Lightweight Materials
Their Properties, Technologies and Advanced Applicability

1.1 Introduction

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Lightweight Materials - Their Properties, Technologies and Advanced Applicability

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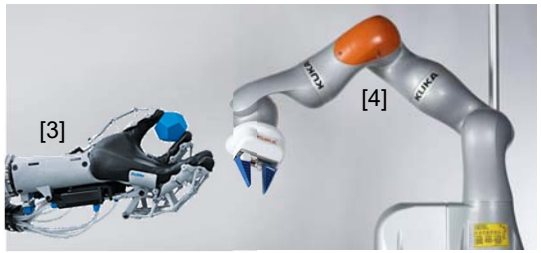
8	3	4.2 Hybrid Composite Materials and Structures (part 2) Mechanical, Thermal and Adhesive Bonding Technologies State of Technology and novel Approaches



Lightweight design

What are the drivers for lightweight design?

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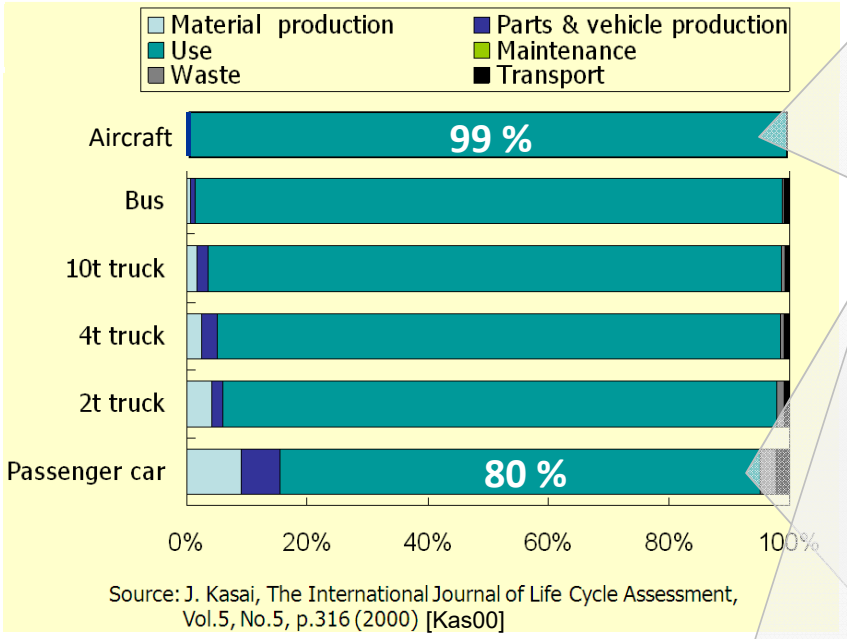
Drivers for Lightweight Design

Energy Demand



Source: J. Kasai, The International Journal of Life Cycle Assessment, Vol.5, No.5, p.316 (2000) [Kas00]

[1]

[2]

CO_2 Emission

Fleet limits (acc. to EU legislation)

- 2012: 130 g/km
- 2020: 90 g/km (further gradually reduced)

[3]

Elektromobility

Range influence:

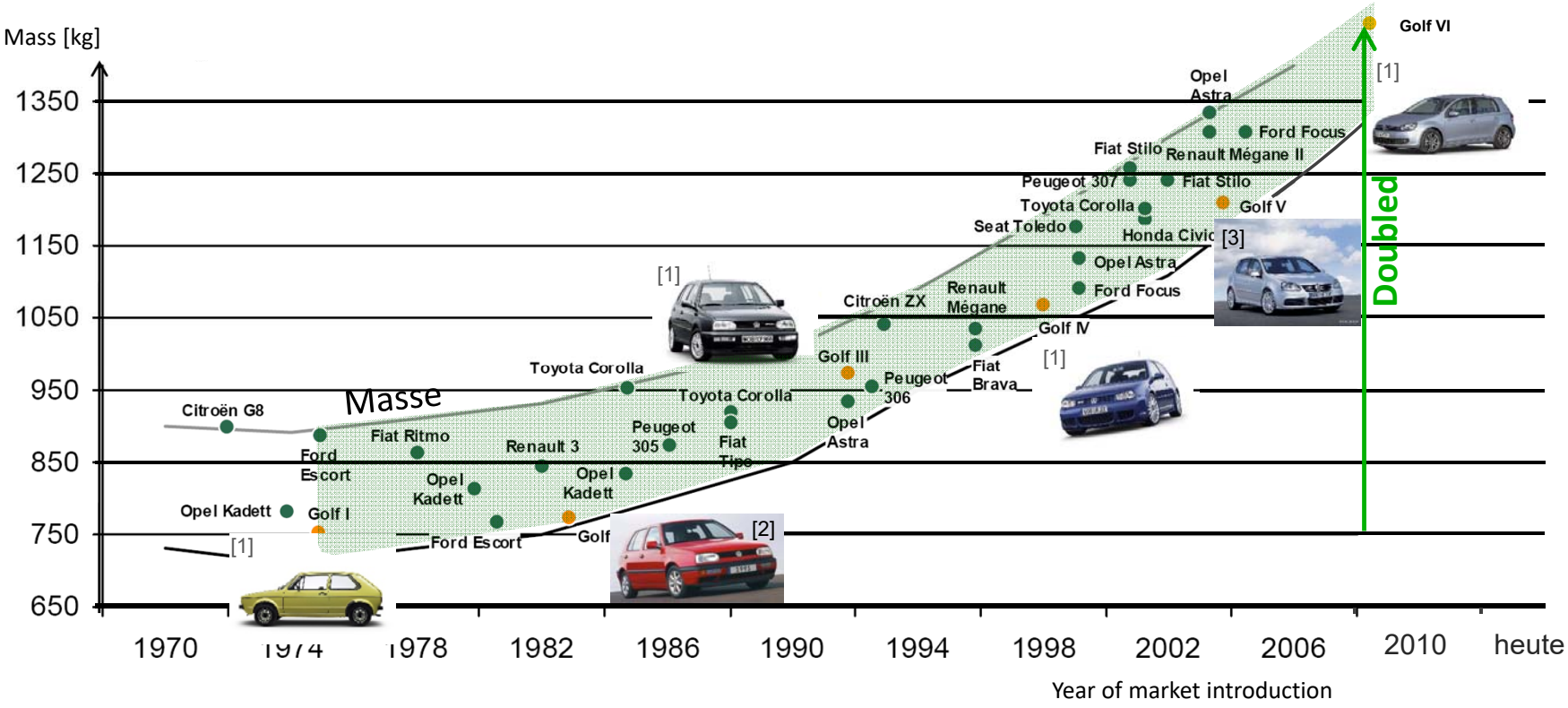
- Compensation mass for battery
- Networking and energy management

[3]

Drivers for Lightweight Design

Energy Demand

- Development over time of vehicle mass and energy consumption during operation :



Drivers for Lightweight Design

Energy Demand

- "Lifeworld Automotive"

  - Sociological aspects
    - Need for mobility, accessibility workplace
    - Need for safety and comfort
    - Understanding of value added, individuality, prestige

  - Econnomical aspects
    - Quality, reliability, ease of repair
    - Costs for maintenance, taxes, insurances
    - Energy consumption (l/100km)

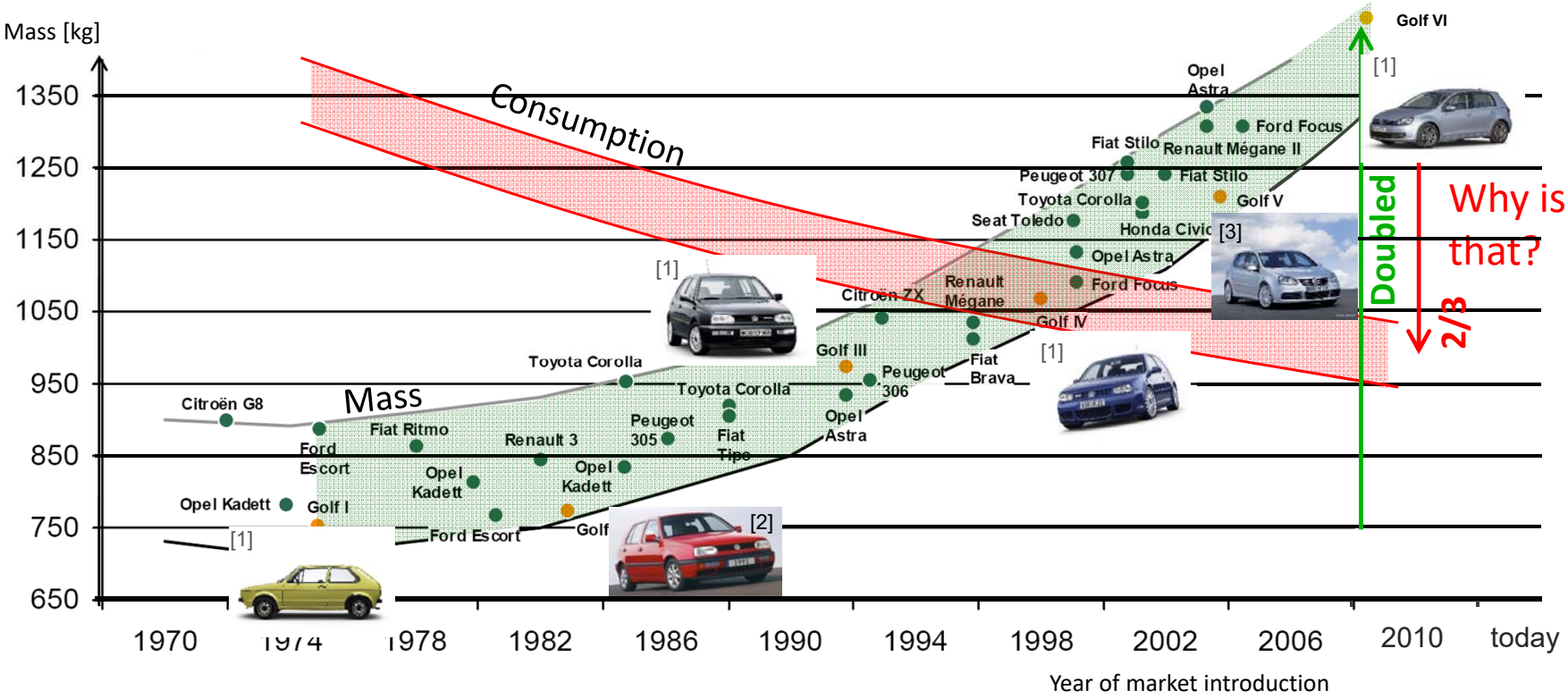
  - Ecological aspects
    - Emission level ($kgCO_2/km$)
    - Life cycle
    - Recycling

[1]

Drivers for Lightweight Design

Energy Demand

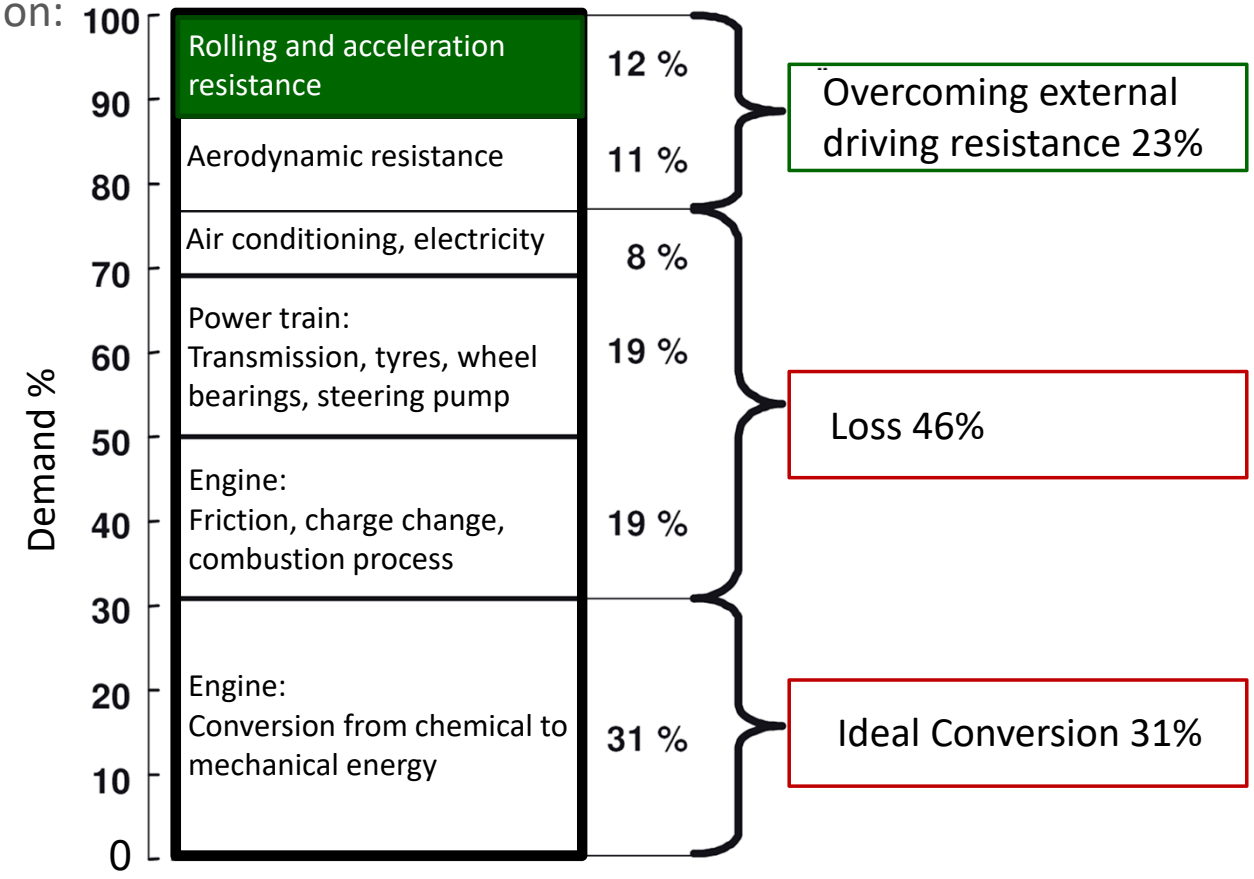
- Development over time of vehicle mass and energy consumption during operation:



Drivers for Lightweight Design

Energy Demand

- Demand Allocation:

