Heavy-Duty Drivelines

The AVL HD E-Axle Technology Showcase

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Today’s Presenters

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Today’s Agenda

1 **About AVL**

2 **Introduction and Target Setting**

3 **System Development**

4 **Hardware Validation**

5 **Production Adaptions**

6 **Q&A**

About AVL

Reimagining Motion

"We are driven by a **passion** to examine the science, mechanics and philosophy of movement. To help create a world that is climate-neutral and one that makes **safe, comfortable, green mobility** a reality for everyone."

Helmut O. List

Chairman and CEO

AVL List GmbH

AVL at a Glance

1948
Founded

75+
Years of Experience

29
Countries Represented

50+
Global Tech and Engineering Centers

12,200
Employees Worldwide

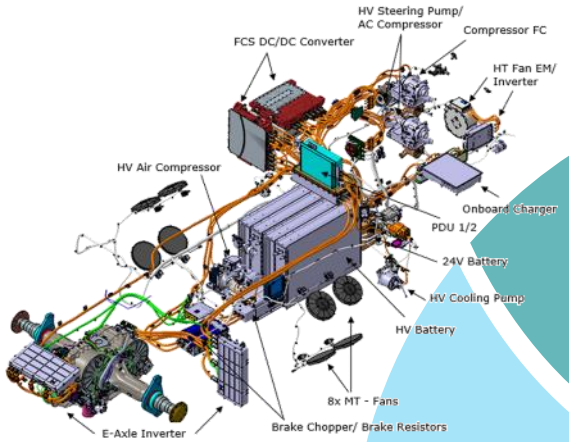
68 %
Engineers and Scientists

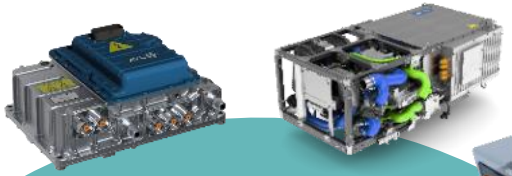
10 %
Of Turnover Invested in Inhouse R&D

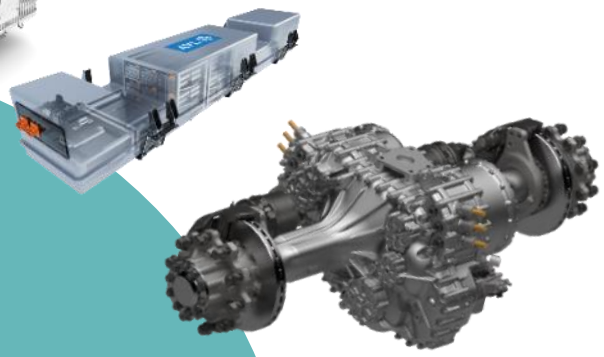
2,200
Granted Patents in Force

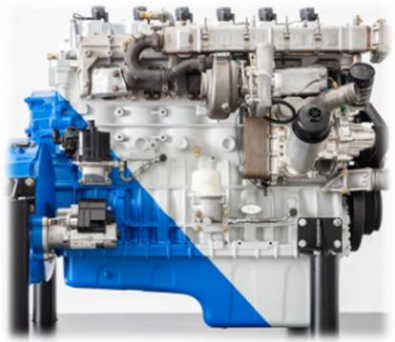
Truck & Bus Focus Areas

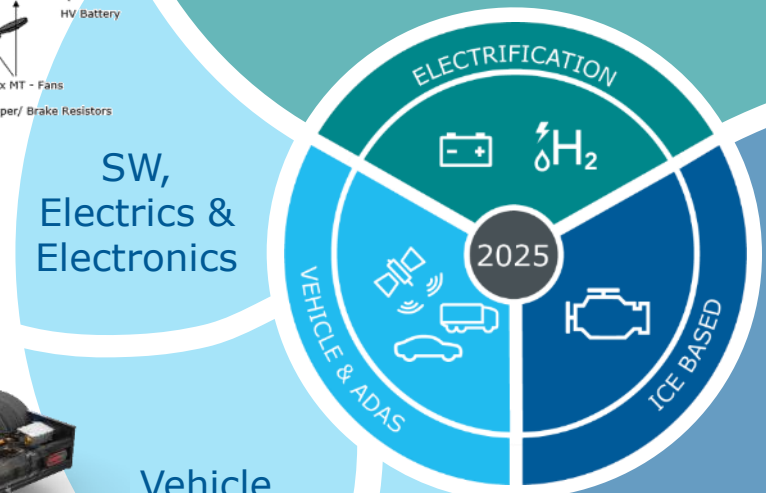
AVL





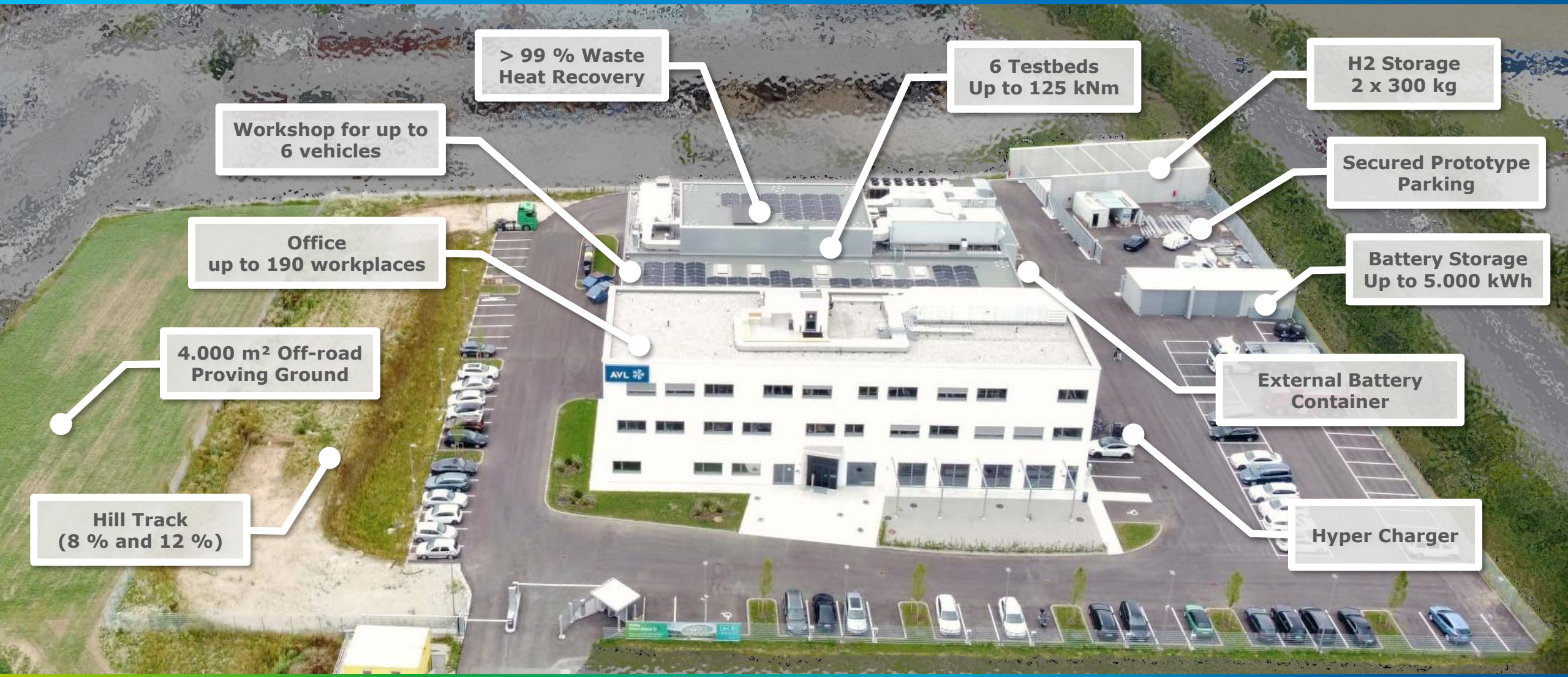






New Tech-Center @Steyr

Total Area of 15.000 m² focused on Flexibility and Multi-Use



Introduction and Target Setting

Challenges

Legislative targets will demand ZEV for all CVs. e-Axles are demanded for compliance with regulatory limits and policy initiatives

Packaging space for batteries and H_2 tanks needs a holistic e-Axle development approach to ensure a compact e-axle structure

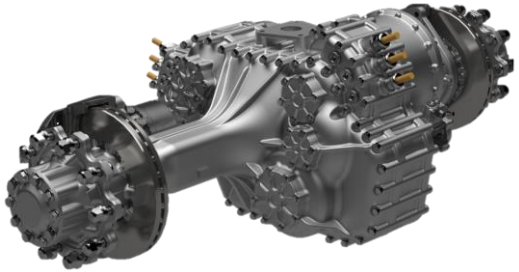
Integrated e-Axles come with high investment costs – Modularity and vehicle segments with high sales numbers are key

Specific OEM needs will require customized engineering solutions

- Fleet structure
- Time to market

Introduction

AVL Is a One-Stop Solution Provider for e-Axles in All Vehicle Classes



2016
AVL R&D – MD eAxle

800V fully integrated inverter

2 speed – 148 kW cont.
16.000 rpm e-motor

2019
AVL R&D – HD eAxle

750 V; 2x direct oil cooled e-motors

2 speed – 360 kW cont.
9.000 rpm e-motors

2020
AVL R&D – Veh. Integr.

Full vehicle conversion to electric powertrain

eAxle and VCU integration

2023
HD eAxle – cust. proj.

44 to vehicle class

Concept development

...

