Accelerating Automotive Aerodynamics Analysis

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Erich Jehle-Graf - *Mercedes-Benz*
Ian Pegler - *NVIDIA*

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Vehicle Manufacturers face **more challenges** than ever before.

Environmental Impact
Broad commitment to car-bon-neutrality from OEMs, Suppliers, and Fleets

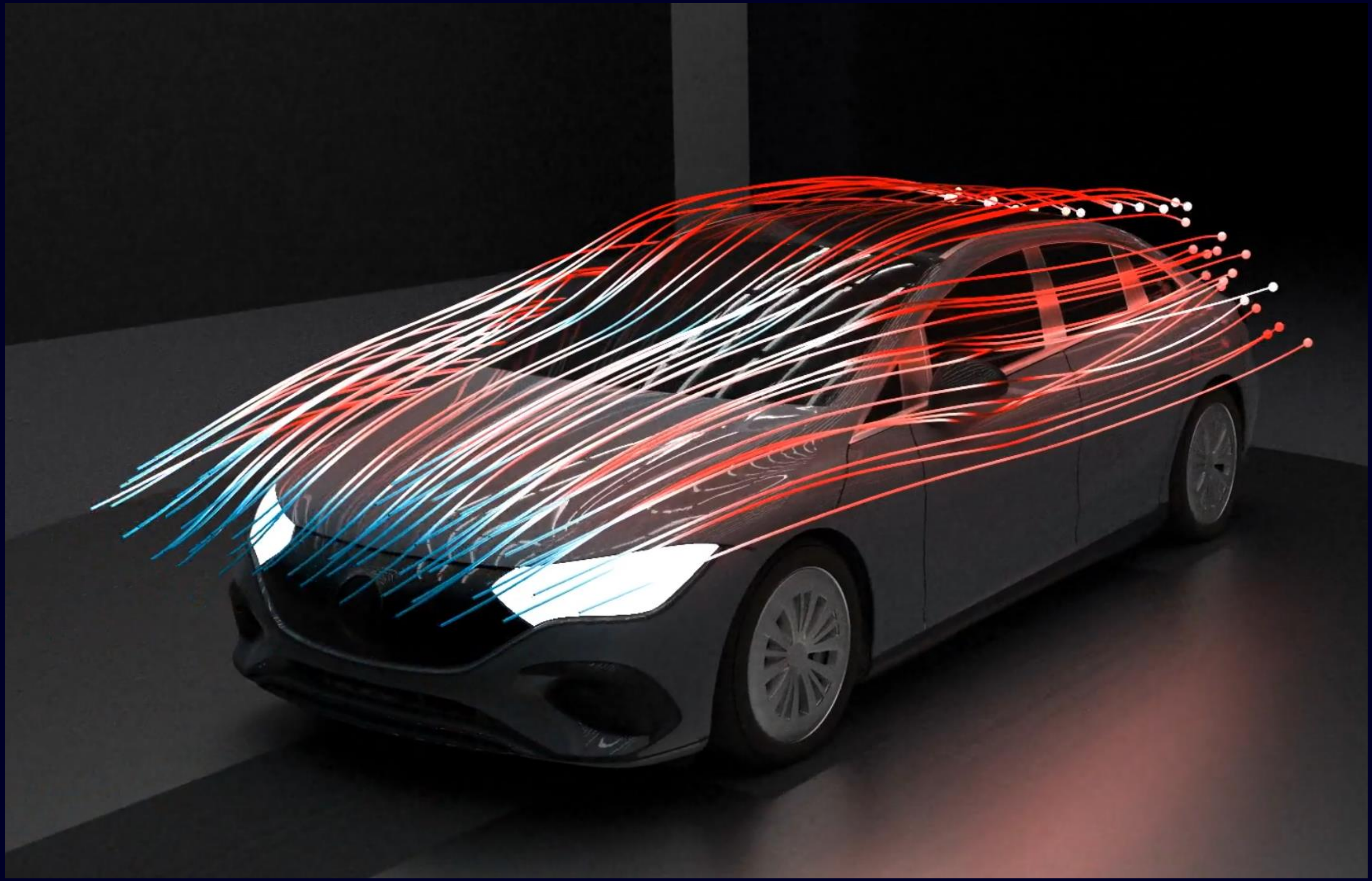
Accelerated Growth
BEVs are now 21% of sales in China

Regulations
2035 ICE banned in EU & many US states

Market Saturation
By 2025, 74 different EV models in North America

Sustainability
70% of Americans say climate change is important

To compete and stay relevant automotive companies must …



Accelerate
the development cycle while engineering
the most competitive vehicles

Maximize
performance, range, safety,
and driving pleasure

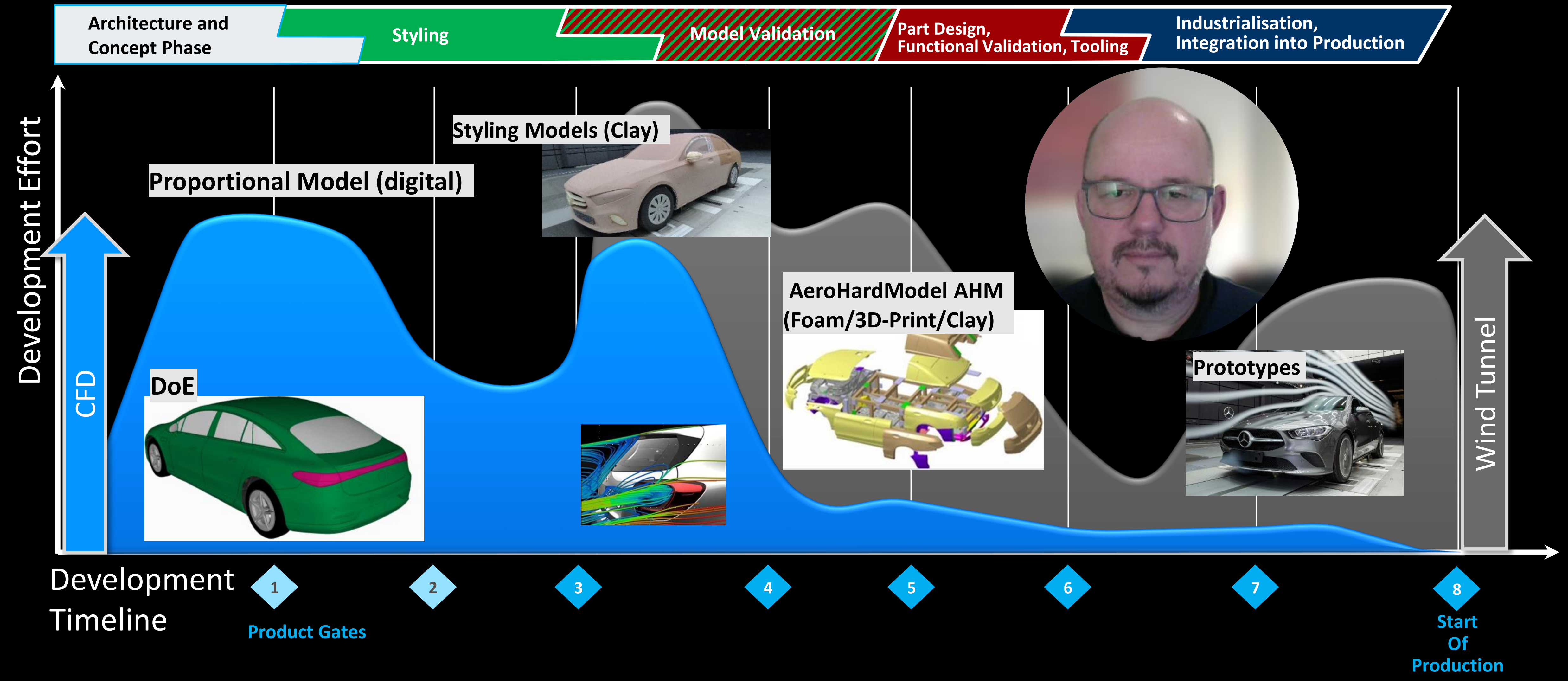
Optimize
development processes for maximum return
on invest and sustainable resource usage

Accelerating Aerodynamics Analysis

Dr. Erich Jehle-Graf

Mercedes-Benz

Aerodynamic Development Process (Drag and Lift): The early phase is 100% virtual but overall, 40% still is wind tunnel testing



Aerodynamics CFD-process (drag and lift):
GPU: Large potential for a reduction of the computational footprint

Aerodynamics CFD-process description:

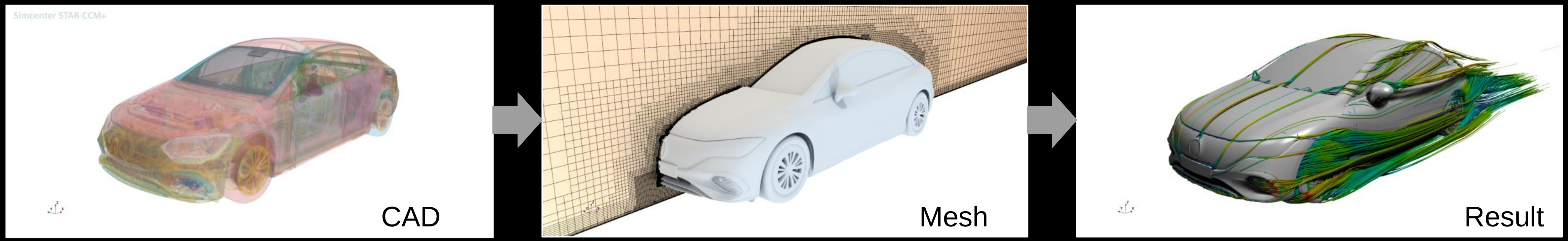
- **Geometrical input:** complete 3D CAD data → approx. 36.000 parts
- **Meshing (Simcenter STAR-CCM+):** Surface wrapping and volume meshing → 250-300 Mio. fluid cells
- **Solving (Simcenter STAR-CCM+):** Coupled iterative finite volume solver → up to 3500 iterations on 700 CPU-cores
- **Overall process time** → 5 h meshing + 5 h solving
- **Fully automated "black box" Process** → 50+ Users, including test engineers

Overall computational effort for one car model:

Up to 300 single model runs + full model DOE's → in the order of 1000 simulations per car model

→ Over 3 Mio. CPU(core)-hours over one car development cycle

Fully automated aero-CFD-process:

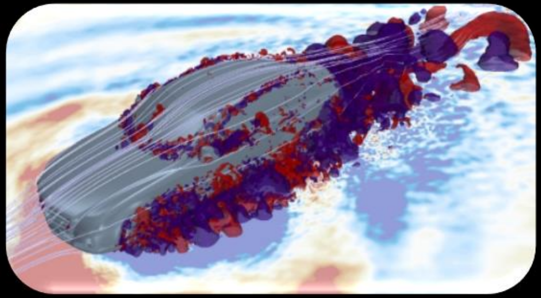


To be at the forefront of the BEV revolution, interior noise comfort is an important factor for customer satisfaction.

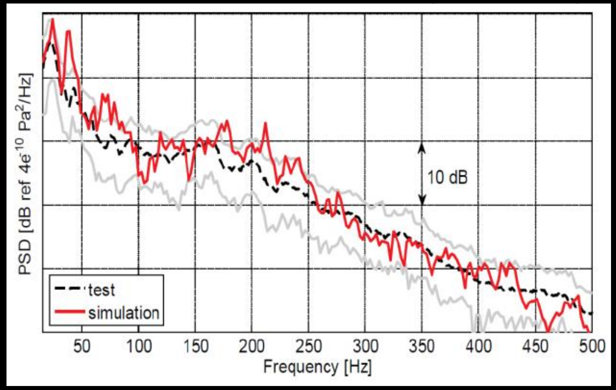
Mercedes-Benz claims to lead in
passenger car comfort with a low interior noise level

In early stages of development, no physical hardware is available for interior noise measurements

But early production prototypes arrive too late to have a significant impact on development



Today, reliable and highly precise aeroacoustics simulations are available



Immense computing power required (several weeks on HPC CPUs)

To enable future optimization processes, turn around times must be significantly shortened

While posing huge opportunities such simulations come at a price...

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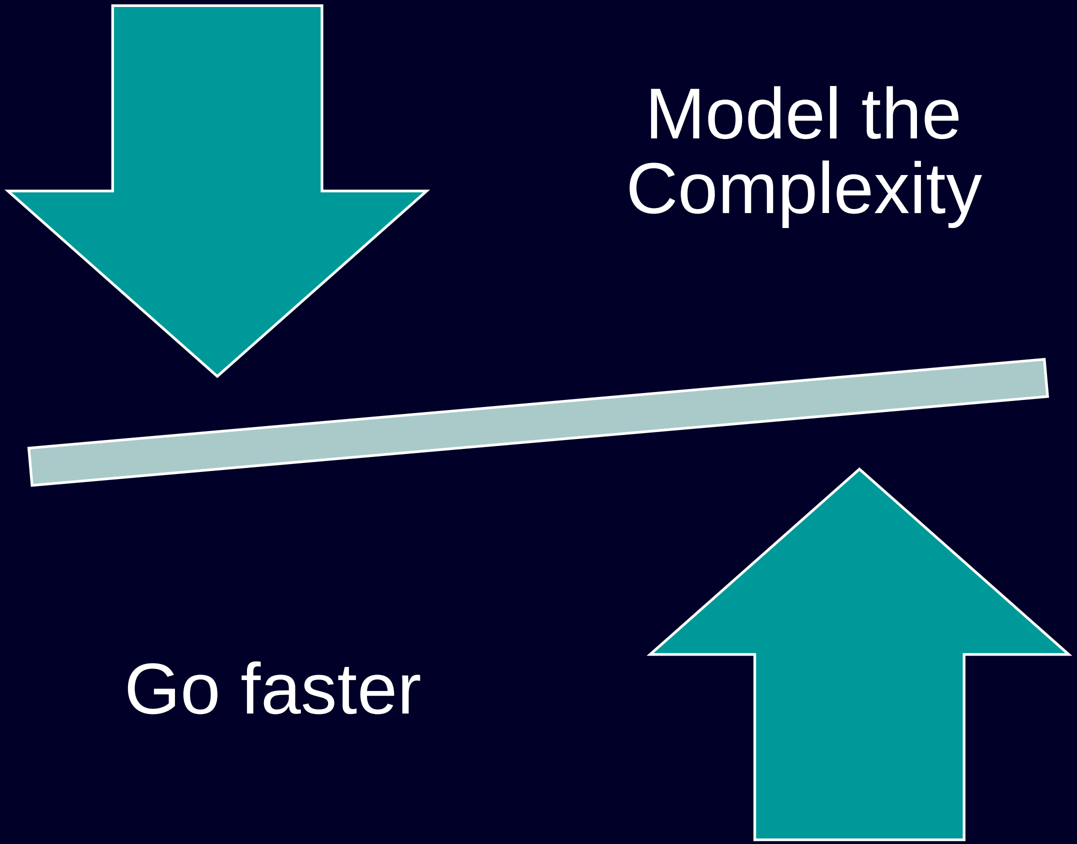
The automotive simulation engineering challenge

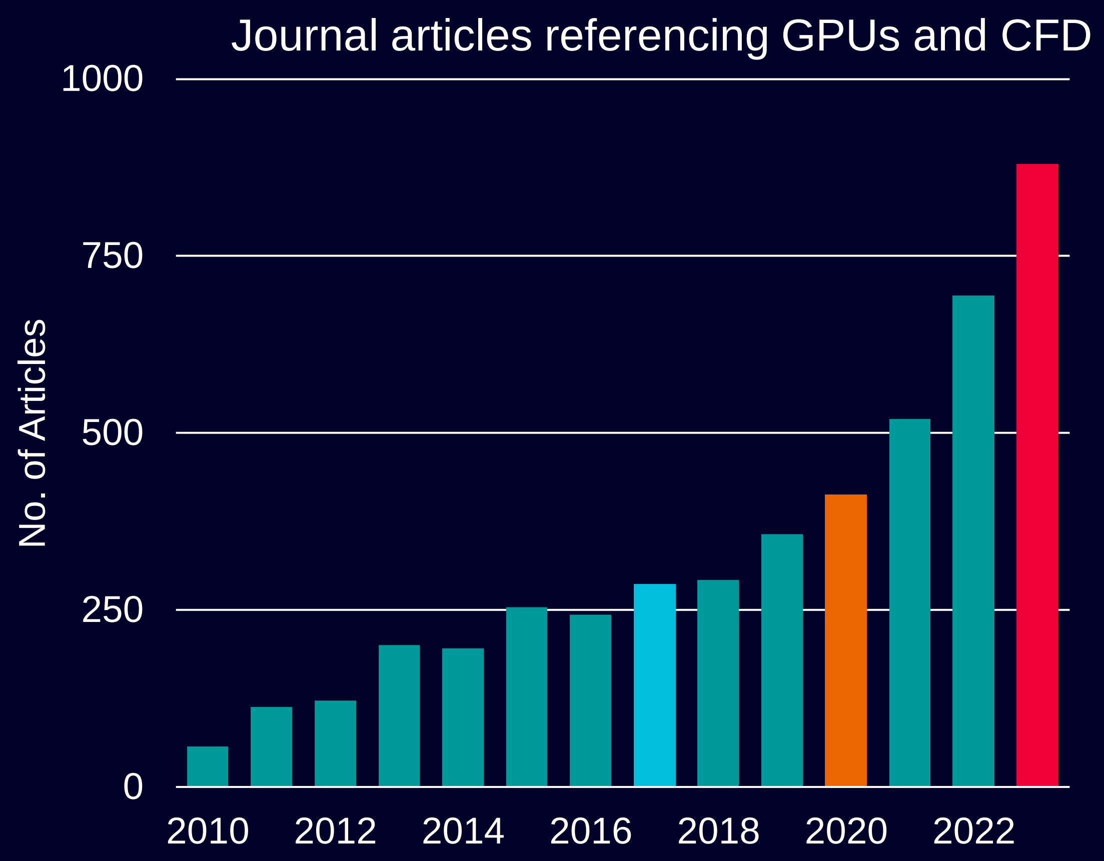
Engineers must model the complexity...