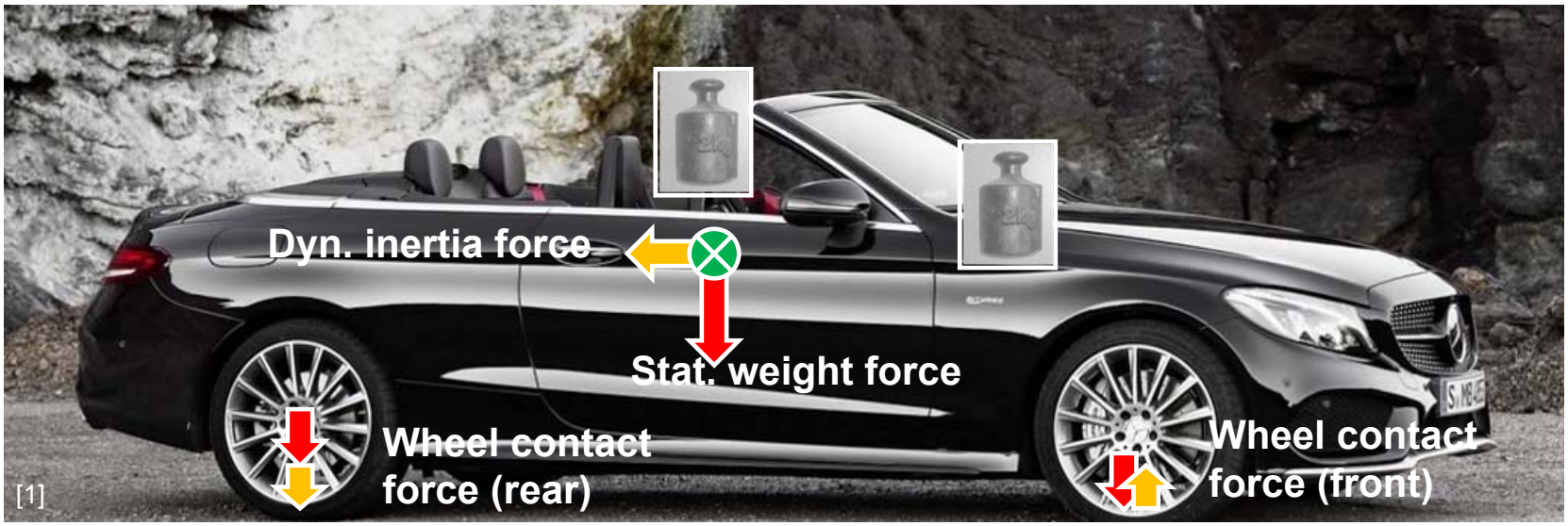


Drivers for Lightweight Design

Energy Demand

- External driving resistance:
  - Rolling resistance $F_R = m \cdot g \cdot f_r$
    - $\rightarrow$ m= Mass [kg]
  - Accelaration restistance $F_B = m \cdot a$

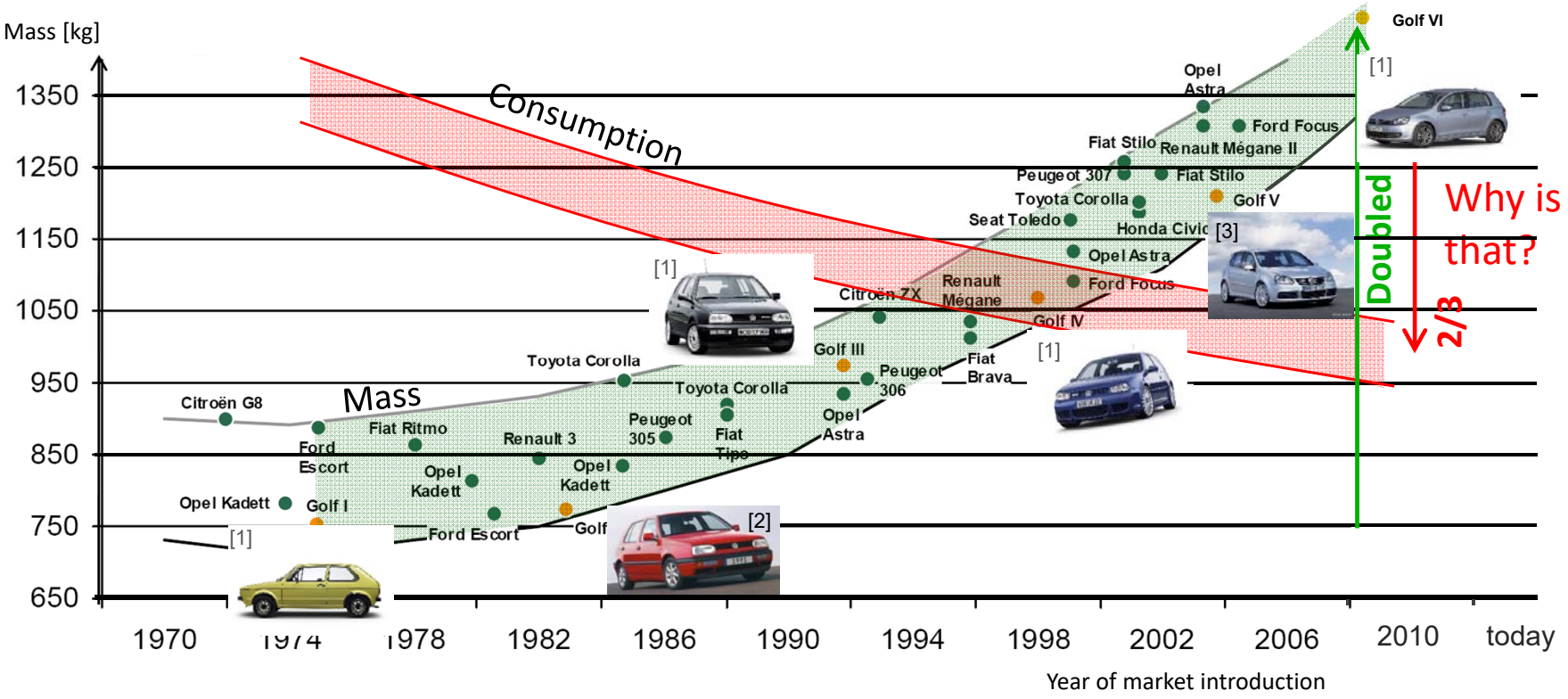
Mass reduction by means of lightweight design



Drivers for Lightweight Design

Energy Demand

- Development over time of vehicle mass and energy consumption during operation:



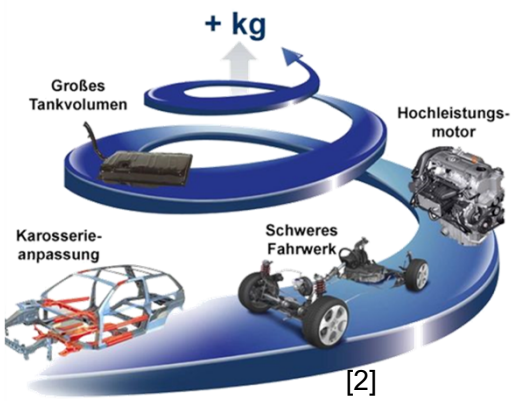
Drivers for Lightweight Design

Energy Demand

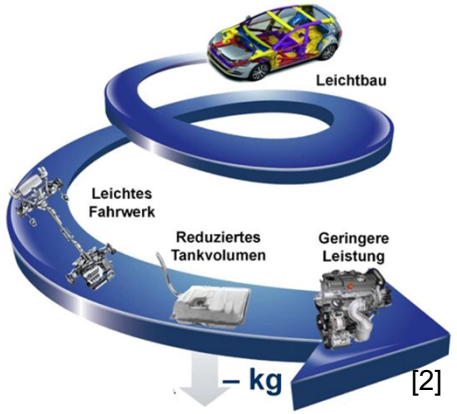
- The “Weight Spiral”:

*„(…) on average, the Golf 7 should **consume 13.9 percent** less according to VW development director Ulrich Hackenberg. (…)* [1]

*At only 1153 kilograms, the "newcomer" has lost a great deal of weight, which makes it even lighter than the Golf 4. "**With the Golf 7, we managed to break through the weight spiral for the first time**," said the responsible manager Markus Kleimann at the end of August at a preliminary presentation for media representatives in Wolfsburg. (…)* [1]



[2]



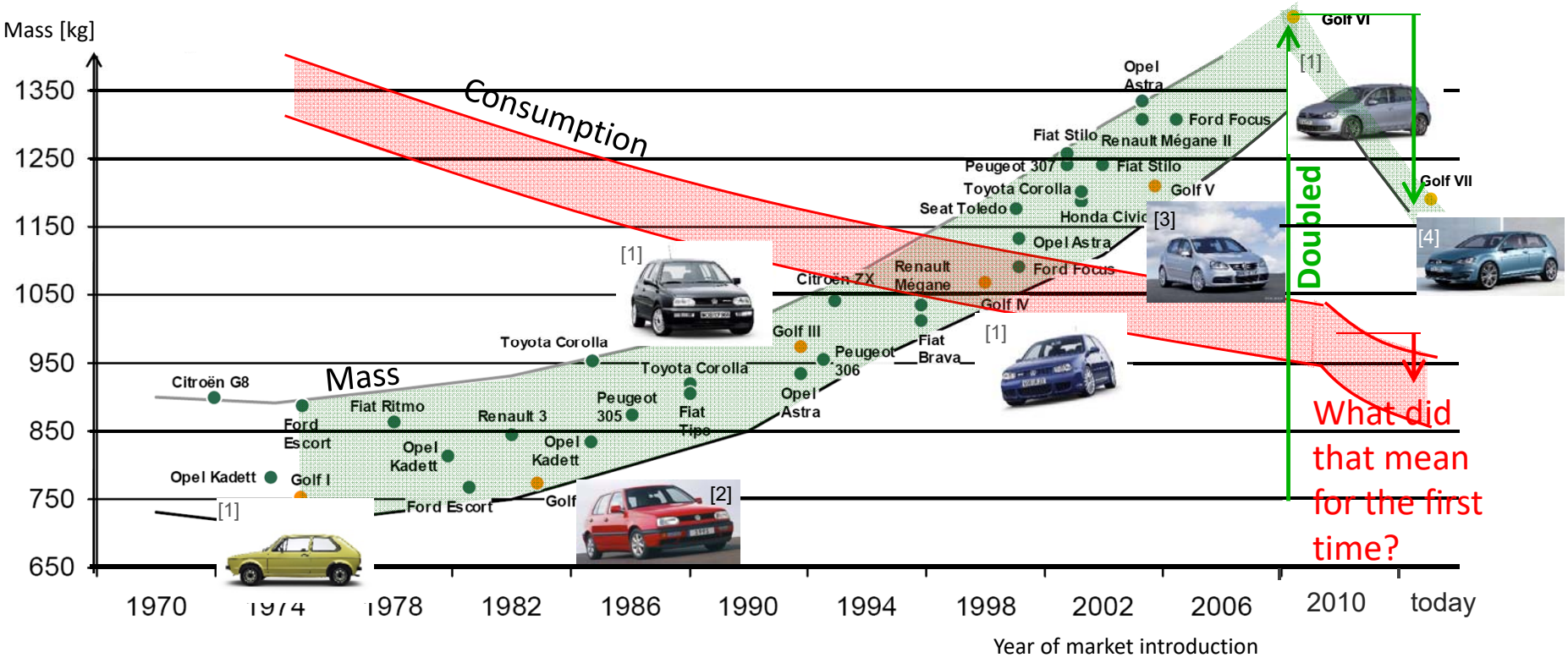
[2]

Further Reading:
Lehmhus, D.; von Hehl, A.; Kayvantash, K.; Gradinger, R.; Becker, T.; Schimanski, K.; Avalle, M.: Taking a Downward Turn on the Weight Spiral – Lightweight Materials in Transport Applications, Materials and Design, Volume 66, Part B, 5 February 2015, Pages 385-389. DOI: http://dx.doi.org/10.1016/j.matdes.2014.10.001

Drivers for Lightweight Design

Energy Demand

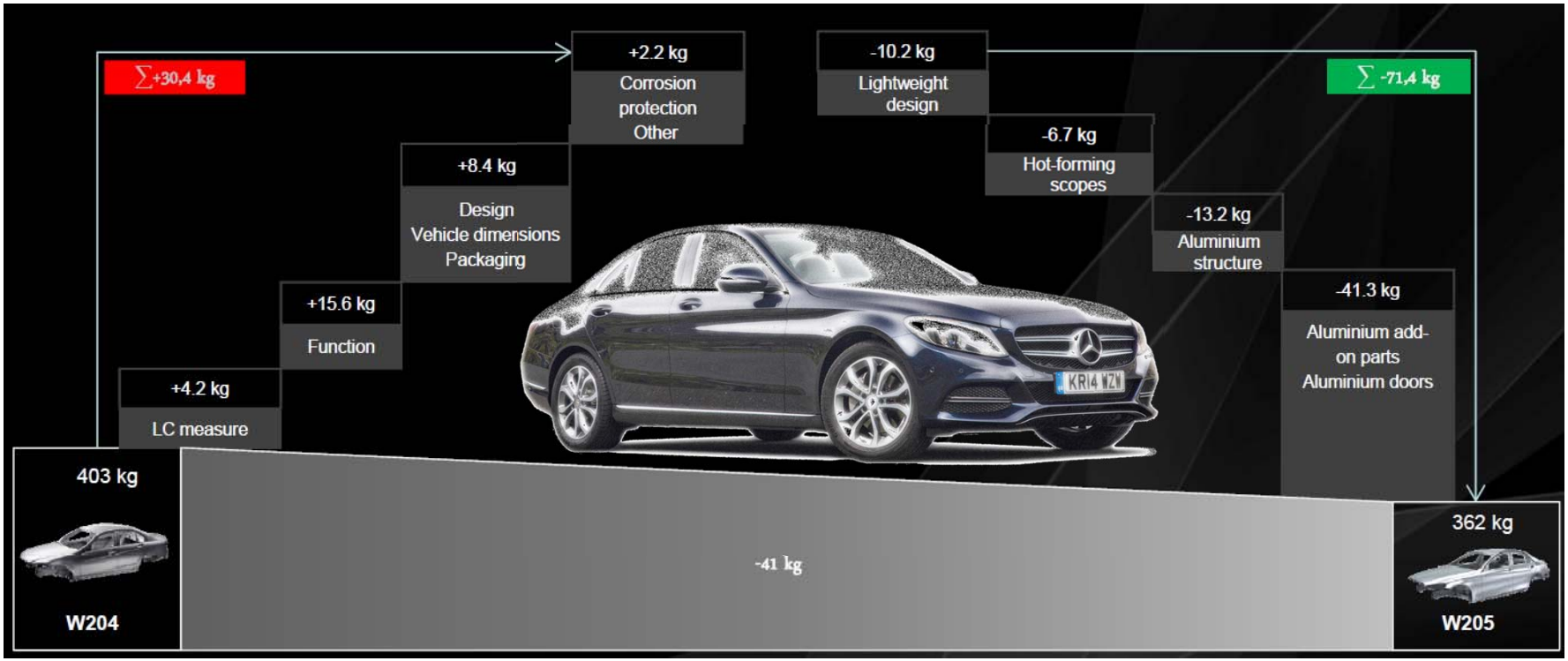
- Development over time of vehicle mass and energy consumption during operation:



Drivers for Lightweight Design

Energy Demand

- Development of the body-in-white from one model generation to the next using the Mercedes C-Class as an example:



[1]

