# Efficient Aero-Acoustic Simulation of the HART II Rotor with the Compact Pade Scheme

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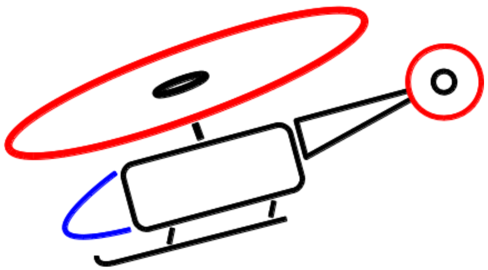


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# Overview

- Motivation
- Theory of Compact Pade Scheme (and JST Scheme)
- Simulation Setup
- Results
  - Prescribed vs computed motion
  - Grid sensitivity study
  - Alternative approaches
- Conclusions

# Motivation

- Simulation of blade tip vortices and vortex structure
    - BVI noise in descent flight
    - Interaction aerodynamics, for example tail shake

- Difficulties with State of the Art Tools
    - 2nd order too dissipative
    - Plenty of grid points and still not there

- Problems with higher order schemes
    - Stability
    - Efficiency

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# *Theory*

# Pade-Scheme

- Higher order finite difference scheme implemented by Stefan Enk in FLOWer → referred to as FLOWer4
    - $4^{th}$ order spatial discretization with $3^{rd}$ order boundaries
    - $4^{th}$ to $8^{th}$ order filtering with down to $2^{nd}$ order boundaries
- Line implicit
- Grid transformation from arbitrary to Cartesian grid
- Not (yet) suitable for transonic flows

Howto get $f'$?

↓

Ansatz

$$f'_{i+2} + f'_{i+1} + f'_{i} + f'_{i-1} + f'_{i-2} = c\frac{f_{i+3} - f_{i-3}}{6h} + b\frac{f_{i+2} - f_{i-2}}{4h} + c\frac{f_{i+1} - f_{i-1}}{2h}$$

Solution through LU-decomposition (Thomas algorithm)

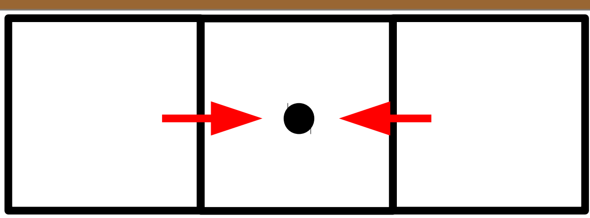
# Jameson vs Pade-Scheme

## Jameson Finite Volume

$$\frac{d}{dt}\int_V \vec{W}\,dV + \oint_S F\,d\vec{S} + \vec{G} = 0$$

$$RES =$$

$$-\frac{\Delta t}{V}[\sum_t F_t(\bar{W})\cdot\vec{S}_t + \vec{G}]$$



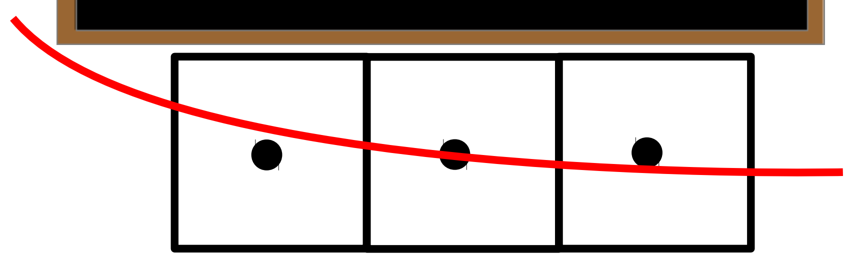
Flux Average

## Pade Finite Differences

$$\frac{d}{dt}(\frac{\vec{W}}{J}) + \sum_i \frac{\partial \hat{F}_i}{\partial \xi_i} + \frac{\vec{G}}{J} = 0$$

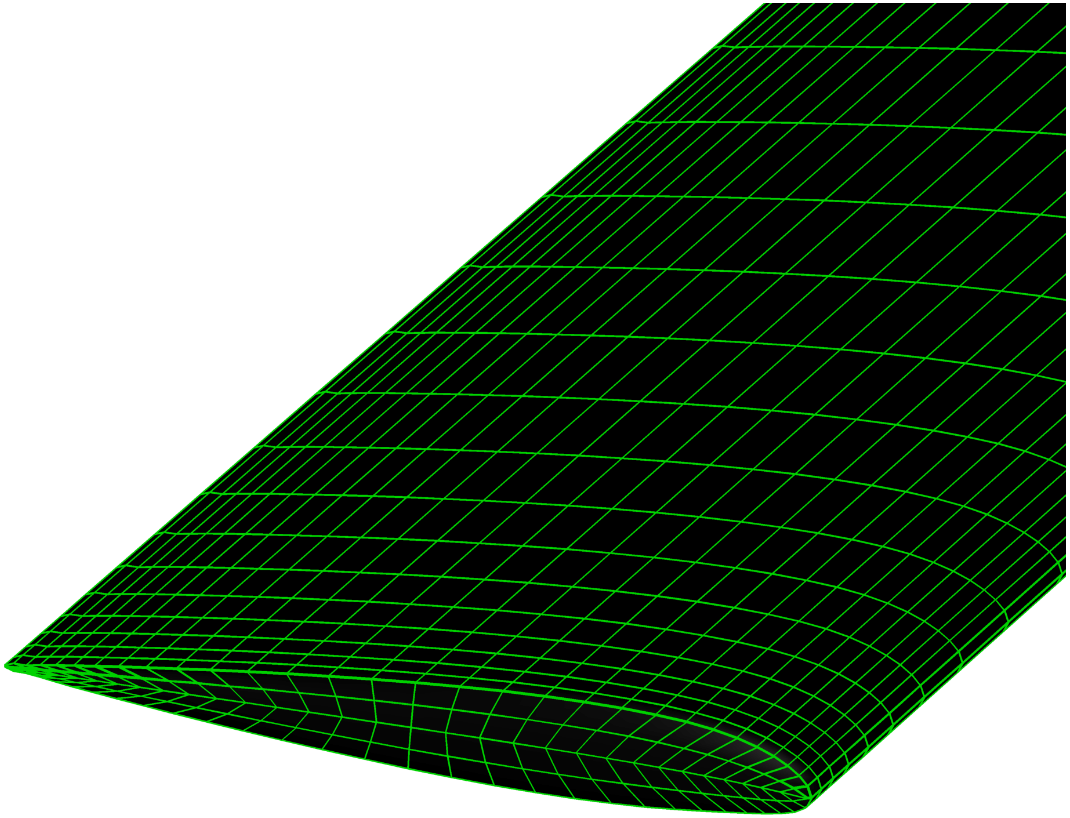
$$RES =$$

$$-\Delta t[J\cdot(\sum_i \frac{\partial F_i}{\partial \xi_i} + \vec{W}\cdot\frac{\partial}{\partial t}(\frac{1}{J})) + \vec{G}]$$