2017
LD eAxle – cust. proj.

6 to delivery truck

1 speed – 60 kW cont.
15.000 rpm e-motor

2020
eAxle ASW development

Generic modular ASW Software approach

MIL proofed ASW available

2020
MD eAxle – cust. proj.

14,5 to vehicle class

Integration of off-the-shelf e-Motors and Inverters

2016 - 2024
eAxle – cust. proj.

Various family and topology studies

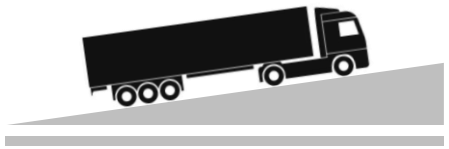
Market studies

Troubleshooting

Introduction
Target Setting

Main Vehicle Performance Parameters

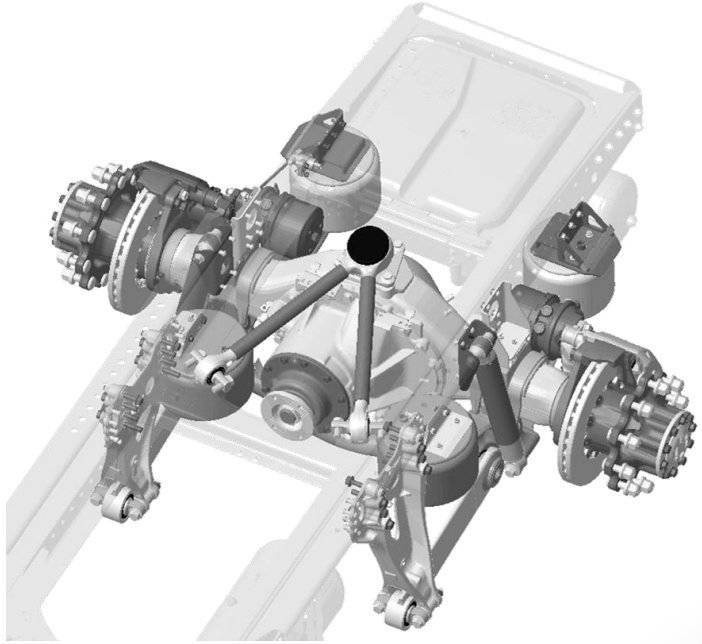
- Derived from real drive cycle (4x2 Truck)
- Required continuous power: **400 kW**



20 % @ peak power

3 % @ 80 kph

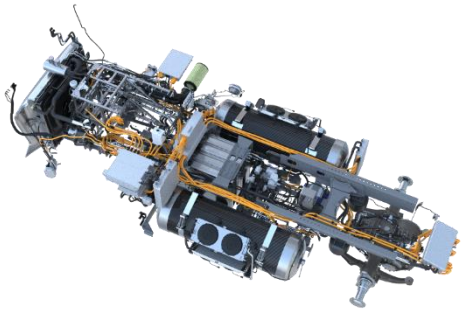
max. speed 100 kph



Conventional Axle Packaging

System Development

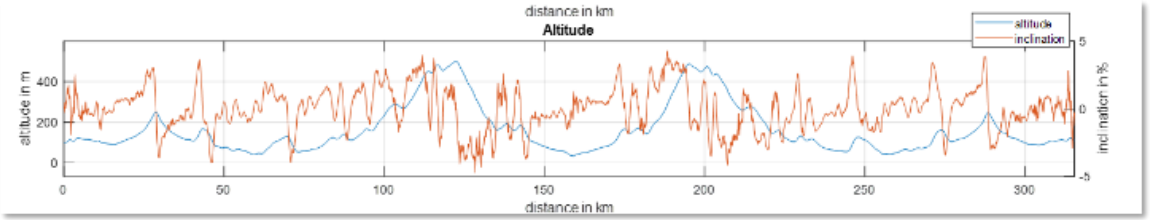
Multistep Workflow
Example Powertrain Sizing



Static rough dimensioning according key requirements

e.g.: 2 % grade @ 80 kph

Mechanical drive power



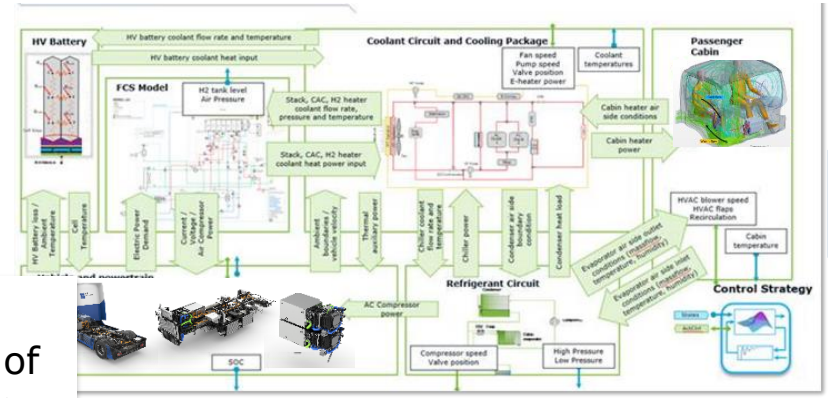
PSO

frontloading .... detailing .... optimizing

Dynamic dimensioning according driving cycle

e.g.: Graz -> Wiener Neustadt -> Graz

Power split for battery and fuel cell



AVL Cruise M

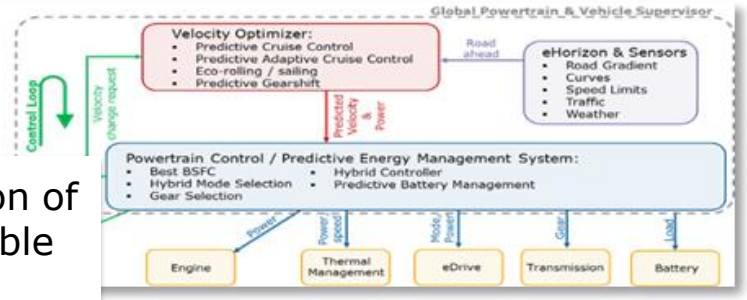
AVL Model Connect

Testbed Connect

Plant model generation

e.g.: detailed VTMS Model, detailed FCS model, battery model, ageing, …

Detailed evaluation of limitations



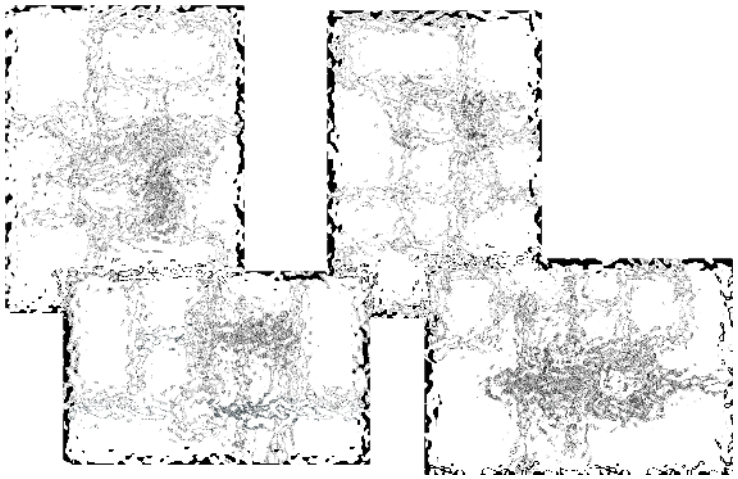
Model enhancement

e.g.: Predictive Energy Management

Optimization of the available energy

Utilizing Pso for Finding the Right e-Axle Topology
Input Data

Different e-axles with different ratio families. Ratio variation within each family concept.



Different driving cycles (combination from EU + US) with different payloads.

