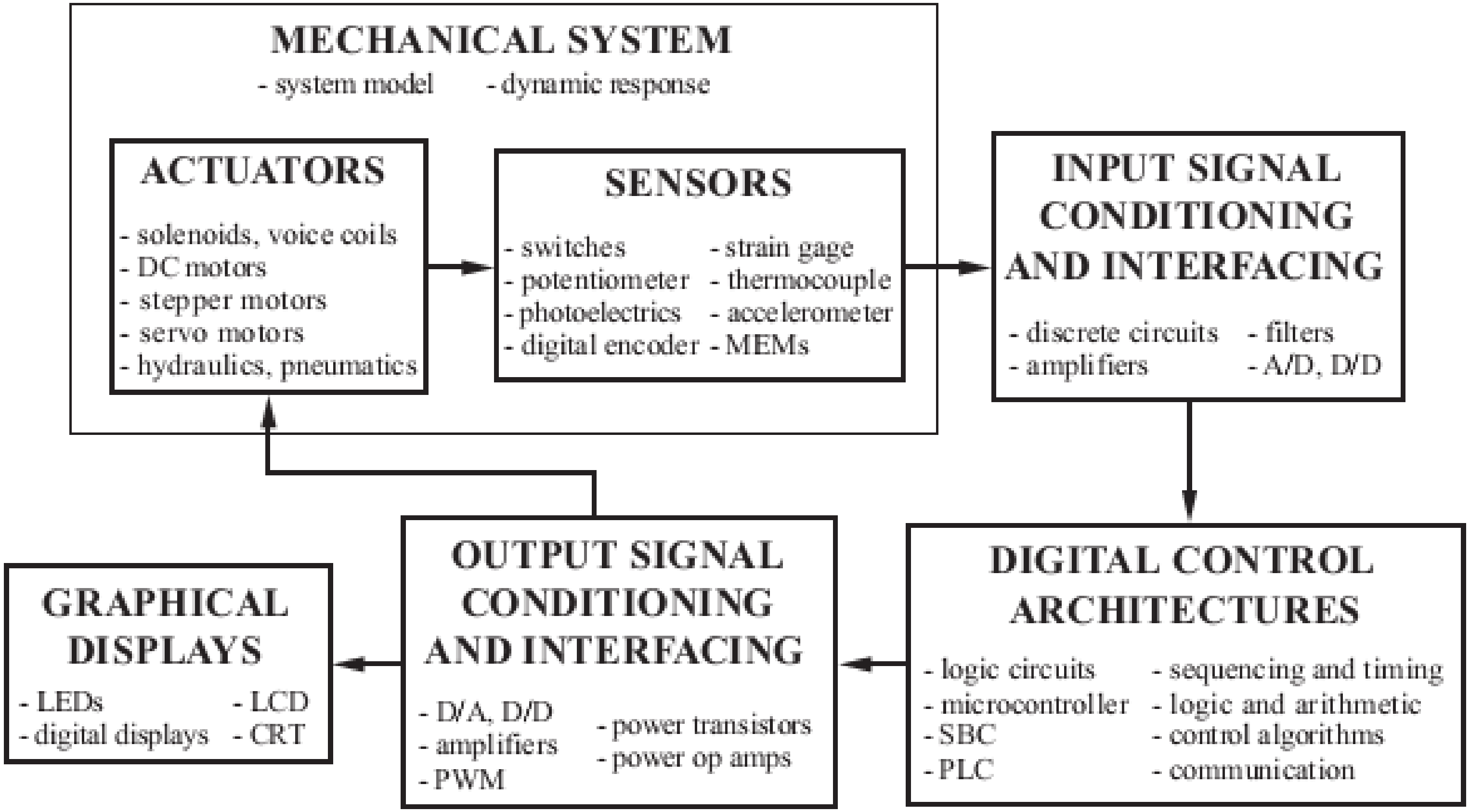
- The word mechatronics was first introduced by the senior engineer of a Japanese company; **Yaskawa**, in **1969**, the company was granted trademark rights on the word in **1971**.

- Yaskawa decided to **quit** his rights on the word in **1982**.



Mechatronics is synergistic integration of mechanical engineering, electronics and intelligent computer control in design and manufacture of products and processes.

A Typical Mechatronics System Components



ADVANCEMENTS IN MECHATRONICS

Advancements in Mechatronics

- Mechatronic products have become increasingly dominant in every aspect of commercial marketplace as technologies, electronics, and computers continue to be developed.

- Presently **major commercial markets** for mechatronic products are in the form:
  - **Automobiles industry**
  - **astronautical systems (Aircraft)**
  - **biological systems.**
  - **Robotics**

- Advancements in mechatronics in the areas of automobile engineering, biotechnology, and aircraft have given rise to specialized disciplines of:

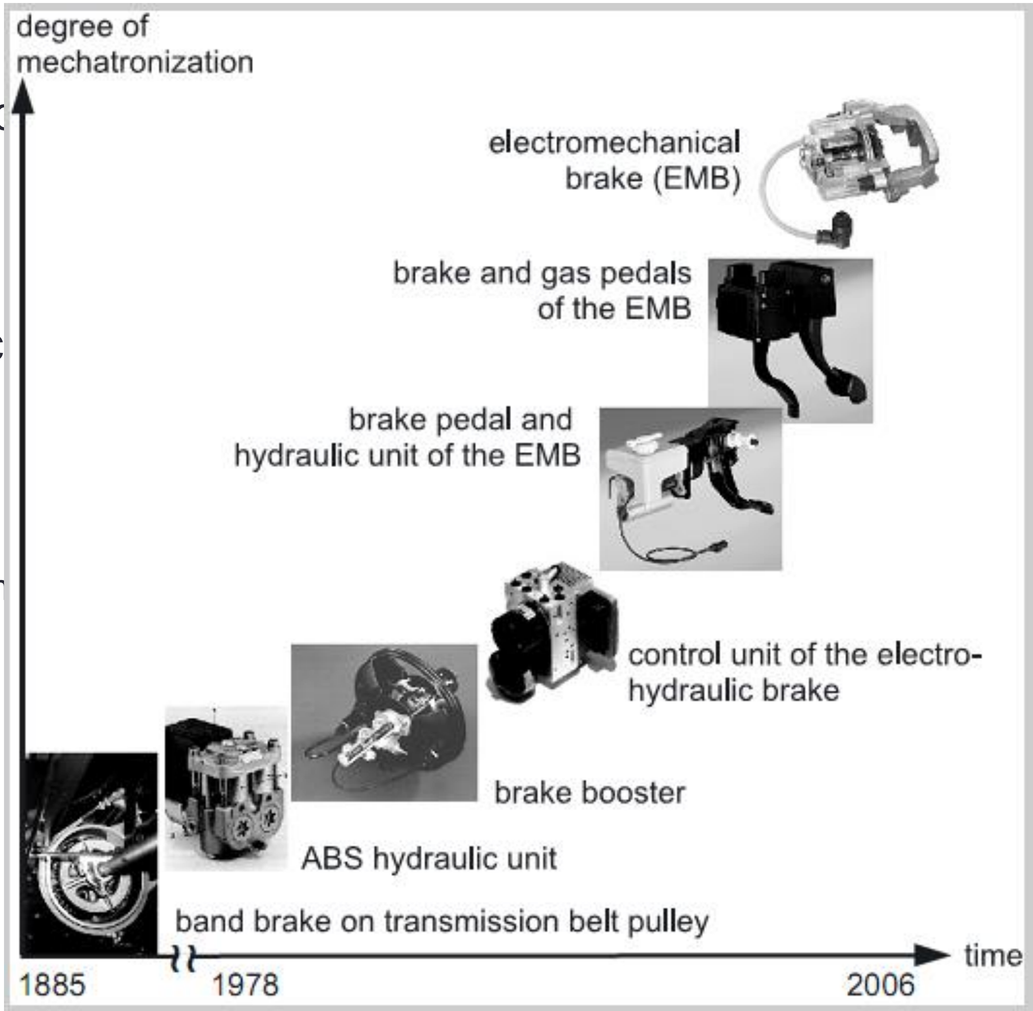
  - **Autotronics ,**
  - **Bionics (Biomechatronics),**
  - **Avionics**.
  - **Industrial Mechatronics**

Autotronics

- The primary motivation for adopting mechatronic systems in automobiles is to make automobiles **safer**, **more comfortable**, **fuel efficient**, and **less polluting systems**.

- **Smart vehicles** are based o
  to **detect the environment**

- **Application** of mechatronic
  major areas:
  - Safety
  - Engine
  - Comfort and convenience
  - Vehicle diagnostics and health
  - braking



Bionics (Biomechatronics):

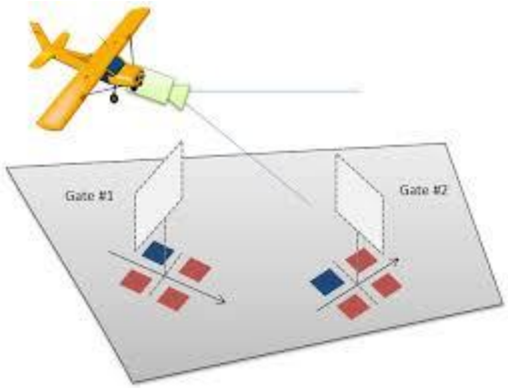
- **Bio mechatronic** is defined as a system that integrates mechanisms, sensors, actuators, power supplies, control and embedded systems, which are the main components of mechatronics systems, to use with biological systems.

- **Bio mechatronic** is using mechatronics concept to **Simulate biological systems**, e.g.: human, animal and bird.