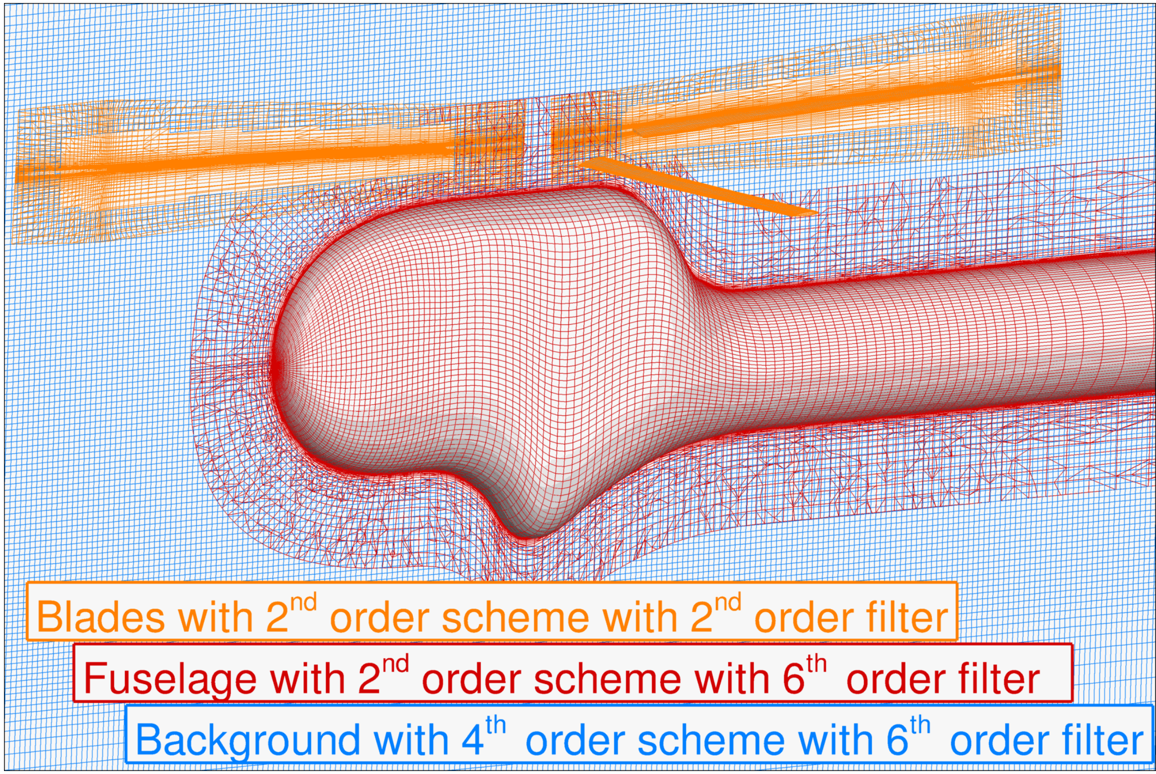
Difference of Fluxes

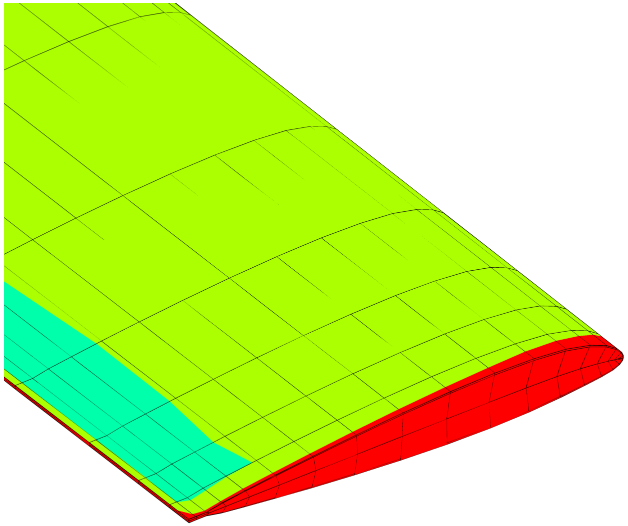
# Simulation Setup



# Numerical Setup

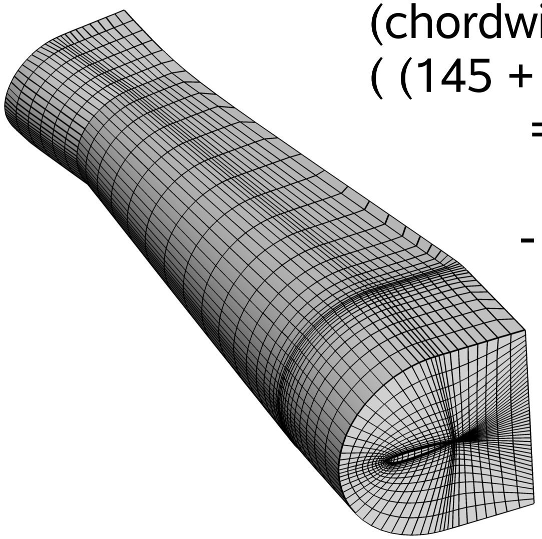
- Dual-Time Stepping with 1, 1/4, 1/8 degrees timesteps
- Residual Smoothing
- 2V Multigrid on JST blocks
- 6th order Pade Filter with 4th order at the boundaries