Payload Variation

HD Cycles	**MD Cycles**
US Cycles	**US Cycles**
EU Cycles	**EU Cycles**

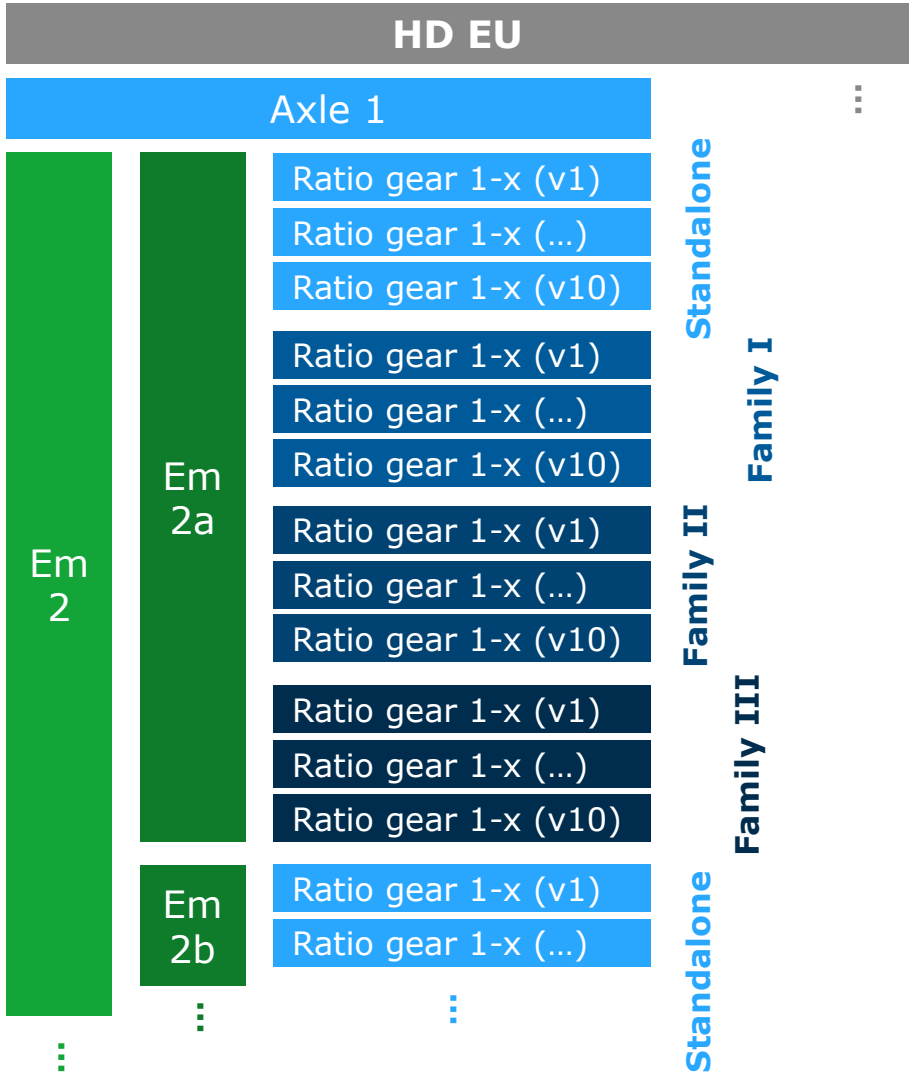
Different e-motor concepts with three different diameters each. Scaling of e-motor power.

Power scaling variation

Em1	Em2	Em3
Em4	Em5	Em6

- Different maximum speed
- Different corner point
- Different outer diameter

Utilizing Pso for Finding the Right e-Axle Topology
Simulation matrix



Explanation of variations

- Each of the axles has different ratio variations
  - Standalone
  - Family I – family III
- Each axle and ratio variation is combined with the different e-motors
  - E-motor with same power, but different outer diameter
- Furthermore, each e-motor (with the different outer diameters) is also scaled in power

Resulting number of overall calculated variants

	Drive cycles	E-axle Topologies	E-motor types (average)	E-motor power scaling	E-motor diameters	Gear ratios (average)	Gear ratio families	Overall variants
	14	**5**	**2**	**3**	**3**	**~10**	**4**	
Overall	x	x	x	x	x	x	x	**~50000**
Per e-axle			x	x	x	x	x	**~720**
Per application		x	x	x	x	x	x	**~3600**
Explanation	HD MD EU US	Axle 1 Axle 2 Axle 3 Axle 4 Axle 5	Em1 Em2 Em3 Em4 Em5 Em6	+0 % +10 % +20 %	123 mm (a) 456 mm (b) 789 mm (c)	Ratio gear 1-x (v1) Ratio gear 1-x (…) Ratio gear 1-x (v10)	Standalone Family I Family II Family III	

Utilizing Pso for Finding the Right e-Axle Topology

KPI Post-Processing via Matlab App

Choice of gear family

Choice of e-motor diameter

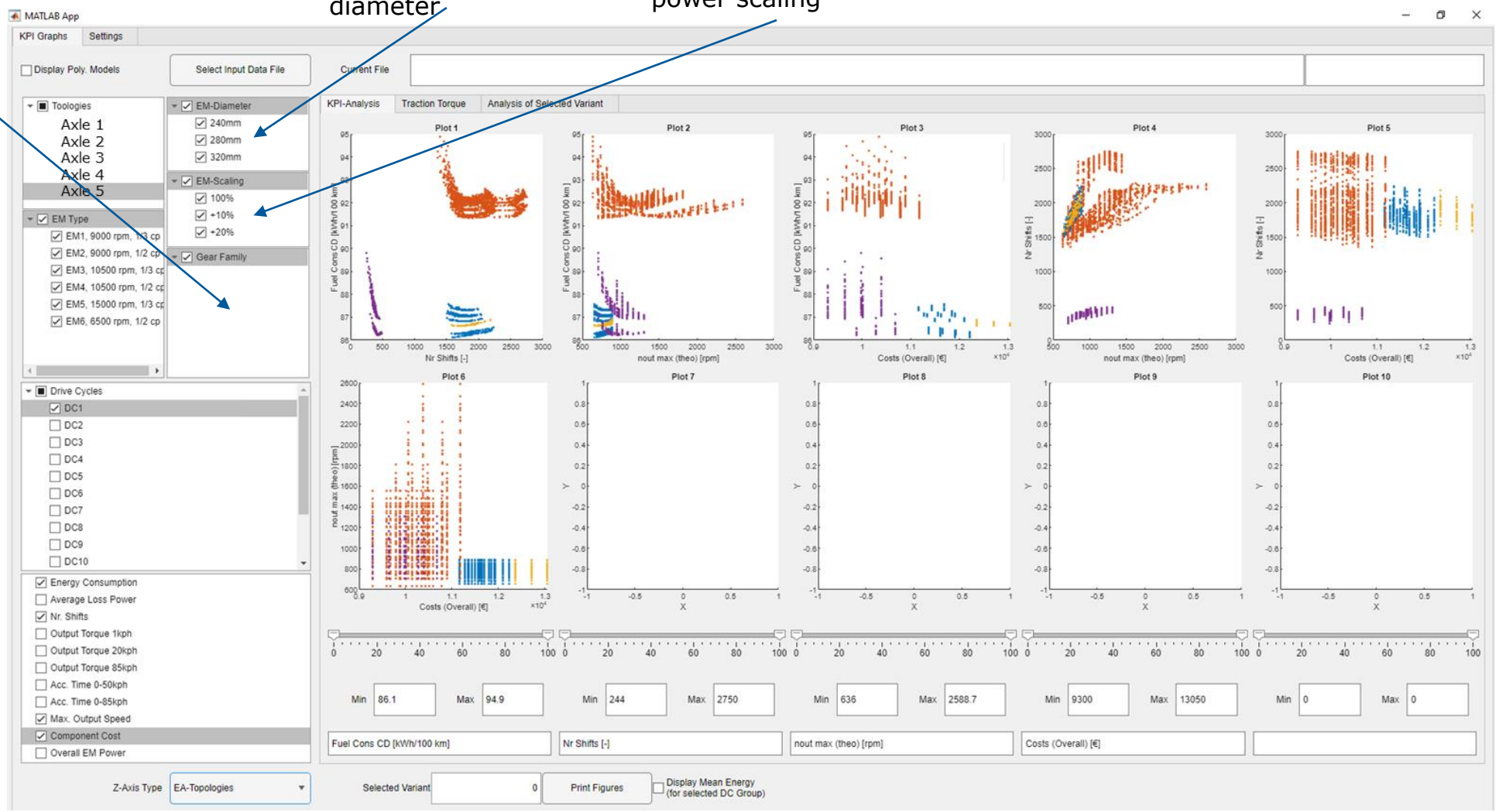
Choice of e-motor power scaling

Choice of axle

Choice of e-motor type

Choice of drive cycle

Choice of KPIs



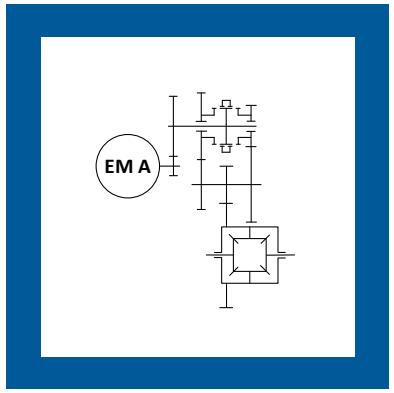
AVL HD e-Axle Development
Modularity Example (MD to HD)

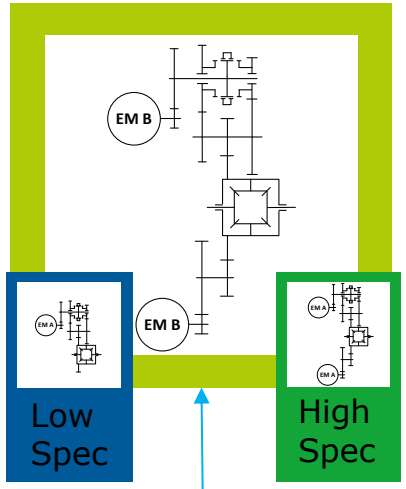
Lead Variant

Application	20 t / 4x2	26 t / 6x2	42 t / 4x2	49 t / 6x4 & 8x4	65 t / 6x4 & 8x4
Peak Power (total)	P peak 270 kW	P peak 360 kW	P peak 540 kW	P peak 540 kW	P peak 810 kW
Continuous Power (total)	P cont 200 kW	P cont 240 kW	P cont 400 kW	P cont 400 kW	P cont 600 kW
Max. torque at wheels	T max 30 kNm	T max 30 kNm	T max 40 kNm	T max 60 kNm	T max 70 kNm