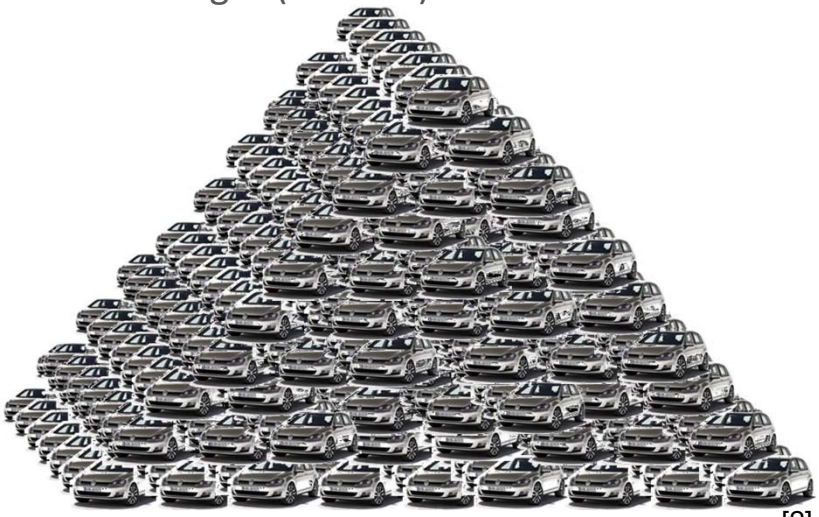
Drivers for Lightweight Design

Energy Demand

- Aviation: Airbus A380

[1]

- Length: 73 m
- Span: 80 m
- Total weight (take off): 560 t



≙ 480 VW Golf

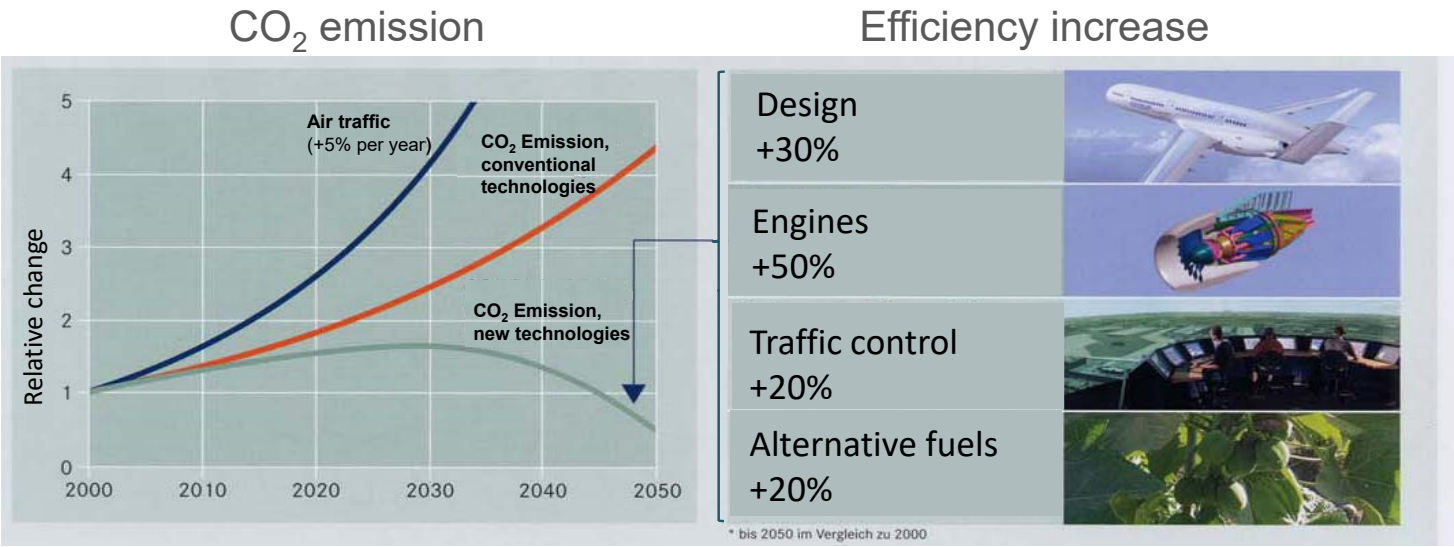
[2]

- Number of passengers: 555
- Kerosene (max.): 310,000 l

Drivers for Lightweight Design

Energy Demand

- Vision 2050 of European Aviation (acc. to [1]):

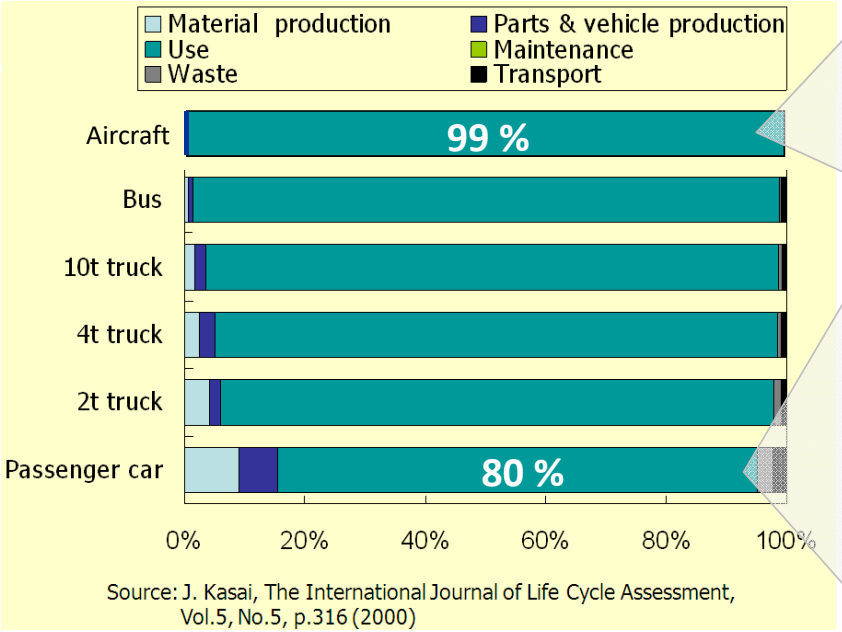


[1]

- minus 75% CO_2 emission (i.e. half of 2005)
- minus 65% riot
- max. 4 h from door to door on 90% of all EU flights

Drivers for Lightweight Design

Energy Demand



Source: J. Kasai, The International Journal of Life Cycle Assessment, Vol.5, No.5, p.316 (2000)

[1]

[2]

- Effect of 1 kg saved mass:
  - Aircraft (basis approx. 60,000 operating hours): approx. 3,000 litres of kerosene

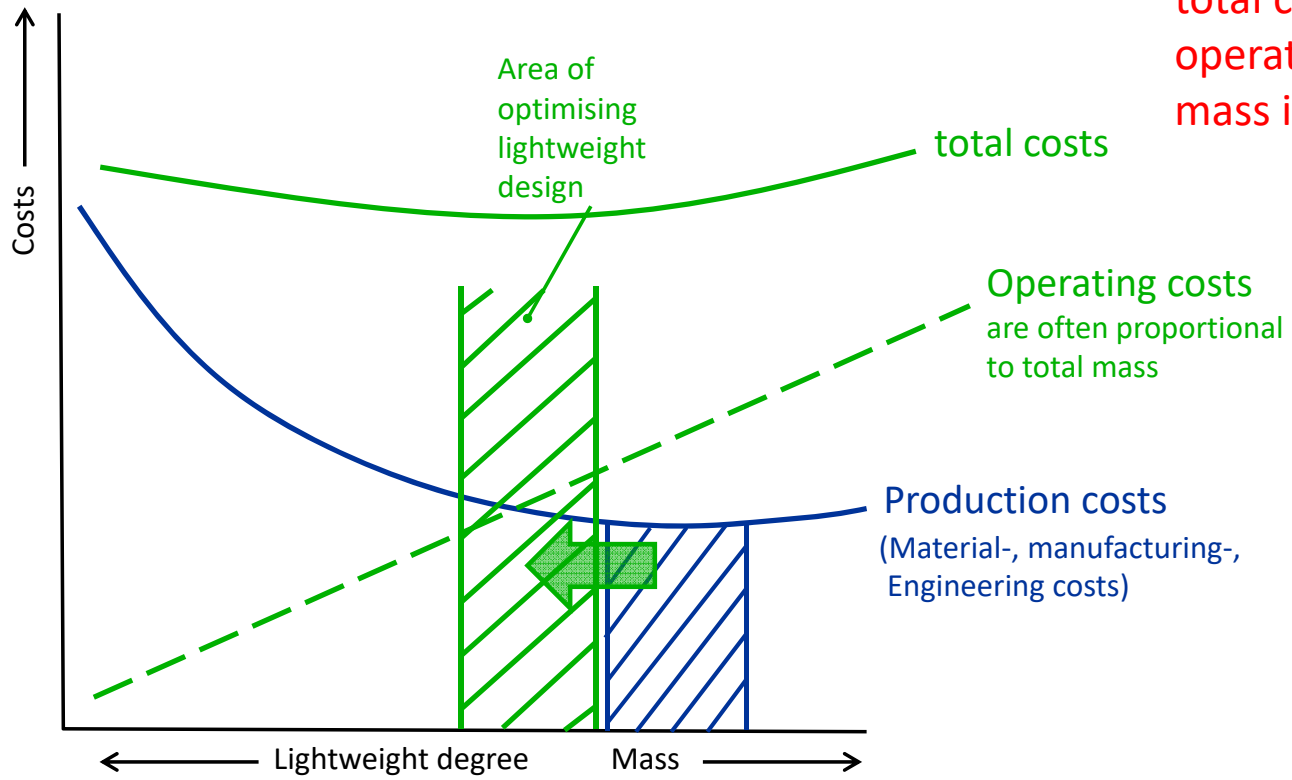
⇨ Lightweight target: Maximum mass reduction at minimum cost

Boundary conditions for lightweight design

Maximum lightweight degree with minimum costs

- Optimizing lightweight design acc. to [1] (e.g. automotive engineering):

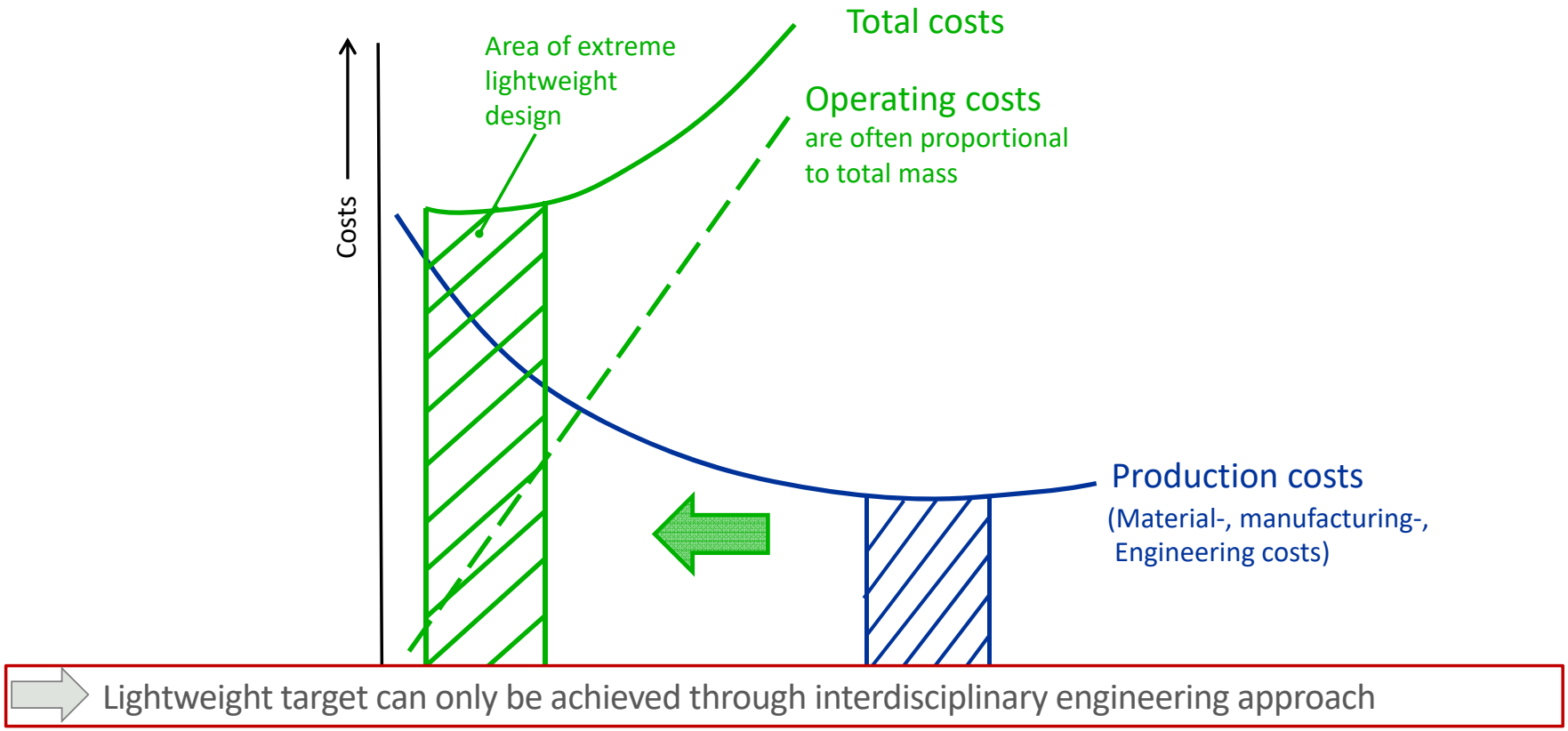
What happens to the total costs when the operating costs per mass increase?