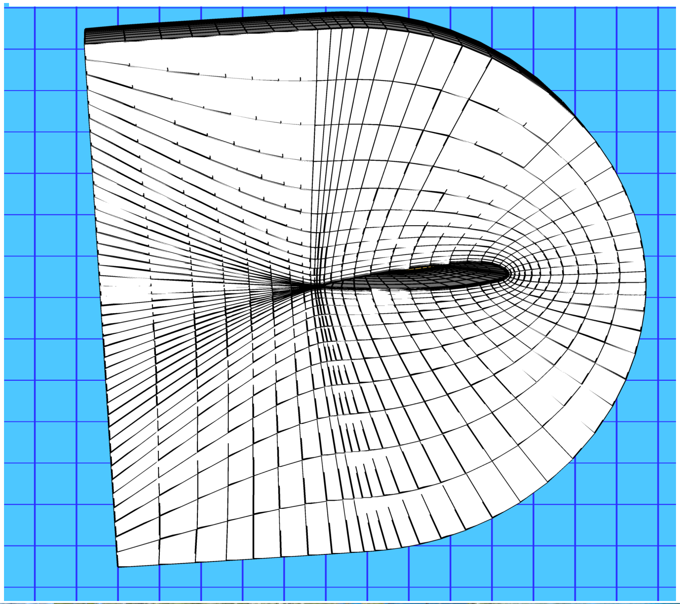


# Grids – RANS Blade Mesh

- C-H topology
- Blunt root, tip and tab
- Outer cell layer matching trickier
- Point distribution
  (chordwise x spanwise x normal) =
  ( (145 + 2 * 41) x (24 + 73 + 48) x 73 )
  = 2.6 mio



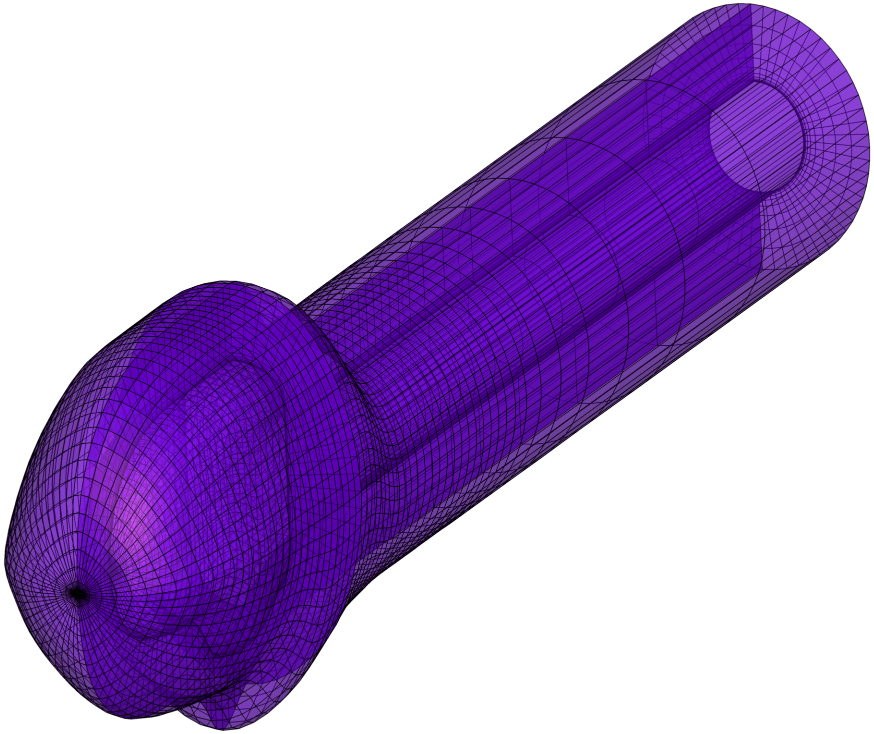
- Y+ = 1 fulfilled on blade, not on blunt surfaces,
  (Y + = 2/4 on level 2/3)



Level 3 shown

# Grid – Fuselage Mesh

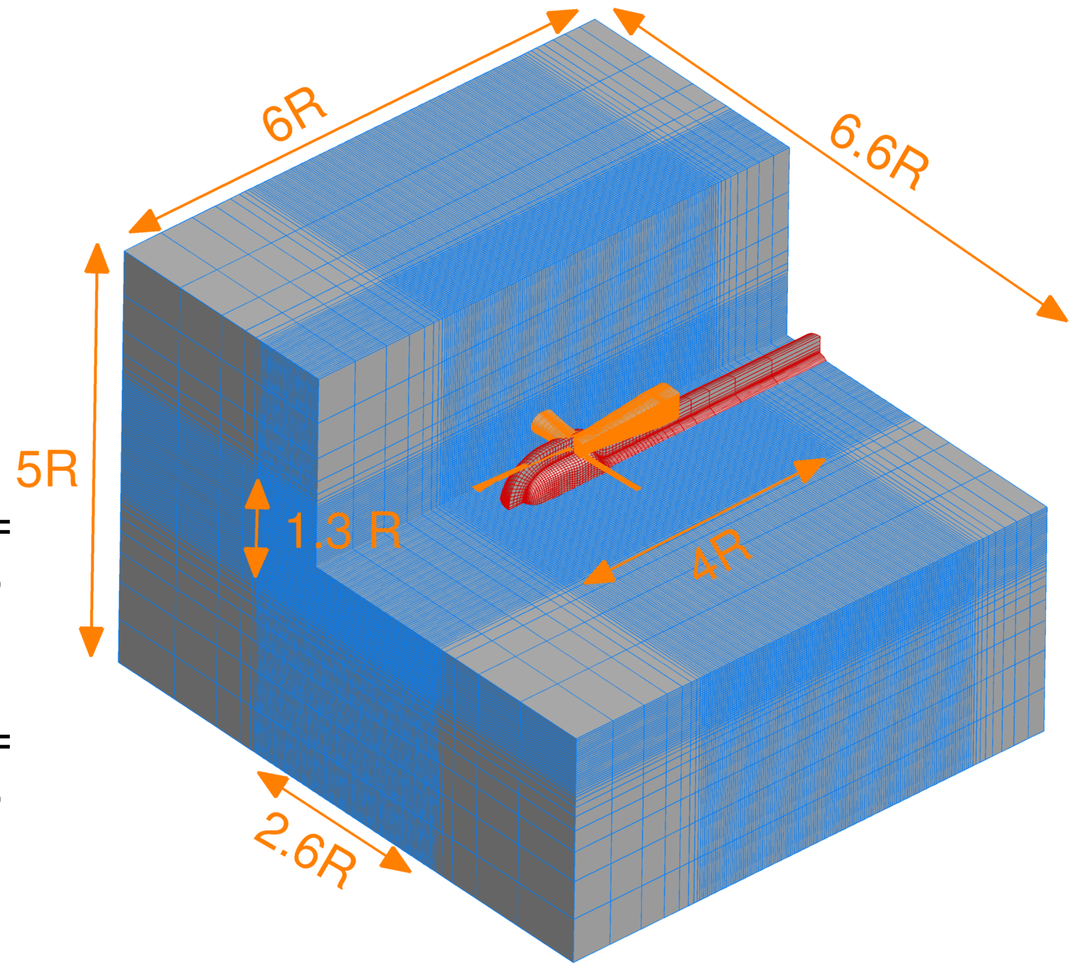
- Required for displacement effects
- Simplified geometry, no hub included
- Point distribution (axial x radial x normal) = ( 257 x 241 x 65 ) = 3.9 mio
- Y+ = 1 on finest level



