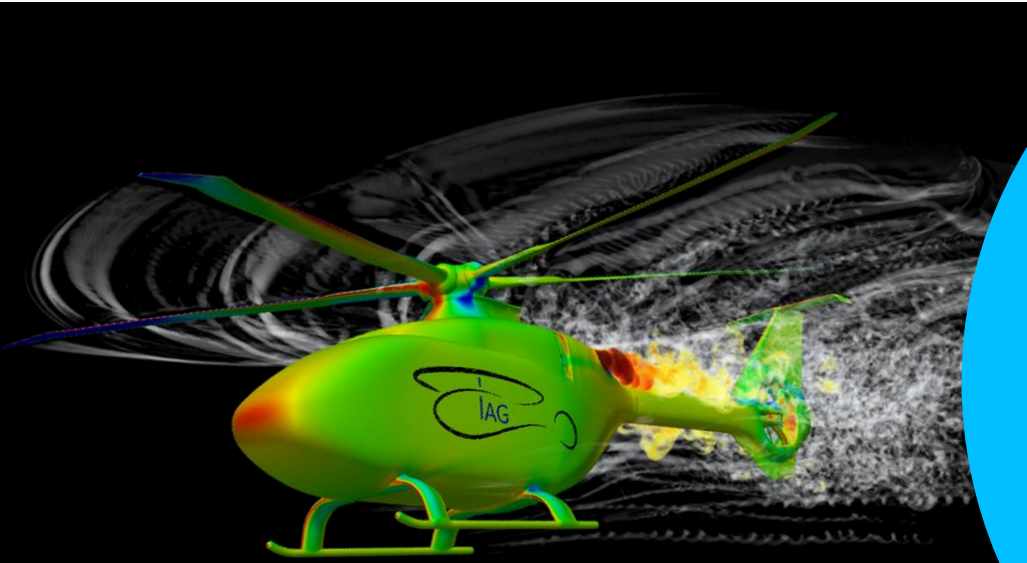
University of Stuttgart
Institute of Aerodynamics and Gas Dynamics



High-fidelity Simulation of Helicopter Flow Phenomena

– HPC aspects in advanced engineering applications

Manuel Keßler,
Johannes Letzgus, Ulrich Schäferlein

NEC HLRS Workshop on
Sustained Simulation Performance
Stuttgart, October 10th, 2017

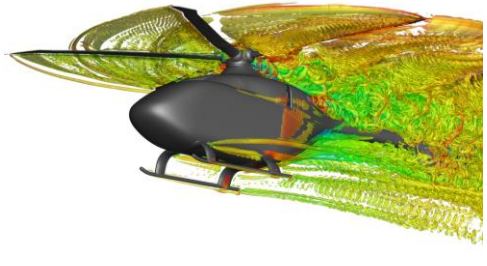
IAG

Introduction

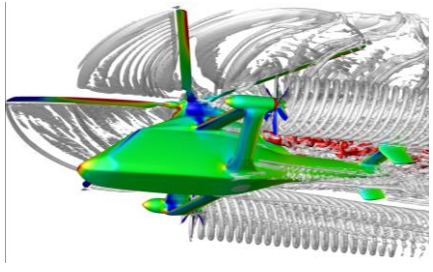
Helicopter and Aeroacoustics Group at IAG

- Aerodynamics and aeroacoustics of (compound) helicopters and contra-rotating open rotors (CROR)
- Simulations of (dynamic) stall and separated flow
- Loads, blade-vortex interactions, rotor noise, …

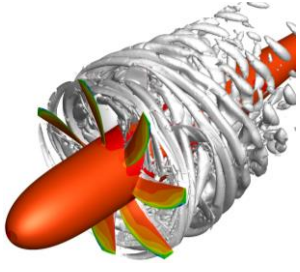
© Airbus Helicopters



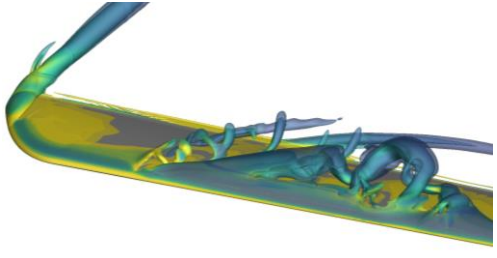
helicopter



compound helicopter



CROR



dynamic stall

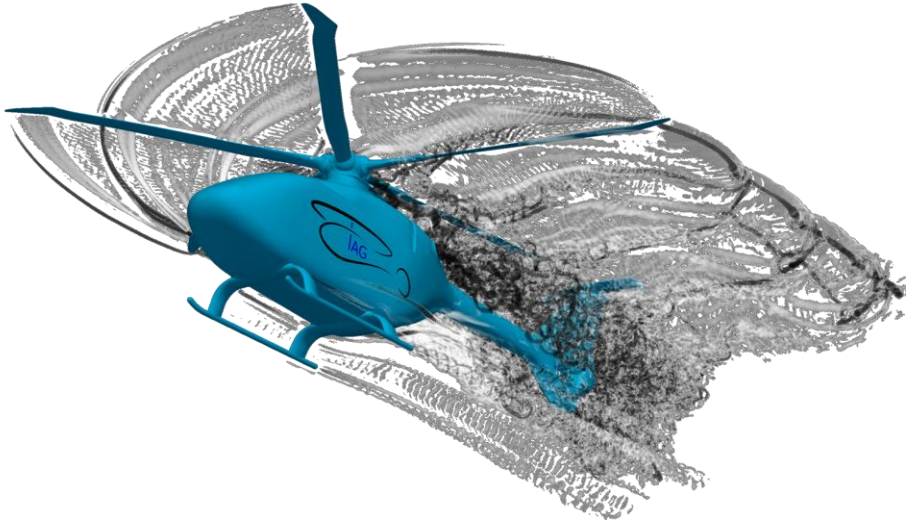
Rotorcraft Simulation

Rotorcraft Simulation

Problem setting

Rotorcraft simulation is *hard*

- Complex flow
  - Many different flow phenomena
  - Coupled and interacting components
  - Multiple scales in space and time



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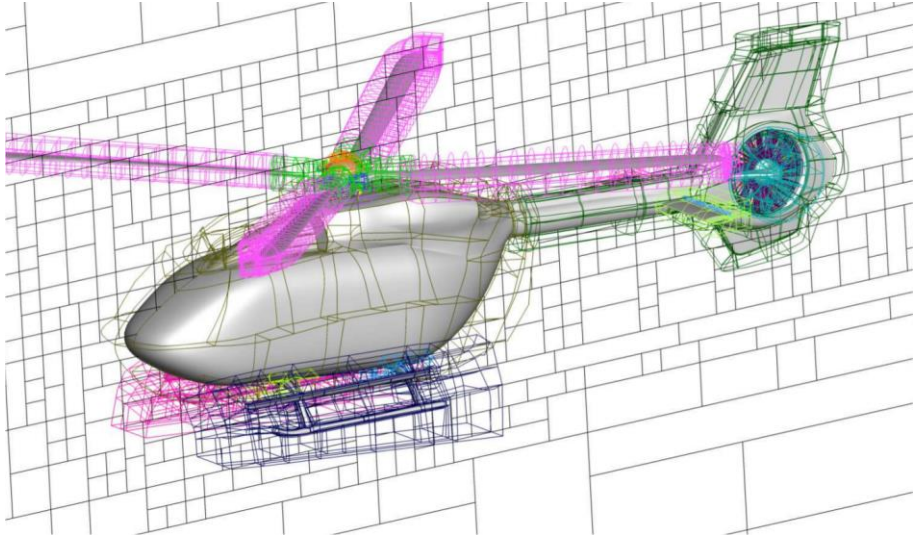

