Investigations of a boxed rotor: The STAR II rotor in DLR's test hall

Gunther Wilke (DLR AS-HEL),
Hideaki Sugawara,Yasutada Tanabe (JAXA)
Oliver Schneider and Berend G. van der Wall (DLR FT-HUB)

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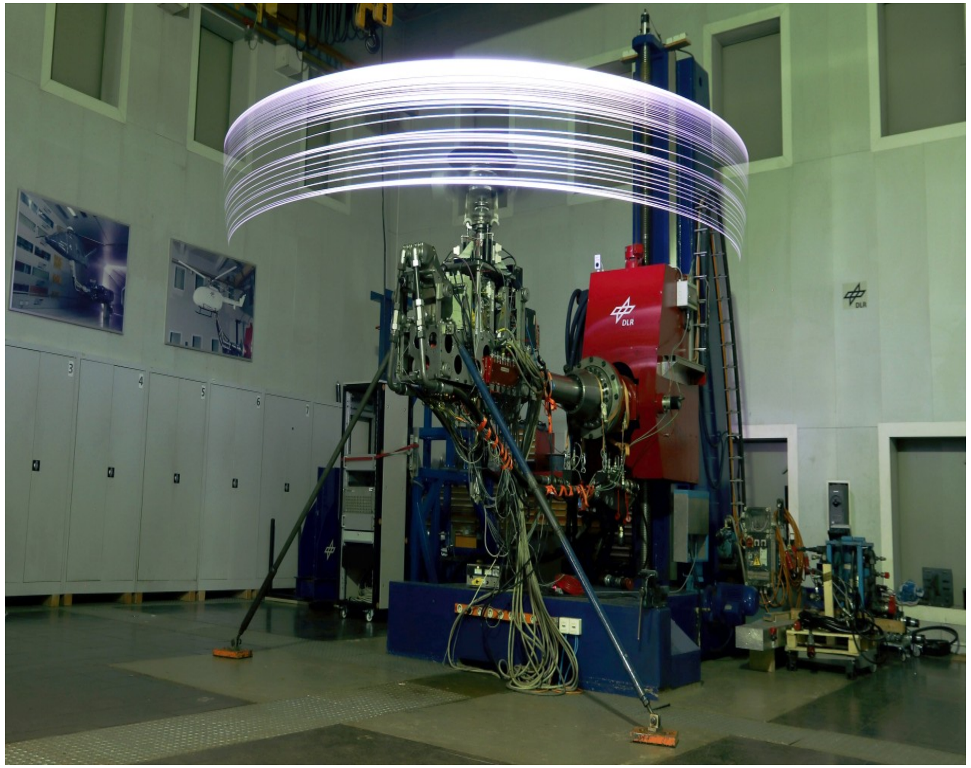
Motivation & Introduction

- STAR II blade in presented in previous presentation
  - Investigation of actively twisted blades within a consortium

- Here we are interested in what is happening inside the pre-test hall in Braunschweig
  - From previous tests, it was observed that maximum thrust and best Figure of Merit is lower than in the DNW-LLF
  - Strong vibrations occur at higher thrusts
  - No PIV carried out during STAR II pre-tests, therefore a CFD investigation is carried out by JAXA & DLR