Boundary conditions for lightweight design

Maximum lightweight degree with minimum costs

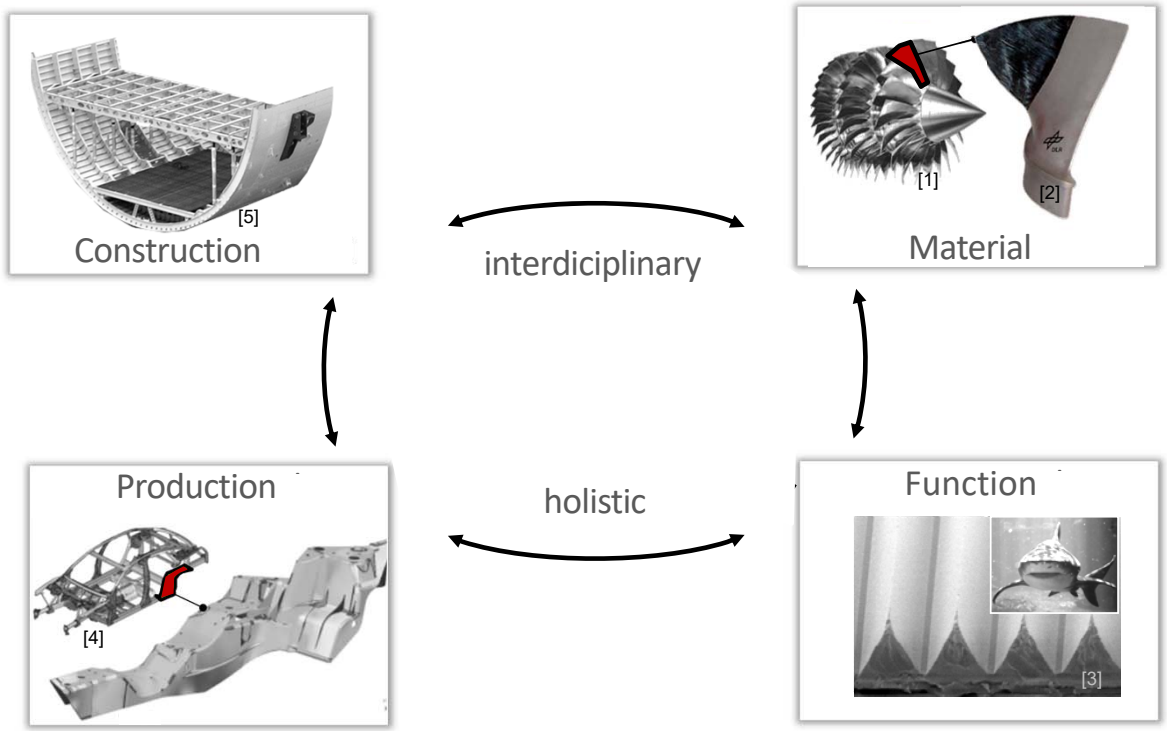
- Extreme lightweight design acc. to [1] (e.g. aircraft design):



Approach

Interdisciplinary and holistic application of lightweight principles

- Aspects:



Lightweight principles

Principles of mass reduction

- Constructional lightweight design (also shape lightweight design)
  - Achievement of the lightweight target by constructive measures (e.g. by framework and shell construction as well as by uniform utilization of the material volume by thin-walled or hollow structures)

- Productional lightweight design
  - Does not only concern the material or the design, but results from advantages of different manufacturing and joining processes (e.g. laser beam welding, tailored blanks/tubes, rolled profiles, hydroforming, die casting, 3D printing etc.).

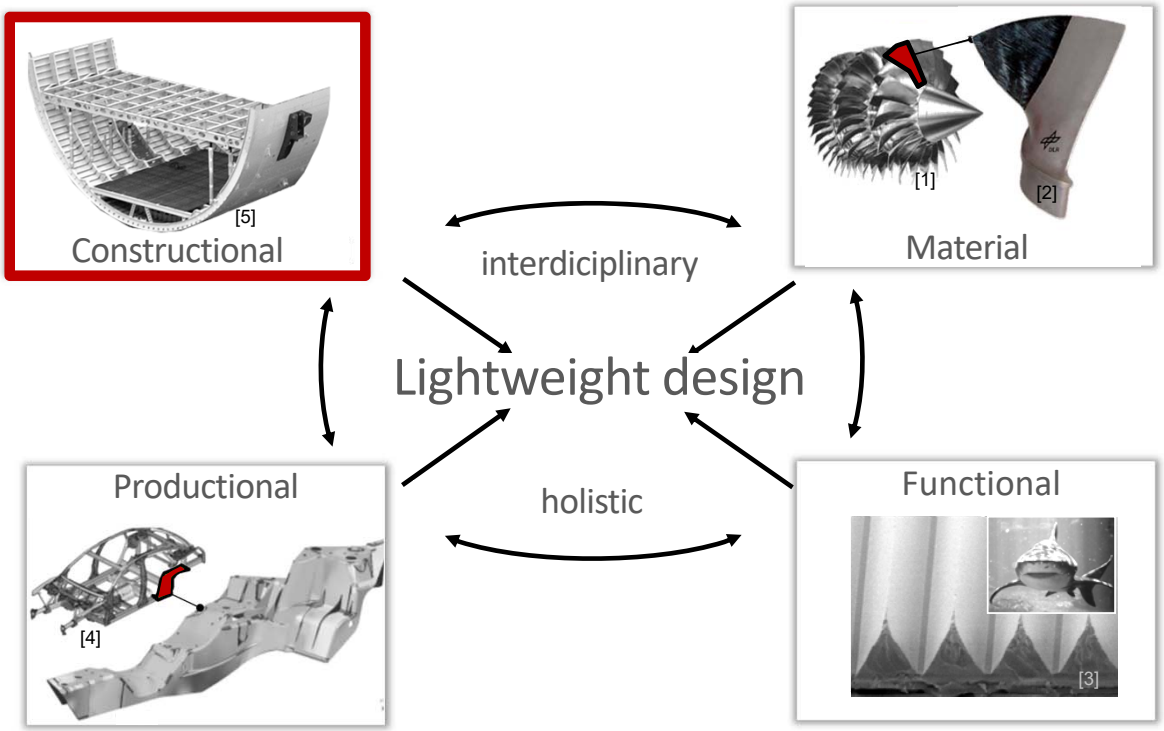
- Functional lightweight design (also adaptiv lightweight design)
  - Integrates additional functions into a component structure on the basis of certain physical-technological properties (e.g. by means of function integration, a single component may become heavier. However, the savings made by function integration make the overall structure lighter).

- Material lightweight design
  - Substitution of the material of a component by another material with better specific material properties (e.g. steel by aluminium, CFRP or hybrid materials)

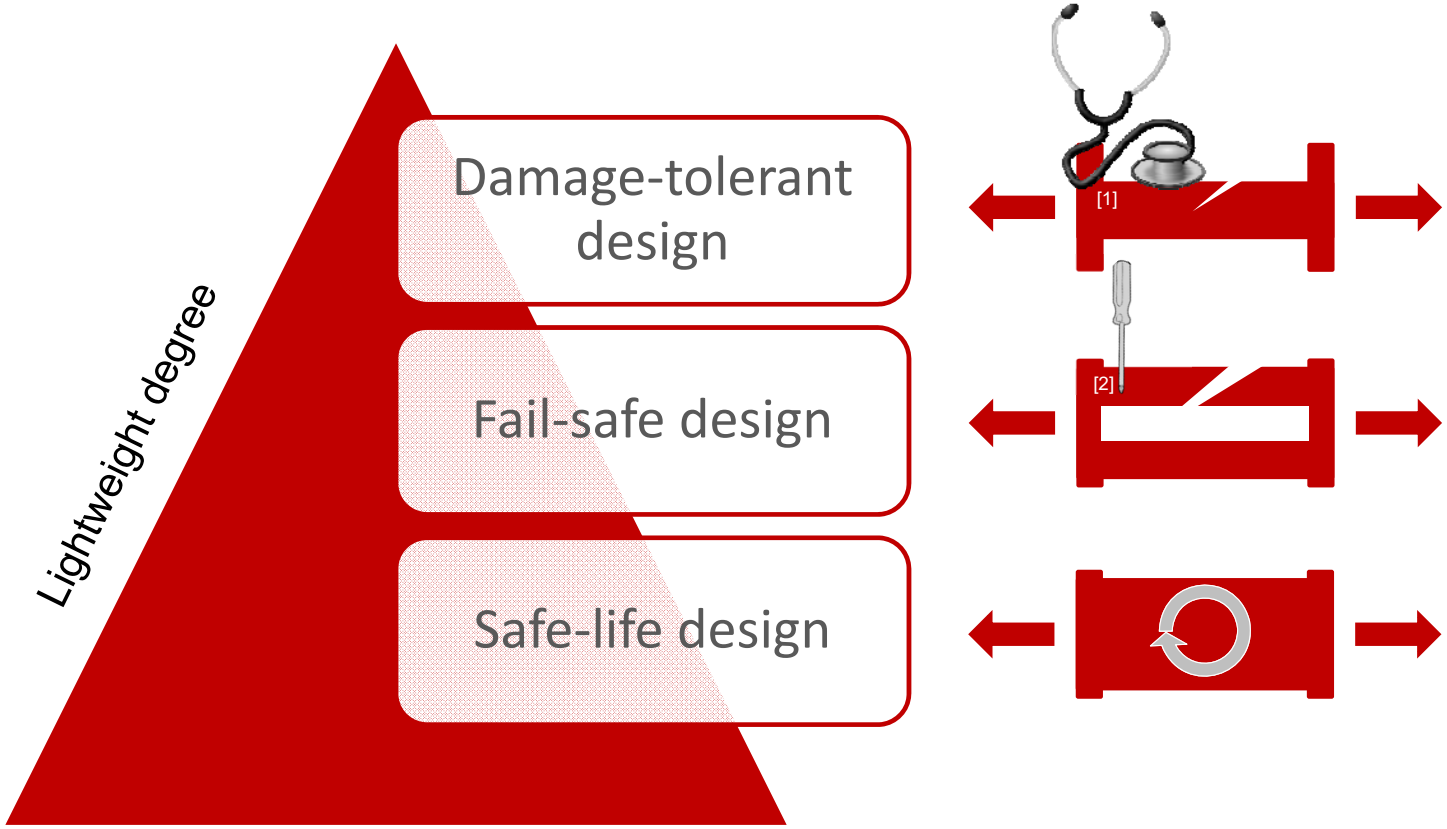
Approach

Interdisciplinary and holistic application of lightweight principles

- Aspects:

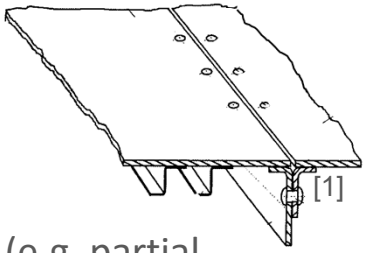


- Design philosophies:



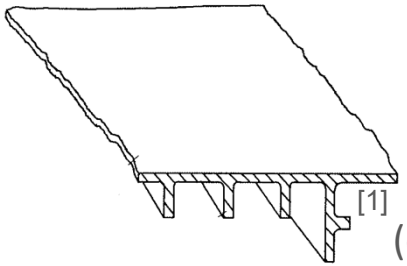
- Design methods:
  - with certain functional properties

Differential design



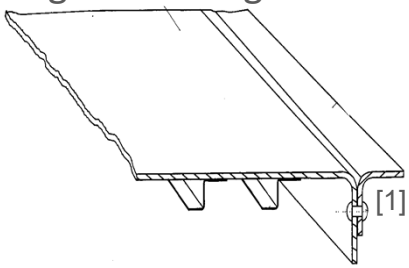
(e.g. partial repair possibilities)

Integral design



(e.g. low notch effect)

Integrative design



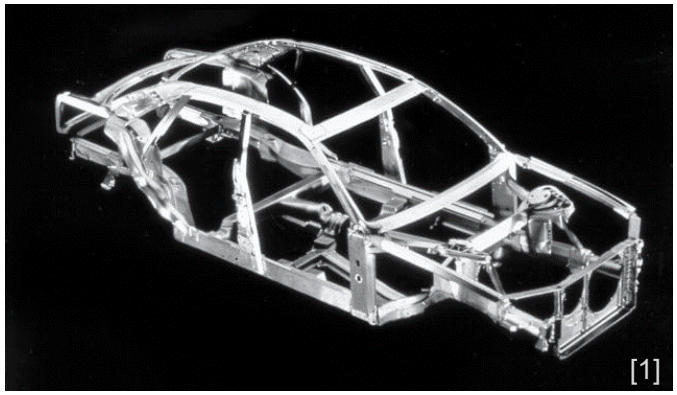
(e.g. meaningful compromise)

Lightweight principles

Constructional lightweight design

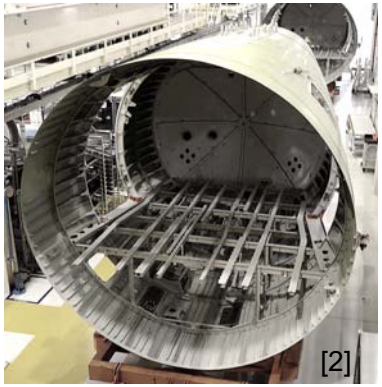
- Design methods:
  - with certain load properties

- Framework design



- frame mainly bears the loads
- Skin is load-free

- Monocoque design

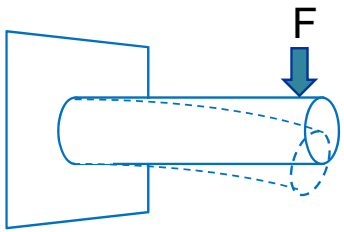


- Load distribution via frame and stringer
- Transmission of shear and normal loads via skin

Lightweight principles

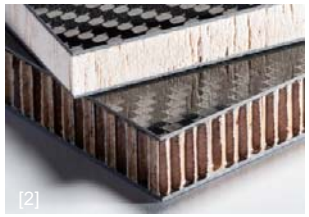
Constructional lightweight design

- Design principles (examples):
  - Reduction of deflection by increasing the moment of inertia and the moment of resistance by means of hollow sections

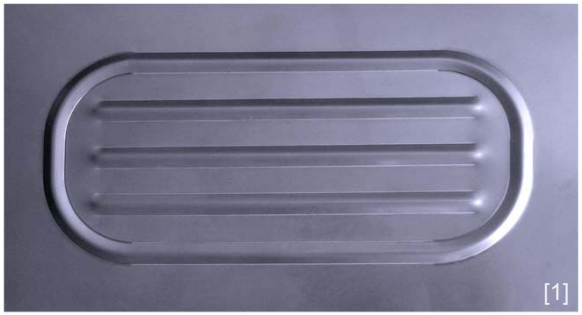


  - or by means of sandwich panels

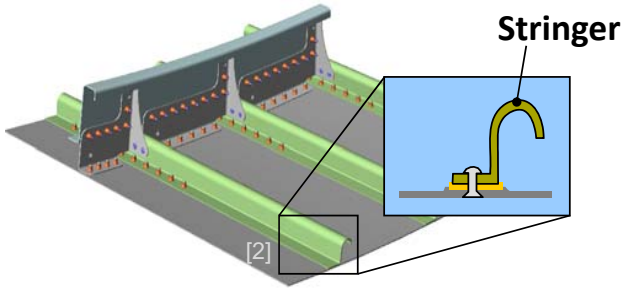
Foam core, honeycomb core and corrugated core panels