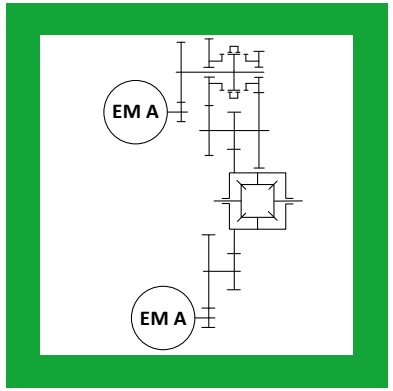
E-motor A
P peak 270 kW
P cont 200 kW

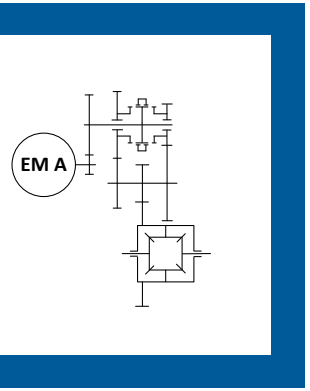
(E-motor B)
P peak 180 kW
P cont 120 kW

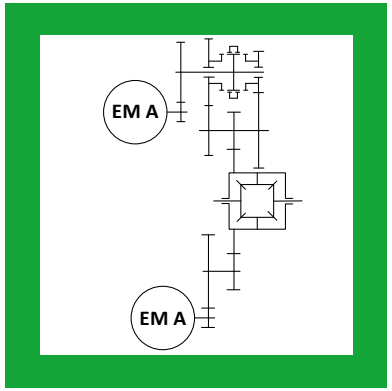


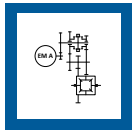


Optimized e-Axle
Optimized variant can be replaced by low spec or high spec variant (dependent on vehicle requirements)

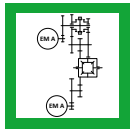




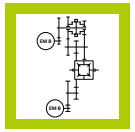




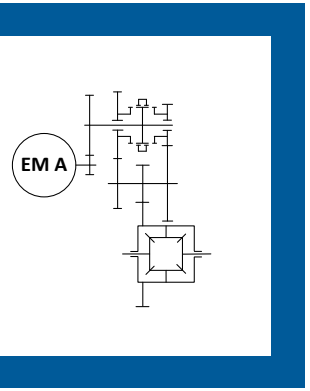
e-axle 270
derived from AVL HD E-Axle 540
Optional: different housings for different axle loads

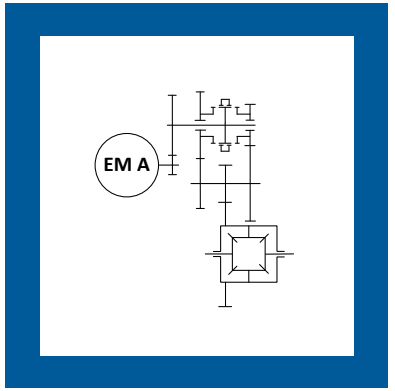


AVL e-axle 540
or adaptation for off road application



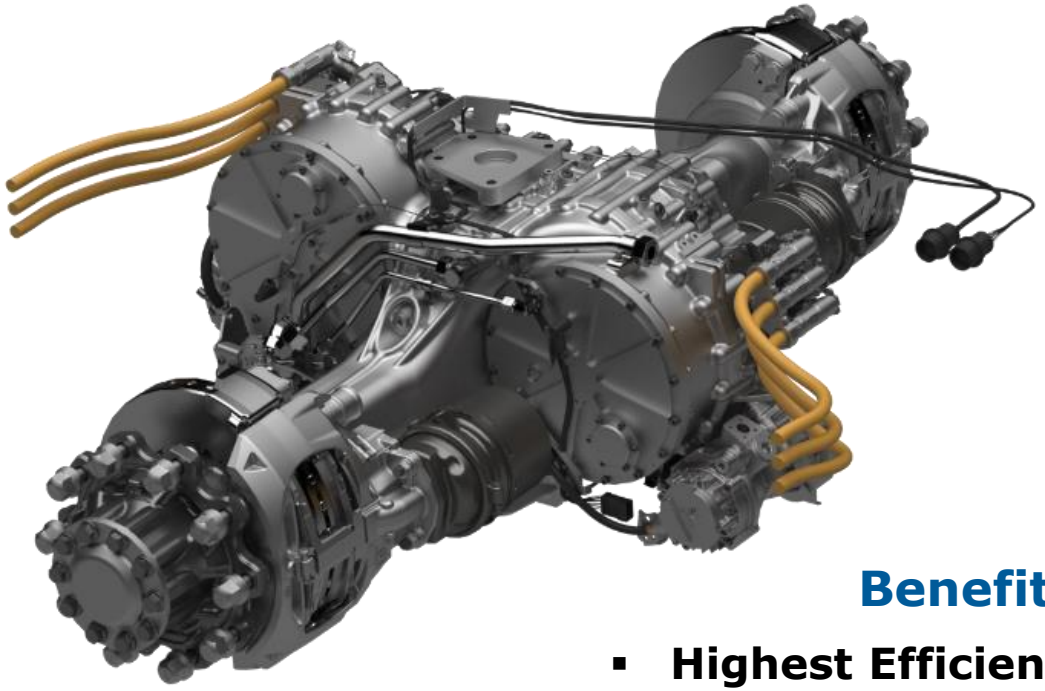
(e-axle 360)
derived from AVL HD E-Axle 540





Conclusion: Wide Range of applications can be covered by **2 (3) e-Axles**

AVL HD e-Axle Development
Technology Demonstrator (A-Sample)

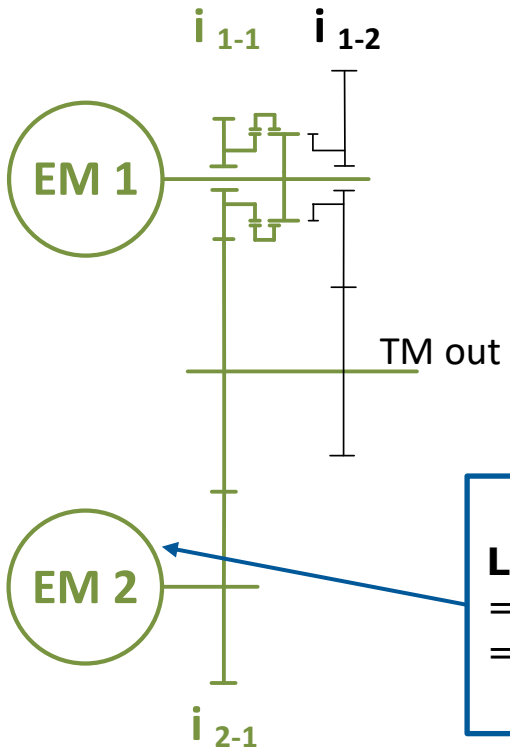


* without brakes

Benefits:

- **Highest Efficiency**
- **Weight < 1.000 kg***
- **Powershift Functionality**
- **Flexible, Scalable and Modular Architecture**

E-motors (PSM)
- 2 x 270 kW peak power
- 2 x 200 kW continuous power
- 9.000 rpm max. rotational speed
- Direct oil cooling for highest torque density