STAR II rotor in test hall during testing
long exposure photograph

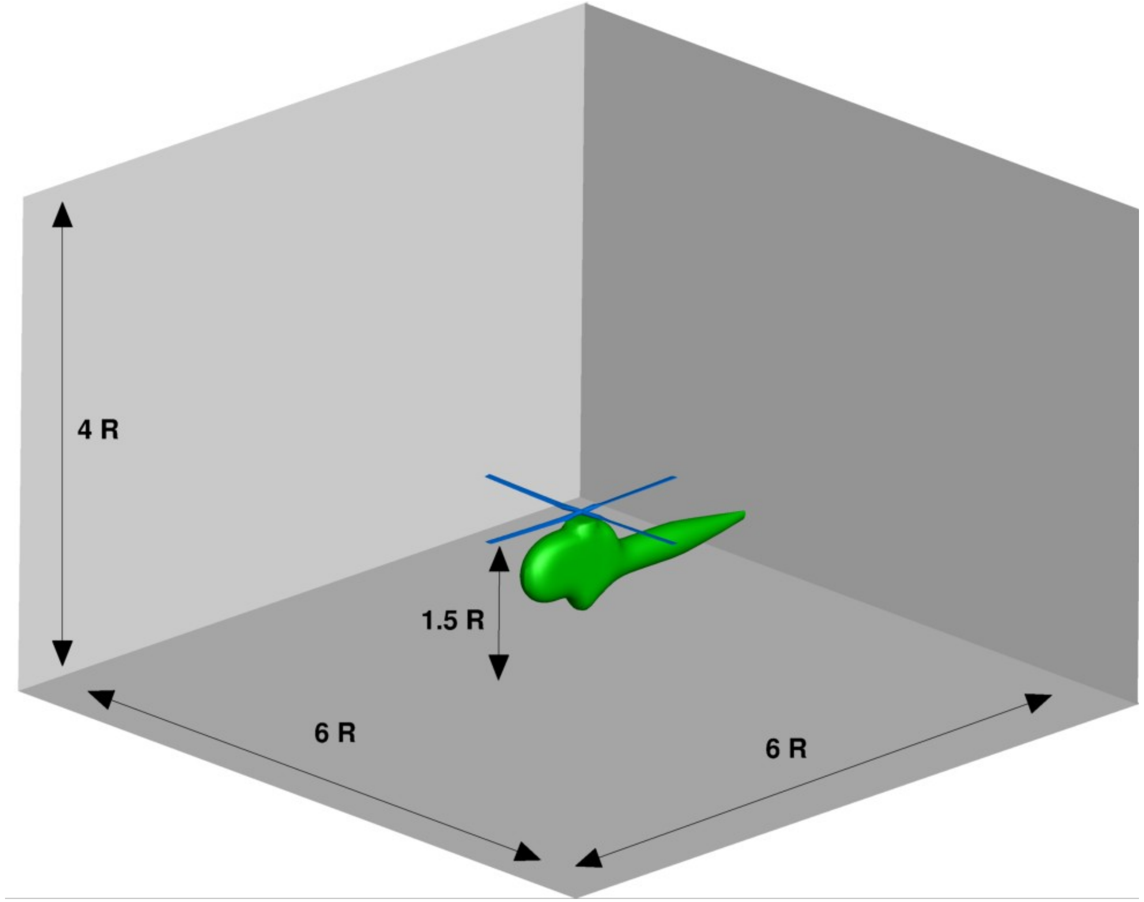
DLR JAXA KARI Konkuk University Korea ONERA THE FRENCH AEROSPACE LAB University of Glasgow DEVCOM ARMY RESEARCH LABORATORY

Overview

- Simulation Approach
- Results
    - Trim convergence
    - Flow Pictures
    - Rotor Performance
    - Loads
- Summary

Simulation Approach – General assumptions

- No prior experience with ‘boxed’ flow rotors
- Simplified assumption of a box, despite heavy duty shelves and other apparati remaining in the pre-test hall
- Cyclic also trimmed to see asymmetric effects, but only collective used in the experiment → can be ignored and not further discussed here
- Estimated required number of revolutions to 50-100 revolutions depending on estimated induced velocity
- Comparison with ‘free’ out-of-ground simulations



