Lightweight Design: The Vanguard of Automotive Engineering
Strategies for Materials and Construction Methods

Prof. Dr.-Ing. Horst E. Friedrich
Dipl.-Ing. Marco Münster
Dipl.-Ing. Gundolf Kopp
Agenda

1. Growing importance of lightweight construction
2. Methodical approach in the development process
3. Lightweight construction strategies
4. Challenge: lightweight construction in the volume segment
5. Concepts for current and future cars
6. Trends in materials and structures yesterday, today and tomorrow
Megatrends

- We are reaching the limits of oil extraction
- Climate change is taking place
- Growing population, concentrated in big cities and conurbations
- Demographic trend

Vehicle concepts

- Lower energy consumption
- Reduced CO₂ emissions
- Alternative and regenerative energy sources
- Automated driving / connectivity
- …
CO₂ emissions in new vehicles in Germany and EU CO₂ limits

Source: KBA; DLR

* Mass-dependent
Total of normal resistances and consumption

\[ \sum F_w = b \cdot (m_g + \sum m_{\text{rot}}) + m_g \cdot g \cdot f_R \cdot \cos(\alpha) + m_g \cdot g \cdot \sin(\alpha) + \frac{\rho}{2} \cdot c_w \cdot A \cdot v^2 \]

B_e = \int b_e \cdot \frac{1}{\eta_{\text{Antrieb}}} \cdot \sum F_w \cdot \frac{v \cdot dt}{\int v \cdot dt}

Normal resistances

Differential consumption factors for 100 kg weight reduction in a vehicle with spark-ignition engine

Source: DLR; Rohde-Brandenburger, Volkswagen AG
Extension of range with small electric vehicles

Example: vehicle parameters
- Vehicle mass: 1000 kg
- Coefficient of resistance: 0.01
- Air resistance factor: 0.32
- Front surface: 2.2 m²
- Usable battery capacity: 28.2 kWh
- Efficiency of drive train: 70%

Source: DLR
Lightweight construction, vehicle dynamics and electromobility

**Influence of lightweight construction on vehicle dynamics**
- Running resistances
- Lateral dynamics dependent on CG (SP)
- Unsprung mass
- Secondary effects

**Opportunity for electromobility**
- Position of battery
- Wheel hub drive

→ Roll behavior
→ Yaw behavior

Lightweight design measures required

- Crosswinds
- Road transverse gradient
- Ruts, stochastic unevenness
- More sensitive to weight

Source: IVK Stuttgart, DLR
From the chain of effects of the traffic system to the methodical development process

- Demand for mobility
  - \( \text{CO}_2 \)
  - Legislation
  - Energy prices
  - ...

- Transport system
  - Requirements
  - Target function
  - ...

- Vehicle concepts and architecture
  - Simulation
  - Optimization
  - ...

- Technology
  - Structural components
  - Crash components
  - Energy converters
  - ...

Quelle: DLR
Lightweight requirement

**Objective:**
- light vehicle with high crash performance (L7e)

**Solution:**
- Body structure in sandwich architecture
  - Skin layers aluminum alloy
  - Foam core polyurethane
- Joining process
  - Crash-stable structural adhesive
  - Welded parts

BIW < approx. 80 kg

Euro-NCAP frontal crash → intrusion approx. 102 mm

Source: DLR
Lightweight design concept

Objective:
- Crash modular, adaptable vehicle front

Solution:
- Energy absorbed through cutting
- Three-dimensional, reinforced light front vehicle structure
- Peeling pipes for adjustment of energy

Approx. 20% lighter than steel reference structure

Source: DLR
Lightweight material design

Objective:
- Light CFRP B-pillar

Solution:
- Layer structure (0/90/±45)
- Manufacture using VARI procedure
- Internal reinforcement with additional Omega profile
Lightweight material design

Objective:
- BIW weight reduction ≥ 85 kg (≥ 30%)
- Lightweight construction costs (cost of parts) ≤ 5 €/kg

Solution:
- Body in white 100 kg lighter than reference (approx. 35%)
- Complete CAD model of the BIW
- Validation of structure (crash, static etc.)
- Specification of joining and production processes
- Life cycle analysis for MMD concept

Materials
- Aluminium sheet
- Aluminium cast
- Aluminium extrusion
- Steel
- Hot-formed steel
- Magnesium sheet
- Magnesium diecasting
- Glasfibre thermoplastic

Percent by weight
- Aluminium 96kg (53%)
- Steel 66 kg (36%)
- Magnesium 11 kg (7%)
- Plastics 7 kg (4%)

Source: VW, DLR
Lightweight shape

Objective:
- A-pillar cast node lighter and more cost-attractive

Solution:
- New design with magnesium alloy
- Integration of suspension strut slot and A-pillar
- Weight saving approx. 50 %
Challenge: lightweight construction in the volume segment

Adjusting lever for lightweight construction:
- Materials
- Concepts
- Production technology
- etc.
- ...

- Weight
- Safety
- NVH
- etc.

Source: VW; Daimler; DLR
Weight saving:
- structural weight reduced by about 100 kg
  - Electrics - 6 kg
  - Drive train - 40 kg
  - Chassis - 26 kg
  - Body - 37 kg

Lightweight design measures:
- High-strength and higher-strength types of steel, reduced sheet thickness (TRB)
- Only using material where it is needed
- Optimal geometry of profiles and surfaces
Concept: Aluminum-intensive
Example: Range Rover V

Weight saving:
- Vehicle about 420 kg lighter than its predecessor
- Weight saved in basic shell approx. 39% (almost 180 kg)

Lightweight design measures:
- External skin panels between 0.9 and 1.5 mm
- All body joints riveted or bonded
- Side parts compressed in a single aluminum component
  → Fewer body joints
- High-strength Al AC300 for the crash structure
Concept: Aluminum-/steel-intensive hybrid design
Example: Audi TT 2nd generation

Weight saving:
- Weight of body: 206 kg
- Reference body in steel would be 48% heavier
- Pure Al body would be 12% lighter

Lightweight design measures:
- Multi-material-design
- Shell and space frame structure combined

Source: Audi
Concept: Bi-module (CFRP-Al-intensive)
Example: BMW i3

Weight saving:
- Vehicle total weight approx. 1195 kg with battery
- Approx. 300 kg saved through new material and purpose-built design

Lightweight design measures:
- Material combination CFC + aluminum
- Bi-modular design
  - "Life" module - CFC monocoque body
  - "Drive" module - crash and structural components, Al chassis

Source: www.bimmertoday.de

CFRP "Life" module

Aluminum “Drive” module

Source: BMW
Concept: CFRP-intensive
Example: F125!

Weight saving:
- CFRP-intensive design approx. 250 kg lighter than current reference
- Front curved and support structures designed as load-bearing assembly unit in CFRP sandwich hybrid design

Lightweight design measures:
- Ultra-light fiber composite body
- Structure-integrated hydrogen storage
- Function integration through CFRP e.g. safety belt integrated into seat structure

Correctly use the good material characteristics of Steel, Aluminum, Composites

Source: Daimler
Summary

- CO₂ limits are driving forward lightweight construction in vehicle design
- Gradual electrification is reinforcing the trend towards lightweight construction
  - Compensation for extra weight of new components
- Further development of construction methods:
  - Increase in MMD in volume-intensive production sector
- Focus for research and development:
  - Consideration overall, methodical approach in the product development process
Thank you for your attention!