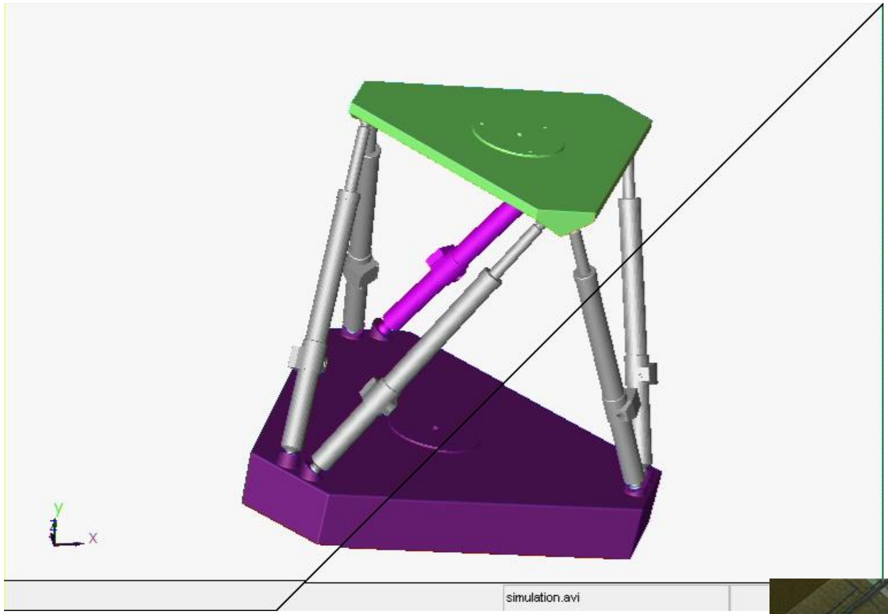
Avionics

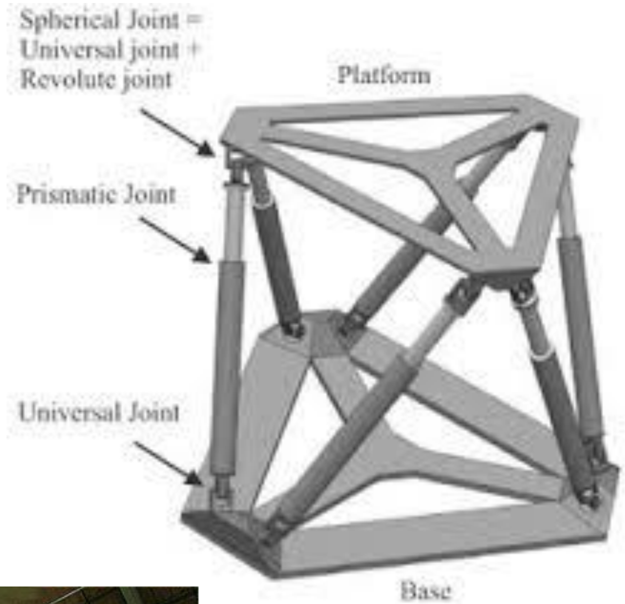
- Numerous and complex mechatronic systems are used in **advanced commercial and military aircrafts**. With the **ever-increasing emphasis on robustness** and **safety**, there is a trend towards using more mechatronic systems in aerospace industry.

- The major applications of mechatronic systems in **aerospace industry** can be classified as follows:
  - ✓ Cockpit instrumentation (flight deck)
  - ✓ Safety devices
  - ✓ Wind tunnel instrumentation
  - ✓ Sensors for fuel efficiency and safety
  - ✓ Microgyroscope (IMU) for navigation and stability



Parallel Robot





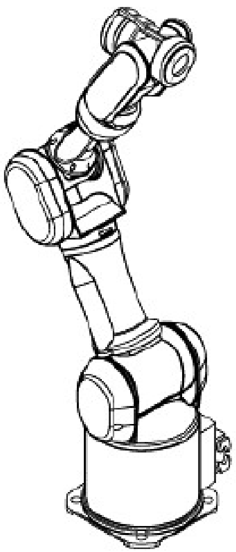
1. The Stewart platform.

Components and subsystems

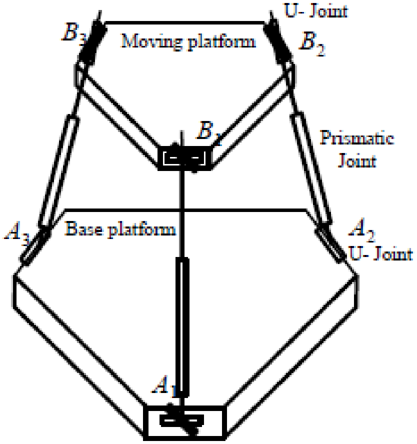
Robot arm:

Serial manipulators
(Single open loop chain)

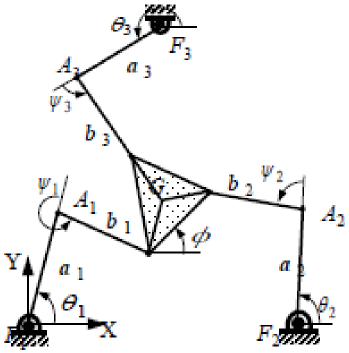
parallel manipulators
(Multiple closed loop chains)



PA-10 redundant manipulators



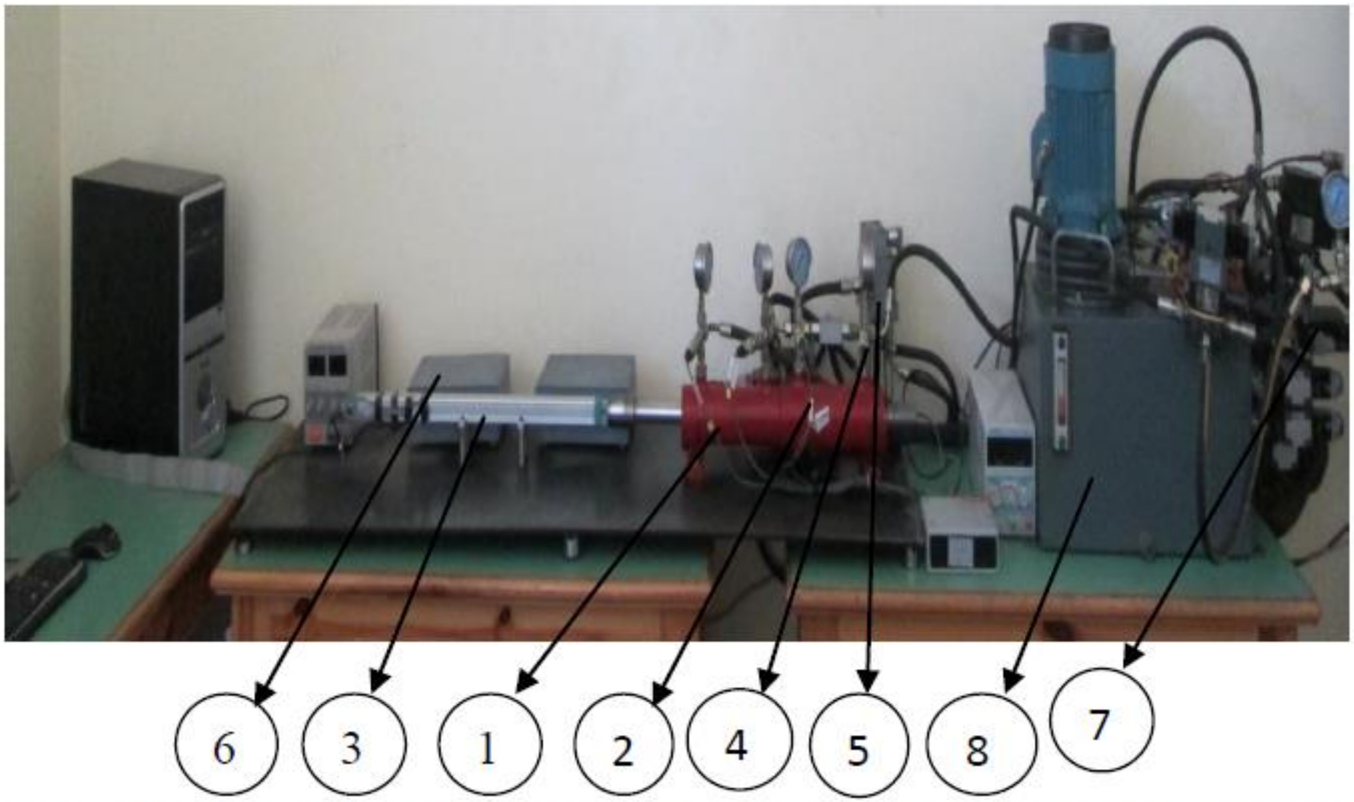
Spatial parallel manipulator



Planar parallel manipulator

Mechatronics on going Research In Waseda University

Control of hydraulic system



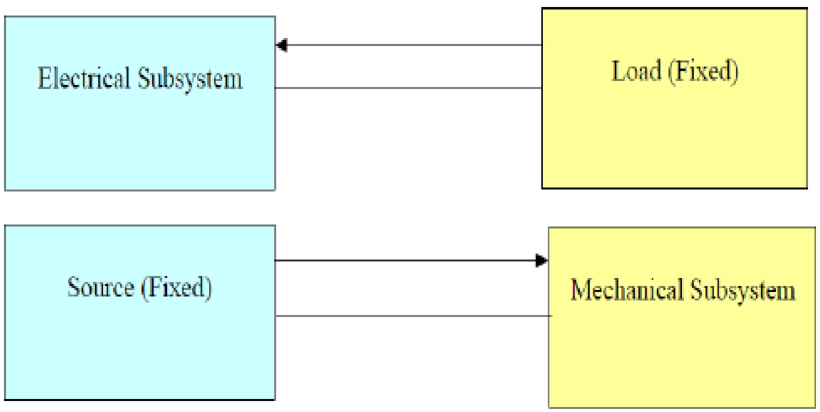
1 Main cylinder, 2 Load cylinder, 3 Linear potentiometer, 4 Pressure transducer, 5 proportional relief valve, 6 Electronic interface, 7 proportional directional valve, 8 power unit (Filter, Electrical motor, Pump, System relief valve, Tank)