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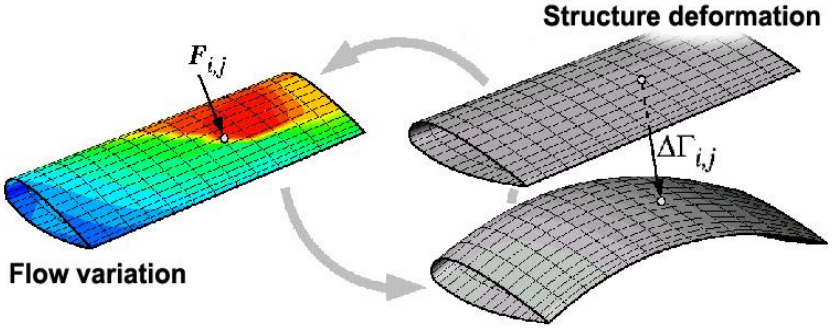
- Complex physics
  - Fluid-structure interaction



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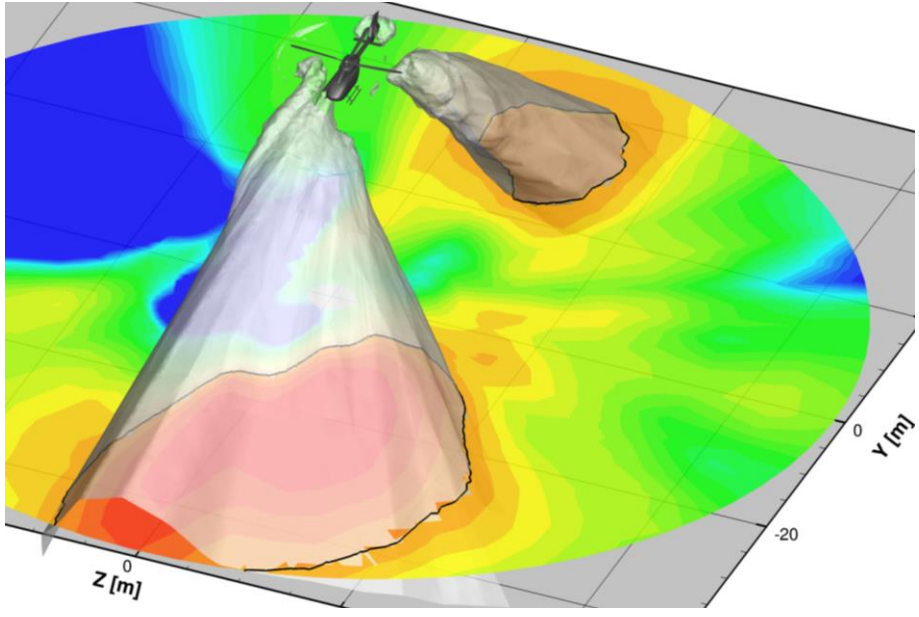

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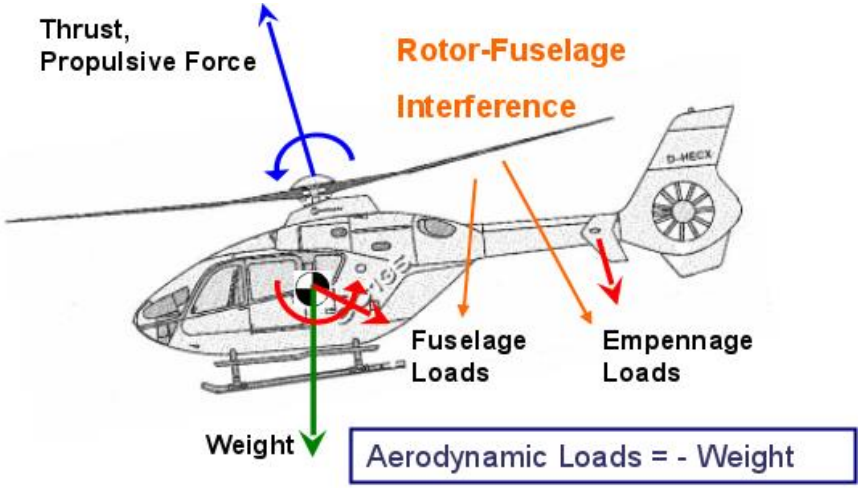
  - Acoustics
  - Free-flight trim



Rotorcraft Simulation

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- Complex flow
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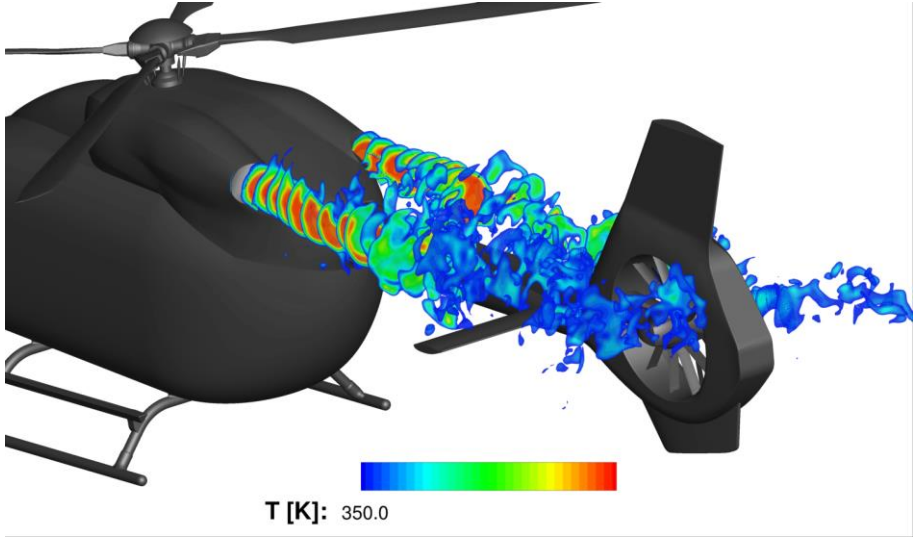
- Complex physics
  - Fluid-structure interaction
  - Acoustics
  - Free-flight trim
  - Engine flow



Rotorcraft Simulation

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  - Many different flow phenomena
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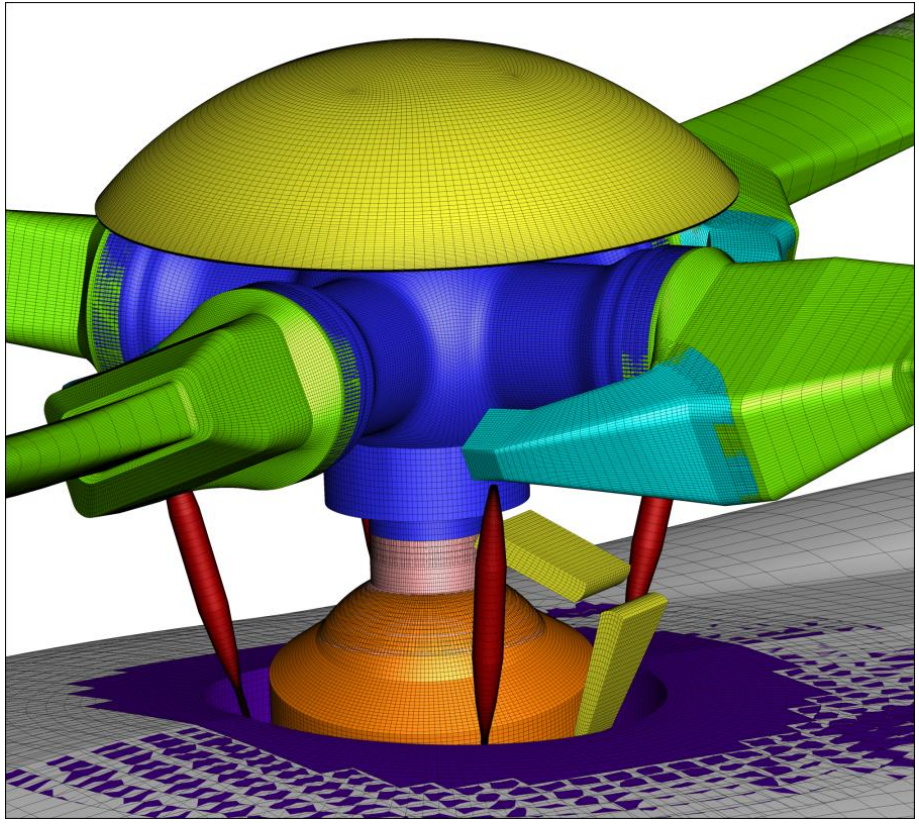
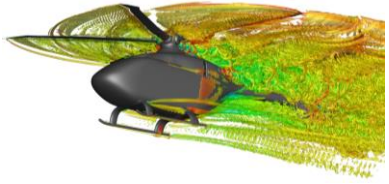
  - Acoustics
  - Free-flight trim
  - Engine flow
- Complex geometry