Simulation Approach – Numerical Setup

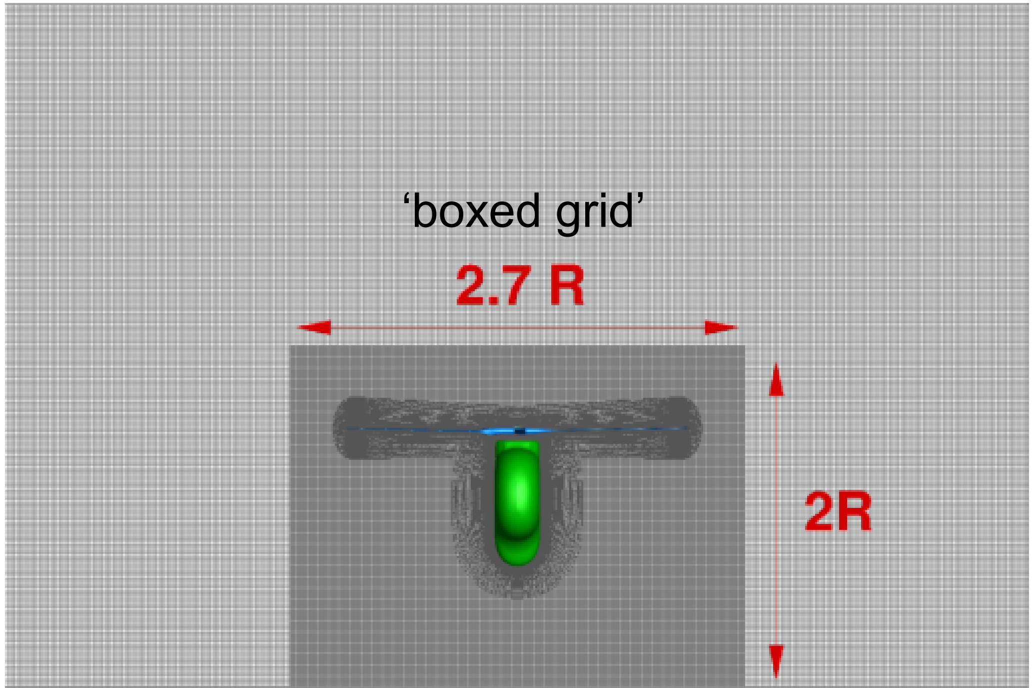
- Both partners used 4th inviscid upwind scheme
- DLR applied SA-DDES-R including laminar-turbulent transition prediction
- JAXA used fully turbulent Menter SST
- Fluid-structure coupled results
- JAXA refined grid near the walls
- DLR included fuselage (even though cover not given in the experiment)