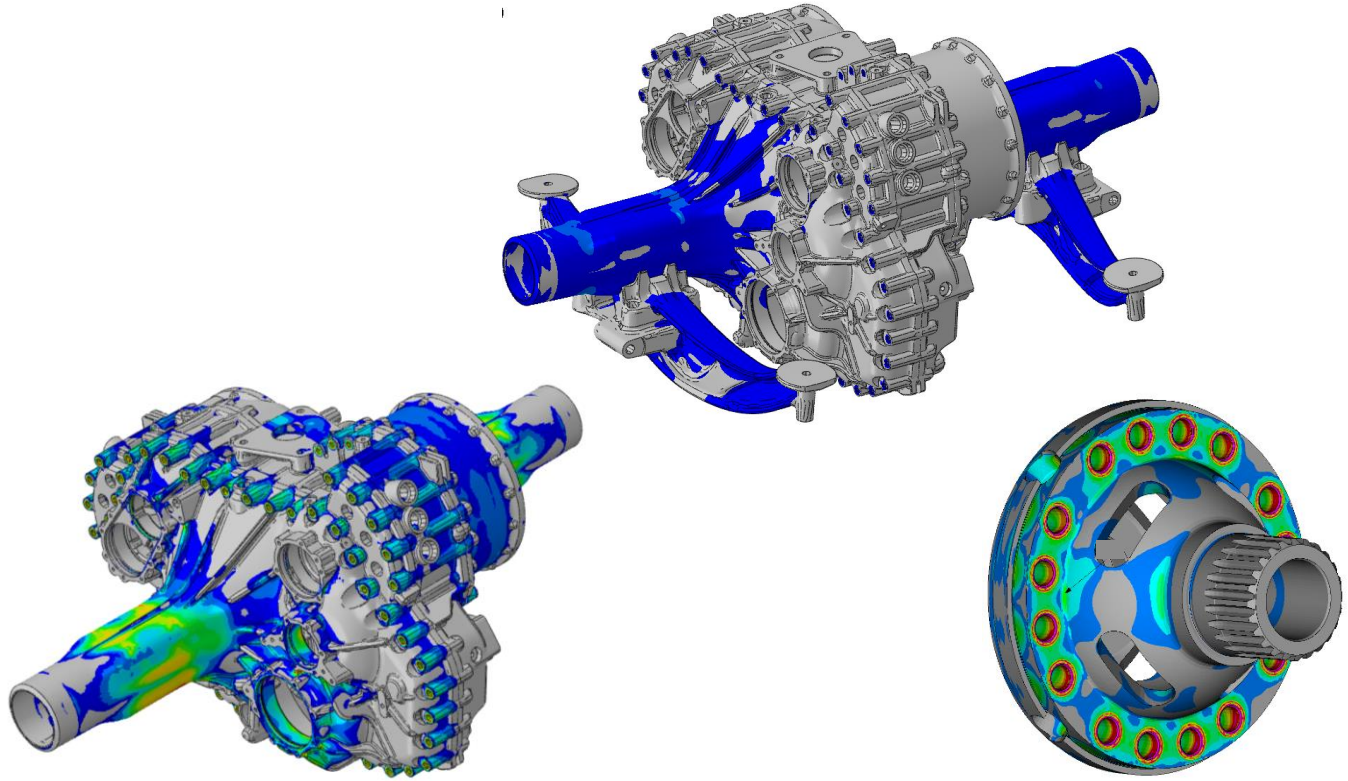


Long Haul Drive Cycle
=> 70 % EM2
= high efficiency

AVL HD e-Axle development
FEA Simulations

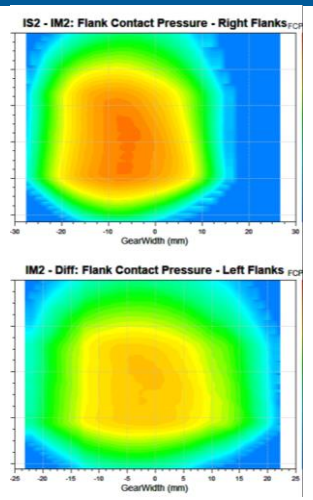
Strength and lifetime of housings, chassis parts and other e-axle components (e.g. differential case, planetary carrier)

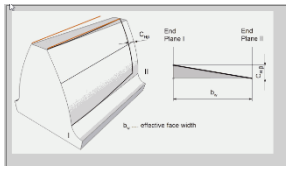
- Various load cases to ensure **structural strength and lifetime** of e-axle and chassis components
  - Static loads
  - Dynamic loads
  - Torque loads
  - Combined loads
- Check of **bolt connections**
- Check of **flange tightness**
- Input for NVH and CFD simulations

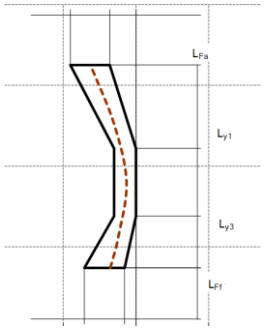


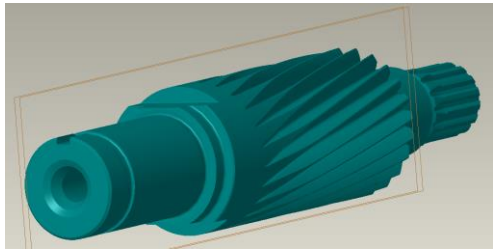
AVL HD e-Axle Development
NVH Optimization

Optimization of gear micro geometry (contact pattern)

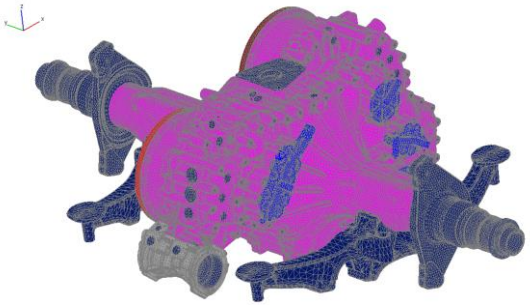


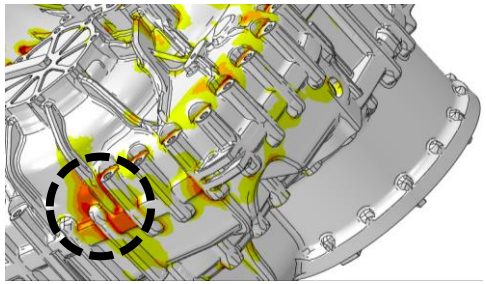


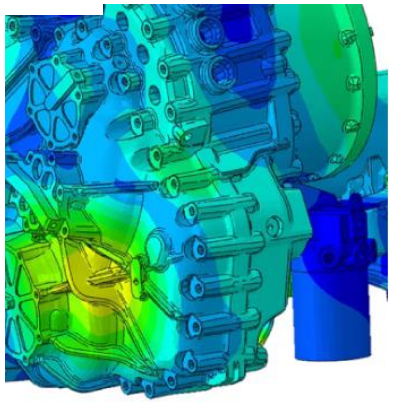




Reduction of structure born noise



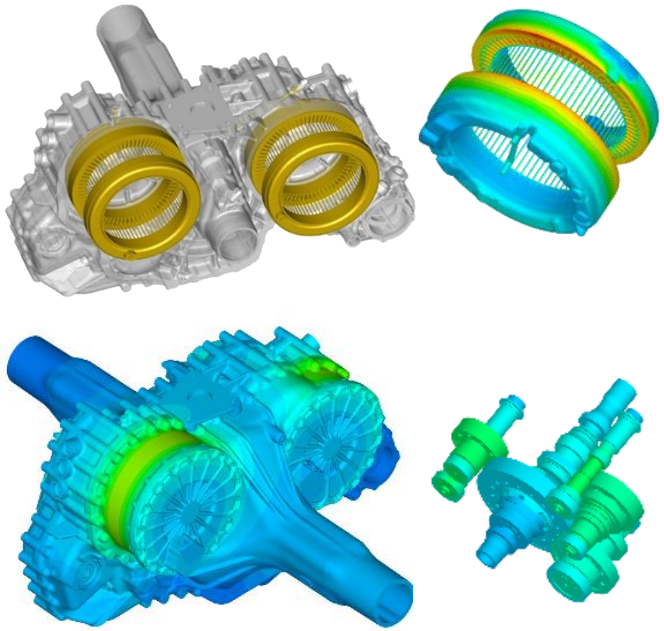




AVL HD e-Axle Development
Simulations for Cooling and Lubrication System

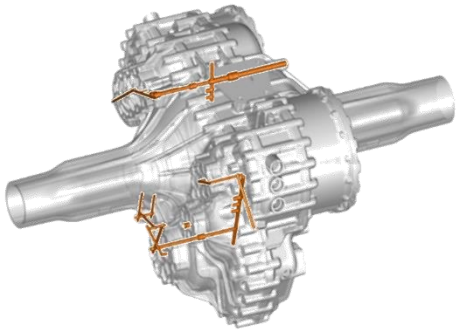
Cooling system

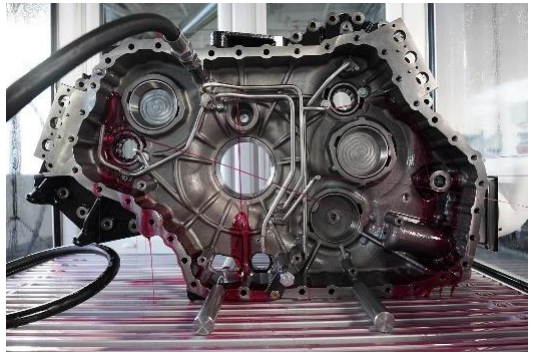
- Simulation of temperature distribution
- Highly efficient direct oil cooling system for high continuous e-motor power
- No overheating of oil and components for high lifetime & short maintenance intervals



Lubrication of transmission components

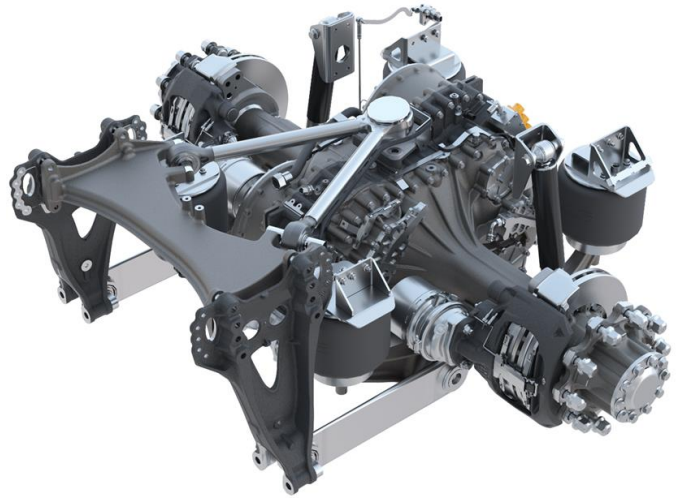
- Simulation of oil distribution
- Validation on test rig
- Defined lubrication oil flows to transmission components for high reliability and durability





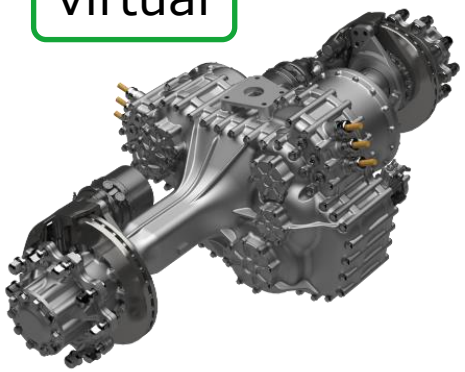
Integration in vehicle

- 3D CFD underhood simulation of heat transfer in installed condition
- Reliable cooling system in real working conditions