MECHATRONIC SYSTEM DESIGN

Mechatronic System Design

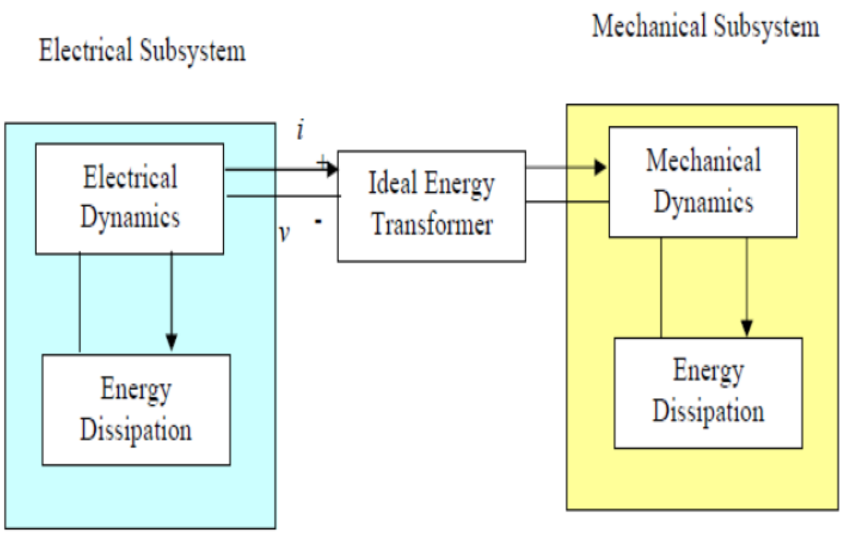
- The **mechatronic design methodology** is based on a **concurrent** (instead of **sequential**) approach to discipline design, resulting in products with more synergy.
- In the designing of a mechatronic product, it is necessary that the **knowledge and necessary information be coordinated amongst different expert groups**.

Conventional Design (Sequential)



Each Subsystem is designed separately and sequentially while keeping the interactions with other subsystems constant, the dynamic interaction is ignored

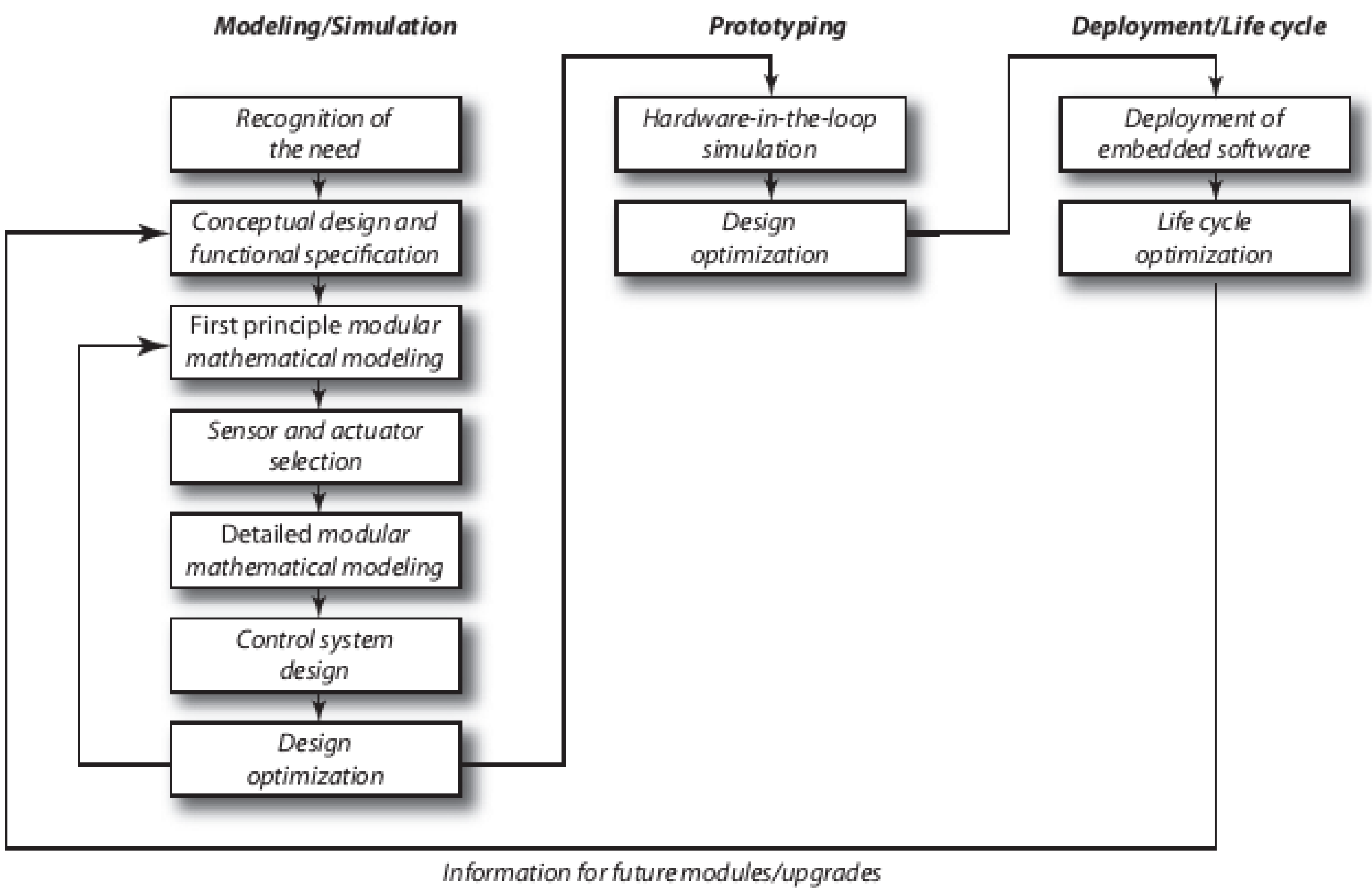
Mechatronic System Design (Concurrent)



Employ an integrated approach for design, development and implementation

Mechatronics Systems Design Process

- The mechatronic design process consists of three phases:
  - Modelling and simulation
  - Prototyping
  - Deployment



ICS 03.100.40; 31.220 VDI-RICHTLINIEN Juni 2004 June 2004

VEREIN DEUTSCHER INGENIEURE	Entwicklungsmethodik für mechatronische Systeme Design methodology for mechatronic systems	VDI 2206 Ausg. deutsch/englisch Issue German/English

Die deutsche Version dieser Richtlinie ist verbindlich.

The German version of this guideline shall be taken as authoritative. No guarantee can be given with respect to the English translation.

Inhalt	Seite	Contents	Page

VDI-Gesellschaft Entwicklung Konstruktion Vertrieb (VDI-EKV)

Ausschuss Entwicklungsmethodik für mechatronische Systeme

VDI-Handbuch Konstruktion
VDI-Handbuch Mikro- und Feinwerktechnik

- **VDI 2206 standard guide, "Design methodology for mechatronic systems", German, 2004.**

ICS 03.100.40; 31.220 VDI-RICHTLINIEN Juni 2004 June 2004

VEREIN DEUTSCHER INGENIEURE
Entwicklungsmethodik für mechatronische Systeme
Design methodology for mechatronic systems
VDI 2206
Ausg. deutsch/englisch
Issue German/English

DESIGN METHODOLOGY FOR MECHATRONIC SYSTEM (VDI 2206)

ICS 03.100.40; 31.220

VDI-RICHTLINIEN

Juni 2004
June 2004

VEREIN DEUTSCHER INGENIEURE	Entwicklungsmethodik für mechatronische Systeme Design methodology for mechatronic systems	VDI 2206 Ausg. deutsch/englisch Issue German/English

Objective of VDI 2206

- The objective of this guideline is to:
  - provide methodological support for the cross-domain development of mechatronic systems.

- The main aspects here are intended to be ***the procedures, methods and tools for the early phase of development***, concentrating on system design. The result of system design is the assured **concept of a mechatronic system**.

- This is understood as meaning the solution established in principle and checked by **verification and validation**.

Structure of the VDI 2206 Guideline

- The guideline has the following structure:
  - Introduction to the development of mechatronic systems
    - This deals with the principles of mechatronic systems. These include a defined understanding of the concepts of mechatronics and the basic structure of mechatronic systems.
  - Development methodology of mechatronics
    - This comprises a three-part procedural model (micro-cycle, macro-cycle, process modules), the methods of model-based system design, supporting IT tools and selected aspects of the organization
  - Application examples.