- Design principless (examples):
  - stiffening by beading



  - or flanging of free edges



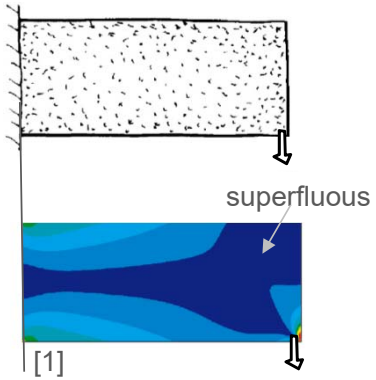
Lightweight principles

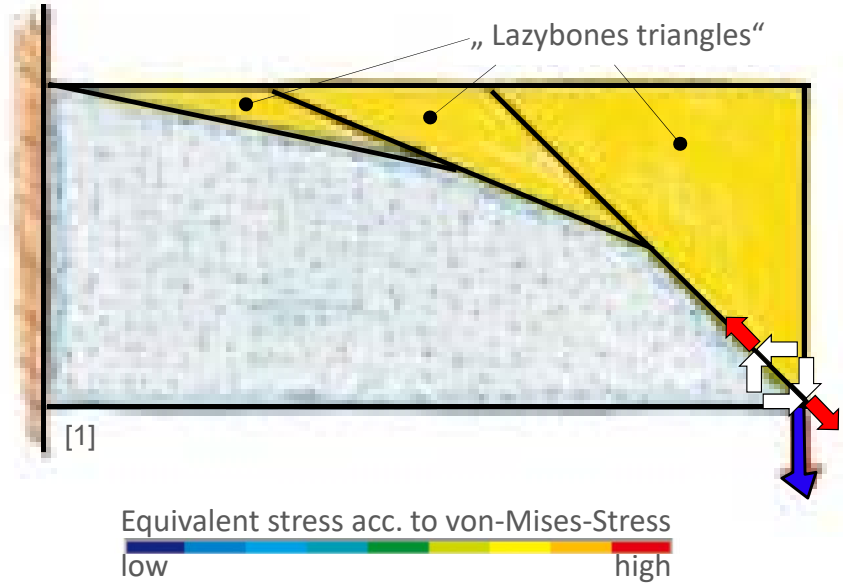
Constructional lightweight design

- Design principles (examples):
  - Use shear squares and tension triangles
  - Remove superfluous material (lazybones triangles)
  - Repeat until the sharp edges or notches are sufficiently rounded

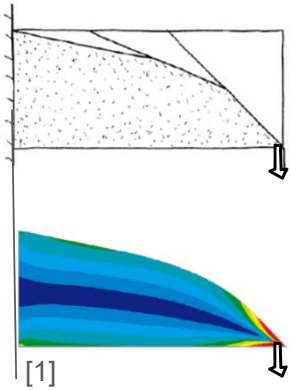
Tension Triangle Method according to C. Mattheck [1]

not optimized (FEM)





Optimized (FEM)



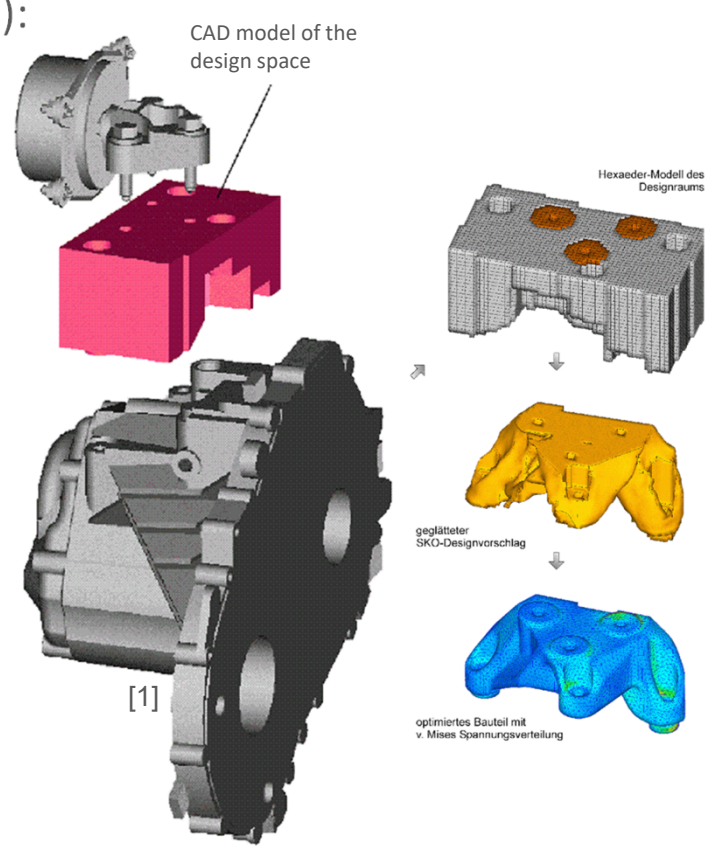
Equivalent stress acc. to von-Mises-Stress

low high

Lightweight principles

Constructional lightweight design

- Design principles (examples):
  - Remove superfluous, i.e. non-load-bearing material using Soft Kill Option (SKO) (e.g. as part of a finite element simulation of the loads)



FE modeling of the design space

Topology and shape optimization

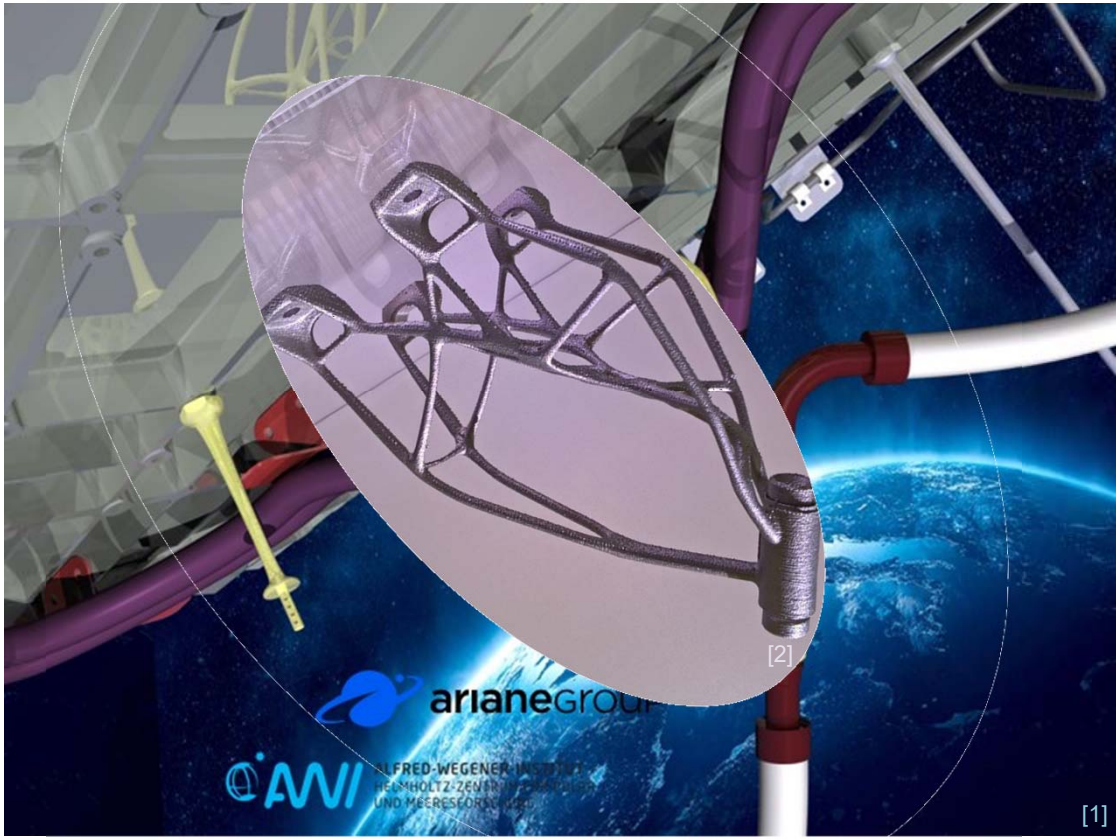
Load optimization

Lightweight principles

Constructional lightweight design

- Design principles (examples):
  - Remove superfluous, i.e. non-load-bearing material using Soft Kill Option (SKO) (e.g. as part of a finite element simulation of the loads)

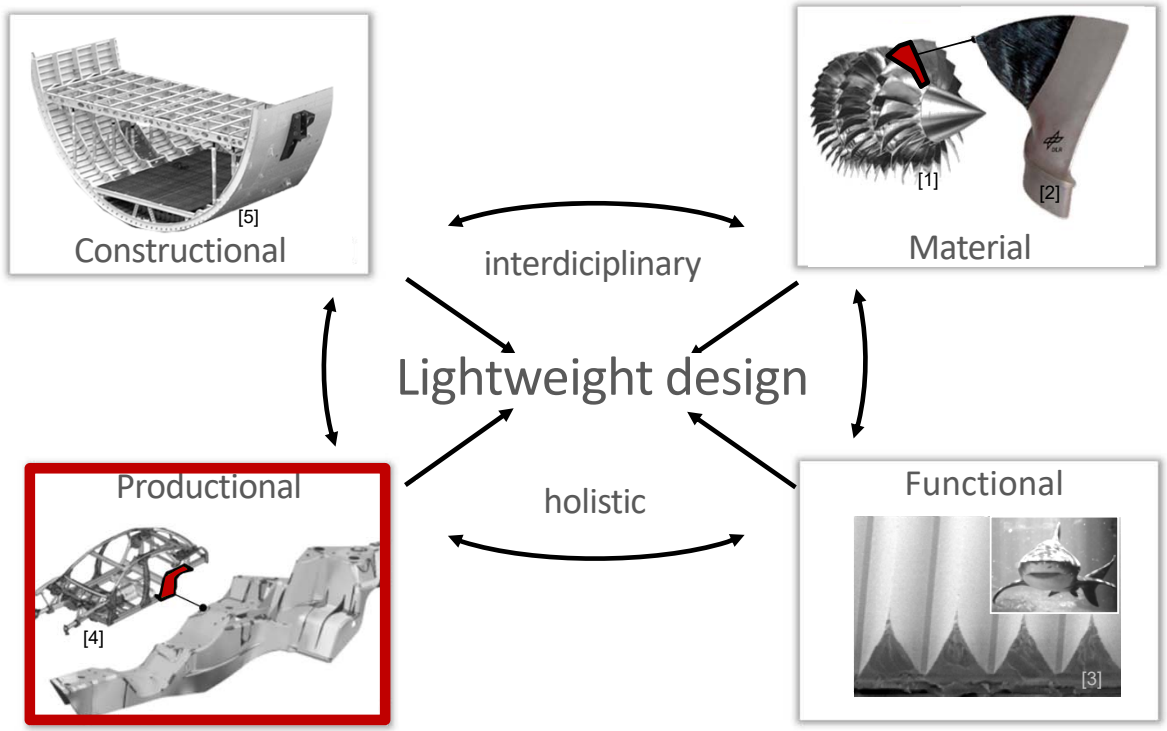
Productional lightweight design



Approach

Interdisciplinary and holistic application of lightweight principles

- Aspects:

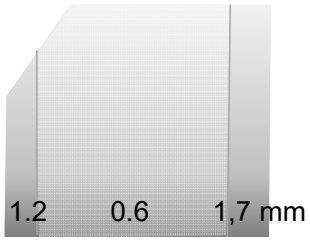


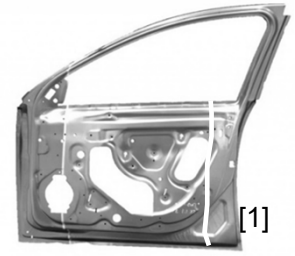
Lightweight principles

Productional lightweight design

- Examples for production-specific lightweight potentials:

- Tailor Welded Blanks

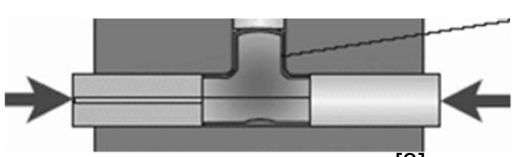



[1]

- Roll profiling

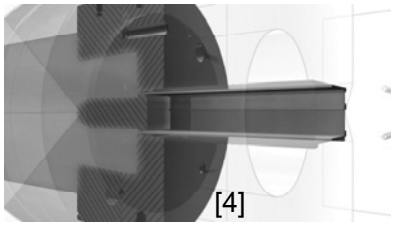

[2]

- Hydroforming

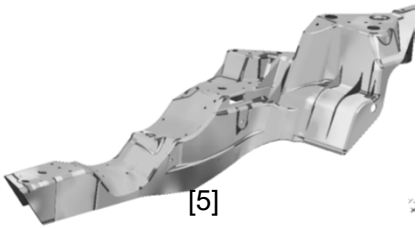


[3]

- Extrusion


[4]

- Die casting

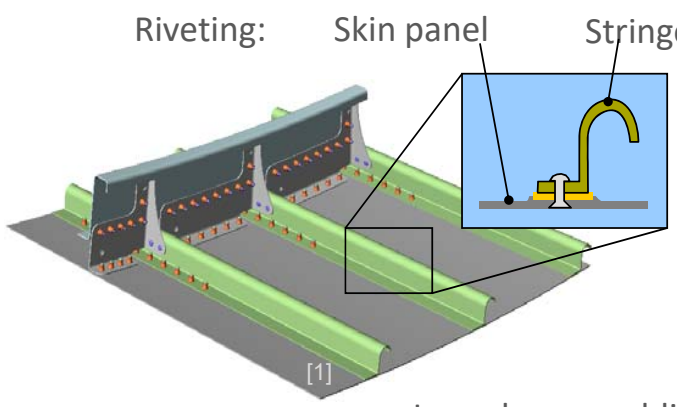

[5]

- Additive Manufacturing


[6]