Level 3 shown

# Grid – Background Mesh

- Continuous, cartesion mesh of inner and outer region
- Laplacian smoothed for Pade scheme
- Inner region points: (inflight x lateral x vertical)= (554 x 422 x 210) = 49 mio
- Total point distribution (inflight x lateral x vertical)= (641 x 481 x 289) = 88 mio

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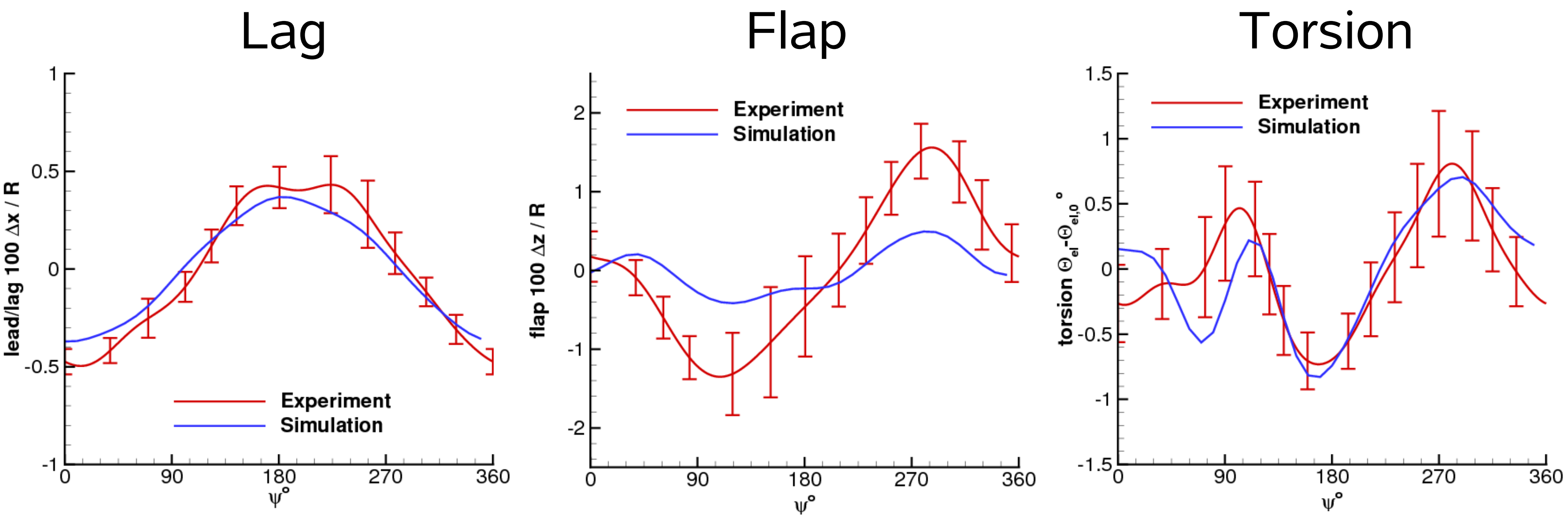
# Grid – Summary

| | coarse | medium | fine |
|---|---|---|---|
| blade | 40k | 323k | 2.6 Mio |
| fuselage | 61k | 490k | 3.9 Mio |
| background | 1.4 Mio | 11 Mio | 88 Mio |
| total | 1.6 Mio | 13 Mio | 103 Mio |

# HART II
# +
# Pade Scheme
# =
# Results !

# Comparison of Prescribed vs Computed Motion




| | θo | θc | θs |
|---|---|---|---|
| experiment | 3.80 | 1.92 | -1.34 |
| computed | 3.72 | 1.87 | -0.98 |

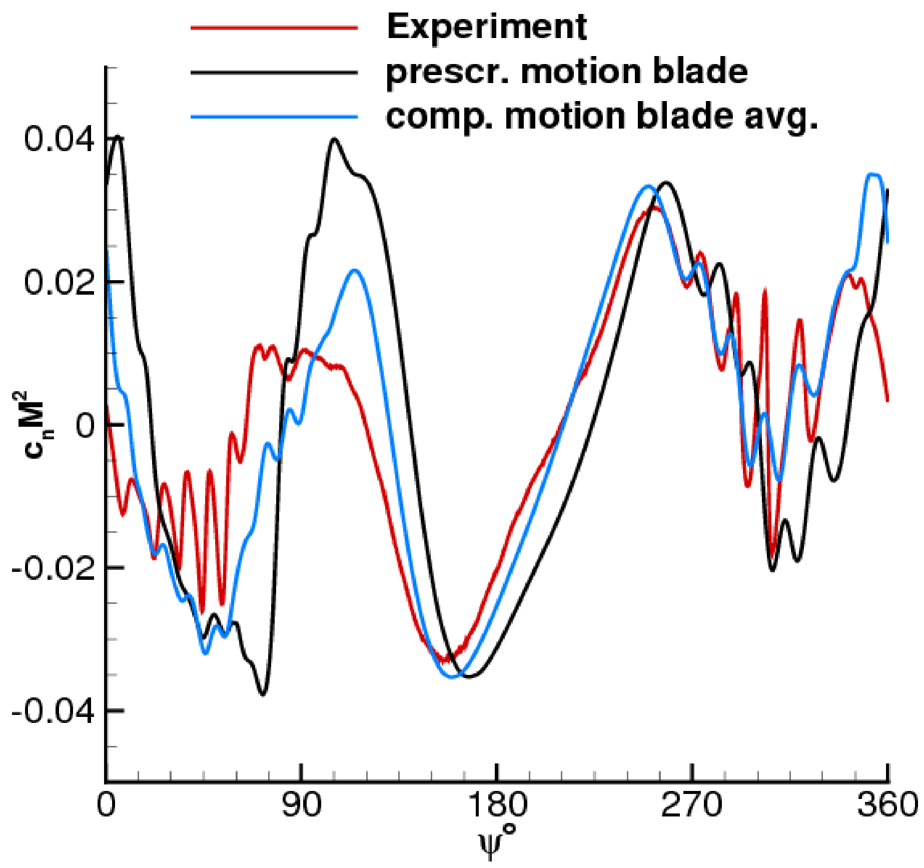
# Comparison of Prescribed vs Computed Motion