...while going faster

The GPU revolution for CFD has truly arrived

The arrival of widespread GPU usage for CFD



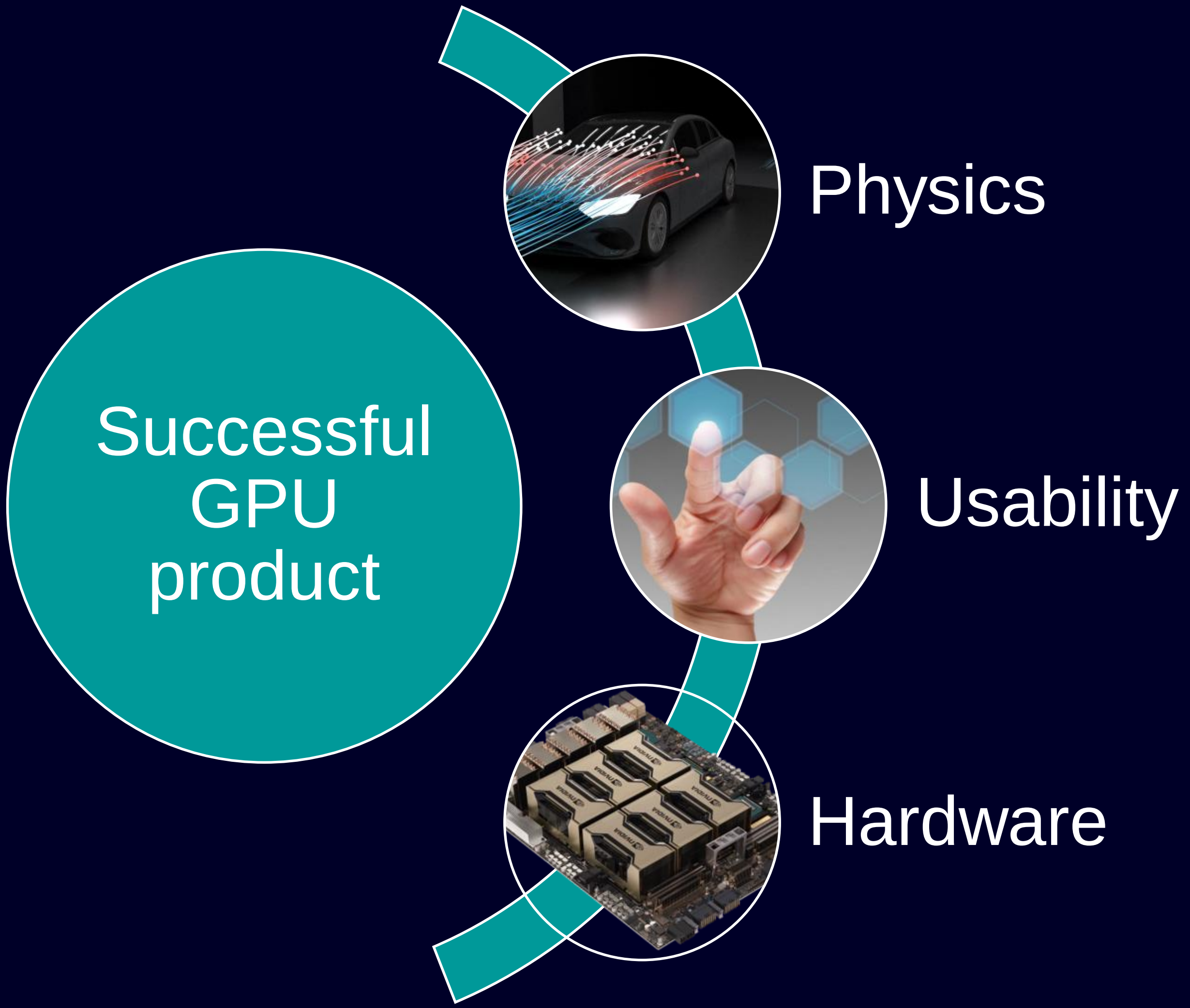
V100:
- Released 2017
- 80 SMs (Streaming Multiprocessors)
- 32GB HBM2 memory

A100:
- Released 2020
- 108 SMs
- 80GB HBM2e memory

H100:
- Released 2023
- 114 SMs
- 80GB HBM3 memory

H200:
- Released 2024
- 141GB HBM3e memory

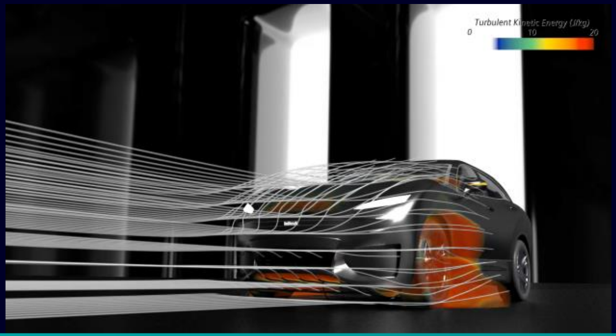
Simcenter STAR-CCM+: Building a production ready GPU-native CFD code



Simcenter STAR-CCM+: Building a production ready GPU-native CFD code
Application focussed approach

Go faster

Model the complexity



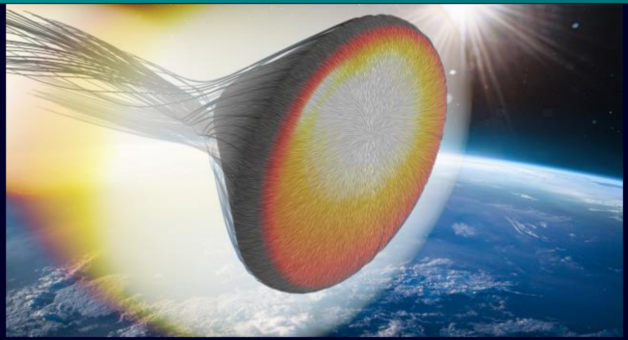
2022.1
Unsteady Vehicle Aerodynamics

2210
Aeroacoustics
High Fidelity Aerodynamics
Heat Transfer

2306
Steady Aerodynamics
Industrial Combustion
Gas Turbine Aerodynamics

2310
Hypersonic Aerodynamics
Gas Turbine Heat Transfer

2402
Multi-timescale heat transfer



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Simcenter STAR-CCM+: Building a production ready GPU-native CFD code
Unified codebase

```
template <class Var_t>
void
GaussGradientEquation<Var_t>::
accumulateGrad(FvRegion const &region, bool const &useRecon) const
{
  Field <GradVar<Var_t >, FaceCell>             gradPhi(region, this->gradVar());
  Field <Var_t      const, FaceCellRecon<3> >     phi_f(region, useRecon, this->var());
  Field <Var_t      const, FaceCell>              phi_c(region, this->var());
  Field <Volume     const, FaceCell>            vol     (region);
  Field <Area<3>    const, Face>                A       (region);

  FieldLoop_begin(f, FaceCellRecon<3>, region)
  {
    Real const phi_av = (vol[f](1)*phi_f[f](0)
                        +
                          vol[f](0)*phi_f[f](1))/vol[f].sum();

    gradPhi[f](0) += (phi_av - phi_c[f](0))*A[f];
    gradPhi[f](1) -= (phi_av - phi_c[f](1))*A[f];
  }
  FieldLoop_end();
}
```


```
template <class Var_t>
void
GaussGradientEquation<Var_t>::
accumulateGrad(FvRegion const &region, bool const &useRecon) const
{
  Field <GradVar<Var_t >, FaceCell>             gradPhi(region, this->gradVar());
  Field <Var_t      const, FaceCellRecon<3> >     phi_f(region, useRecon, this->var());
  Field <Var_t      const, FaceCell>              phi_c(region, this->var());
  Field <Volume     const, FaceCell>            vol     (region);
  Field <Area<3>    const, Face>                A       (region);

  FieldLoop_begin(f, FaceCellRecon<3>, region)
  {
    Real const phi_av = (vol[f](1)*phi_f[f](0)
                        +
                          vol[f](0)*phi_f[f](1))/vol[f].sum();

    gradPhi[f](0) += (phi_av - phi_c[f](0))*A[f];
    gradPhi[f](1) -= (phi_av - phi_c[f](1))*A[f];
  }
  FieldLoop_end();
}
```