AVL HD e-Axle Development
Thermal Virtual Validation

virtual



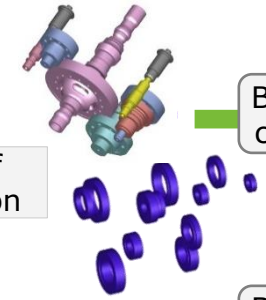
real

Conjugate Heat Transfer Simulation

Losses e-motor

Boundary condition

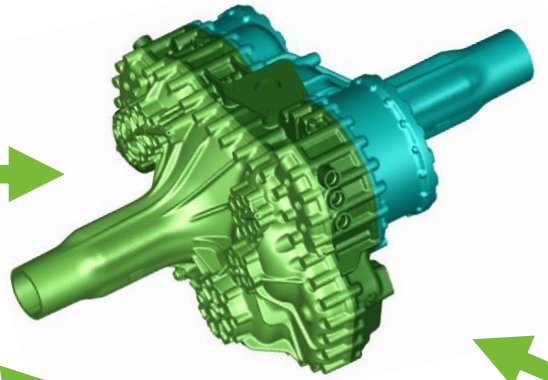
Losses of transmission



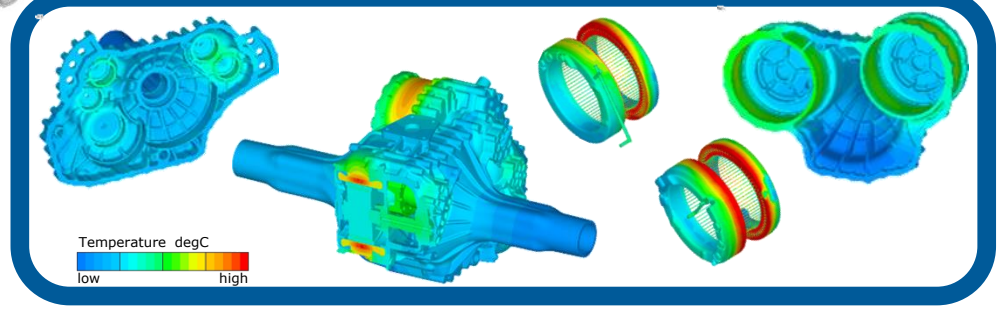
Boundary condition

Cooling

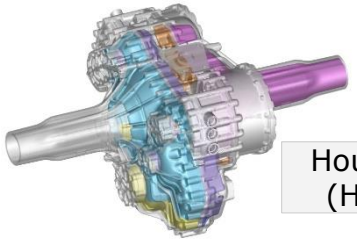
Boundary condition



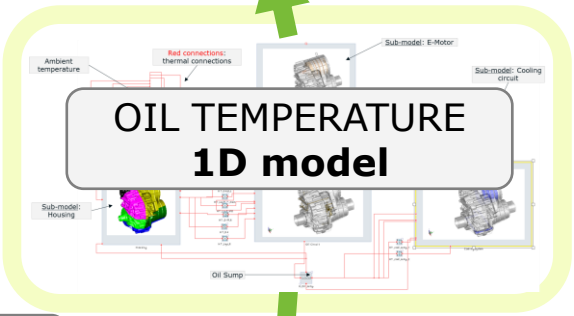
Thermal 3D CFD model



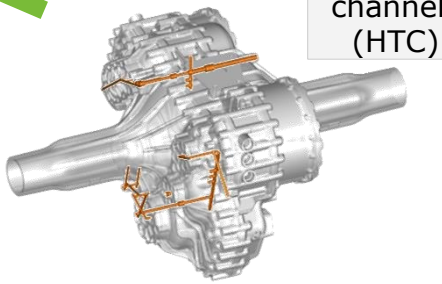
Boundary condition



Housing (HTC)



Boundary condition

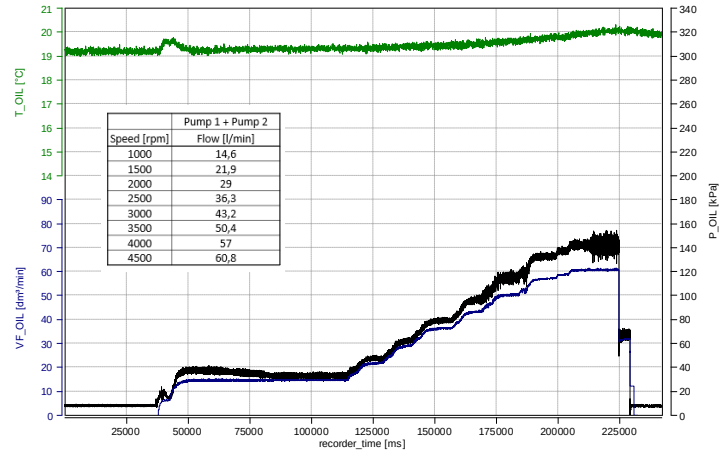


Oil supply channels (HTC)

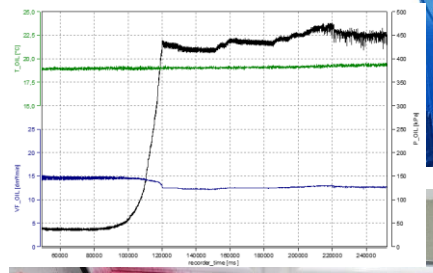
Hardware Validation

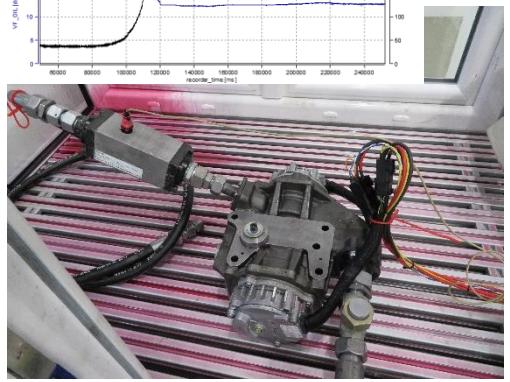
AVL HD e-Axle Development
Lubrication Test

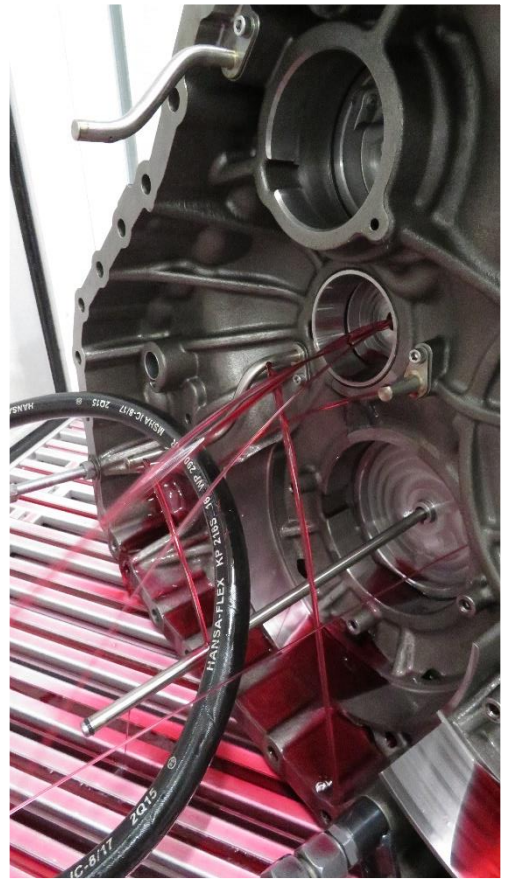
- Oil distribution test
- Pump performance test
- Pressure relive valve adjustment / function test
- Delta p measurements



	Pump 1 + Pump 2
Speed [rpm]	Flow [l/min]
1000	14,6
1500	21,9
2000	29
2500	36,3
3000	43,2
3500	50,4
4000	57
4500	60,8