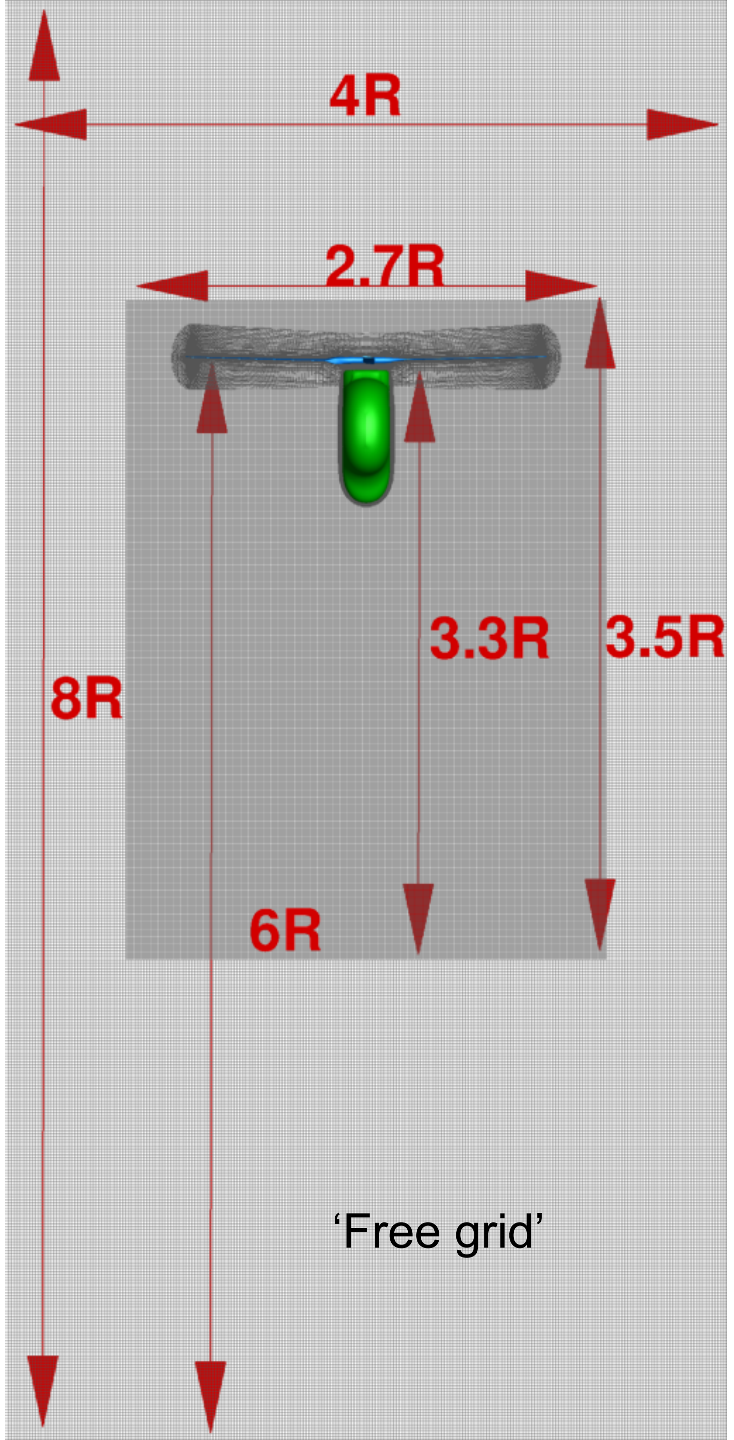
case	boxed		free	
partner	DLR	JAXA	DLR	JAXA
$\Delta\psi$	0.5^o	0.1^o	0.5^o	0.1^o
blade cells				
chord	128	141	128	141
span	128	157	128	157
normal	64	71	64	71
boundary layer	20	25	20	25
total blade	1 M	1.5M	1 M	1.5 M
fuselage cells	1 M	-	1 M	-
background grid				
$\Delta x/c_{ref}$	14%	20%	14%	20%
total bg	55 M	91M	69M	107M
total sim.	60 M	97M	74 M	113M

Table 1: Grid Metrics.

Simulation Approach – DLR grids

- DLR utilized hanging grid nodes to have a refined area near the rotor in both conditions
- Farfield distance assumed out-of-ground hover for 3 rotor diameters
- Applied Froude (source/sink) boundary condition for free simulation