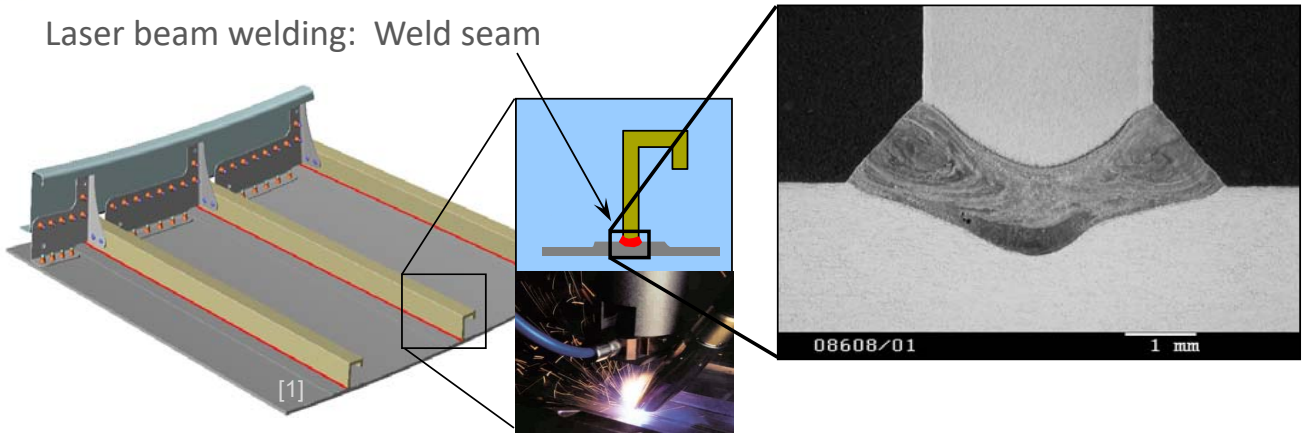
1.1 Introduction

- Example: Laser beam welding



Disadvantages of riveting

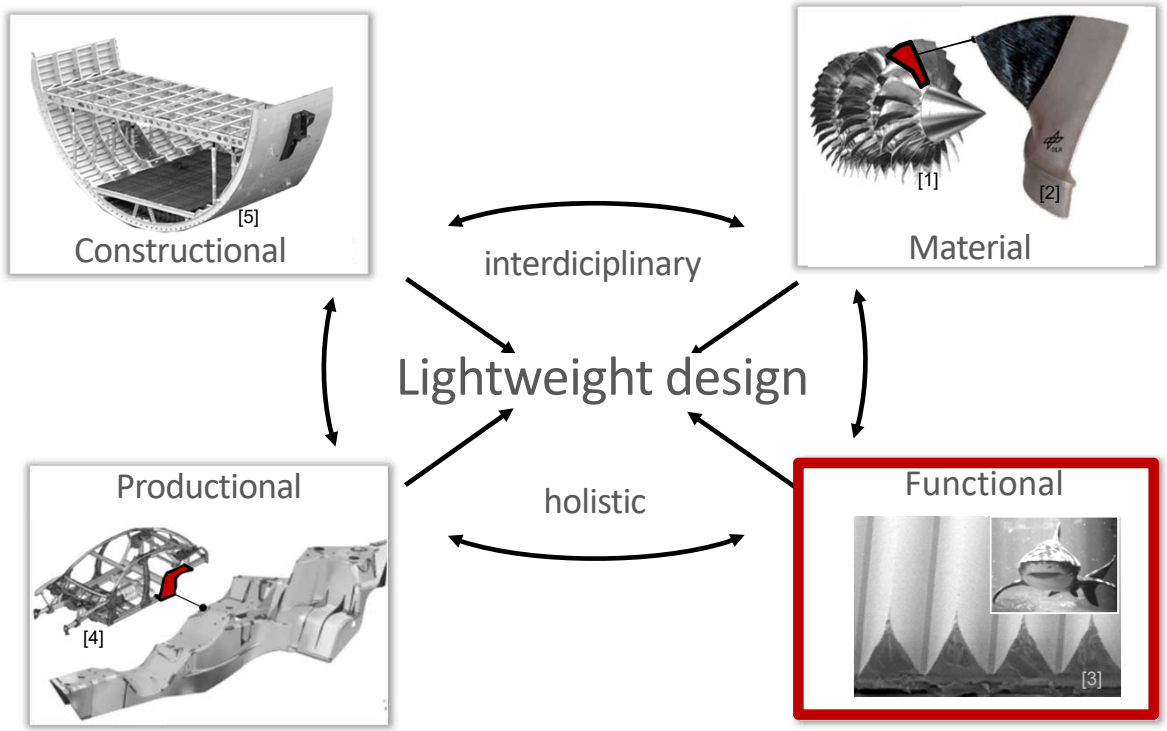
- High weight
- Time-consuming joining process
- High susceptibility to corrosion



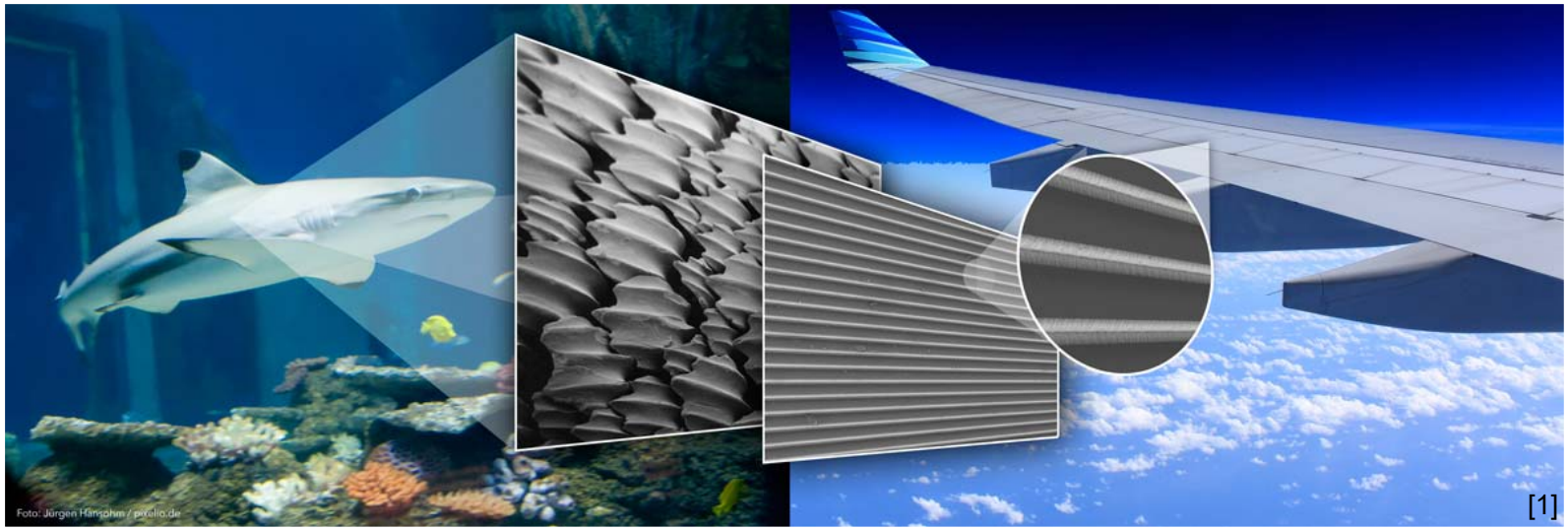
Approach

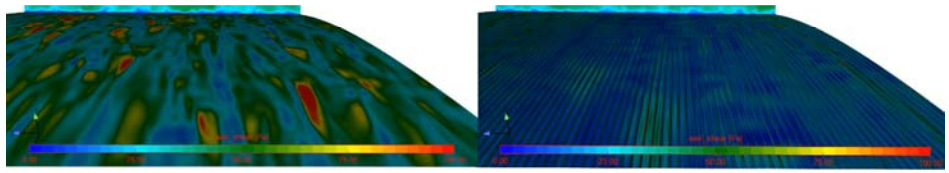
Interdisciplinary and holistic application of lightweight principles

- Aspects:



- Integration of additional functions into the component structure:
  - Example: Bionik approach of imprinting riblet surface structures on aircraft skin sheets




[1]

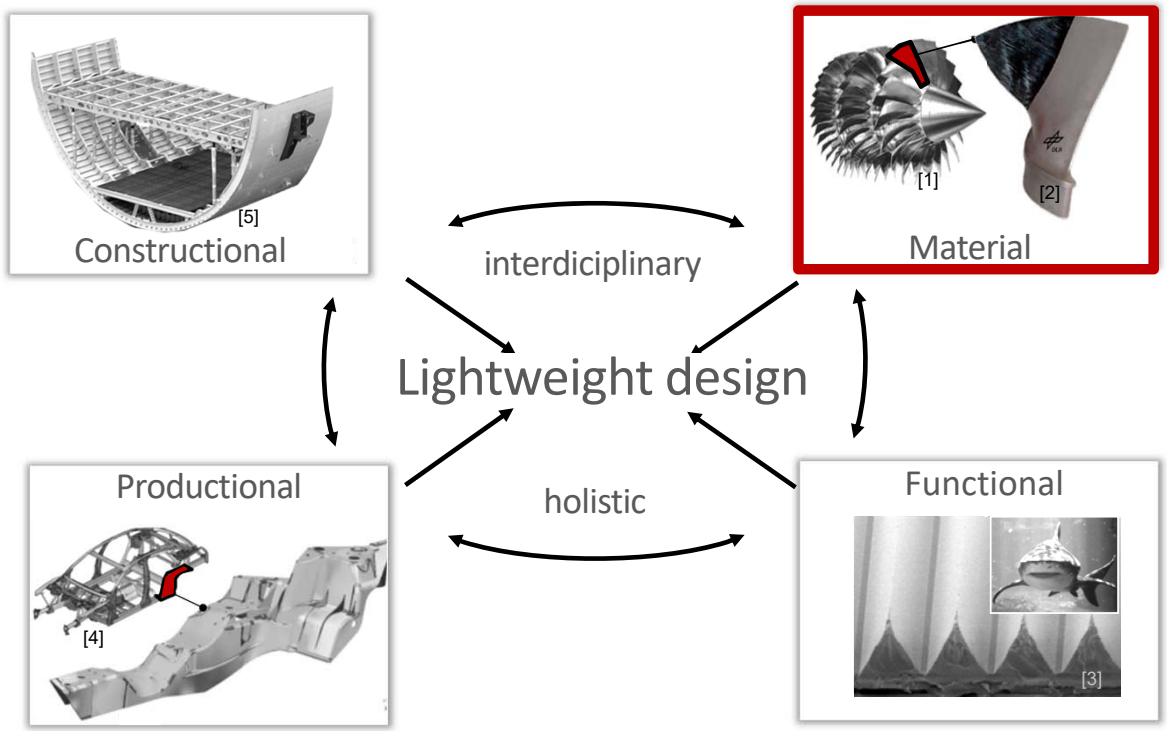
Without Riblets

With Riblets

Approach

Interdisciplinary and holistic application of lightweight principles

- Aspects:

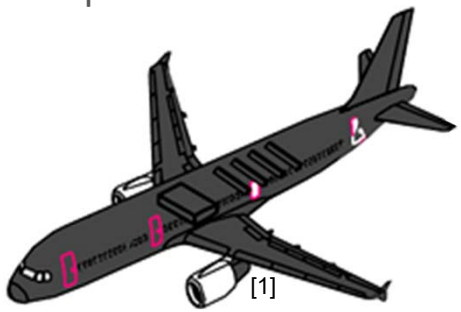


Material lightweight design

Material proportions in advanced areas of application

- Long range aircraft

  Example Airbus A350XWB



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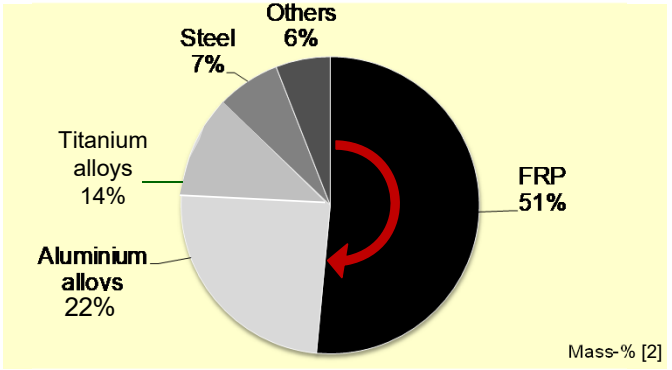
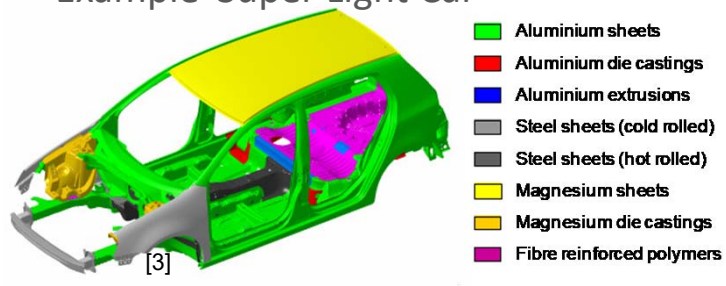


- Compact Class Car

  Example“Super Light Car”



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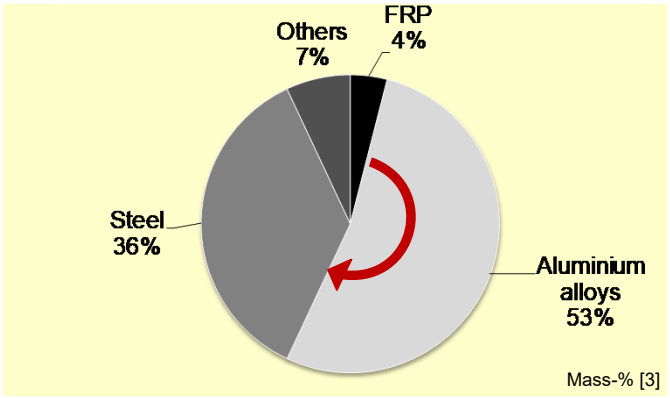
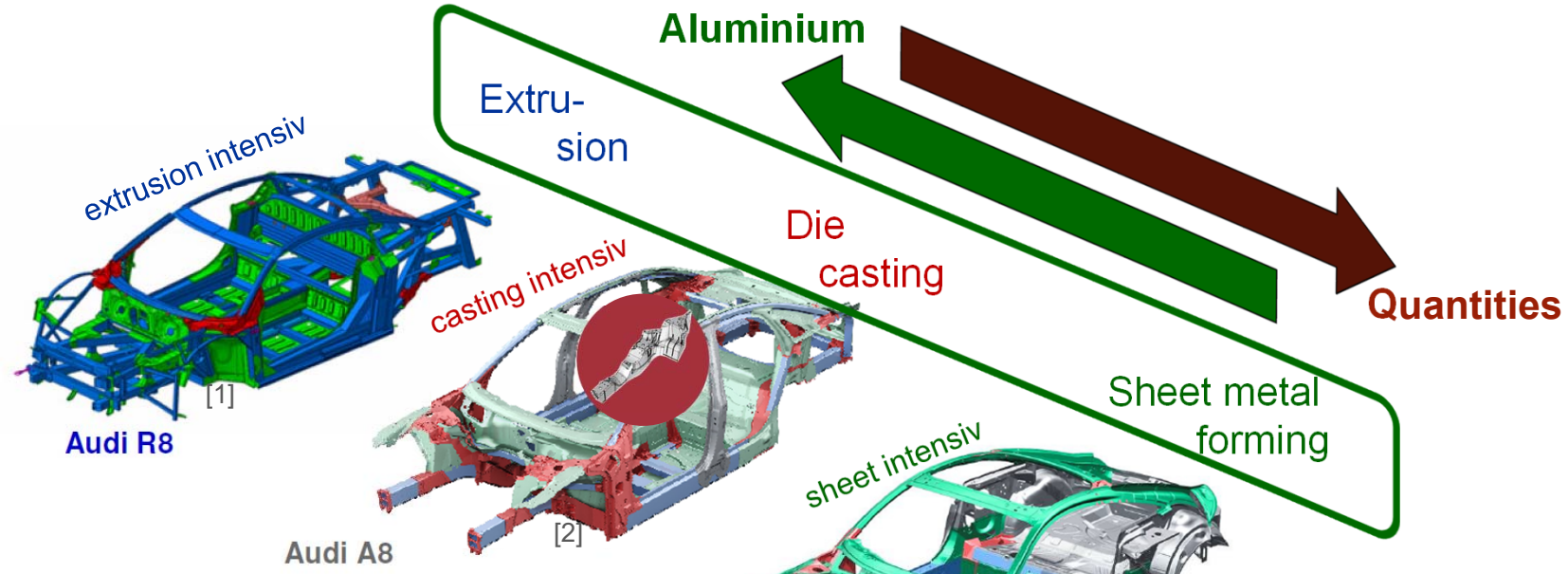