- Motion agrees on a fair level for the computed case

- Loads agree better

  → continuing with coupled simulation

| | thrust | req. power |
|---|---|---|
| experiment | 3300 N | 18.7 kW |
| prescribed | 3825 N | 25.5 kW |
| simulated | 3304 N | 22.0 kW |

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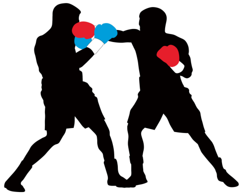
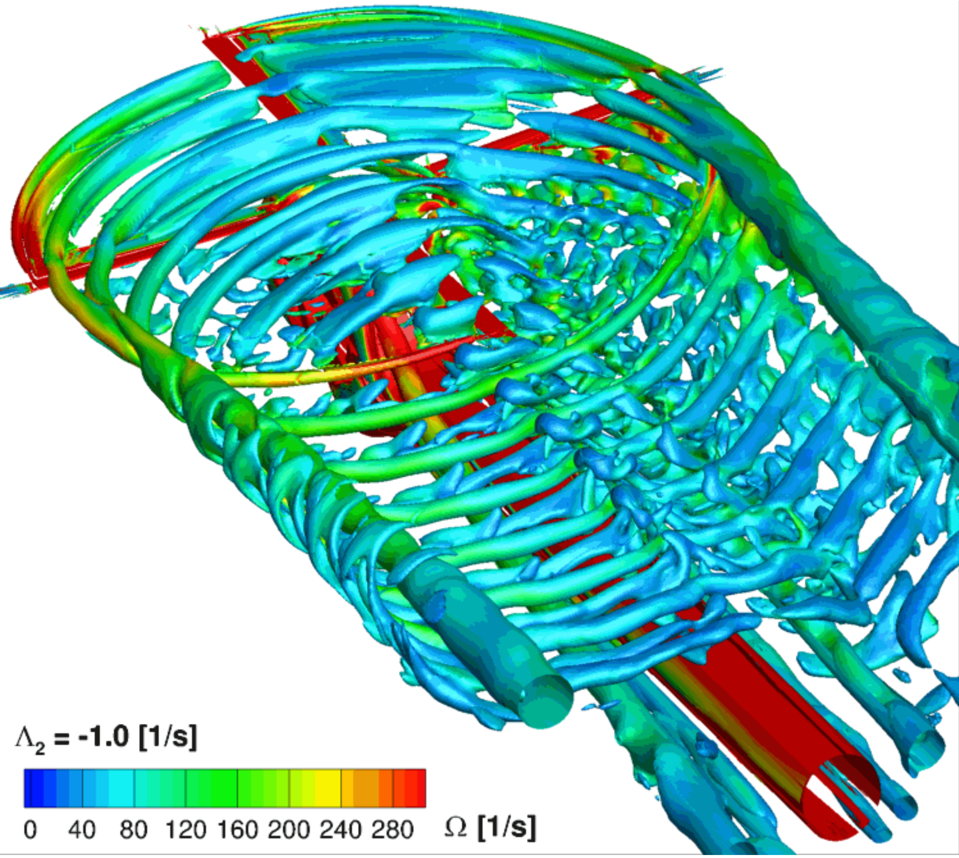
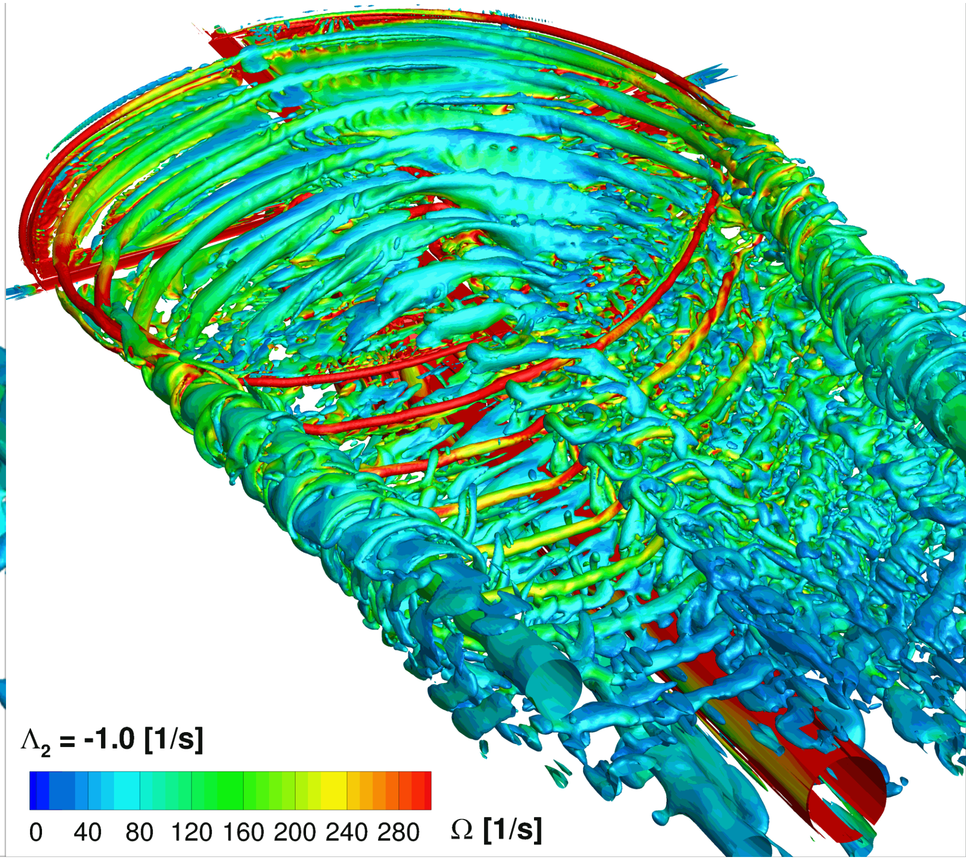