CPU

GPU

Accelerated Aerodynamics and Aeroacoustics - Mercedes EQE

Simcenter STAR-CCM+ on NVIDIA GPUs

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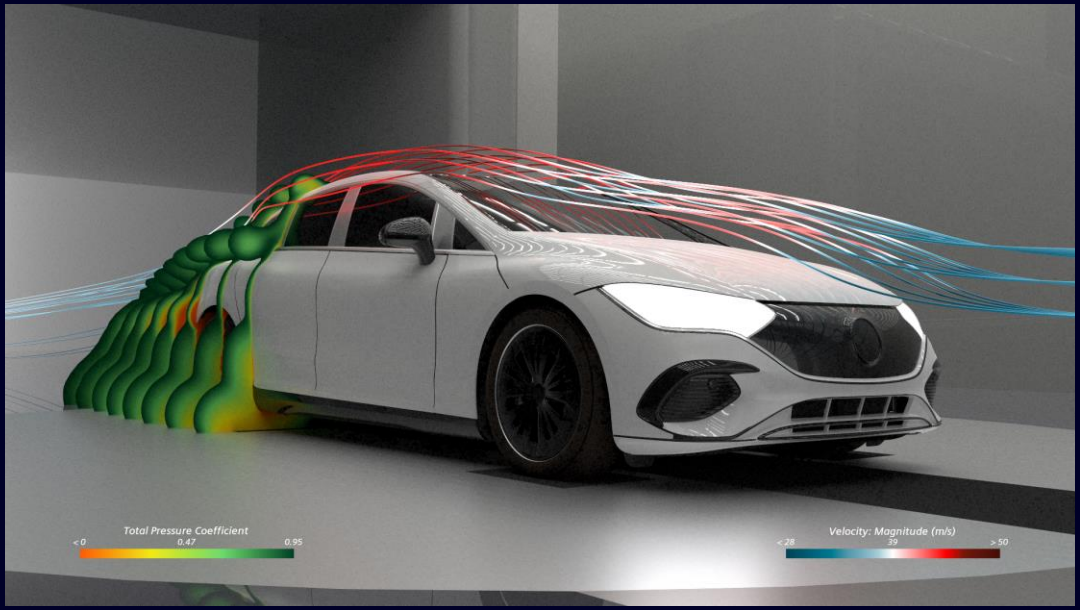
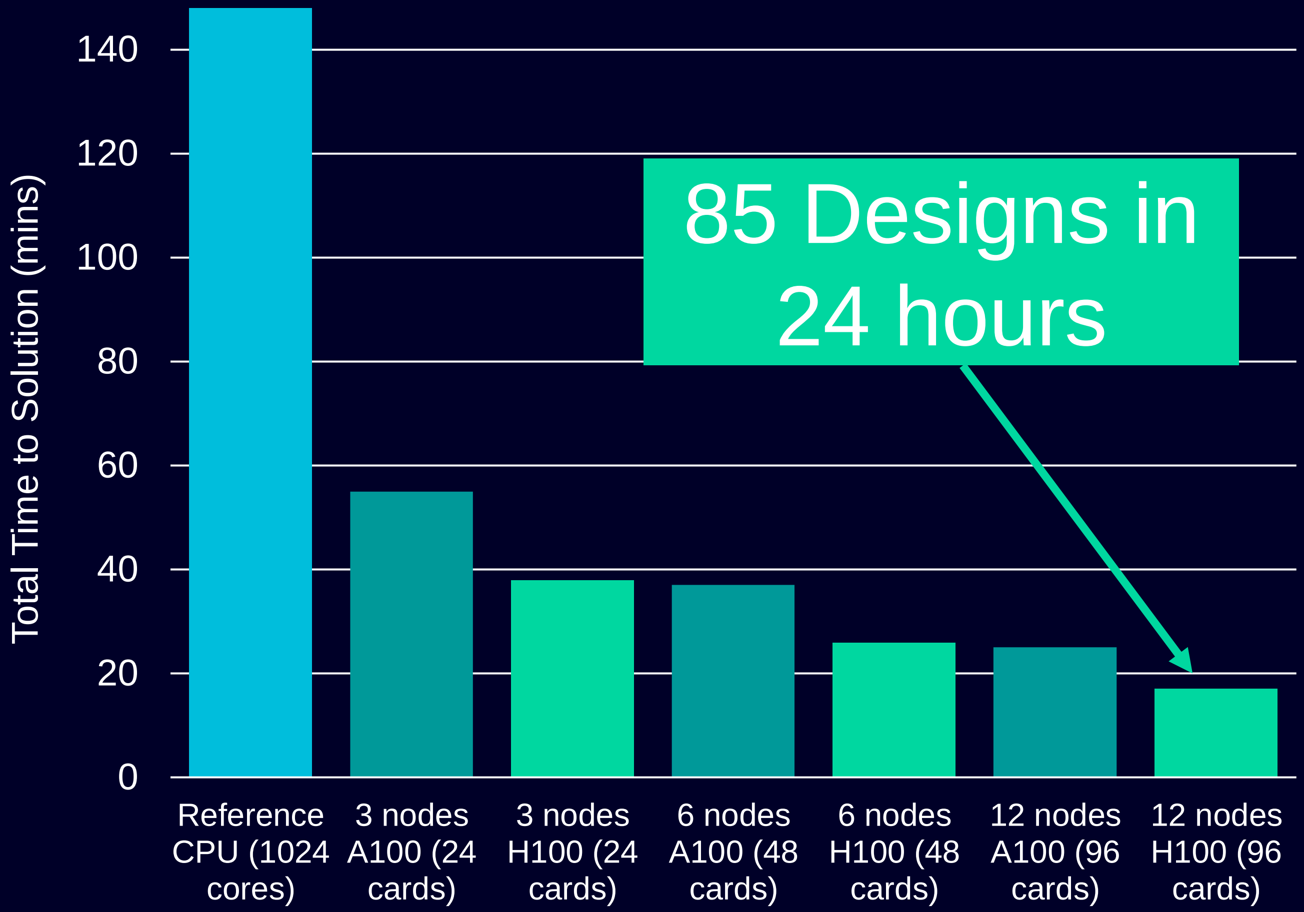
Accelerated Aerodynamics
Mercedes EQE





CPU: 32 core dual socket, 2.4GHz clock speed, 256MB L3 cache

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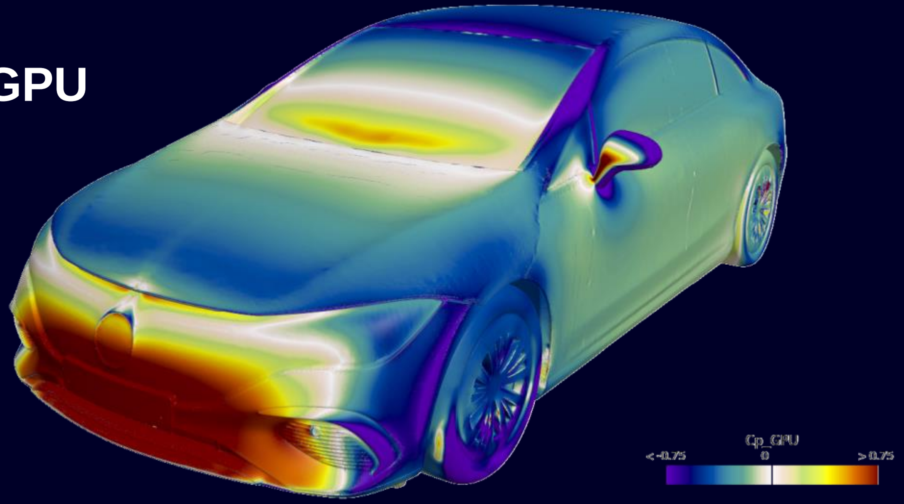
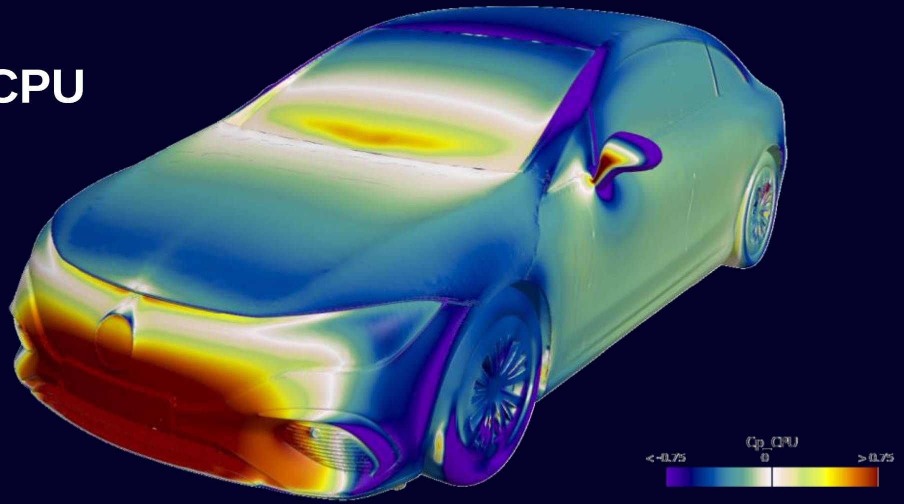
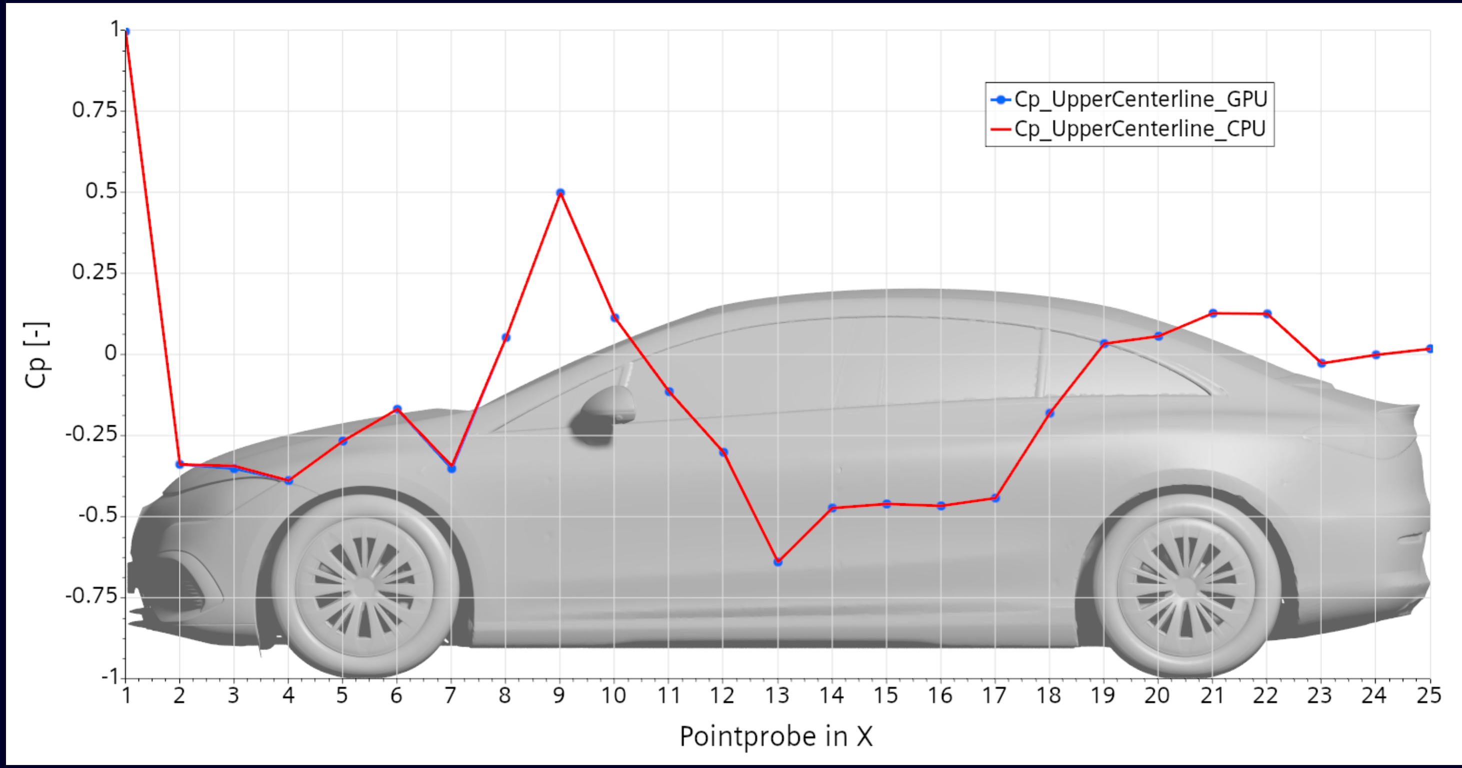
Accelerated Aerodynamics
Mercedes EQE – Results Consistency