Shift in material proportions leads to changes in manufacturing technologies

Material lightweight design

Material proportions in advanced areas of application

- Example: Aluminium dominated automotive body



Sheet
Casting
Extru-
sion

Features of the ASF architecture

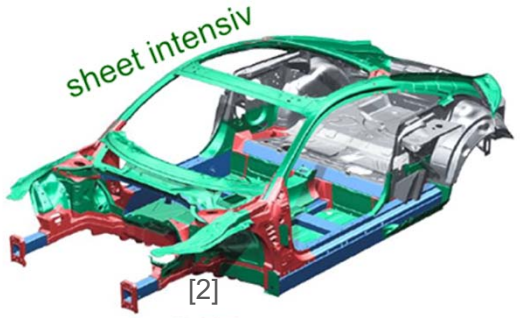
- flat sheet metal parts
- large multifunctional castings
- geometrically simple extruded profiles
- Component and function integration

Material lightweight design

Material proportions in advanced areas of application

- Example: Aluminium in automotive industry

[1]



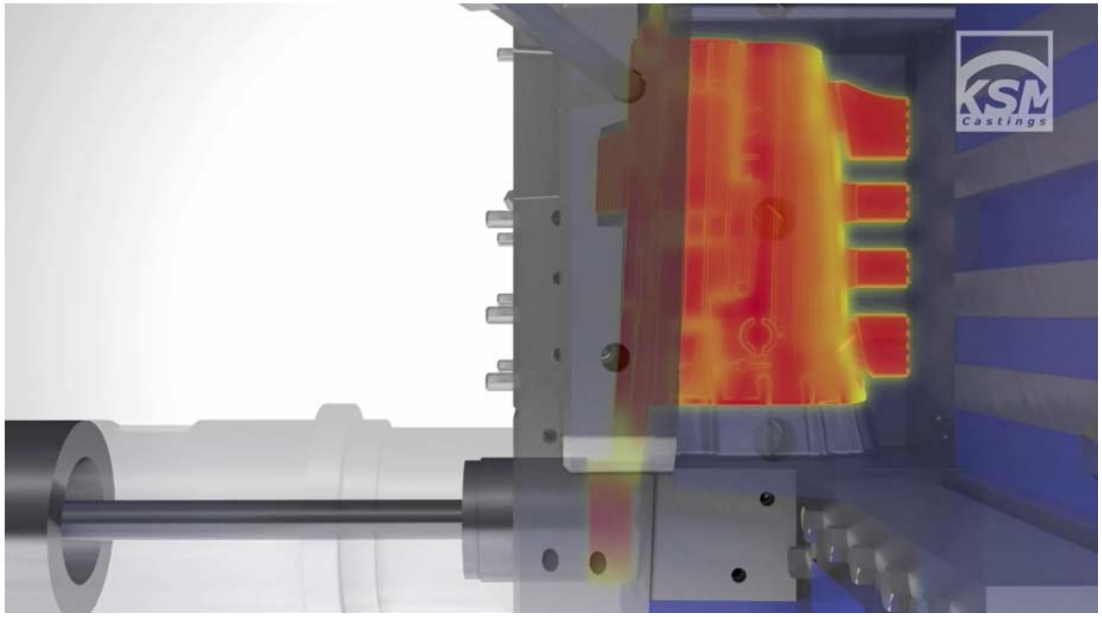
[2]

Audi TT

Material lightweight design

Material proportions in advanced areas of application

- Example: Aluminium in automotive industry



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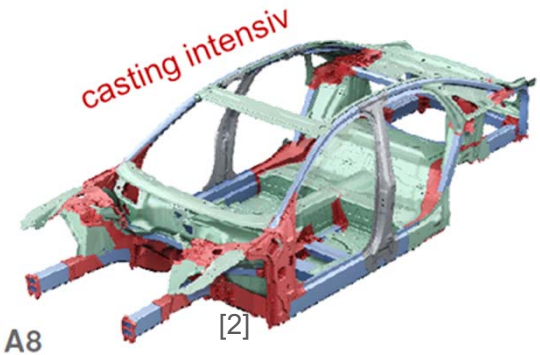


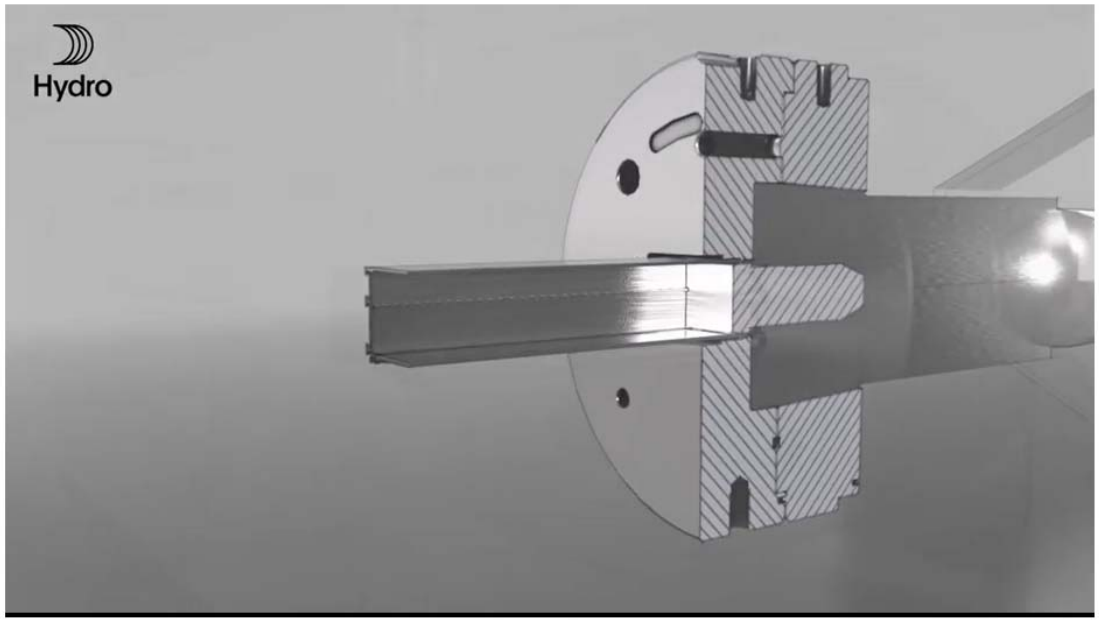
Audi A8

[2]

Material lightweight design

Material proportions in advanced areas of application

- Example: Aluminium in automotive industry



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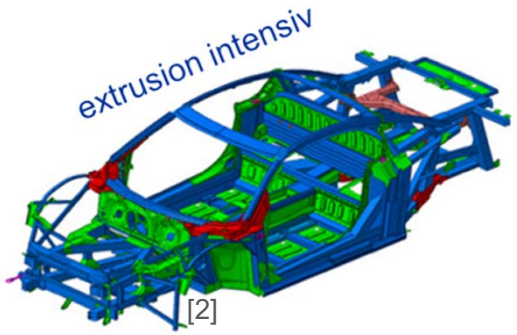
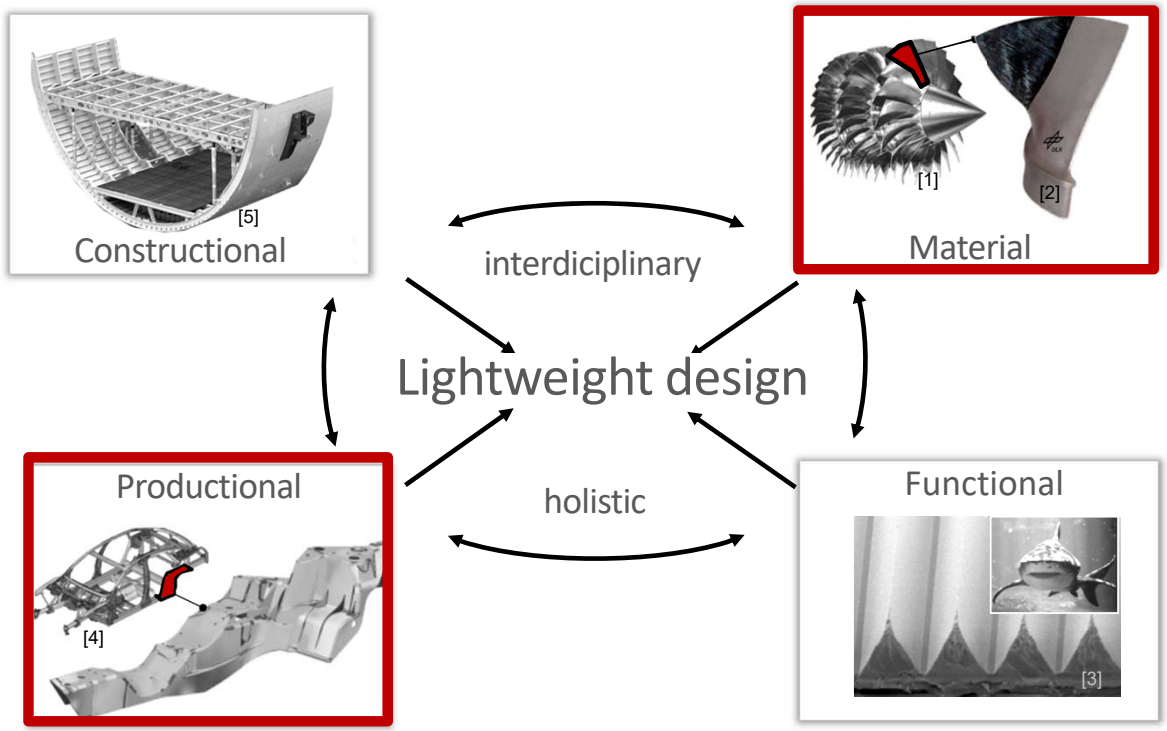


[2]

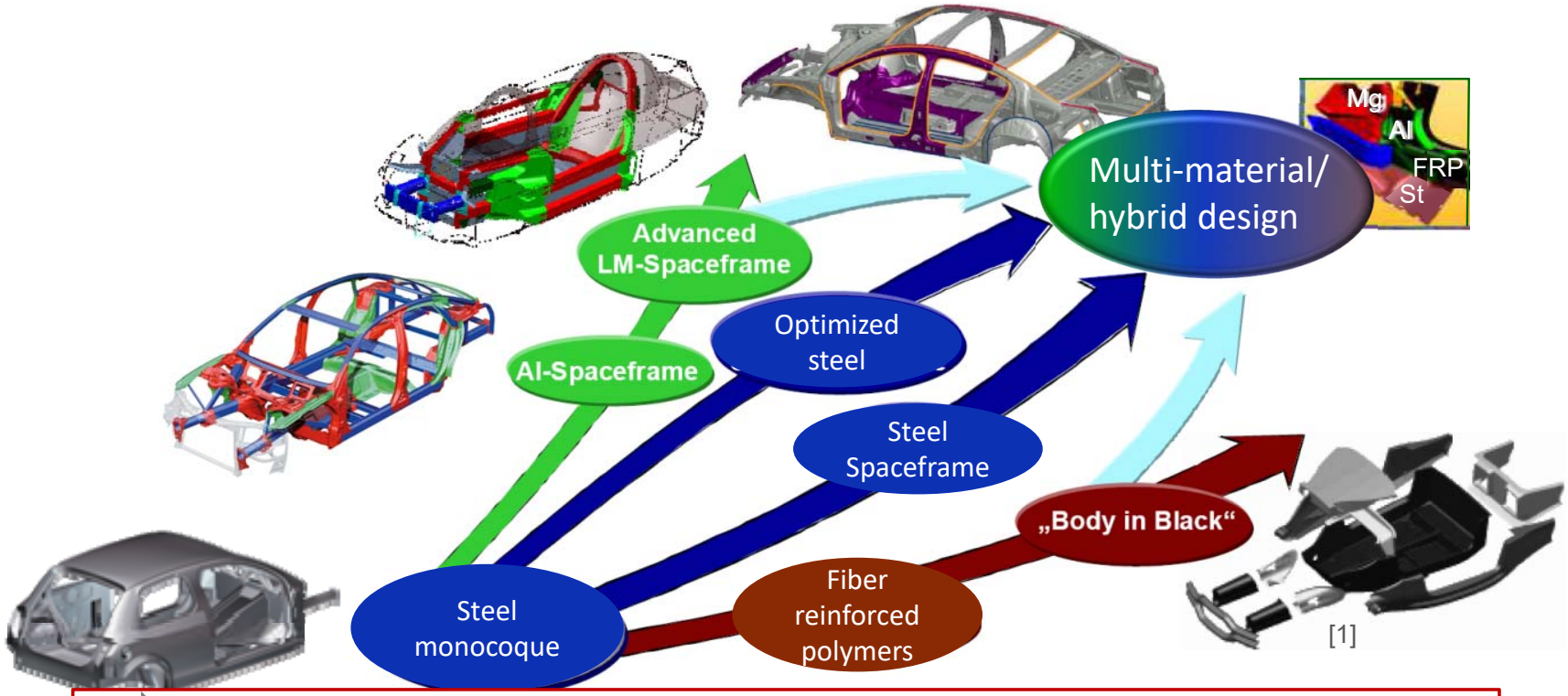
- Aspects:


Constructional
[5]
Material
[1]
[2]
interdiciplinary
Lightweight design
Productional
[4]
holistic
Functional
[3]

Material lightweight design

Material proportions in advanced areas of application

- Example: Multi-material automotive body (acc. to [1])



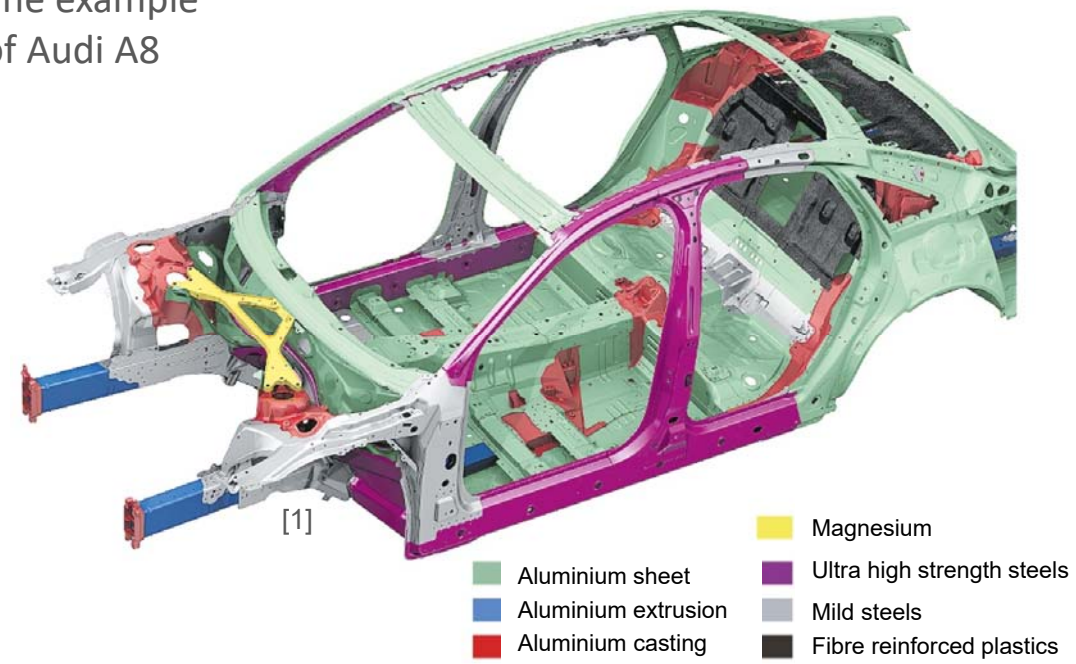
The trend is to bring the right material with the right properties to the right place.