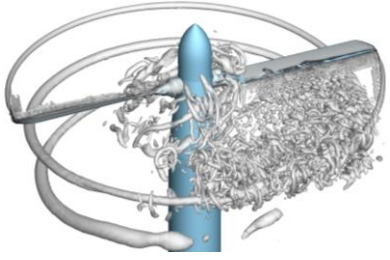


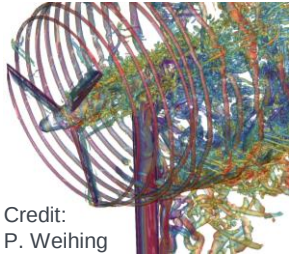
Flow Solver

CFD code FLOWer

- Developed by DLR, enhanced by IAG
- Block-structured finite volume solver
- Implicit 2nd-order dual-time stepping
- 2nd-order spatial JST or 5th order WENO scheme
- Detached-eddy simulation (DES) methods
- Optimized for HPC on Hazel Hen
  - MPI file I/O (e.g. 14 GB field solution written in 1.2 s)
  - up to 750 million grid cells using 24,000 cores





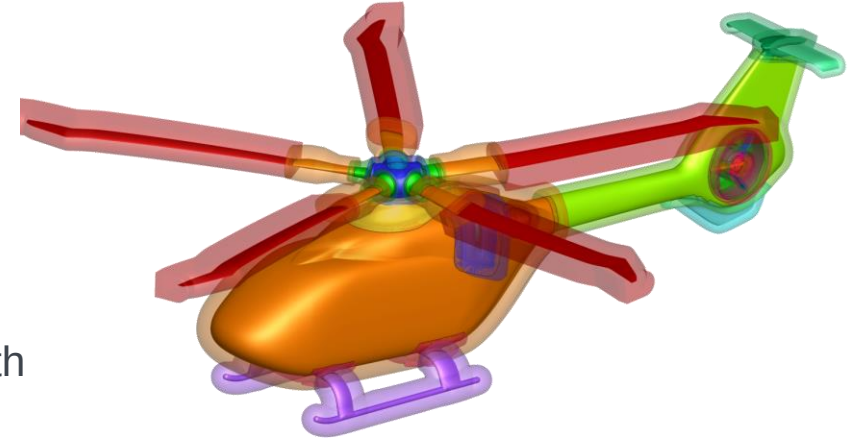


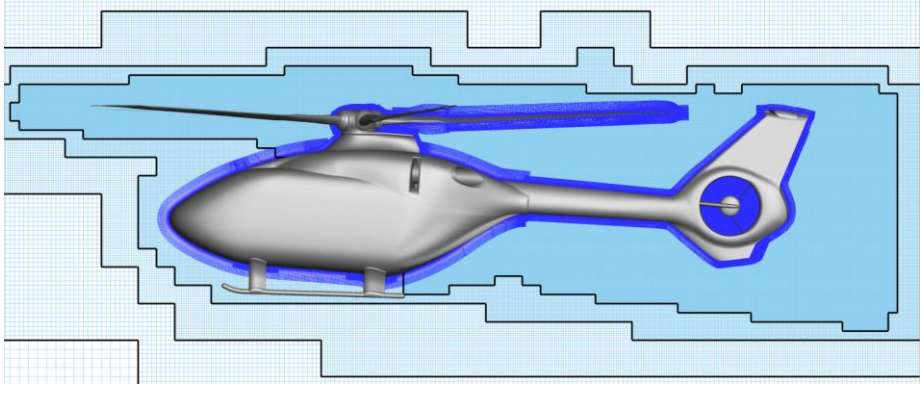
Credit:
P. Weihing

IAG-FLOWer enhancements

Grid methodology

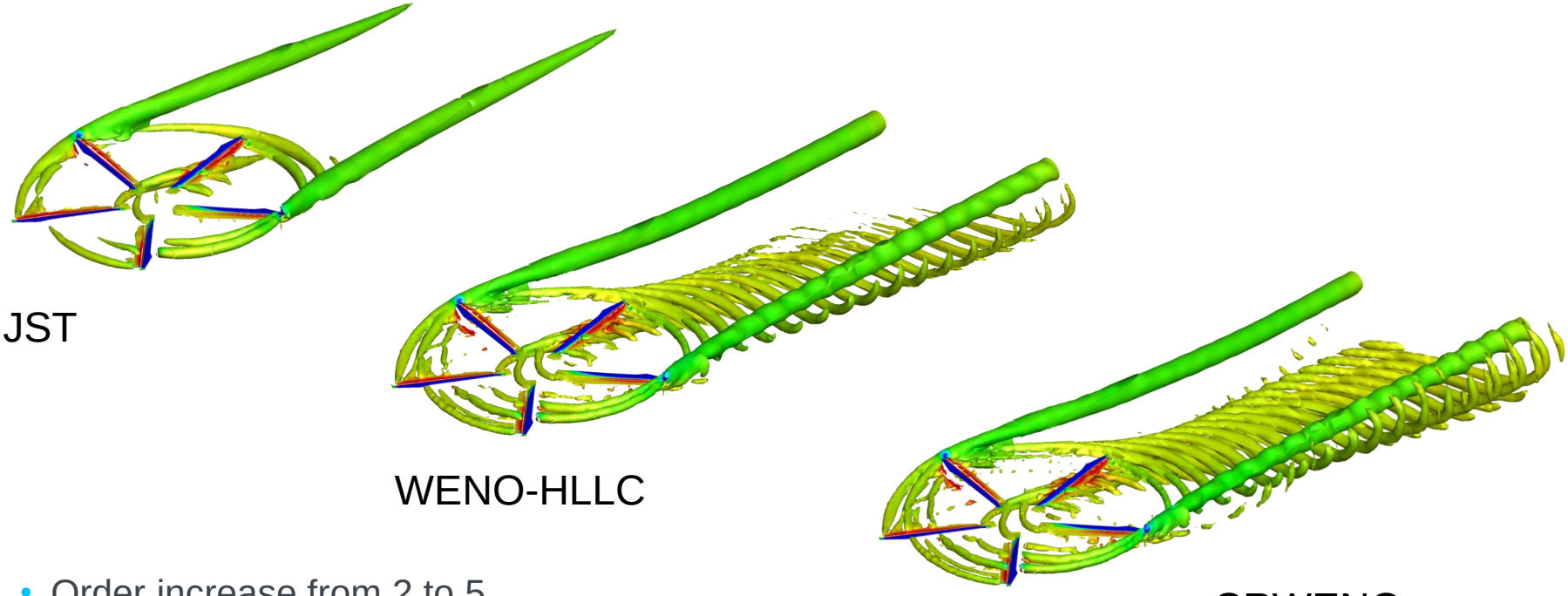
- Chimera technology of overlapping grids
- Relatively small body grids
- Automatically generated background grid with refinement specifications
  <10 min. for 10^9 cells