GPU



CPU





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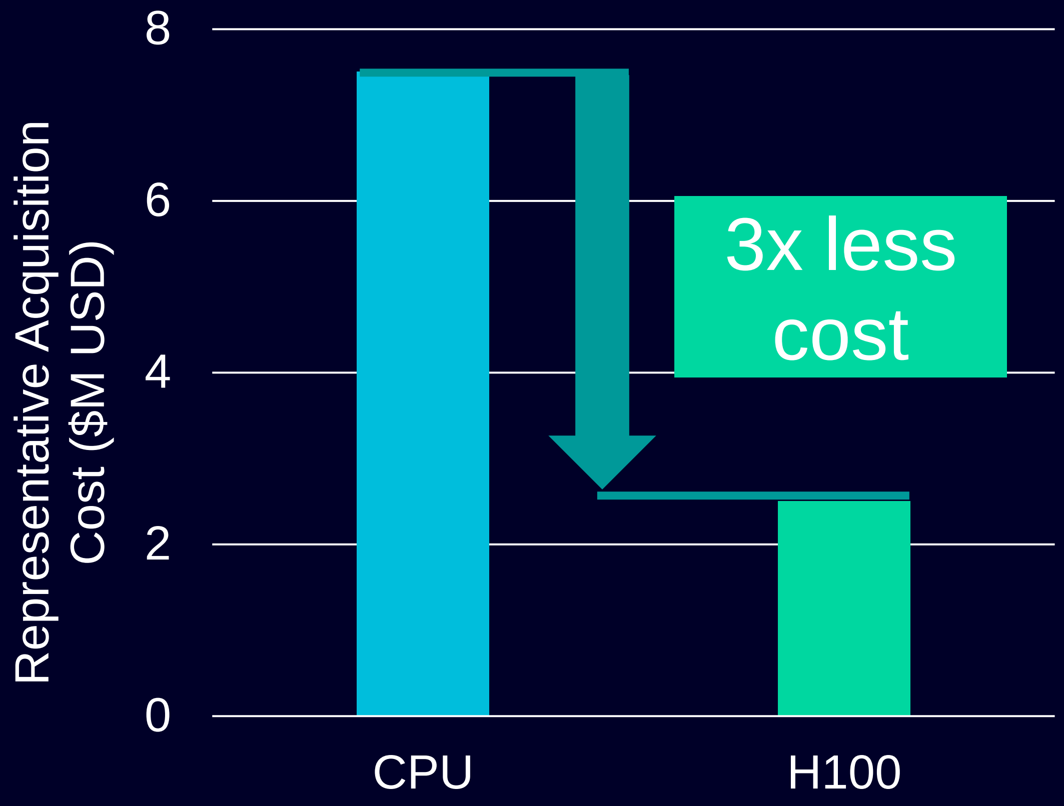
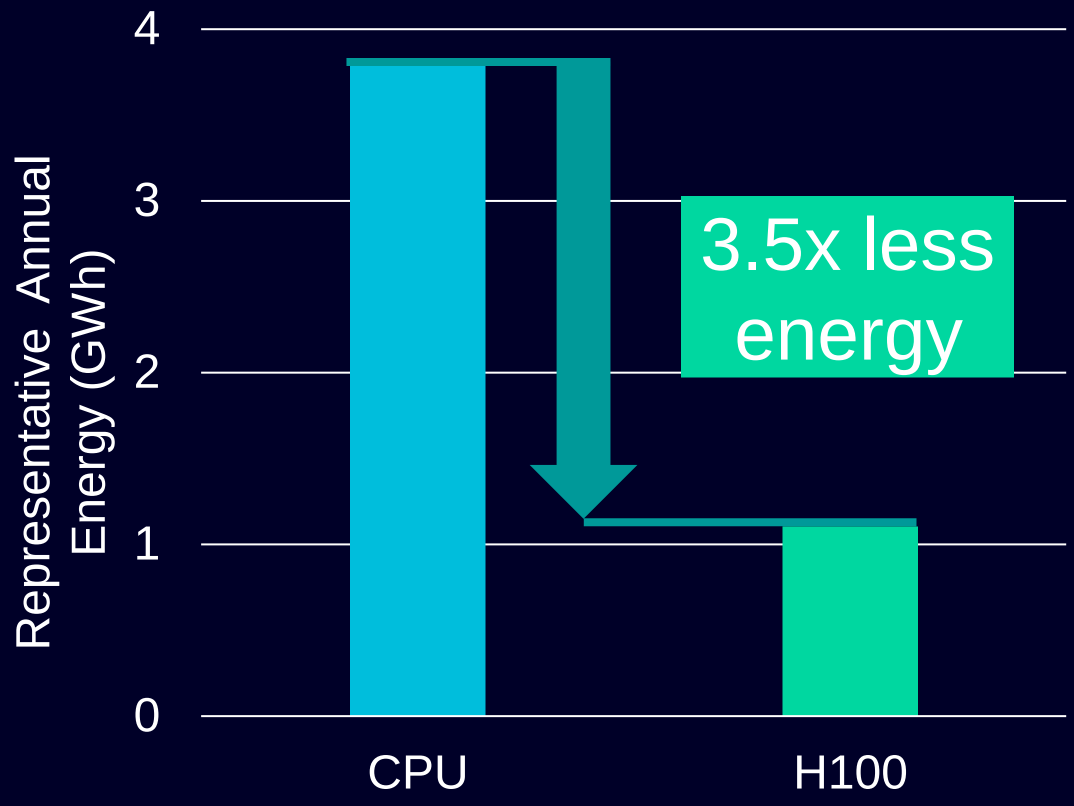
Accelerated Aerodynamics
Estimated savings





Cost estimates using NVIDIA pricing, energy estimates using listed TDP values of each configuration