DEVELOPMENT METHODOLOGY OF MECHATRONICS

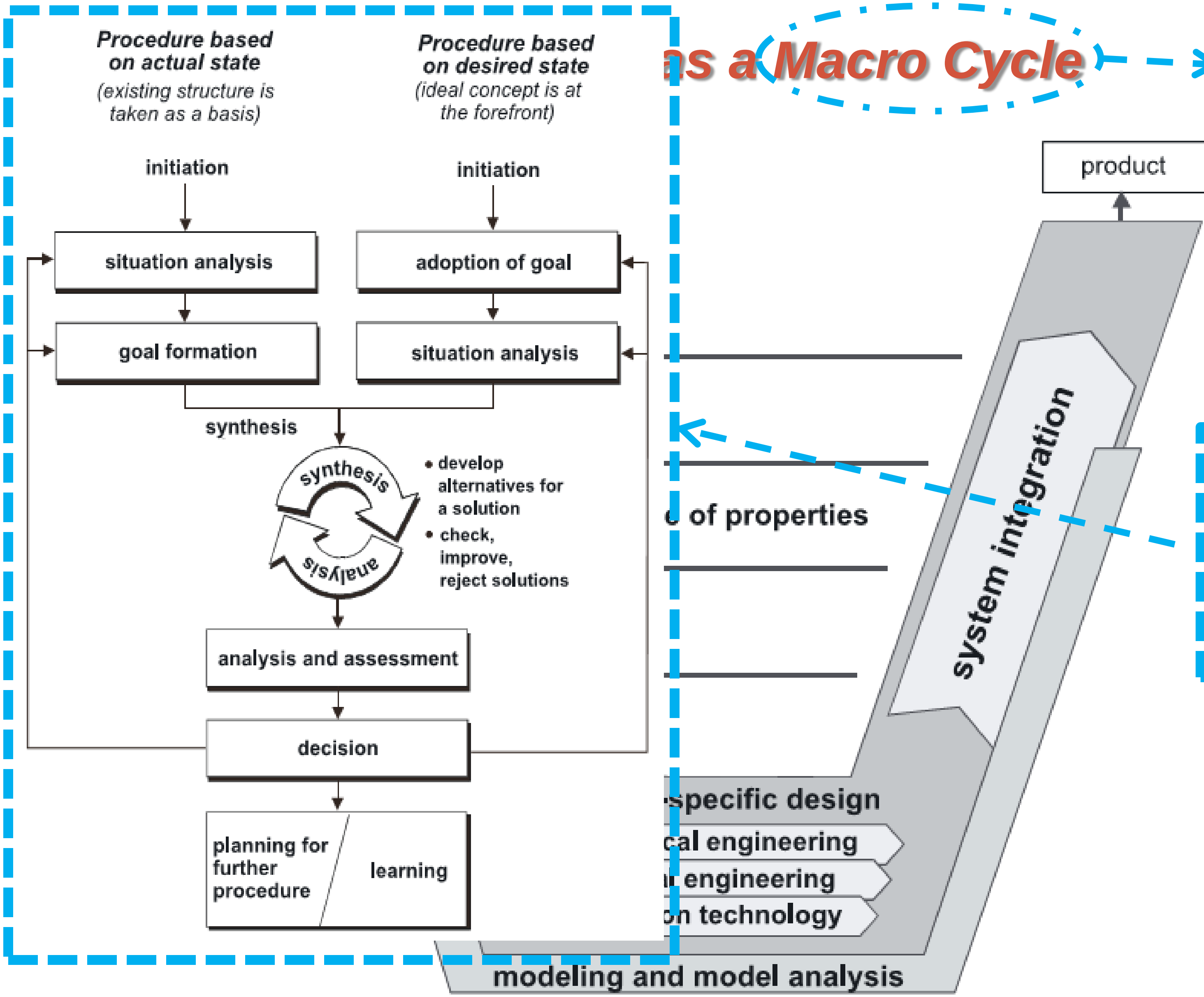
Design Procedures

- **Main procedures:**
  - **Requirements.**
  - **System design.**
  - **Domain specific design.** ***(Modelling and model analysis)***
  - **System integration.**
  - **Assurance of properties.**

These main procedures will be done by V model which describe the generic procedure for designing mechatronic systems

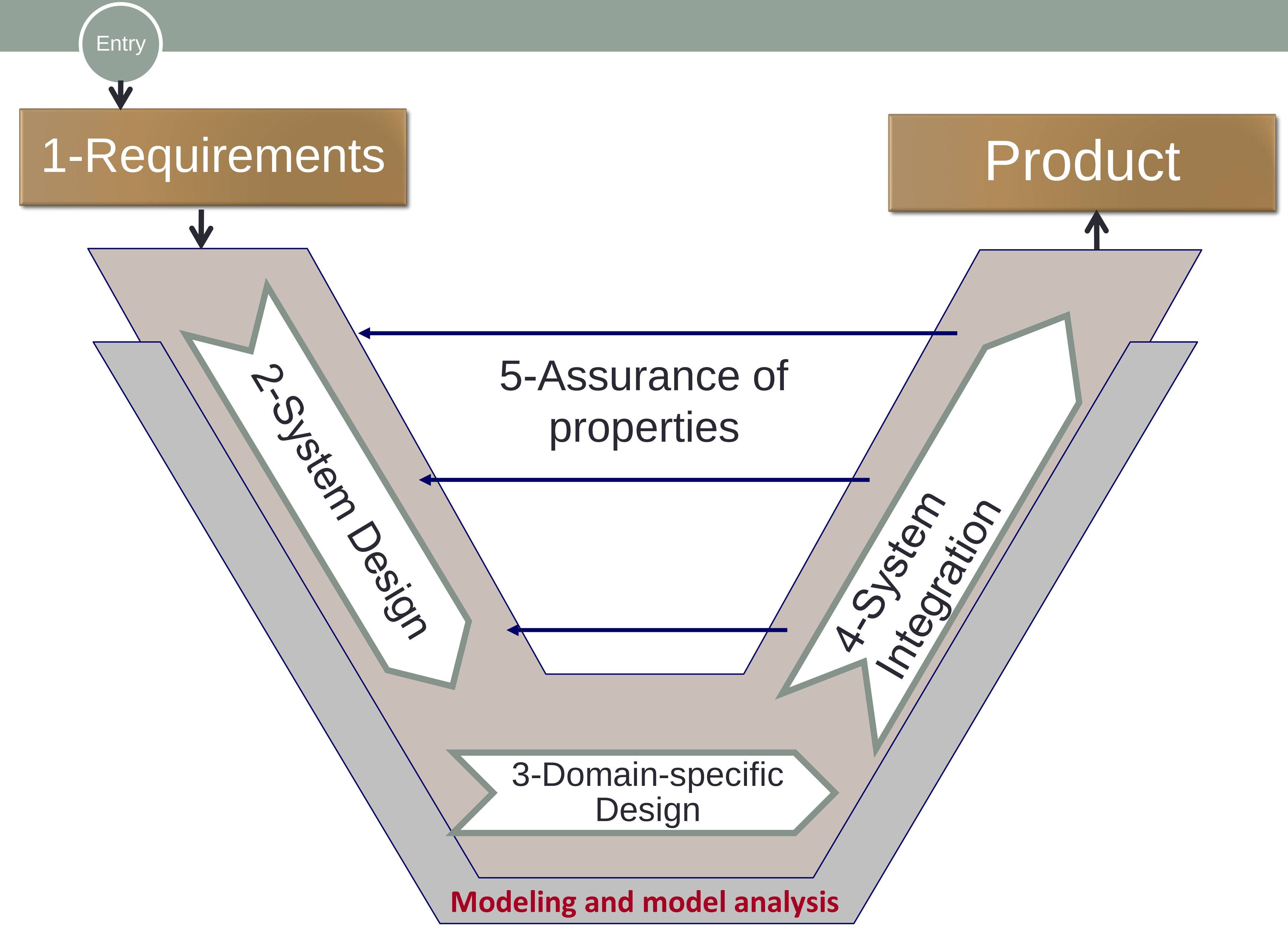
V Model

…as a Macro Cycle



What is the meaning of this?

To know this we must know micro cycle first


Entry
1-Requirements
Product
2-System Design
5-Assurance of properties
4-System Integration
3-Domain-specific Design
Modeling and model analysis

1-Requirements

- **Requirements:**
  - The starting point
  - The defined object was specified more precisely and described in the form of requirements
  - These requirements at the same time from the measure against which the later product is to be assessed
- **Example: High speed pick and place robot**

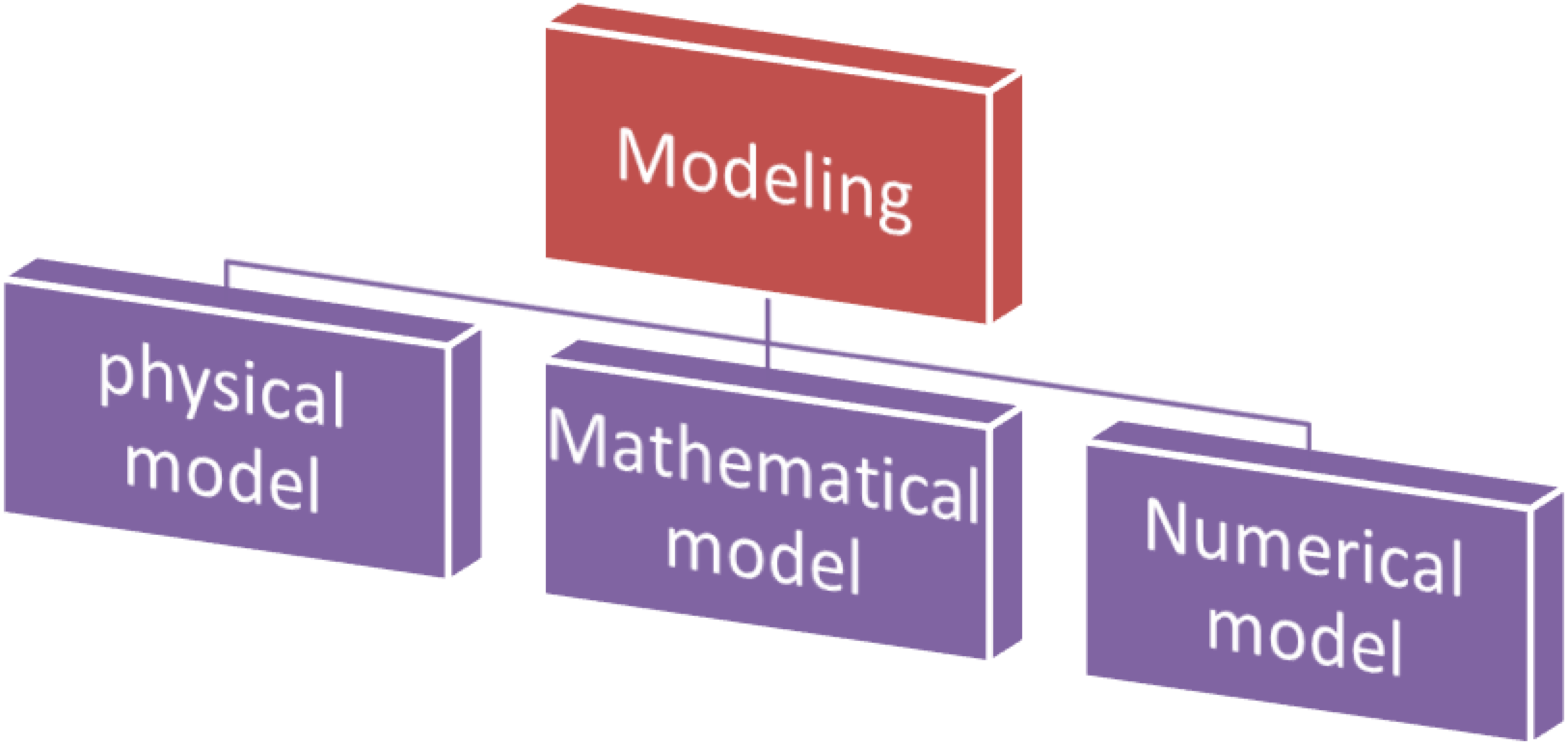
1) **Speed (average cycle time)**
2) **Maximum work space**
3) **Pay load**
4) **environment that will work in**
5) **Material**

ABB IRB 360	
Payload	1,3,6,8 Kg
Workspace	800, 1130 mm
Cycle time	500 prod/min
Material	Steel

2-System Design

- **System design:**
  - The aim is to establish a cross domain solution concept which describes the main physical and logical characteristics of the future product
  - For this purpose, the overall system must be broken into main subsystems (for example mechanical, electrical, after that single part for each one)
- **Example: KUKA Serial Robot**

3-Modelling and model analysis



What is the difference between them?