IAG-FLOWer enhancements

Spatial order



JST

WENO-HLLC

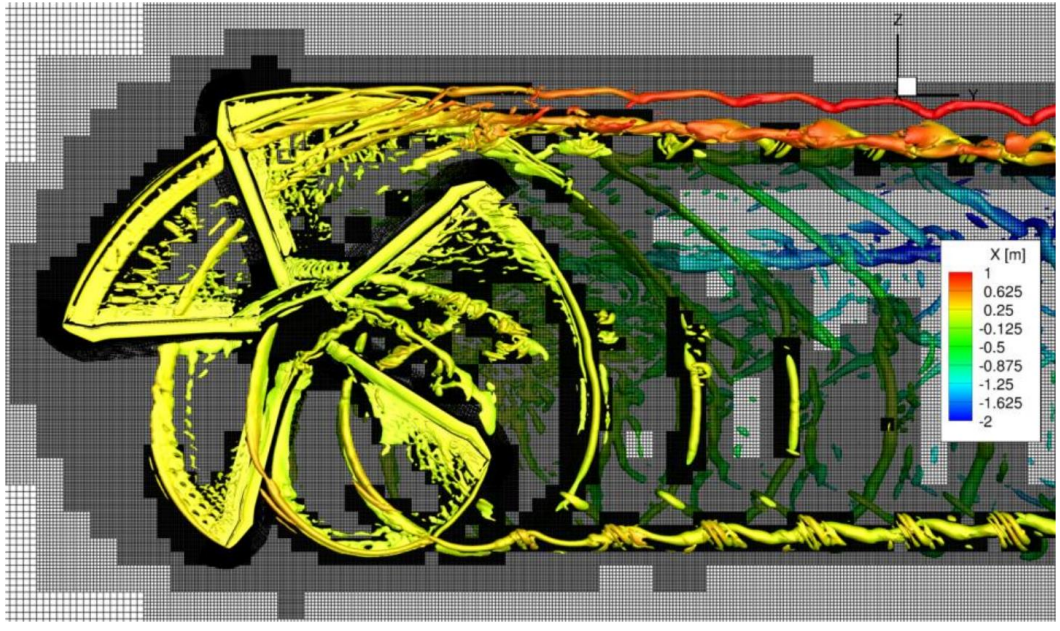
CRWENO

- Order increase from 2 to 5 significantly improves accuracy at moderate computational cost (+100%)

IAG-FLOWer enhancements

Grid refinement

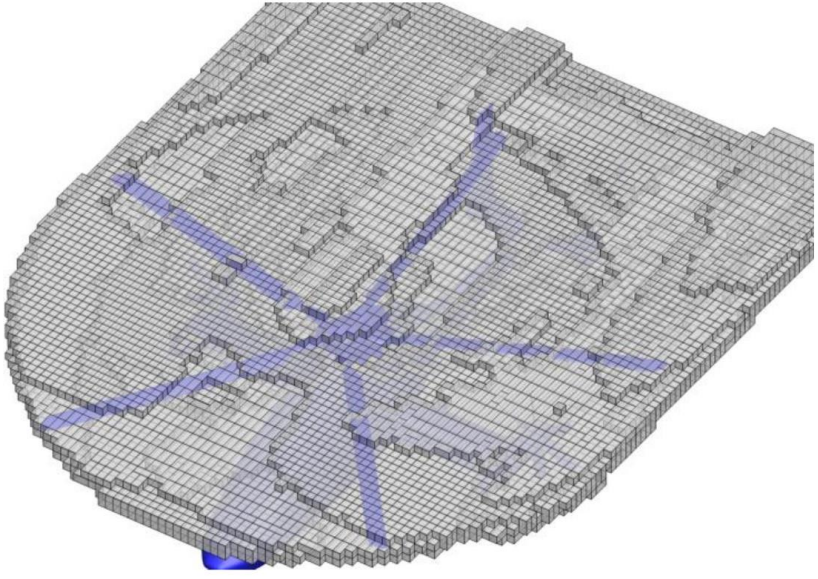
- Automatic background grid generation allows refinement based on
  - Full revolution
  - Recent solution, including temporal extrapolation
- Significant cell savings
- Increased accuracy