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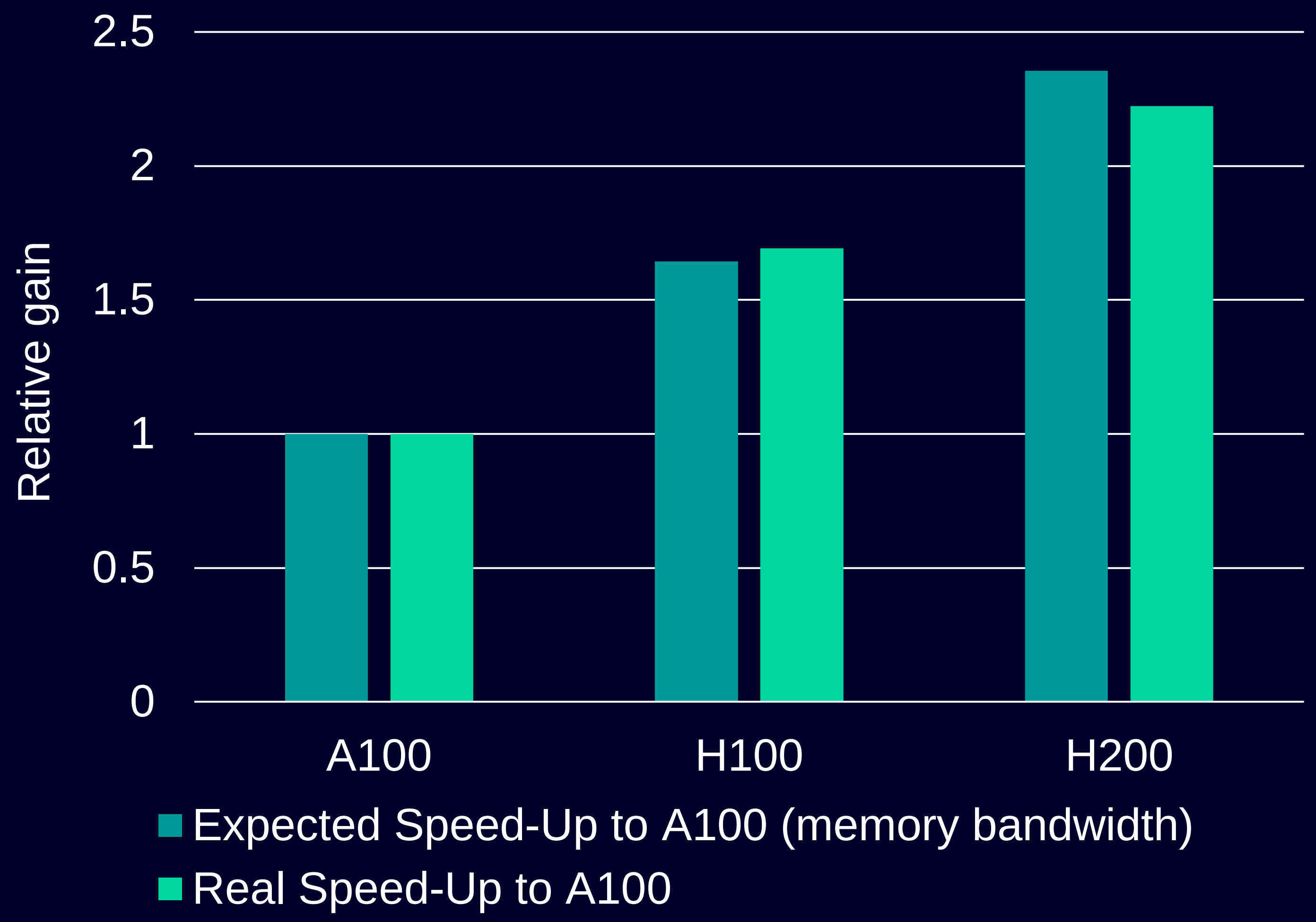
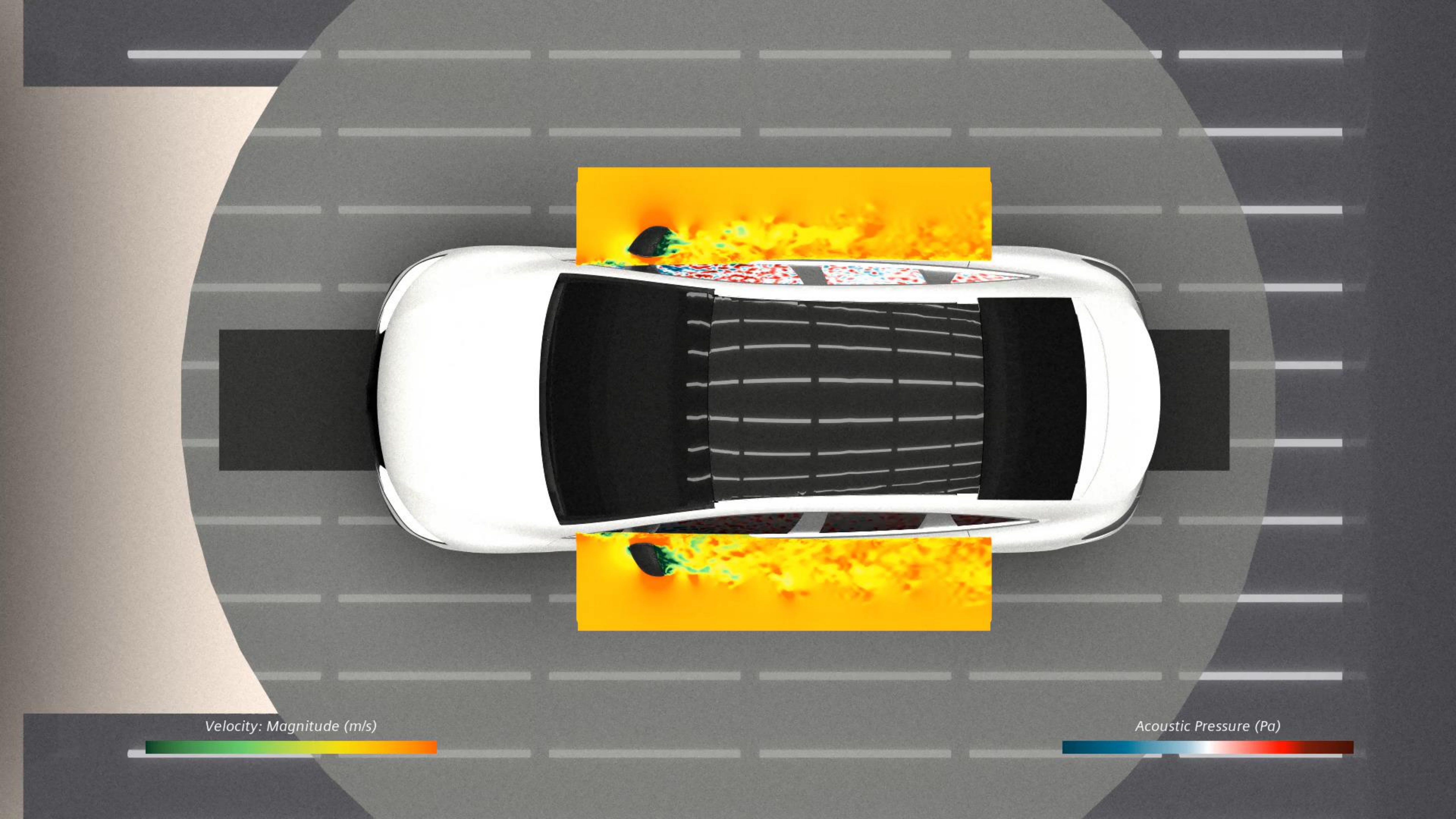
Accelerated Aerodynamics

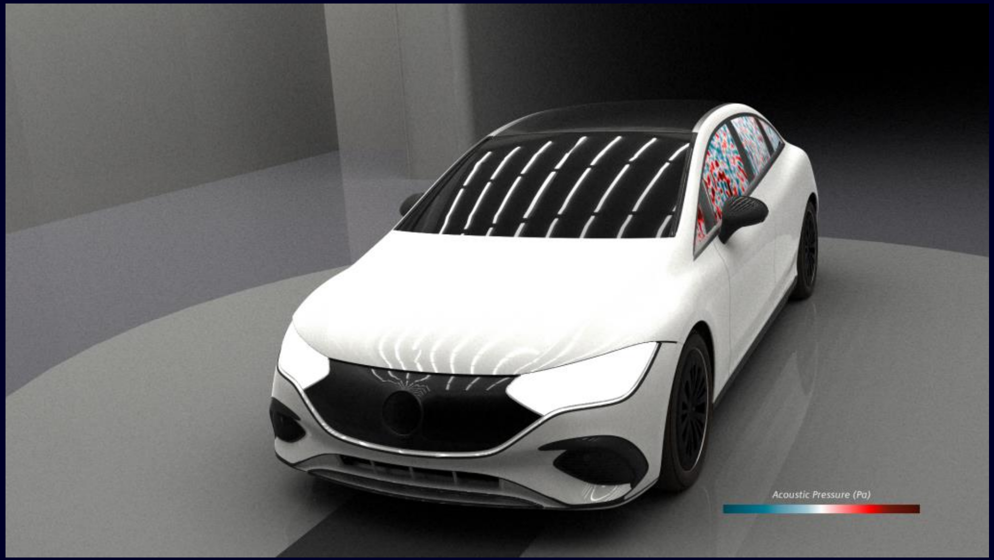
Hardware generational comparison – single node 115M cells