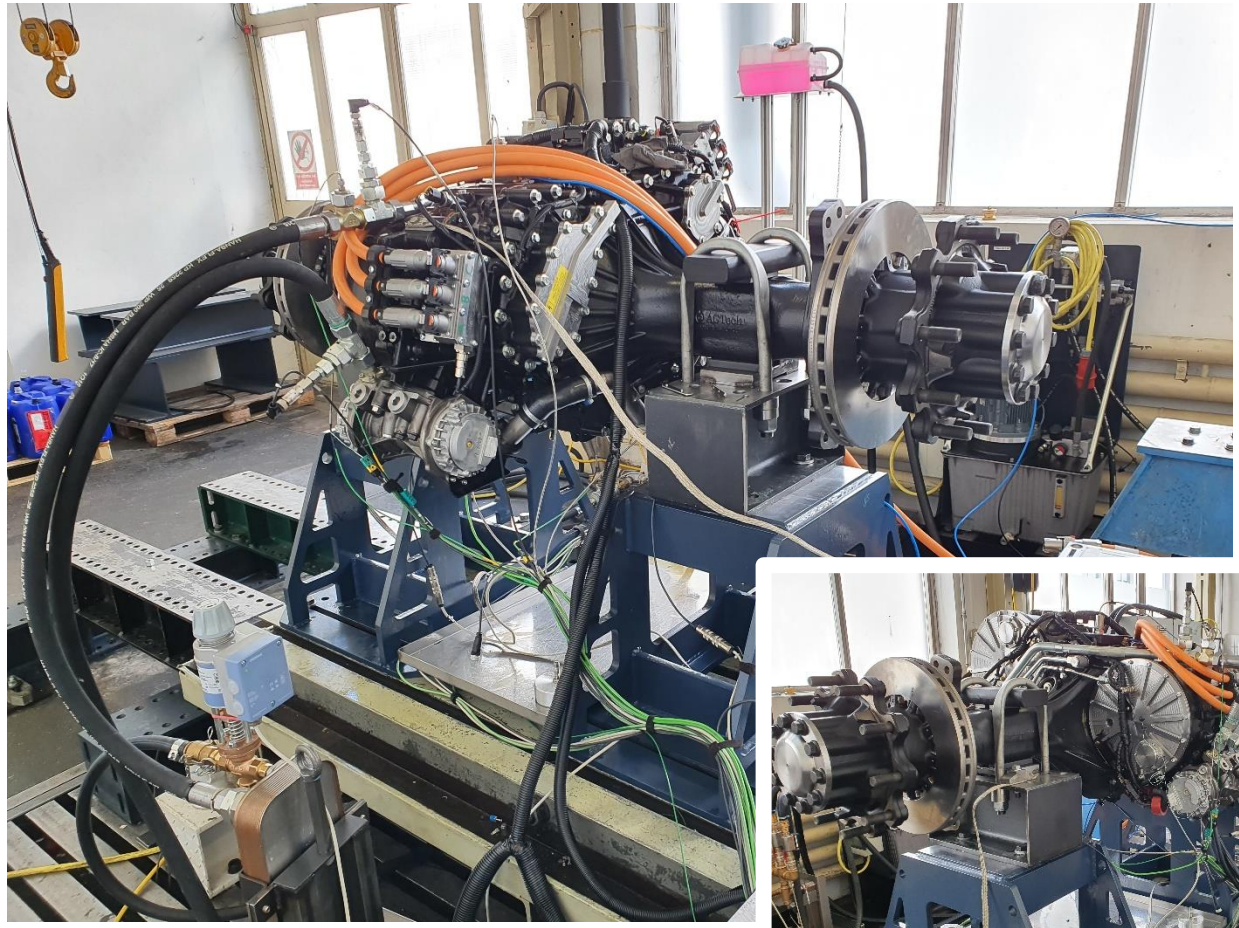






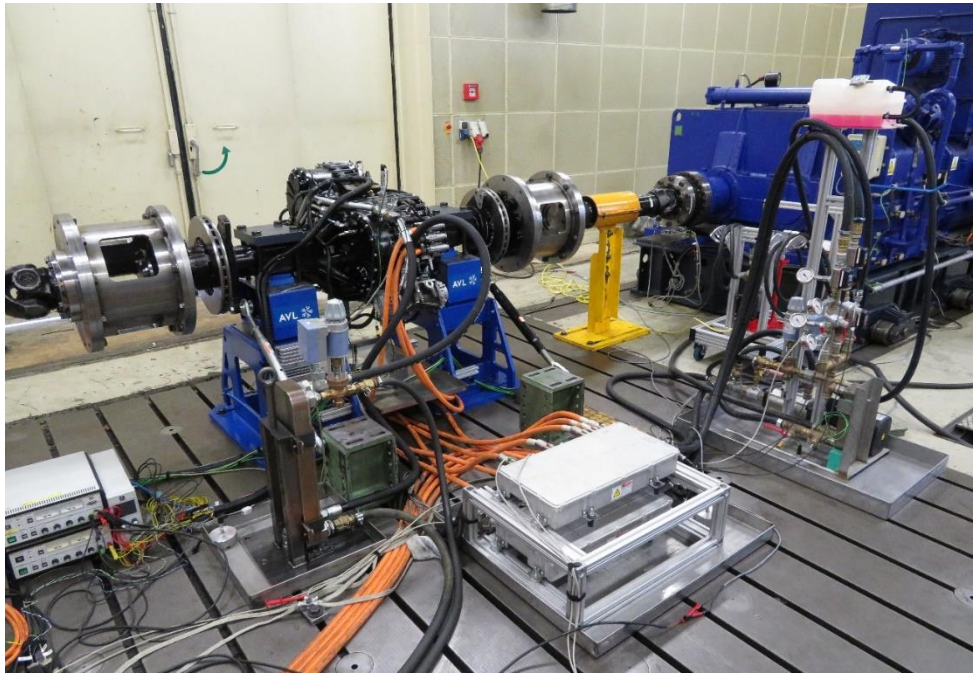
AVL HD e-Axle Development
Basic Function Test – No Load

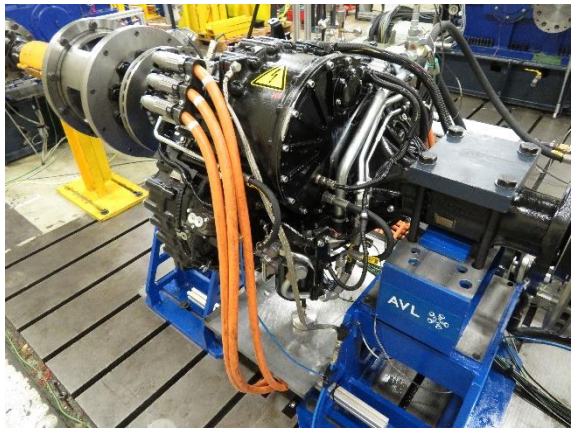
- Resolver adjustment
- Inverter measurements
- E-Motor measurements
- Parameter check
- SW Check
- Shifting function check

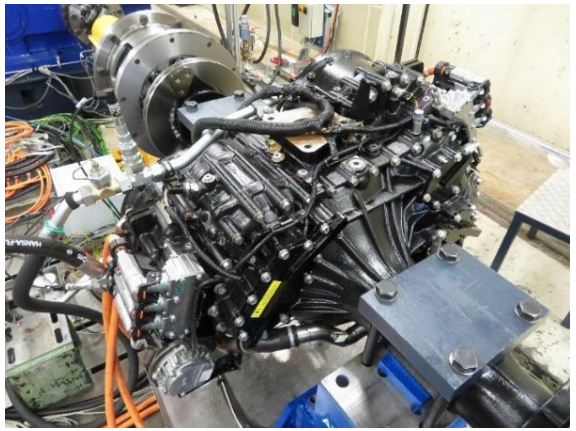


AVL HD e-Axle Development
Basic Function Test – Under Load

- Shifting behavior measurement
- Resolver adjustment
- Inverter measurements
- Temperature behavior (E-Motor, Inverter, System)
- Run in
- SW adjustments / checks