Physical model

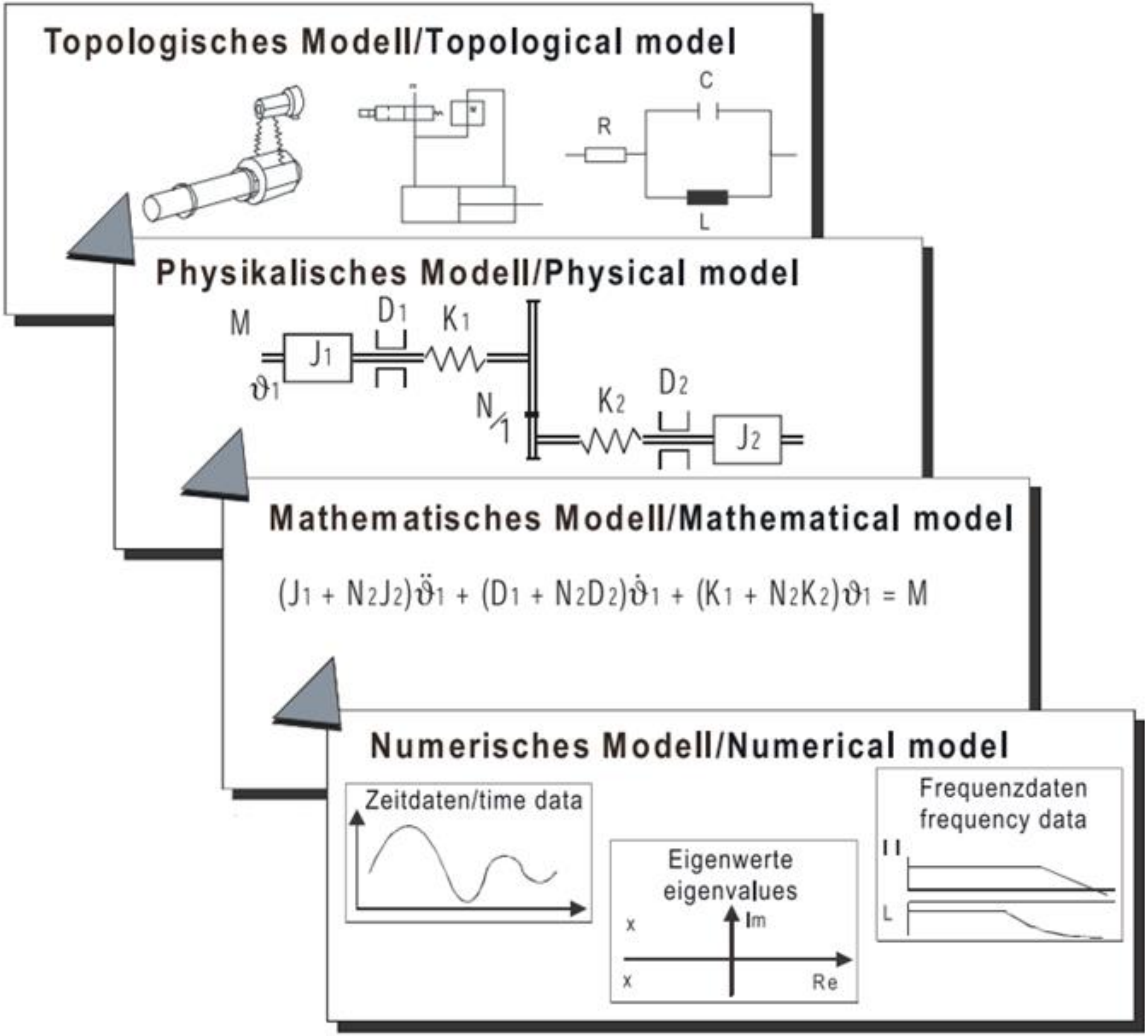
- it is created from **topological description**
- This representation is defined by system -**adapted variables** such as for example **masses and lengths in case** of **mechanical systems** or **resistances and inductances** in the case of **electrical systems**,

Mathematical model

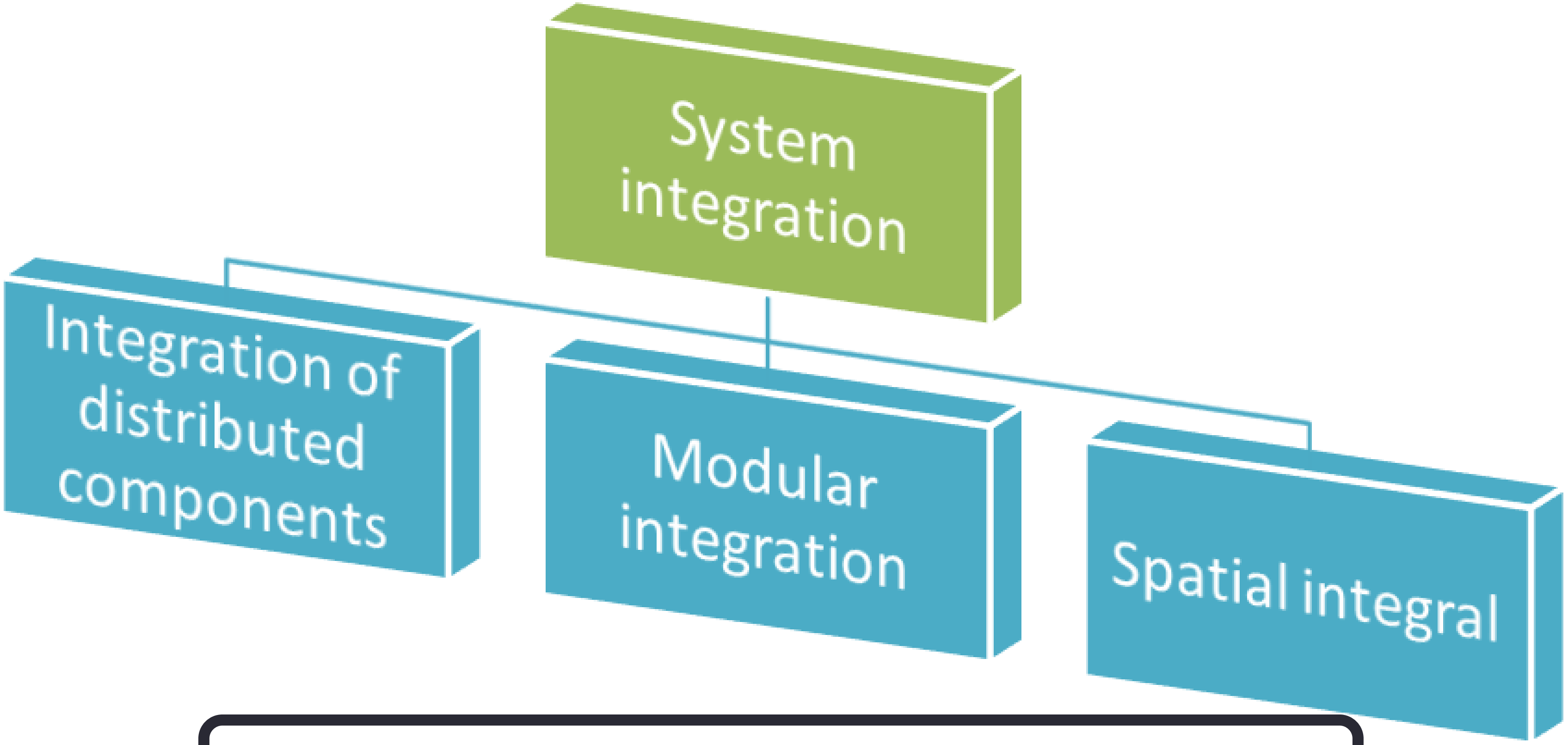
- The physical properties of the **physical model** are formulated with the aid of **mathematical descriptions**

Numerical model

- The **Mathematical model** is then prepared in such a way that it can be **algorithmically handled and subjected to a computer aided** process, for example **simulation**


Topologisches Modell/Topological model
C
R
L
Physikalisches Modell/Physical model
M
D1
K1
J1
ϑ1
N/1
K2
D2
J2
Mathematisches Modell/Mathematical model
$(J_1 + N_2J_2)\ddot{\vartheta}_1 + (D_1 + N_2D_2)\dot{\vartheta}_1 + (K_1 + N_2K_2)\vartheta_1 = M$
Numerisches Modell/Numerical model
Zeitdaten/time data
Eigenwerte
eigenvalues
Im
Re
x
x
Frequenzdaten
frequency data
L

4-System Integration



What is the difference between them?

4-System integration

Integration of distributed components	Modular integration	Spatial integration
• **Components** such as **sensors and power actuators are connected to one another via signal and energy flows** with the aid of communication systems	• The **overall system is made up of modules** of defined **functionality and standardized dimensions** .	• **All components are spatially integrated** and form a complex functional unit, for **example integration of all elements of a drive system (controller, power actuator, motor, transfer element, operating element) into a housing** .