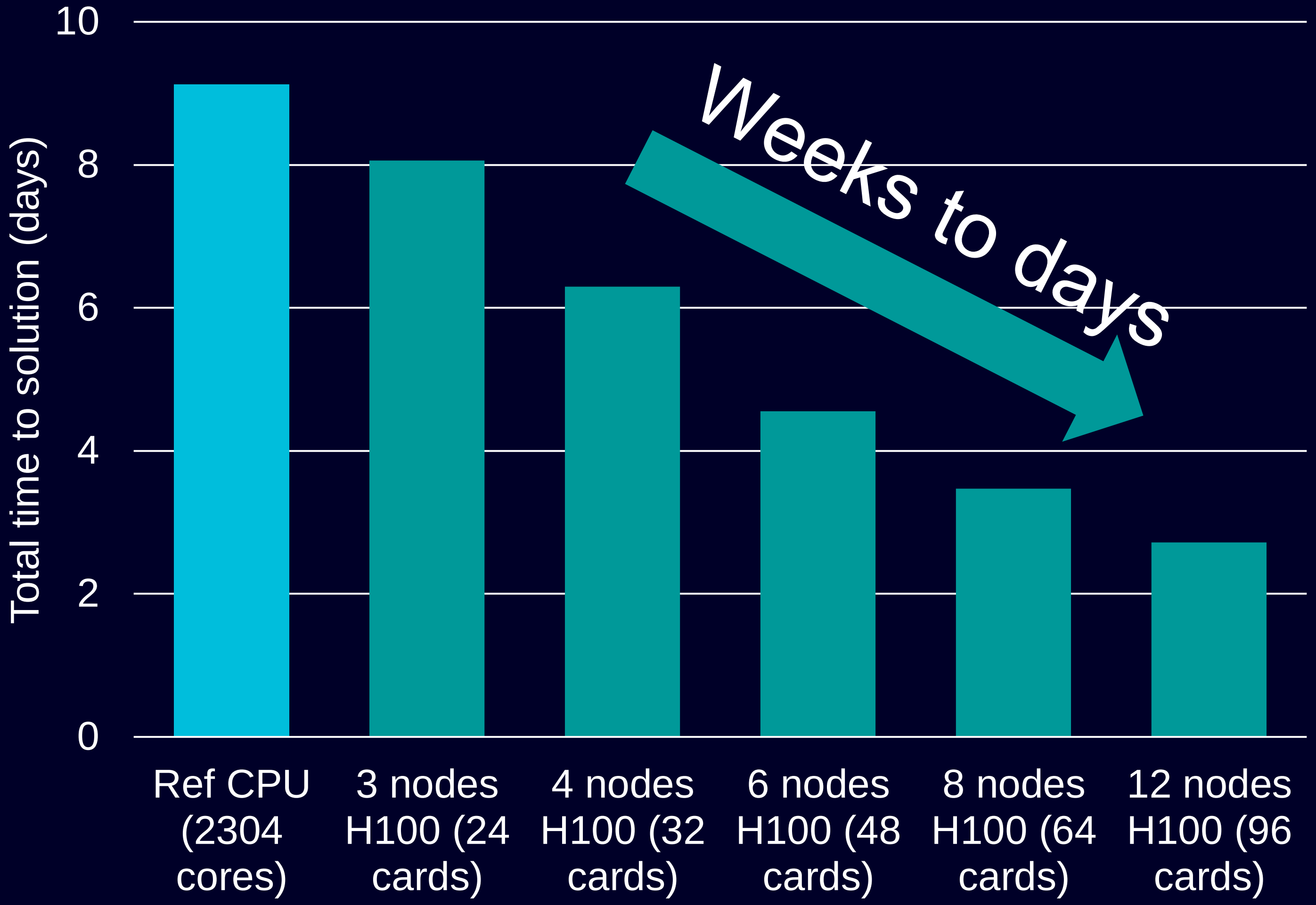


GPU (SXM)	Memory (GB)	Memory Bandwidth (TB/s)
A100	80 (HBM2e)	2.04
H100	80 (HBM3)	3.35
H200	**141 (HBM3e)**	**4.50**


Velocity: Magnitude (m/s)
Acoustic Pressure (Pa)

Accelerated Aeroacoustics
Mercedes EQE





Total time to solution estimated assuming 50,000 timesteps per simulation based on 100 timesteps sampled data

CPU: 32 core dual socket, 2.8GHz clock speed, 256MB L3 cache

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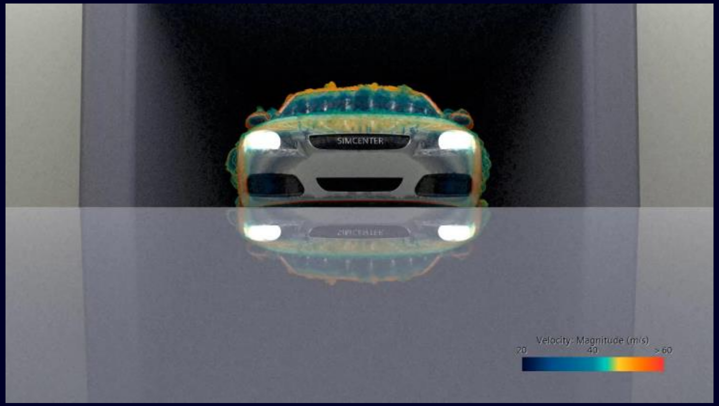
Simulation and a comprehensive digital twin is the key enabler

Aerodynamics

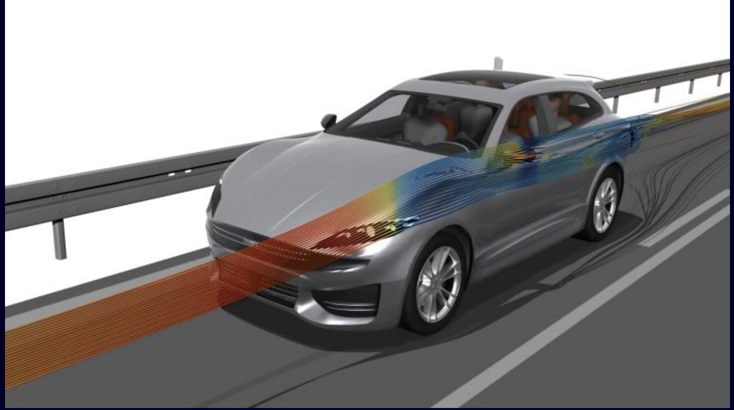


Aeroacoustics

Thermal Management

Water Management

Cabin Comfort



E-Powertrain

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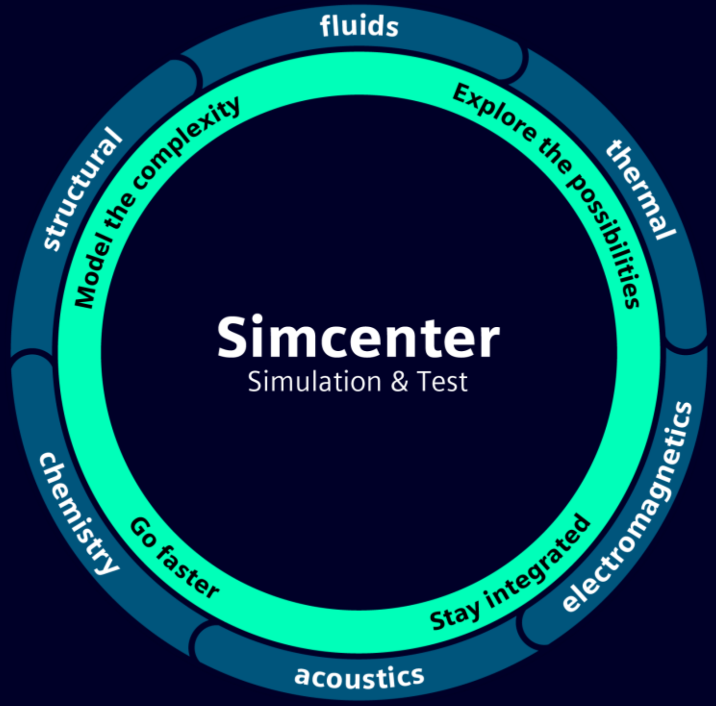
Transform Engineering
Drive productivity, empower innovation