# Grid Sensitivity Study (JST vs Pade)




JST

Hybrid-Pade

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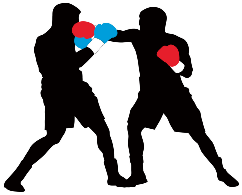

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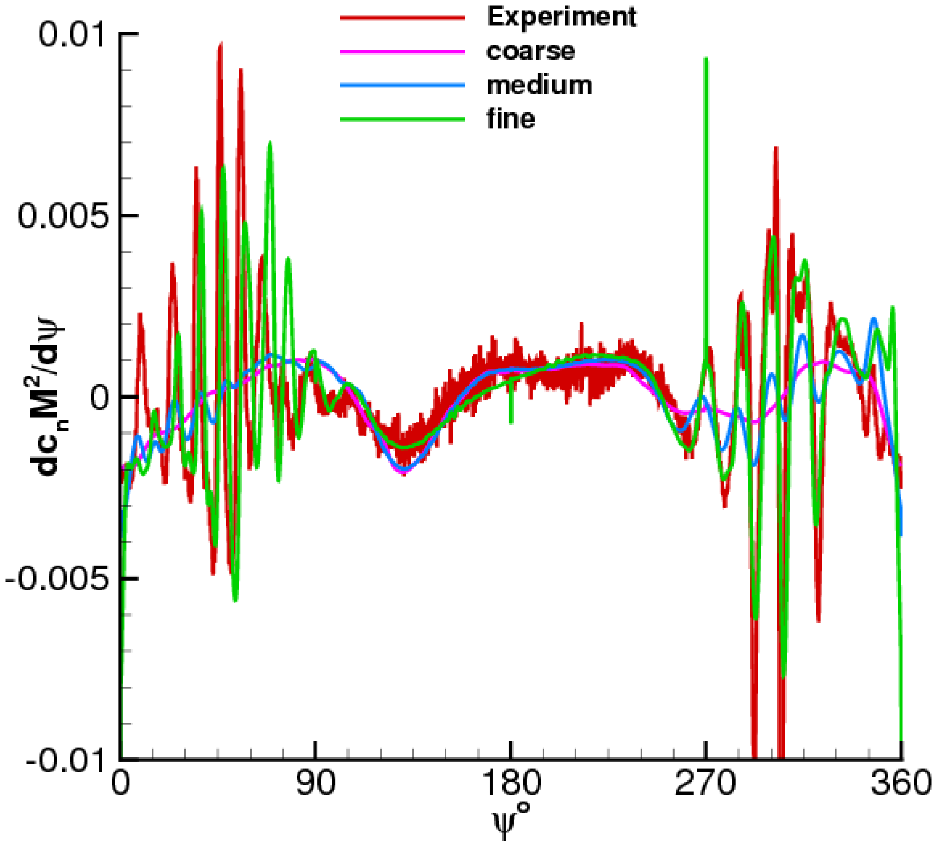
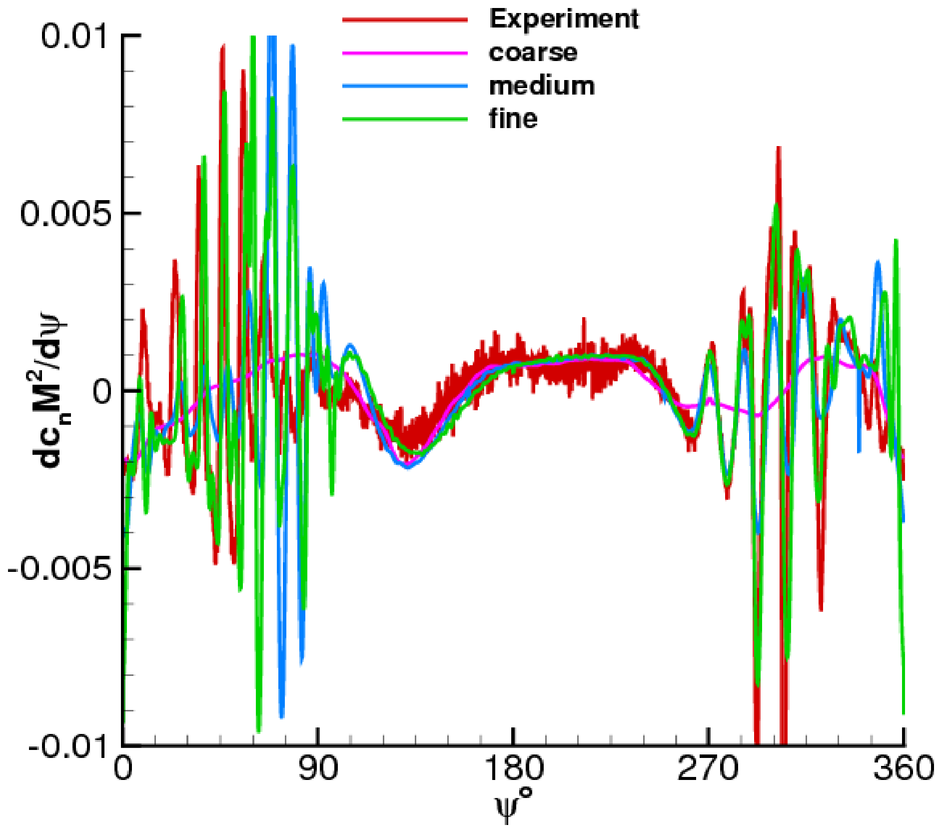
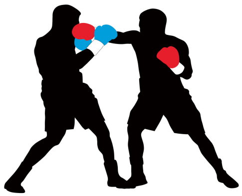