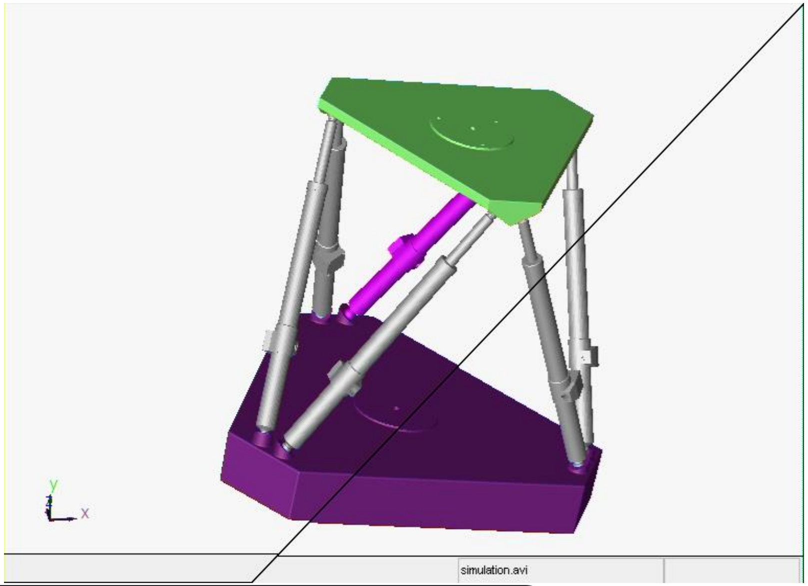
4-System Integration

Hardware in the loop (HIL)

- Is the integration of **real components** and **system models**

Software in the loop (SIL)

- Is the integration of system models in a **common simulation** in a common simulation environment with the modeled process **(Controlled system)**



By LabView or MATLAB

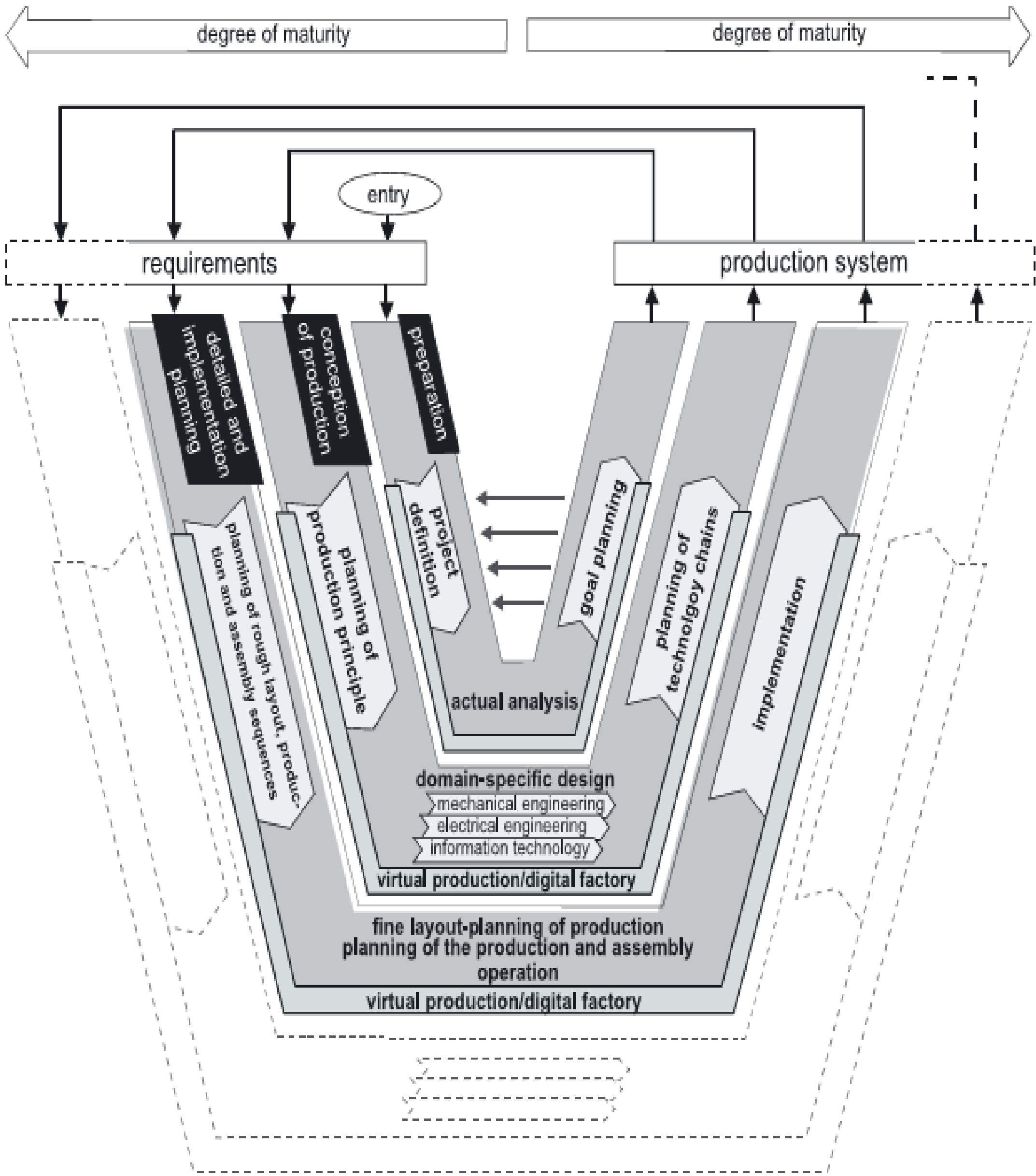
5- Assurance of properties

- The progress made with the design must be **continually checked** on the basis of the **specified solution concept** and **the requirements by:**

Verification	Validation
• Verification means checking whether the way in which something is realized and whether it coincides with the specification. • Verification is the answer to the question : Is a correct product being developed? For example, does a software program coincide with the deception of algorithms.	• Validation means testing whether the product is suitable for its intended purpose or achieves the desired value. • Validation is the answer to the question : Is a right product being developed?

Finally: Mechatronics product

- Product: is the result of a **continuous macro cycle**
- **A Complex Mechatronics** product is generally not produced within **one macro-cycle**
- **Degree of maturity** are for example:
  - ➢The laboratory specimen
  - ➢The functional specimen
  - ➢The pilot-run project

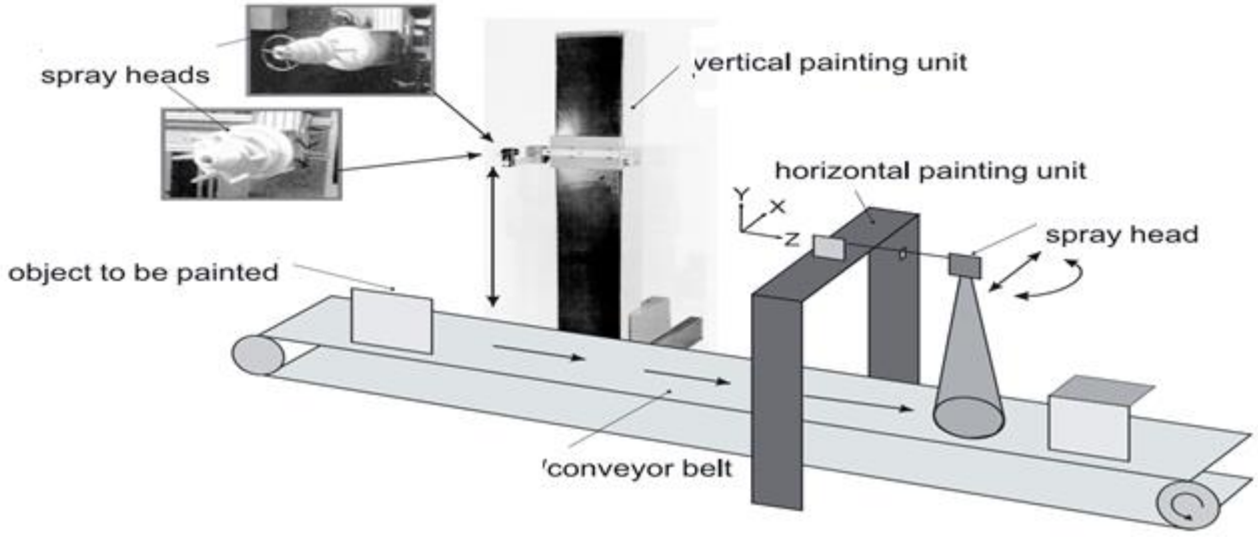


Example

Design of the drive unit of a simple painting system

For painting mass-produced articles (kitchen appliances, audio and video equipment, aluminum wheel rims), painting systems in the form of continuous lines are often used. On these, the objects to be painted pass continuously through the system on a conveyor belt. The paint is applied by a number of spraying units, the oscillating movement of which runs either vertically (for the side surfaces of the object) or horizontally (for the upper side of the object)

Basic Representation of the Continuous line



1-Selected requirements

1. Desired speed in *x* direction: 1 m/s
2. Distance at constant desired speed in *x* direction over the belt: 700 mm
3. Maximum oscillating amplitudes in *x* direction in the range of constant desired speed: +- 3 mm
4. Electric drive
5. The geometrical requirements as shown in fig