IAG-FLOWer enhancements

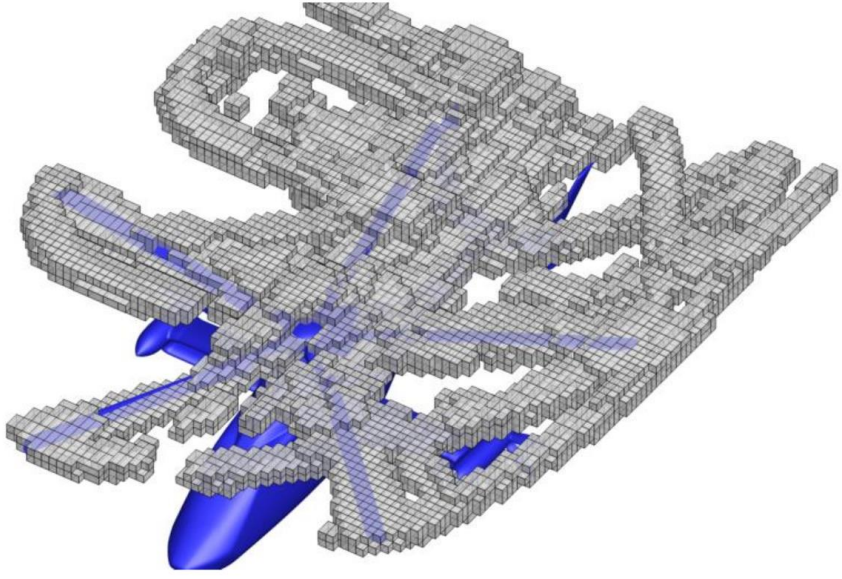
Grid refinement

- Periodic Adaptation



- 178 Mio. Cells

- Time resolved Adaptation

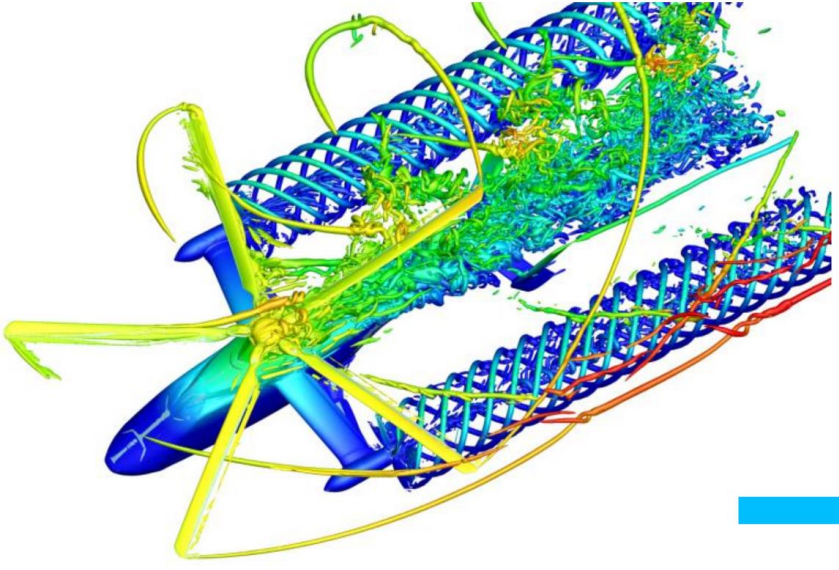


- 119 Mio. Cells

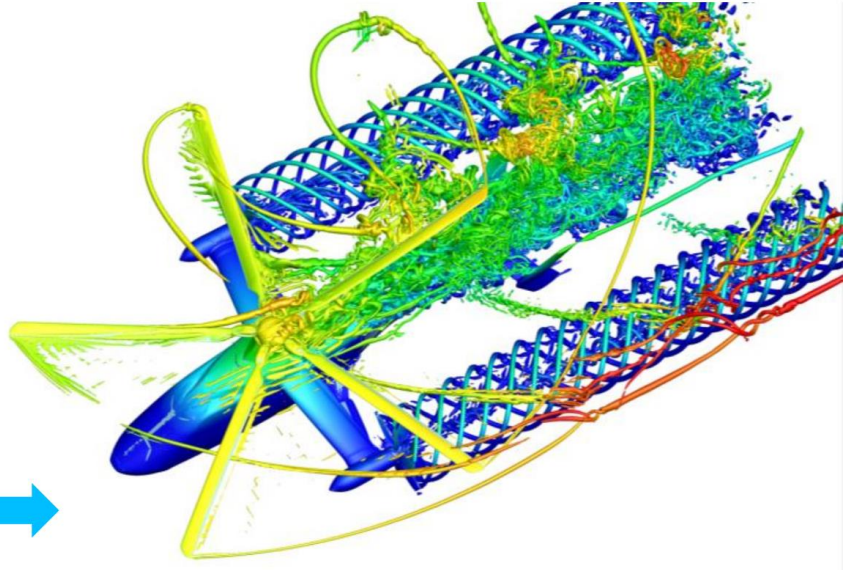
IAG-FLOWer enhancements

Grid refinement

- 6%



- 3%



HPC Optimization

Code optimisations

Core level

- Core level performance is *important*
- Continuous profiling and monitoring

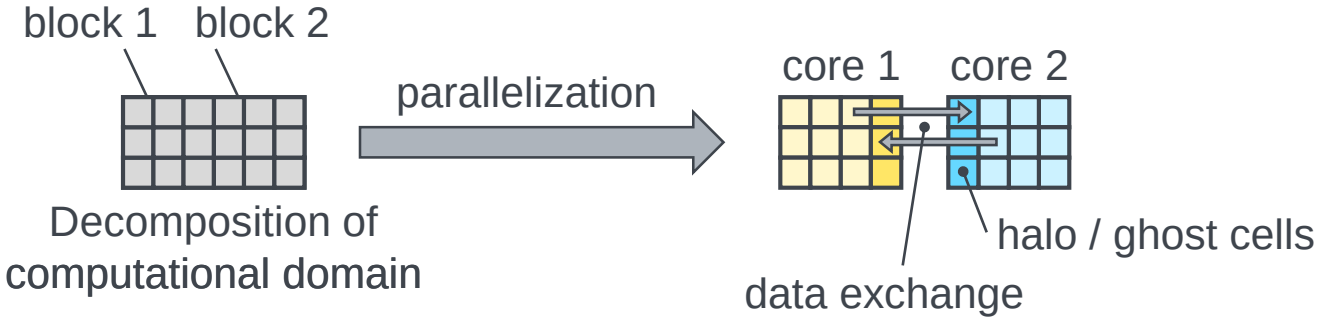
- Cache utilization
  - Blocking
- Vectorisation
  - Code streamlining
  - If-replacement

- Sometimes sacrifices maintainability!

⇒ close to 6 GFLOPs in application (not only tuned trivial benchmarks), including I/O!

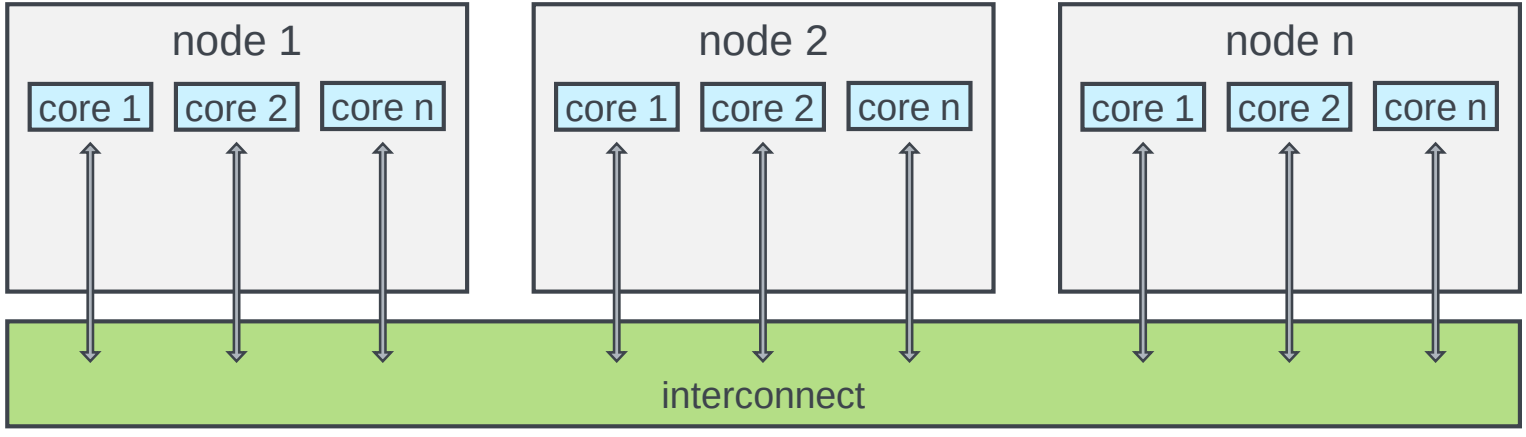
Optimization of Code Parallelization

Reduce Communication!



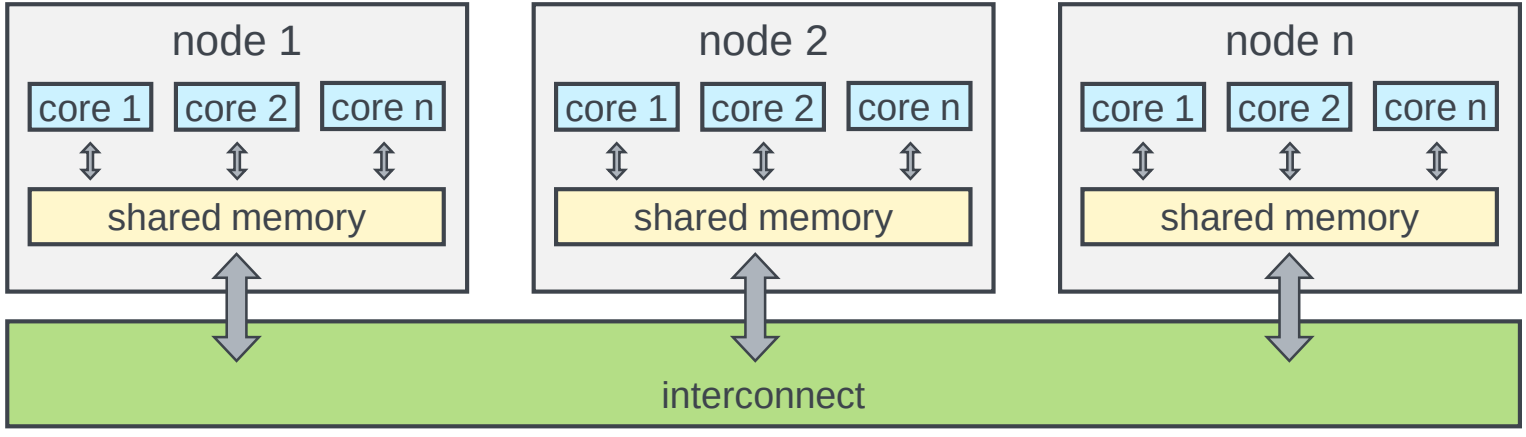
Optimization of Code Parallelization

Core-to-Core Communication (c2c)



Optimization of Code Parallelization

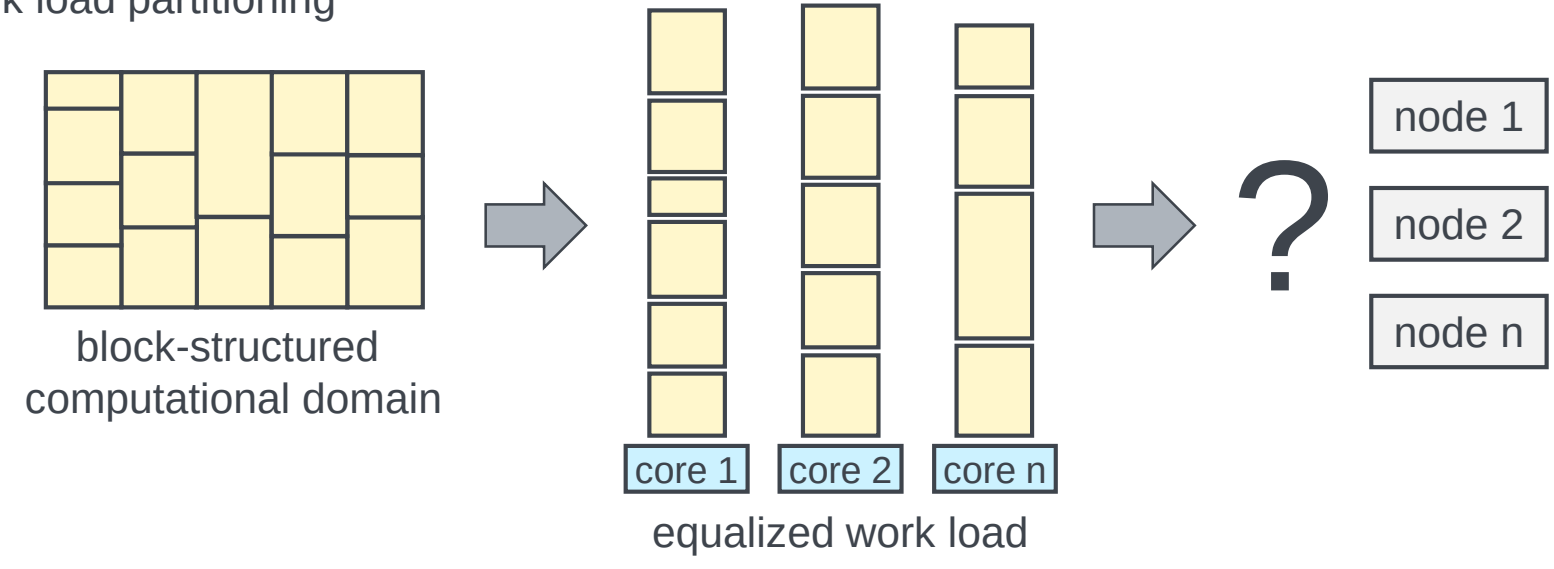
Node-to-Node Communication (n2n)