Material lightweight design

Material proportions in advanced areas of application

- Example: Multi-material automotive body

The example of Audi A8



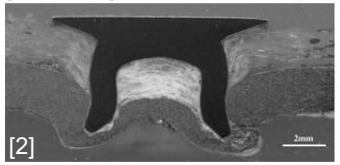
Material lightweight design

Material proportions in advanced areas of application

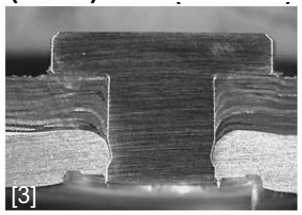
- Example: Multi-material automotive body

Flow Drilling Screwing

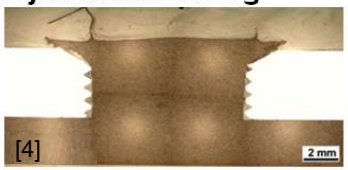
Self-piercing riveting (hollow)



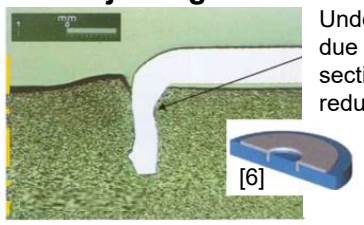
Self-piercing riveting (solid)



Injection Clinching

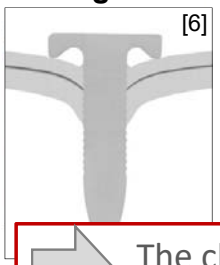


Collar joining

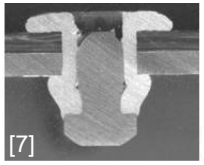


Undercut due to cross section reduction

High speed bolting



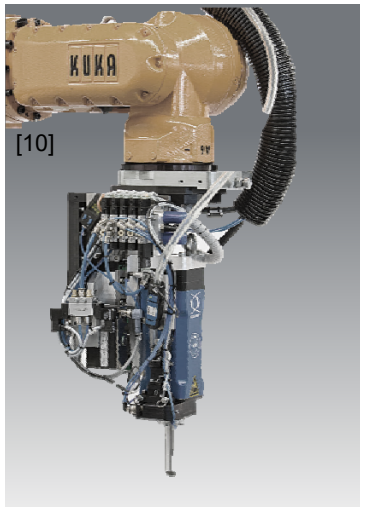
Blind riveting



Flat clinching

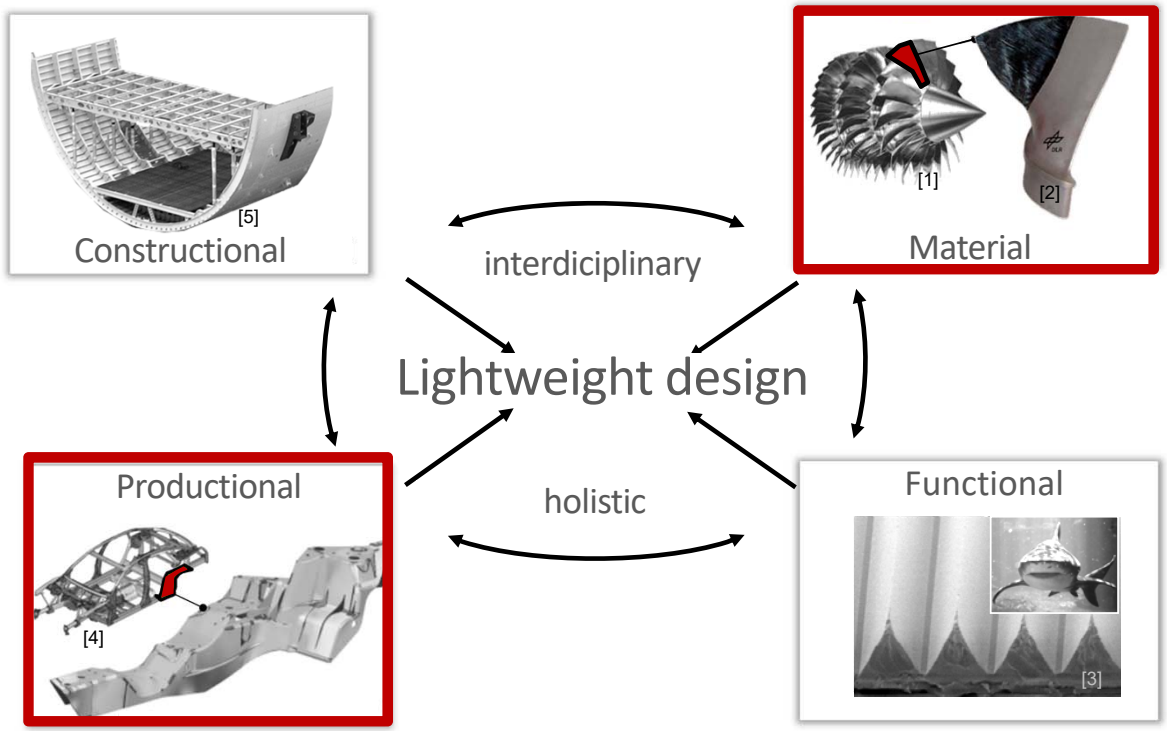
Thermo-mechanical shape joining

Mechanical joining



The challenge is to find the best compromise between material compatibility and process efficiency.

- Aspects:


Constructional
[5]
Material
[1]
[2]
interdiciplinary
Lightweight design
Productional
[4]
holistic
Functional
[3]

Introduction in the short course on Advanced Light Alloys

Summary

- ...
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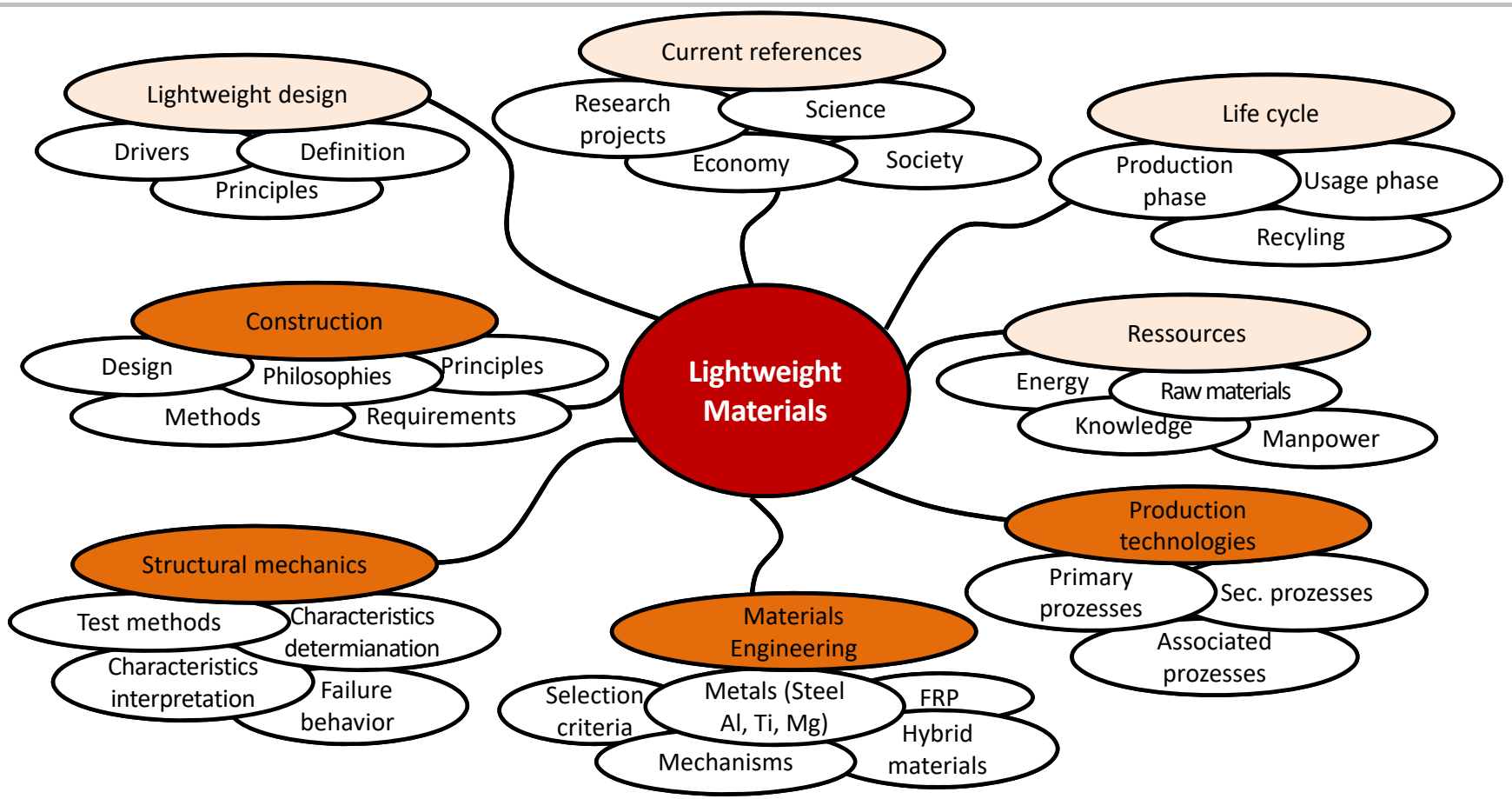
Lightweight Materials - Their Properties, Technologies and Advanced Applicability

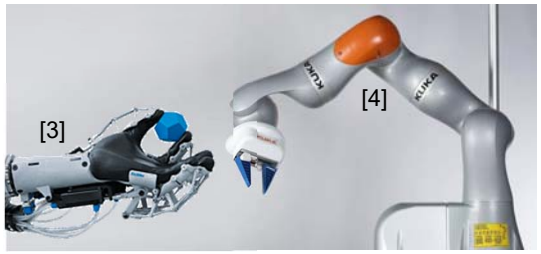
Subject Map



Lightweight Materials - Their Properties, Technologies and Advanced Applicability

Content

Series No.	Number of Lectures	Title/Content
1	1	1.1 Introduction Drivers of lightweight design and interdisciplinary solution approaches
	1	1.2 Material oriented approaches From component load to Materials Selection
	1	1.3 Metallic Materials Mechanisms of Strength Increase and their Industrial Use
2	3	2.1 Advanced Alloys (part 1): Steels Multi-Phase Steels and TRIP/TWIP for Automotive Applications
3	3	2.2 Alloys (part 2): Aluminium Alloys Age-hardenable Alloys for Automotive and Aerospace Applications
4	2	2.3 Advanced Alloys (part 3): Titanium Alloys α, near-α, $\alpha+\beta$ and meta-stable β Alloys for Aerospace Applications
	1	2.4 Advanced Alloys (part 4): Magnesium Alloys High-Strength cast and wrought Alloys for Automotive Applications
5	3	3.1 Metal Additive Manufacturing (part 1) The Process Chain from Powder to finished Part
6	3	3.2 Metal Additive Manufacturing (part 2) State of Technology and novel Alloys and Processing Approaches
7	3	4.1 Hybrid Composite Materials and Structures (part 1) Terms and Definitions Technological Aspects on Materials Combination
8	3	4.2 Hybrid Composite Materials and Structures (part 2) Mechanical, Thermal and Adhesive Bonding Technologies State of Technology and novel Approaches



Lightweight Materials
Their Properties, Technologies and Advanced Applicability

IWT
Leibniz-Institut für Werkstofforientierte Technologien

Universität Bremen

NYU TANDON SCHOOL OF ENGINEERING

Lightweight Materials
Their Properties, Technologies and Advanced Applicability

This video was produced with the support of the Centre for Multimedia in Teaching (ZMML) in the ForstA digital project.

ForstA digital is integrated within the framework of ForstA*integriert*, funded by the German Ministry BMBF, funding code 01PL17030

Lightweight Materials - Their Properties, Technologies and Advanced Applicability

Literature (selection of textbooks and reference books)

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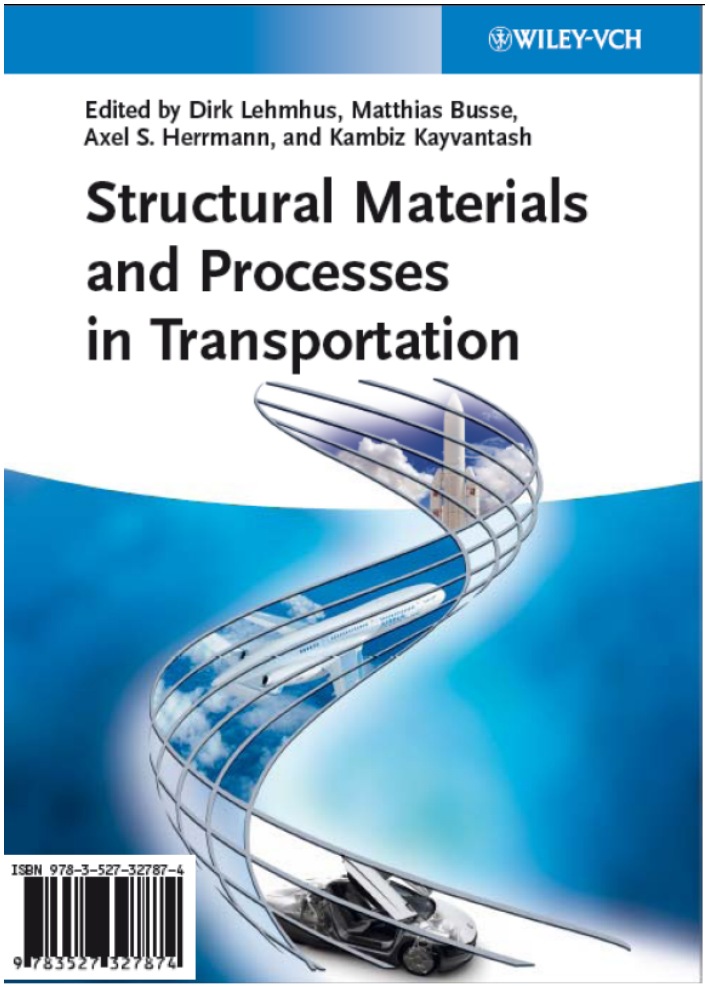
Further reading



http://onlinelibrary.wiley.com/book/10.1002/9783527649846

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Table of figures 1

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Table of figures 2

Slide(s)	Reference(s)
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