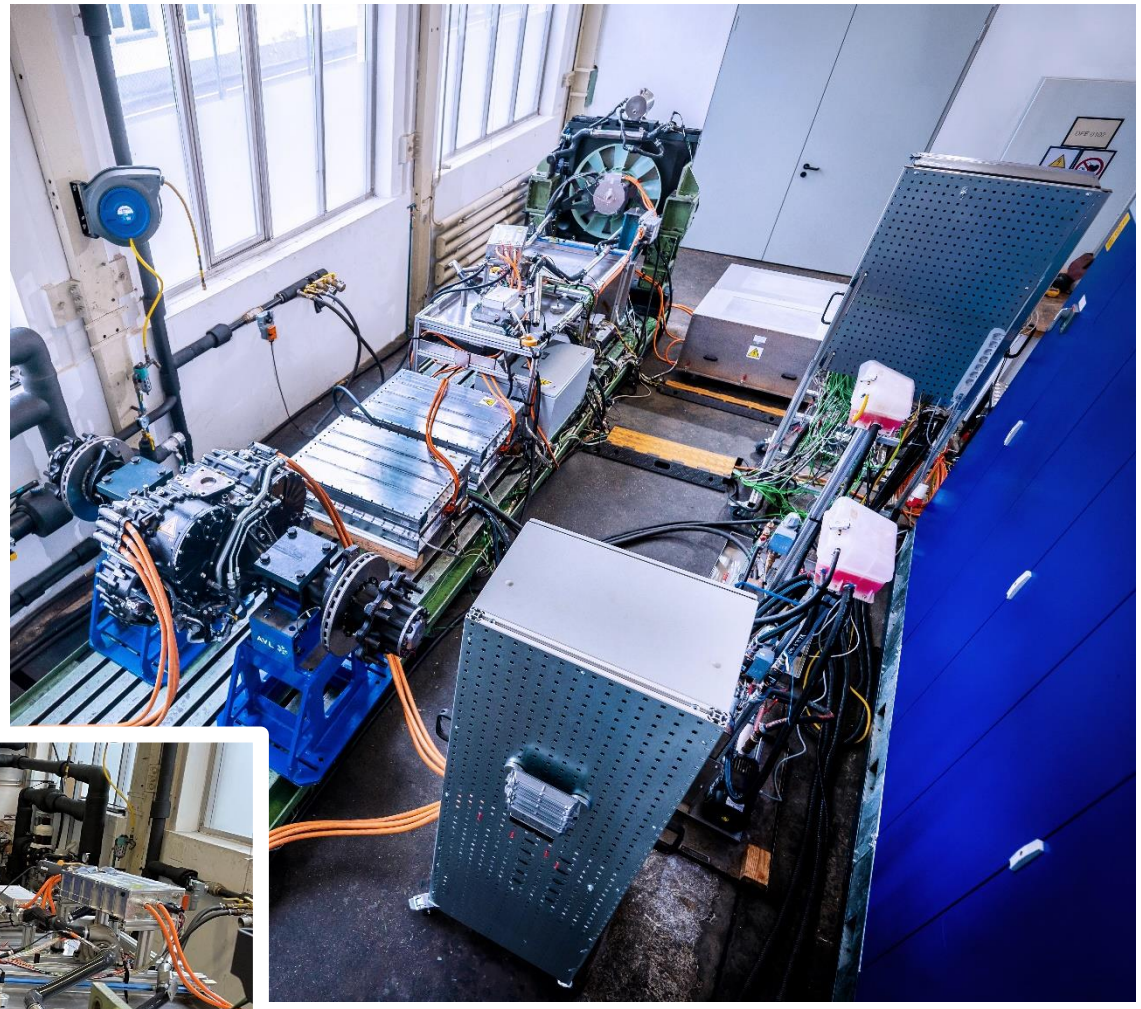


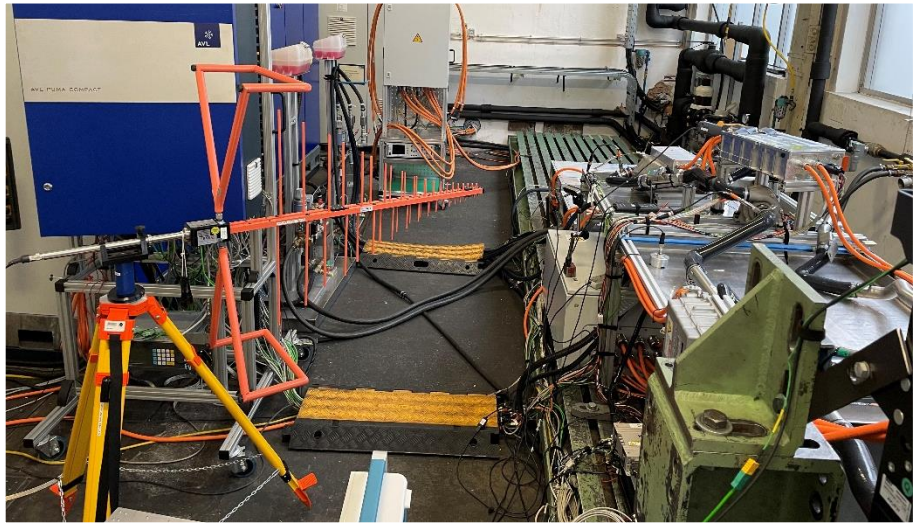
AVL HD e-Axle Development
Contact Pattern Test

- At nominal torque (all gears, pull and coast)
- At peak torque (all gears, pull and coast)

AVL HD e-Axle Development
Vehicle Integration Tests

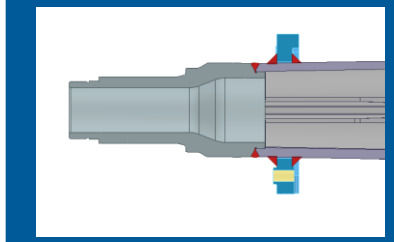
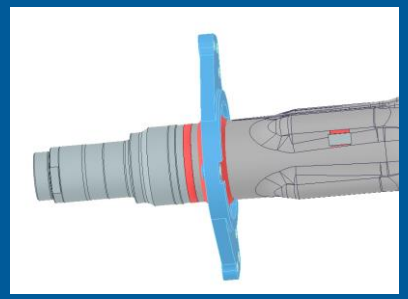
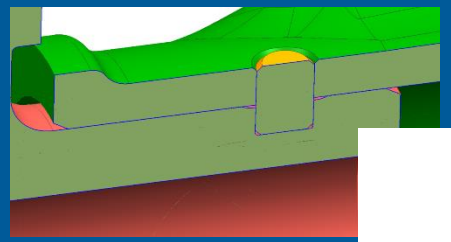
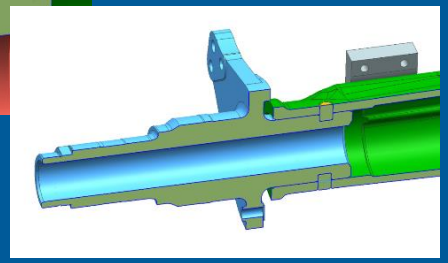
- Batterie tests
- E-Axle tests
- E-Motor/Inverter tests
- Thermal / cooling performance tests
- EMC pre-tests
- SW tests
- Communication tests
- Fault injection testing



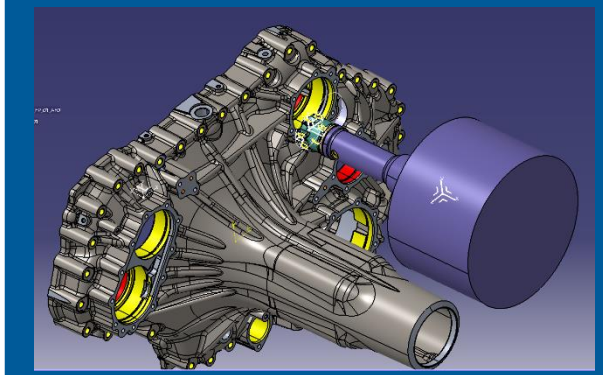
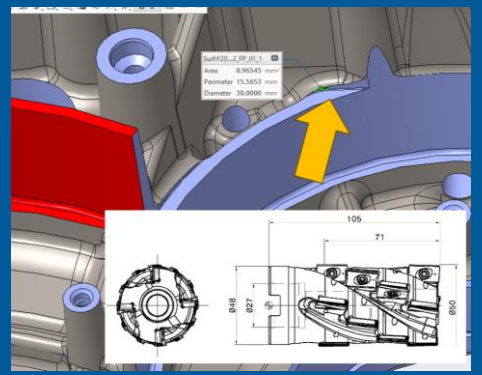


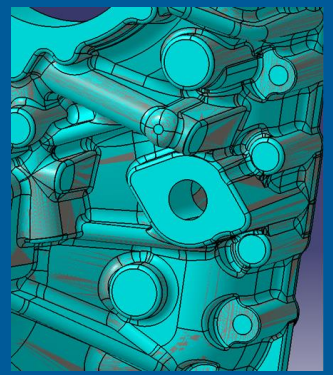
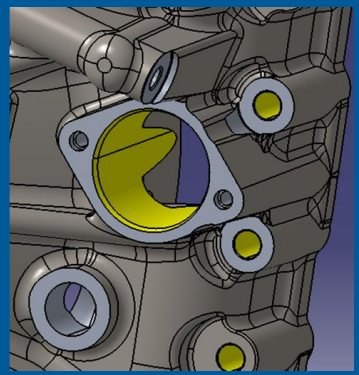
Production Adaptations

AVL HD e-Axle Development
Adaptations for Production

Switch from a "welded brake bracket" to a forged part with press fit

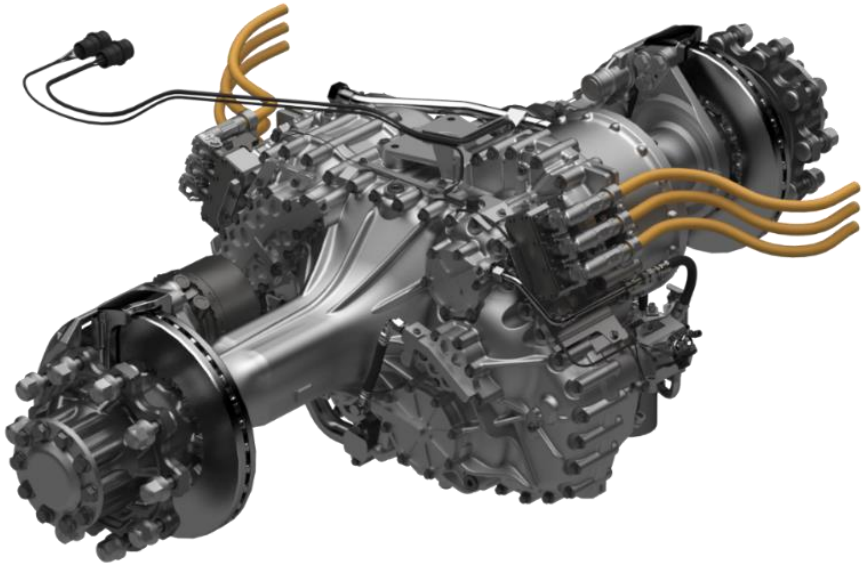



Detail adaptations for cheaper and more reliable machining

AVL HD e-Axle Development Adaptations for Production

Conclusion and Summary



- ✓ AVL has the experience for development of e-axles fulfilling all relevant series requirements
- ✓ Simulation based approach leads an optimized arrangement for the e-axle
- ✓ The chosen topology with 2 oil cooled e-motors and multi-speed transmission enables flexible operating strategies to balance efficiency and durability
- ✓ The flexible and modular concept can be adapted for various applications with different boundary conditions
- ✓ Virtual and physical testing proved the capability of the AVL HD e-axle for the application in commercial vehicles
- ✓ **The gained know-how and the individual technology building blocks can be applied to all future projects**

Q&A

Contact

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