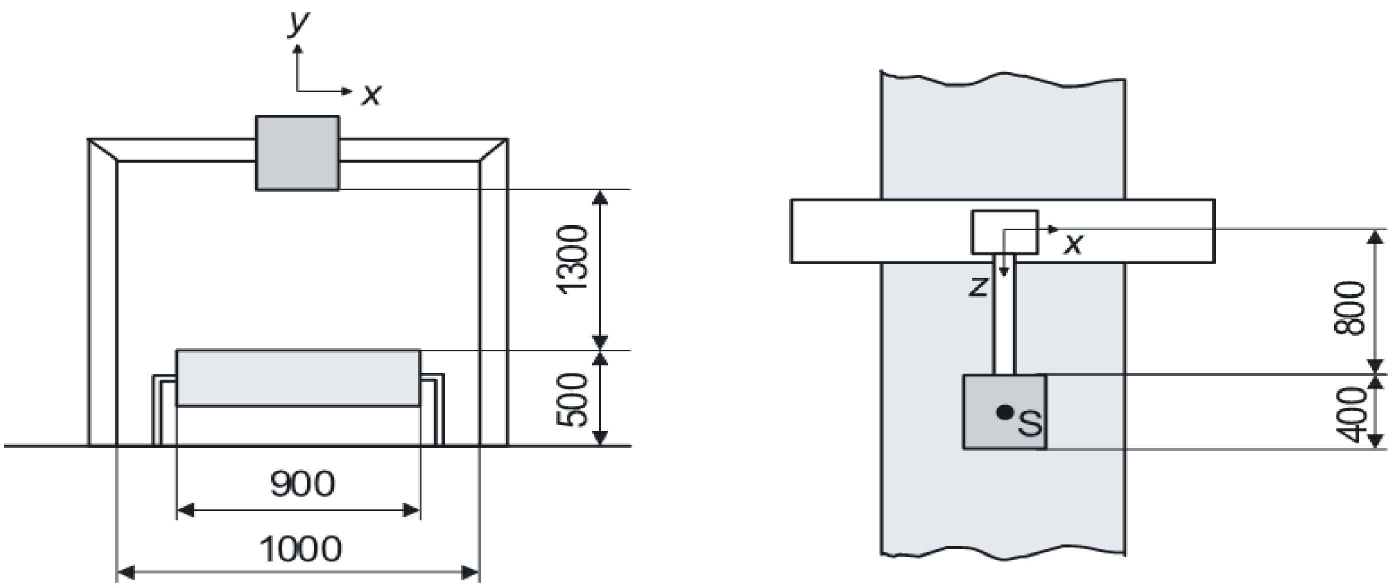
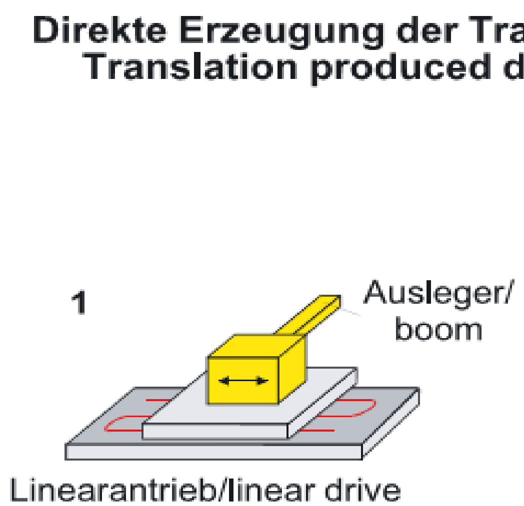


Fig. 4-12. Geometrical requirements

2-System Design



1-How to transform From Rotation into translation?

2-What is the Need rough dimensioning to the Mechanical and electrical drive elements?

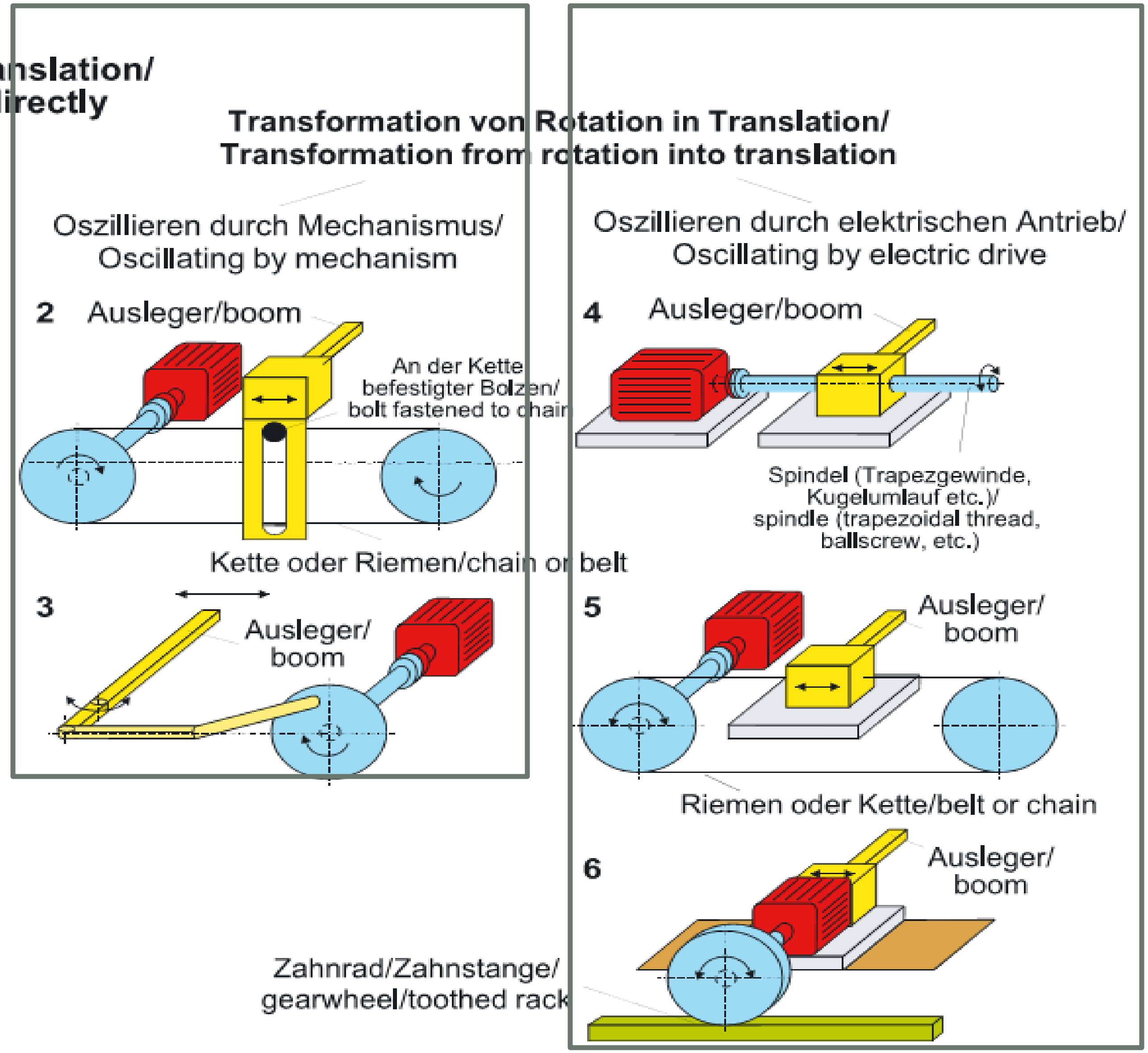
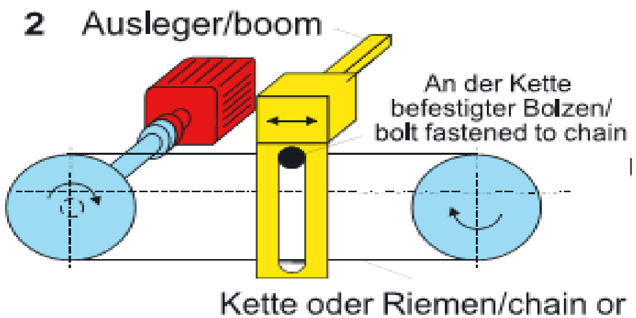
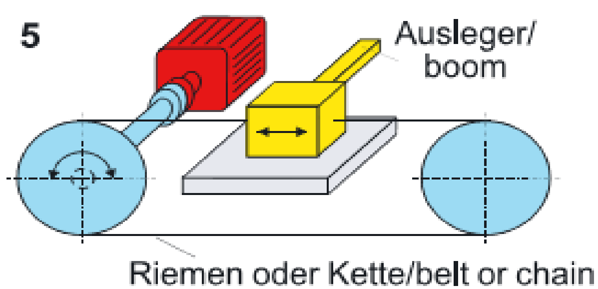


Fig. 4-13. Solution variants of the system design

- A more precise assessment of the variants cannot be made within the scope of this guideline.
- However, it should be noted that variants of type 2 represent a solution that is customary in practice, but have great problems with mechanical loads and wear in the connecting link guide and also lead to inflexible kinematics in the returning area. Therefore, variant 5 with a brushless DC motor in combination with a toothed belt drive is to be considered by way of example.