Optimization of Code Parallelization

Balancing of Work Load and Communication

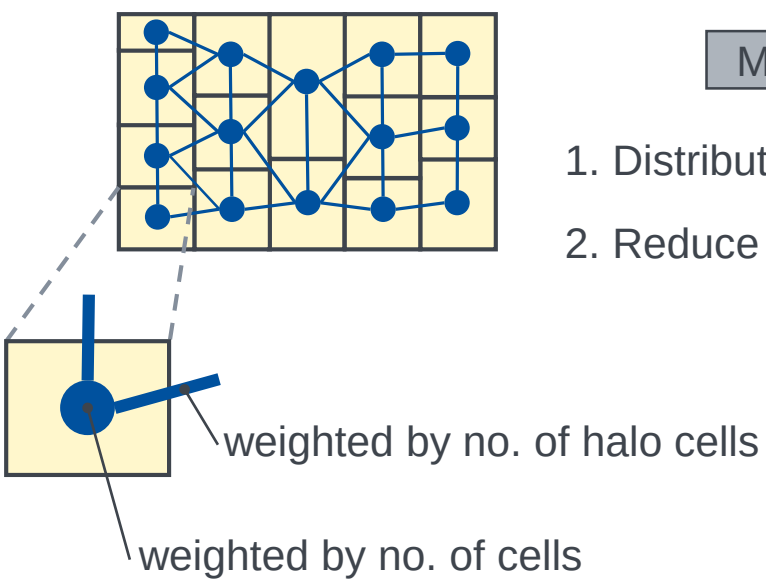
- Work load partitioning

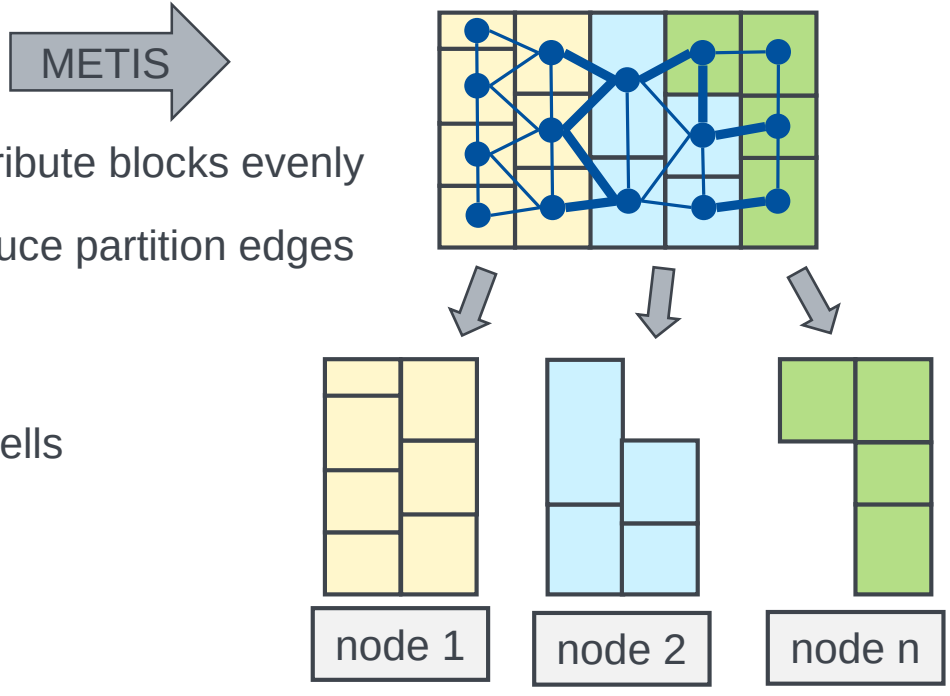


Optimization of Code Parallelization

Balancing of Work Load and Communication

- Graph partitioning using METIS library

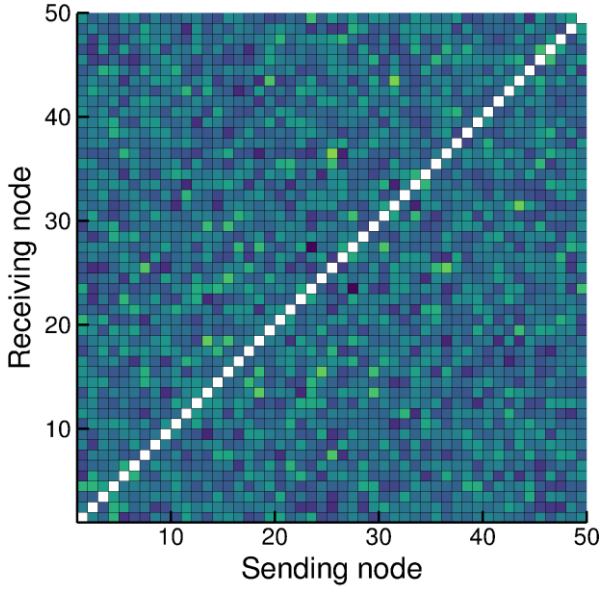


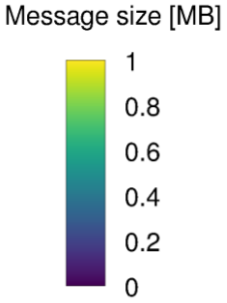


Optimization of Code Parallelization

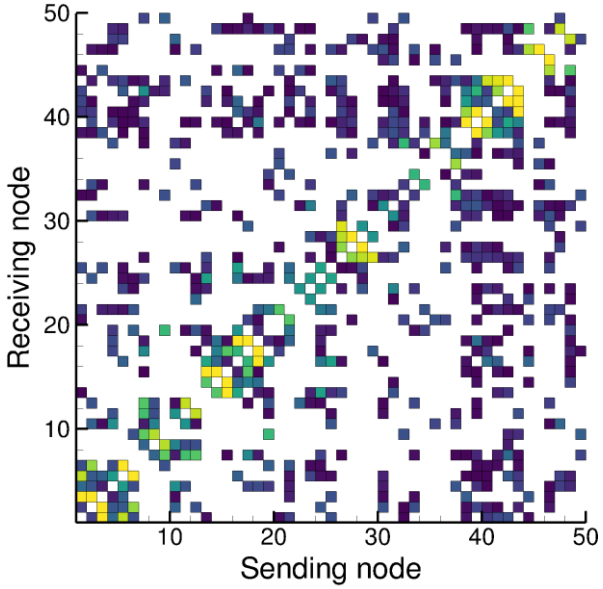
Communication Paths of Test Case using 50 Nodes