Production ready
Mercedes EQE aerodynamics and aeroacoustics

Cost & energy efficient
Upto 3x cost reduction and 4x energy reduction

Go faster
Increasing throughput – 85 designs in 24h

Consistency
Simcenter STAR-CCM+ - hardware agnostic



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Contact

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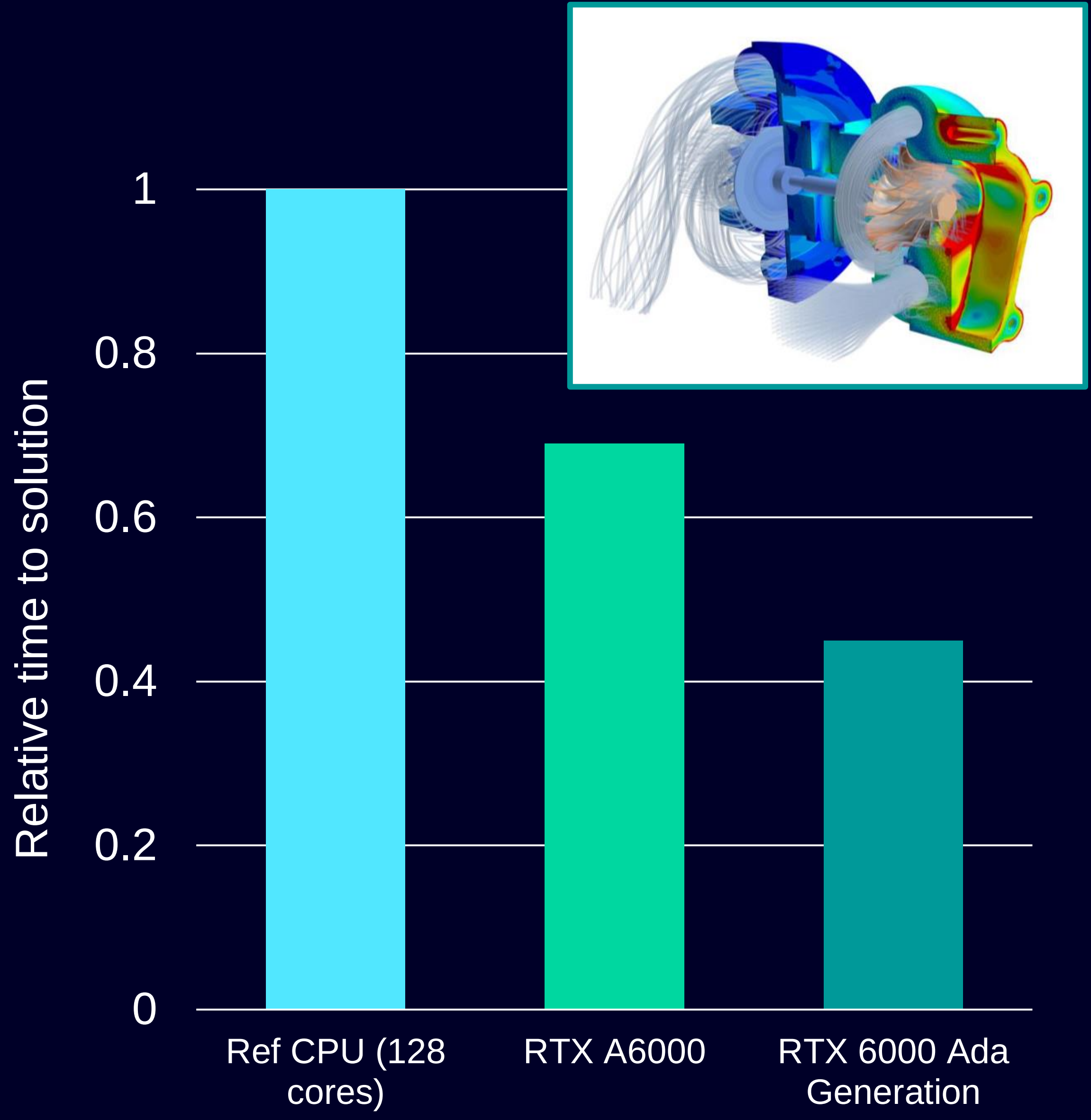
Back-up slides

Component level analysis
Don’t forget the workstation GPUs!

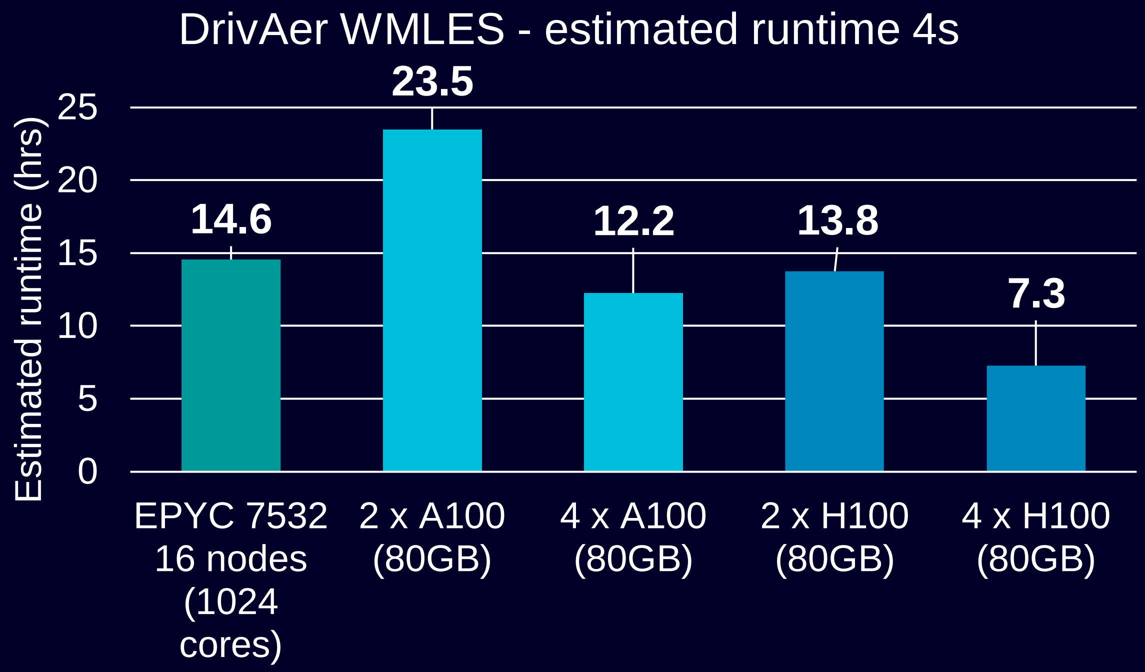
GPU	RAM (GB)	Estimated maximum no. of cells	
		Segregated	Coupled
Quadro RTX4000	8	6.4M	3.2M
Quadro RTX6000	24	19M	9.6M
RTX A6000 / RTX 6000 Ada Generation	48	38M	19.2M

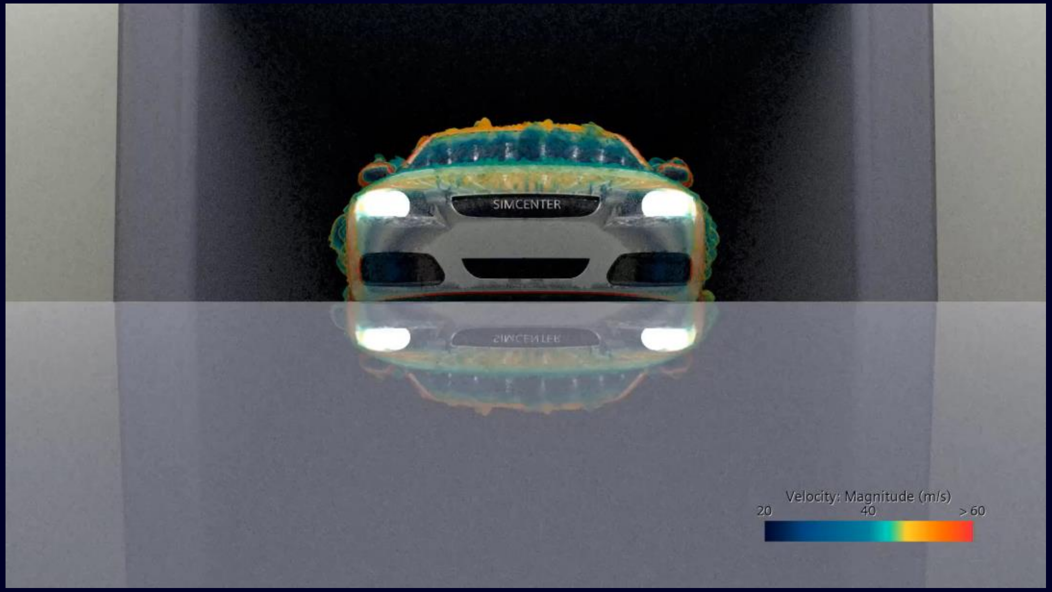


GPUs for Simulation
Example application: Wall-Modeled LES with H100s

H100 GPUs are supported from Simcenter STAR-CCM+ 2302

- Latest HPC GPU card available from NVIDIA
- Shows a good performance improvement relative to A100
- 4s modelled time in 7.3 hours on 4 x H100 cards





CPU: 16 nodes dual socket 32-Core Processor CPUs (1024 CPU cores), 2.4 GHz, 256 GB RAM per node
GPU: A100, PCIe 80GB configuration with AMD EPYC 7763, 2.45 GHz CPU. H100, SXM 80GB configuration with Intel Platinum 8380, 2.3 GHz. Simcenter STAR-CCM+ 2402