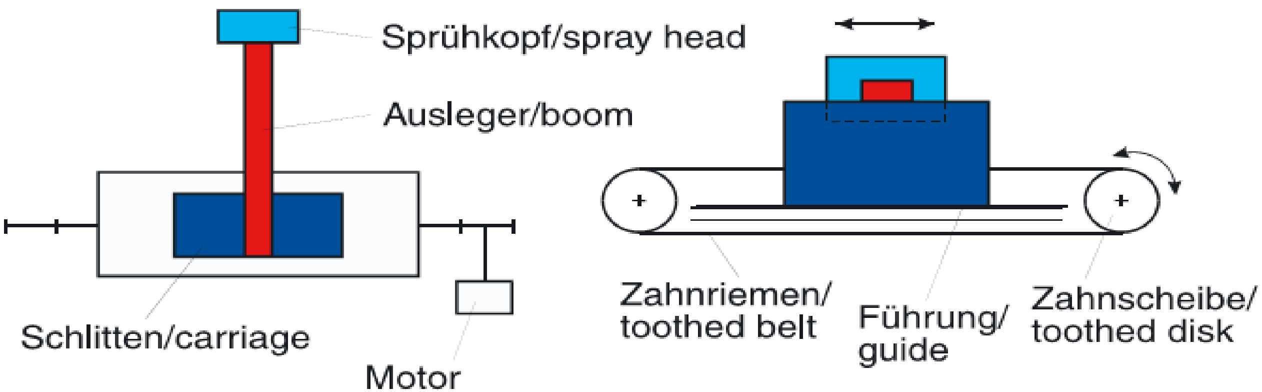


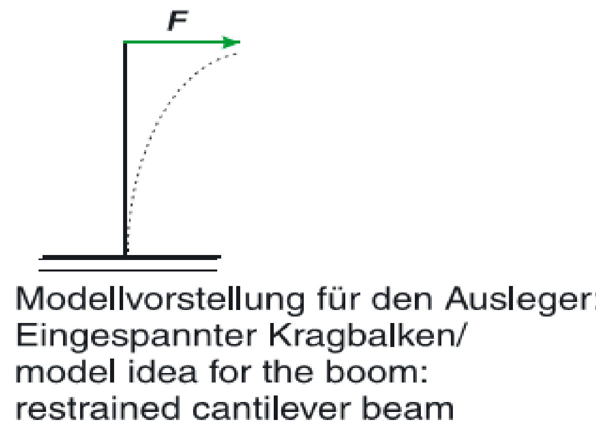


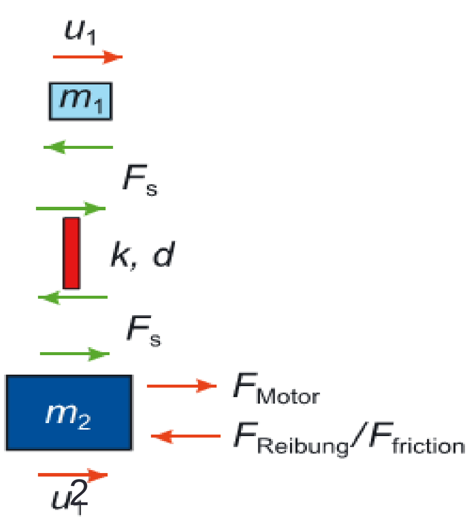
3-Assessment and Selection of Variants?

Fig. 4-13. Solution variants of the system design

3-Modelling and Simulation







$$-m_1 \cdot \ddot{u}_1 - F_s = 0$$

$$F_s = F_k + F_d = k \cdot (u_1 - u_2) + d \cdot (\dot{u}_1 - \dot{u}_2)$$

$$u = \frac{F \cdot 1^3}{3EI} \quad \to k = \frac{3I}{1}$$

$$-m_2 \cdot \ddot{u}_2 + F_s + F_{Motor} - F_{Reibung} = 0$$

$$F_{Motor} = 2 \cdot M_{el} / d_{Zahnscheibe}$$

Figure 4-14. Formulating the differential equations for the simple mechanical substitute model

The DC motor used is described by its winding inductance and winding resistance and also two constant factors k_i and k_E with the equations

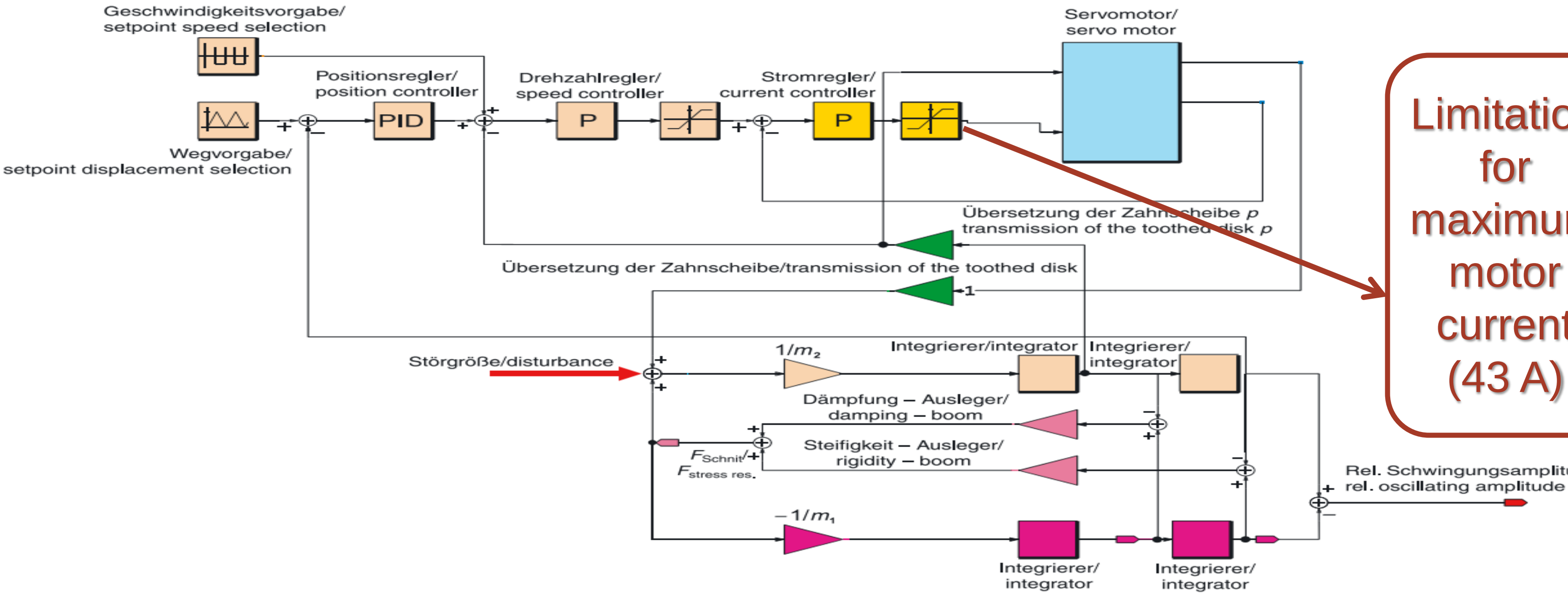
$$\dot{i} = \frac{1}{L} \cdot (U_{motor} - R \cdot i - k_E \cdot \dot{\varphi})$$

$$M_{el} = k_i \cdot i$$

The term $k_E \cdot \dot{\varphi}$ describes the mutual induction and couples the mechanical and electrical equation systems.

Control structure

- ❑The system is designed as a cascade control with three PID controllers.
  - In the inner cascade, the current control ensures that the inductance of the motor winding which limits the rate of current rise is compensated by an increased motor voltage.
  - The middle cascade comprises the speed control of the motor,
  - while the outer cascade controls the position. The desired displacement is also additionally fed forward here as a pre control.



Limitation for maximum motor current (43 A)

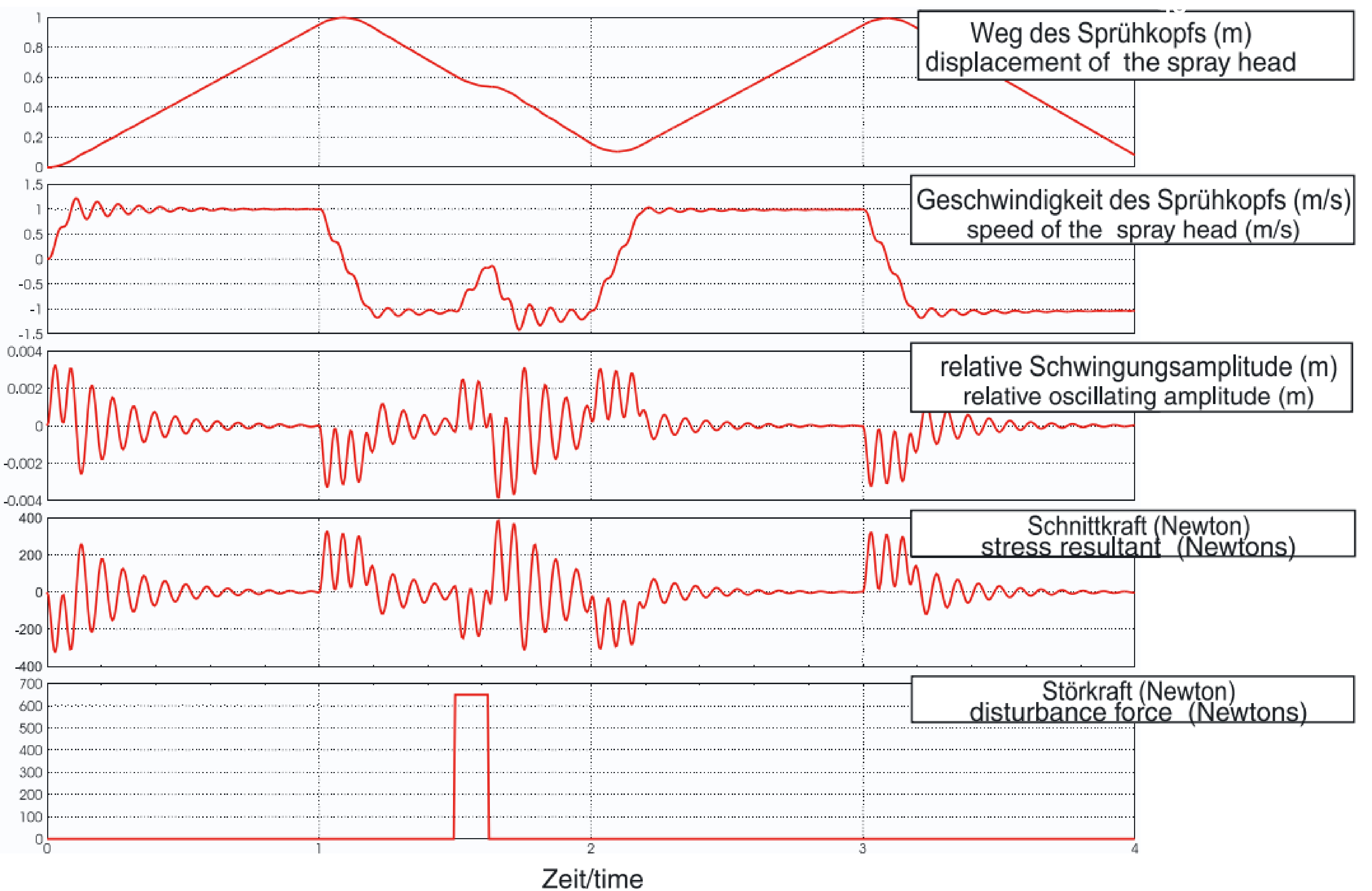


Fig. 4-16. Simulation results of the block diagram from Figure 4-15

FINALLY INTEGRATION VALIDATION AND VERIFICATION