Pure work load partitioning





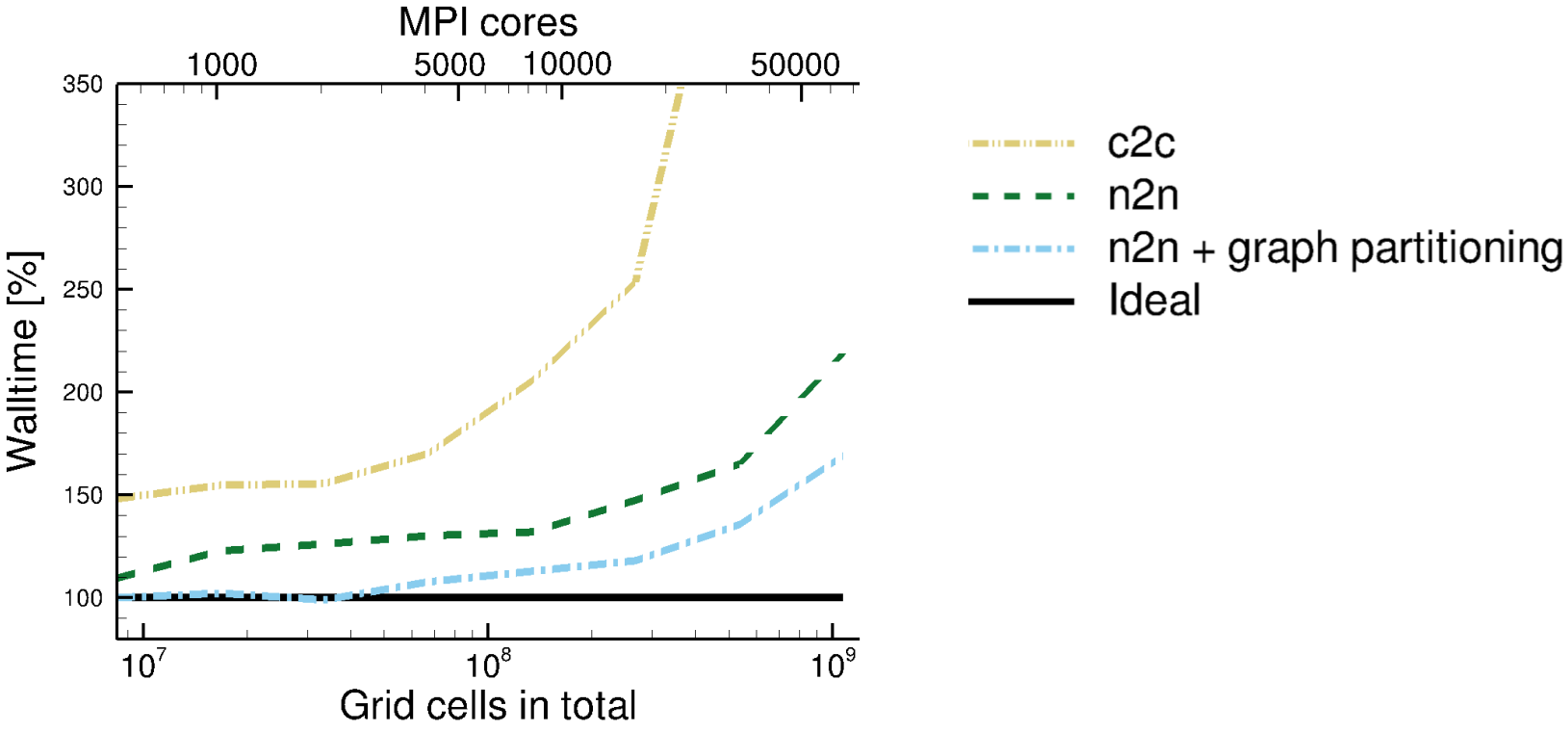
Graph partitioning



- Total size of messages 18 times smaller, number of messages 3.5 times lower

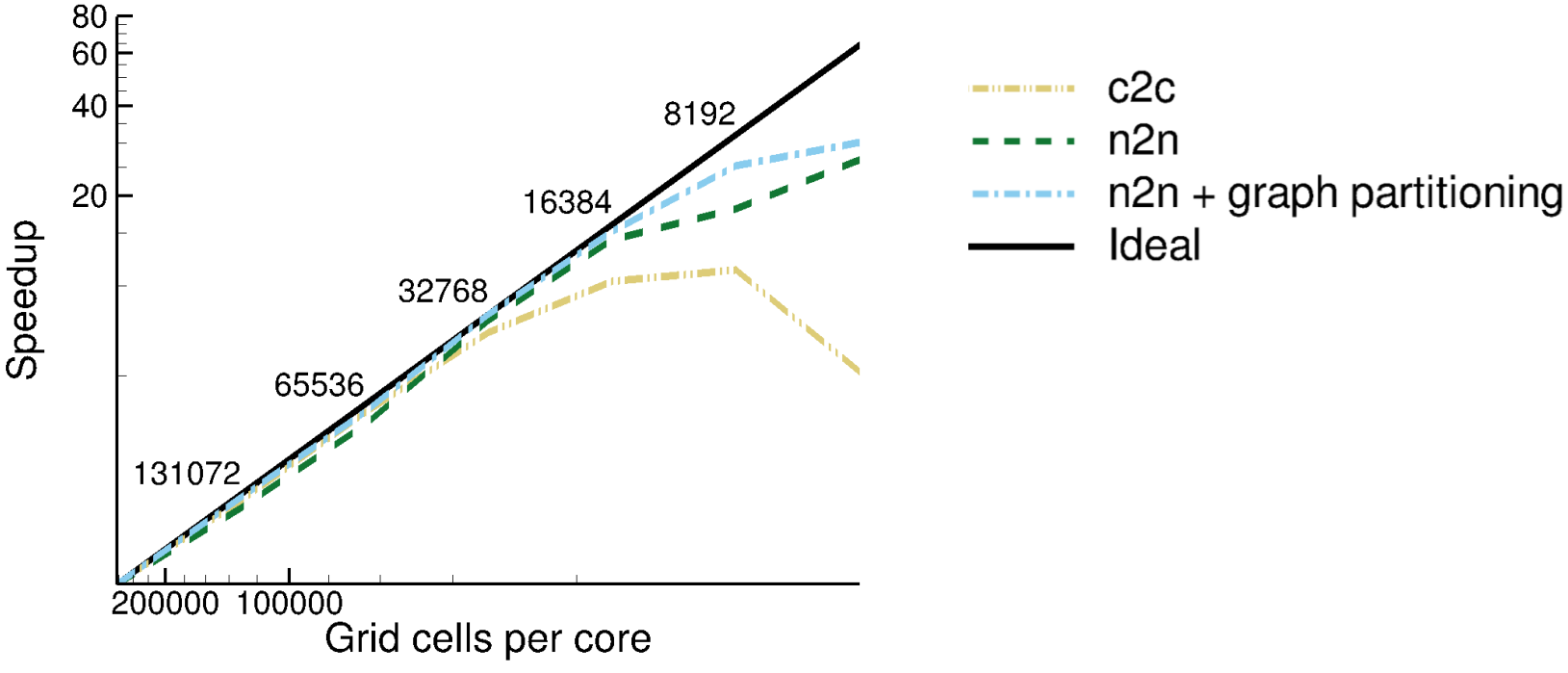
Optimization of Code Parallelization

FLOWer Weak Scaling on XC40, 16384 Cells per Core



Optimization of Code Parallelization

FLOWer Strong Scaling on XC40, 130 Million Cells Case

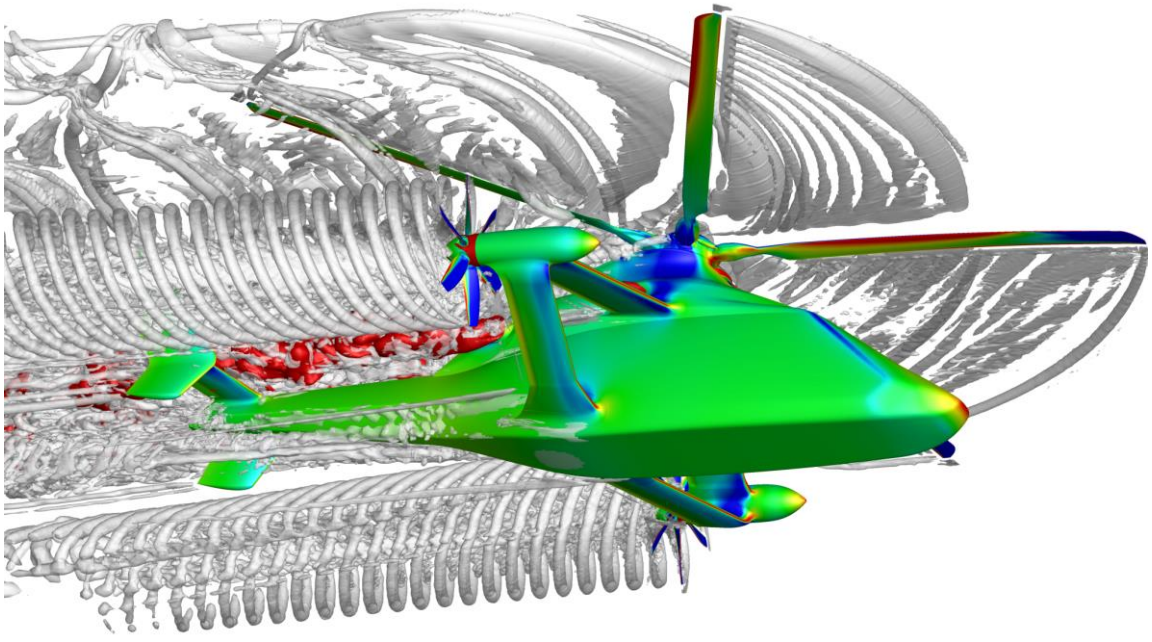


Results

Rotorcraft simulation results

Performance

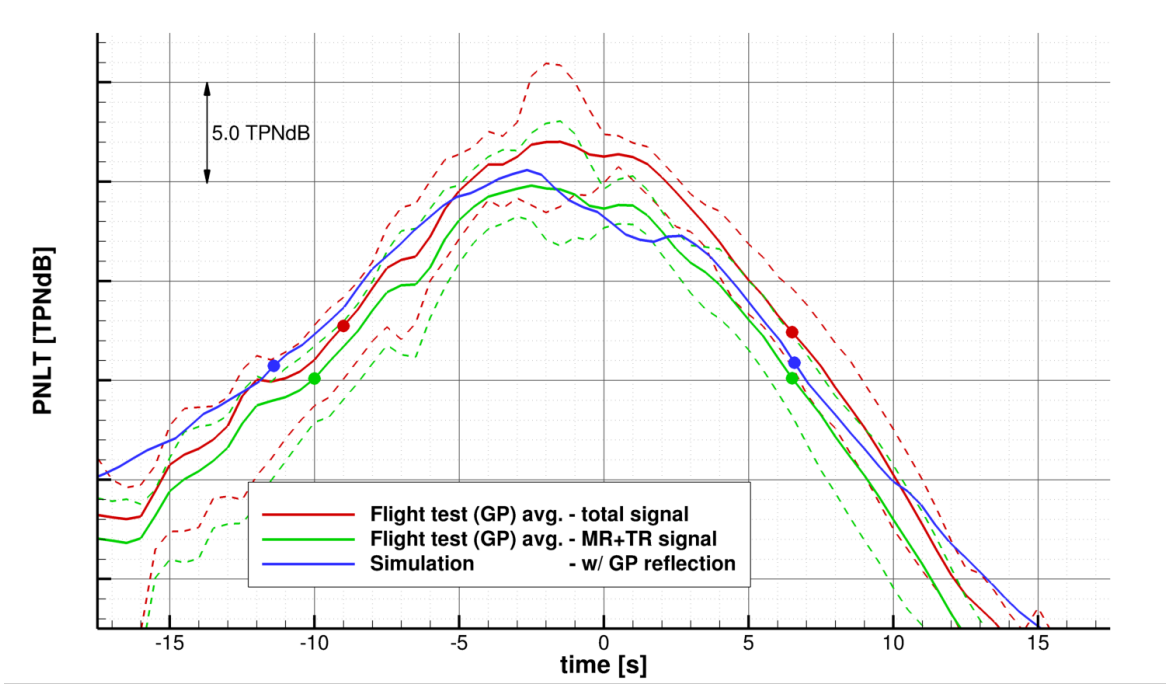
- Power prediction
- Flight mechanics
- Operations optimisation



Rotorcraft simulation results

Noise

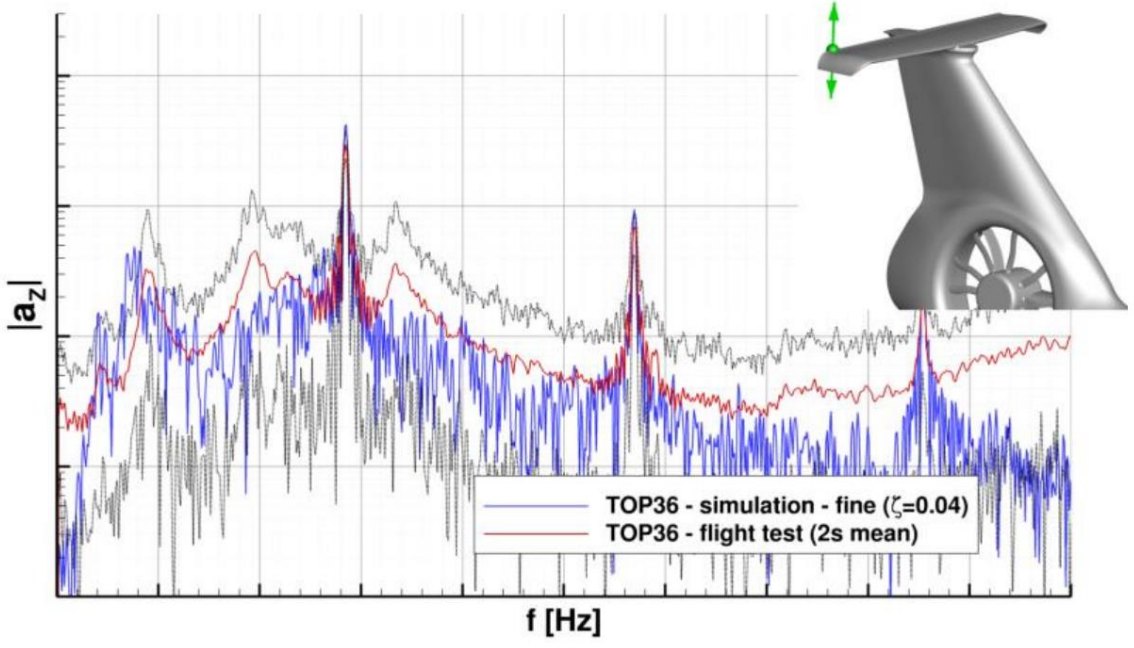
- Noise certification predictions
- Airframe influence
  - Reflection
  - Shadowing



Rotorcraft simulation results

Tail Shake

- Severe vibrations in fast forward flight
- Occurring on several helicopters
- Try and error as afterfix



Conclusions

Conclusions

Engineering

- Interesting engineering applications are in reach for simulation using current HPC
- Find solutions for problem, not problems for solutions
- Identify the relevant parts and necessary ingredients
  - Physics
  - Numerics
- Validation and benchmarking are important, but only intermediate steps along the road
- Focus on progress in science, or valuable data in industry, not toy problems

- Judge cautiously whether results justify the effort (manual, computational)

Conclusions

HPC

- (High) Performance has many dimensions
  - Modeling
  - Numerics
  - Core-level
  - Scaling
- Trading numerics (convergence rates) for computing may pay off – or may not
- Tailoring to the machine/hardware is beneficial at scale
- Tuning is a continuous process, to obtain excellent results with reasonable effort
- HPC is not a goal in itself, but a tool to obtain valuable results

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- HPC is not a goal in itself, but a tool to obtain valuable results

The purpose of computing is insight, not numbers! – R.W. Hamming

University of Stuttgart
Institute of Aerodynamics and Gas Dynamics

Thank you!

Manuel Keßler

e-mail kessler@iag.uni-stuttgart.de
phone +49 (0) 711 685-63419
fax +49 (0) 711 685-53419

University of Stuttgart
Institute of Aerodynamics and Gas Dynamics (IAG)
Pfaffenwaldring 21
D-70569 Stuttgart