JST

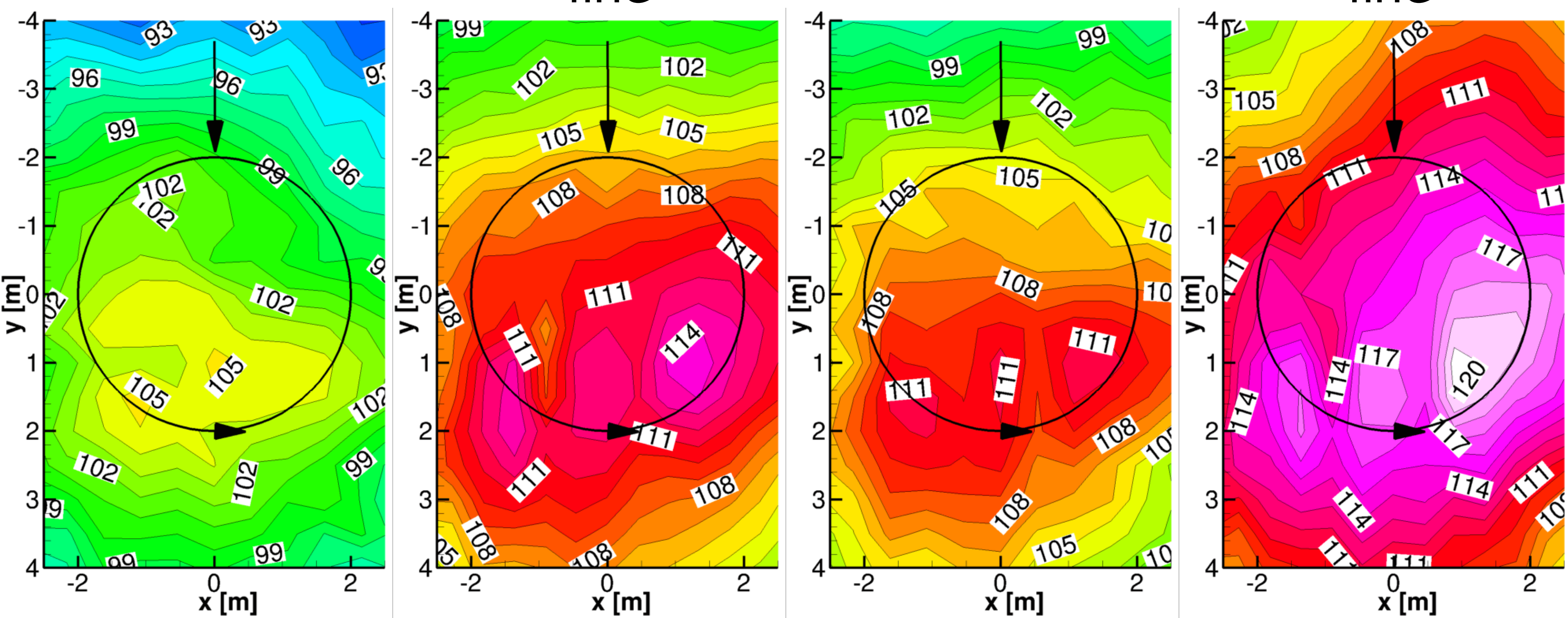



Hybrid-Pade



# Grid Sensitivity Study (JST vs Pade)

medium fine medium fine




JST Hybrid-Pade

Cost increase about 50%

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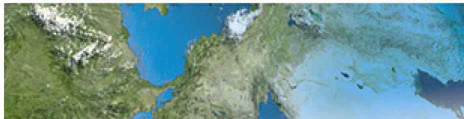
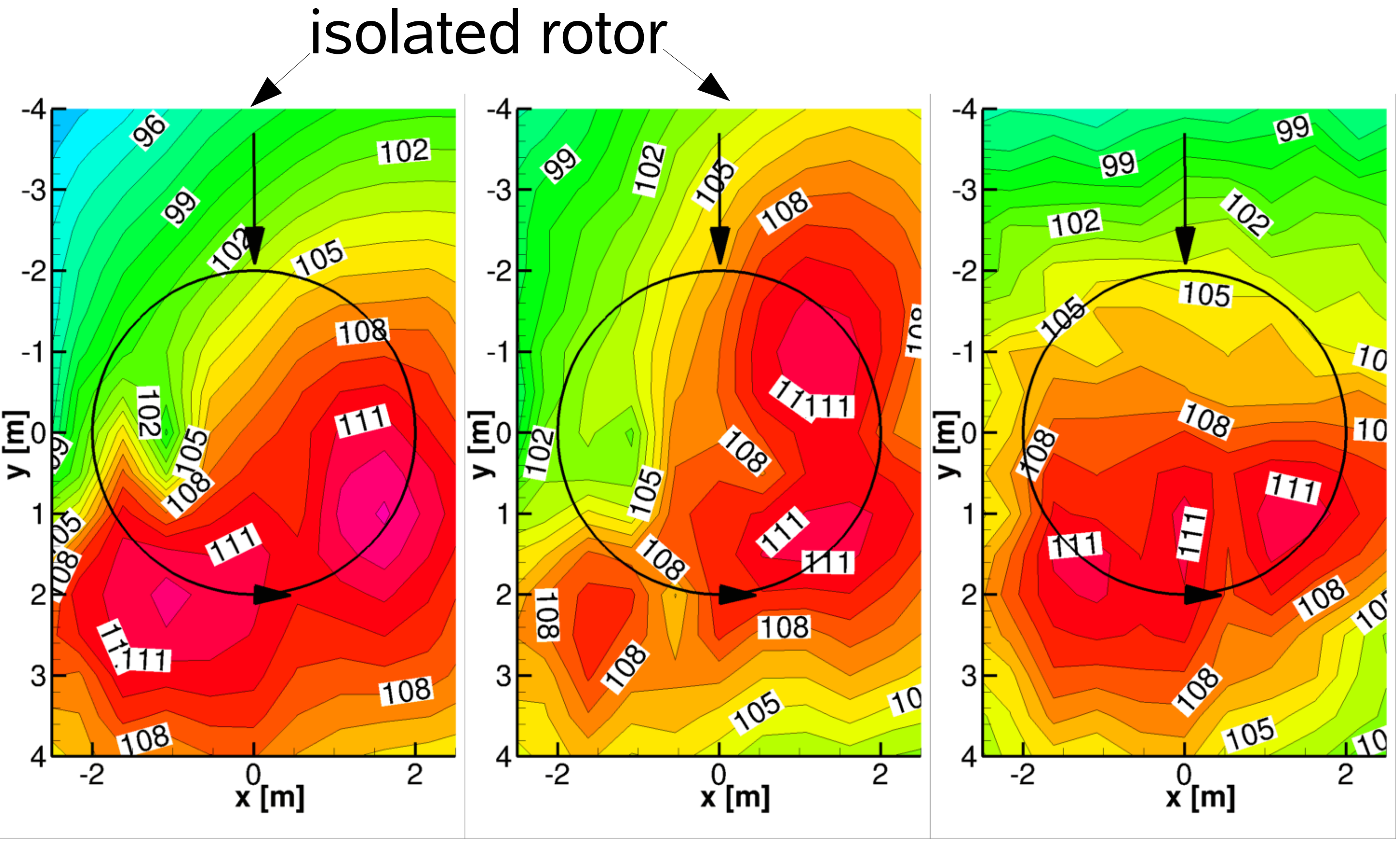
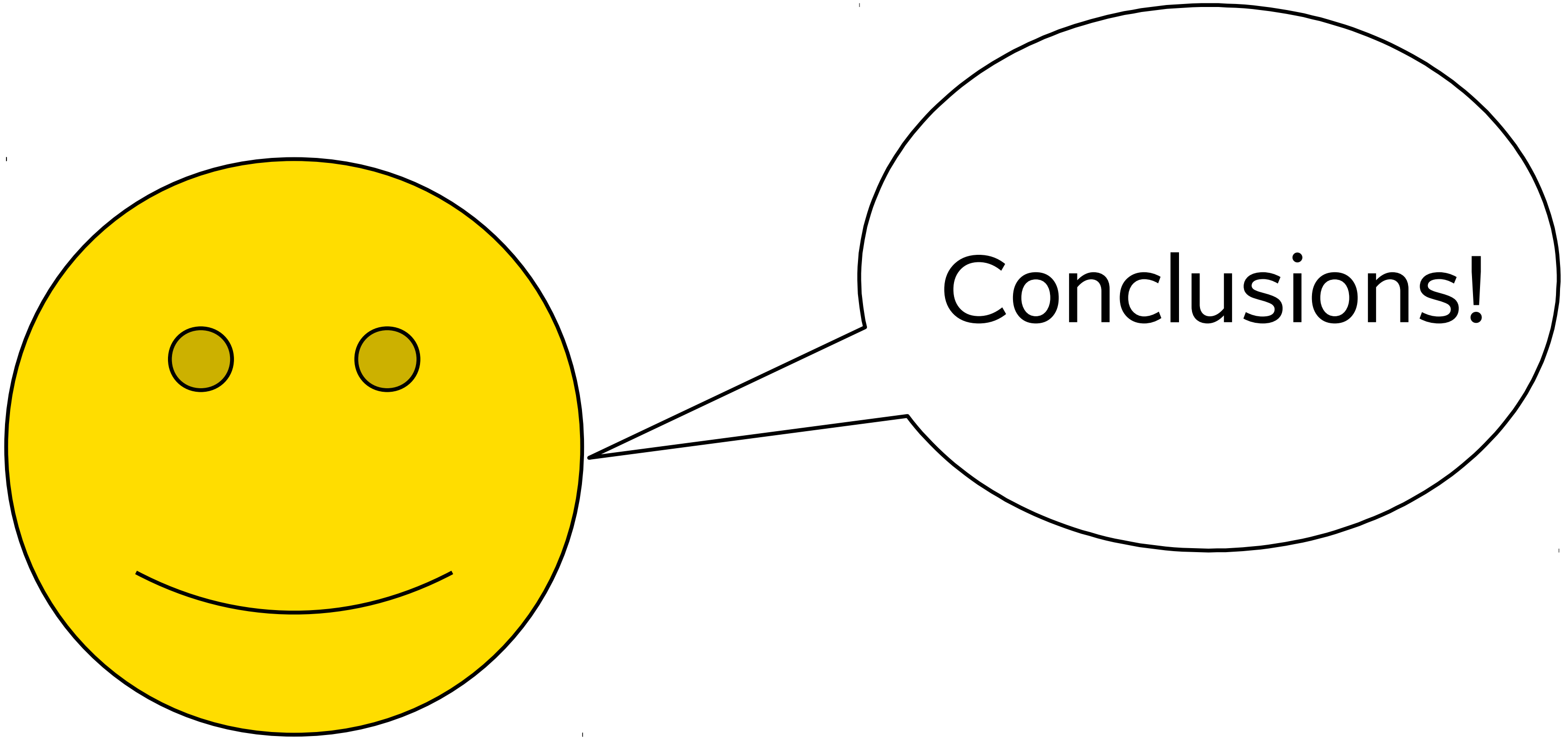


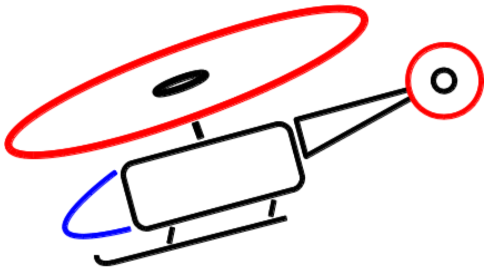
# Alternative Simulation Techniques




inviscid viscous +fuselage

| | Runtime factor |
|---|---|
| inviscid | 63% |
| viscous | 76% |
| fuselage | 100% |


Conclusions!



# Conclusions

- Established a hybrid simulation environment within FLOWer with the a 4th order compact Pade scheme

- Computed motion results better than prescribed motion
  still discrepancies in the HOST+FLOWer coupling

- Hybrid simulation with Pade scheme significantly improved vortex conservation → better loads correlation → better acoustic correlation

- Medium mesh setup almost as good as fine mesh setup when using Hybrid over classical JST

- For design purposes the viscosity as well as the fuselage can be neglected ~ 37% runtime improvement