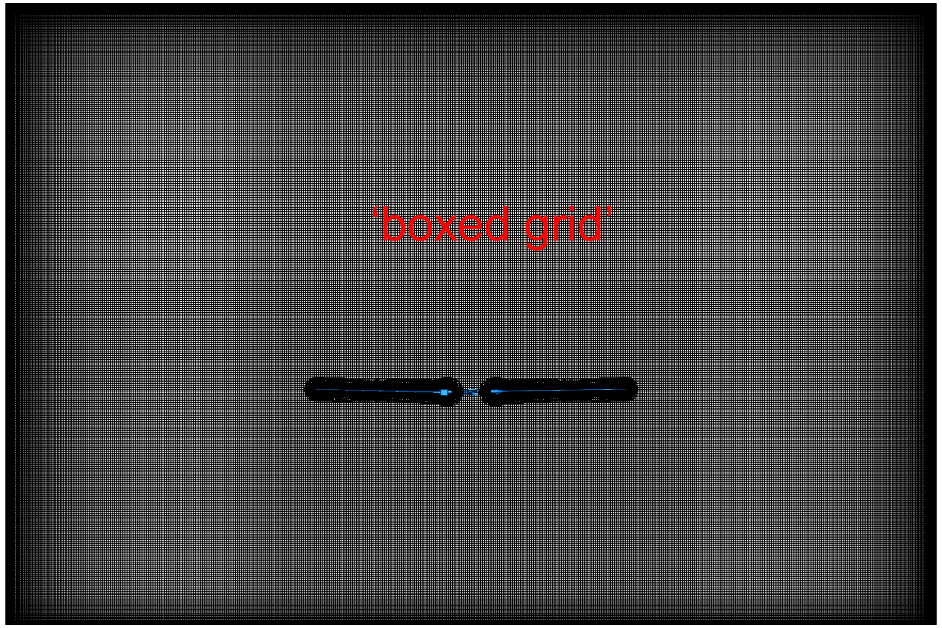


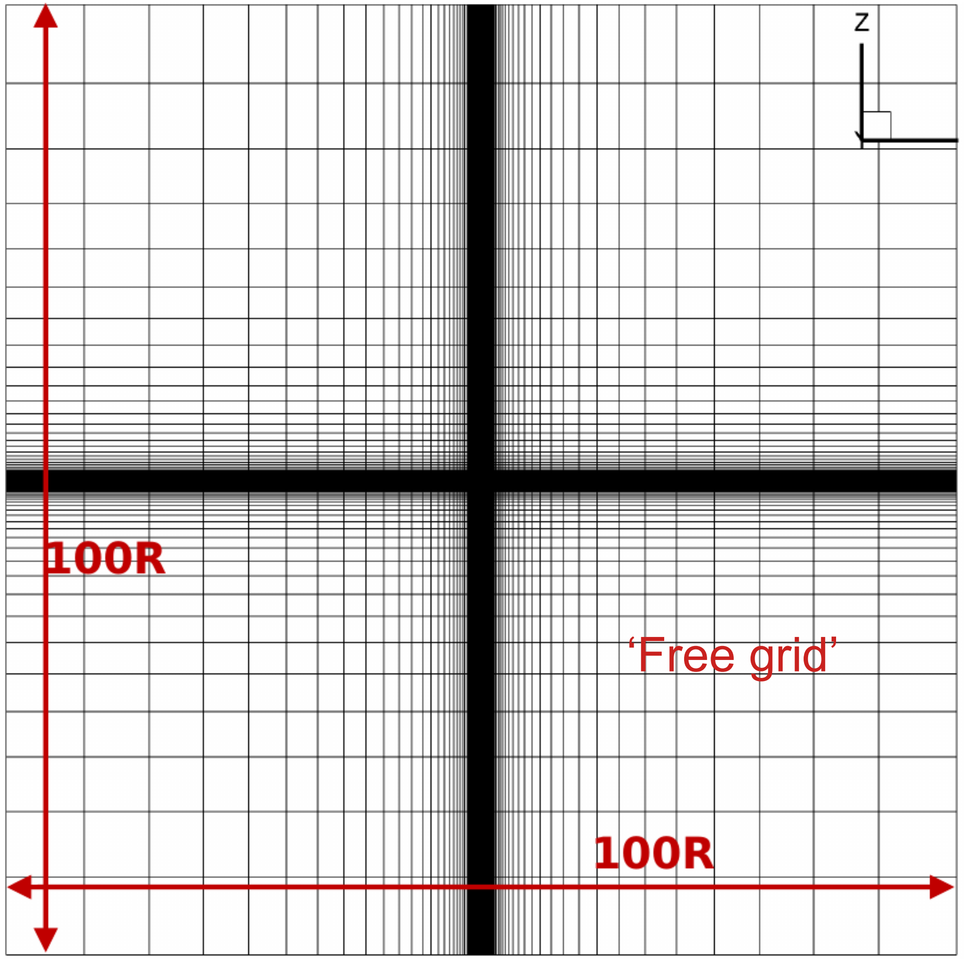


Simulation Approach – JAXA grids

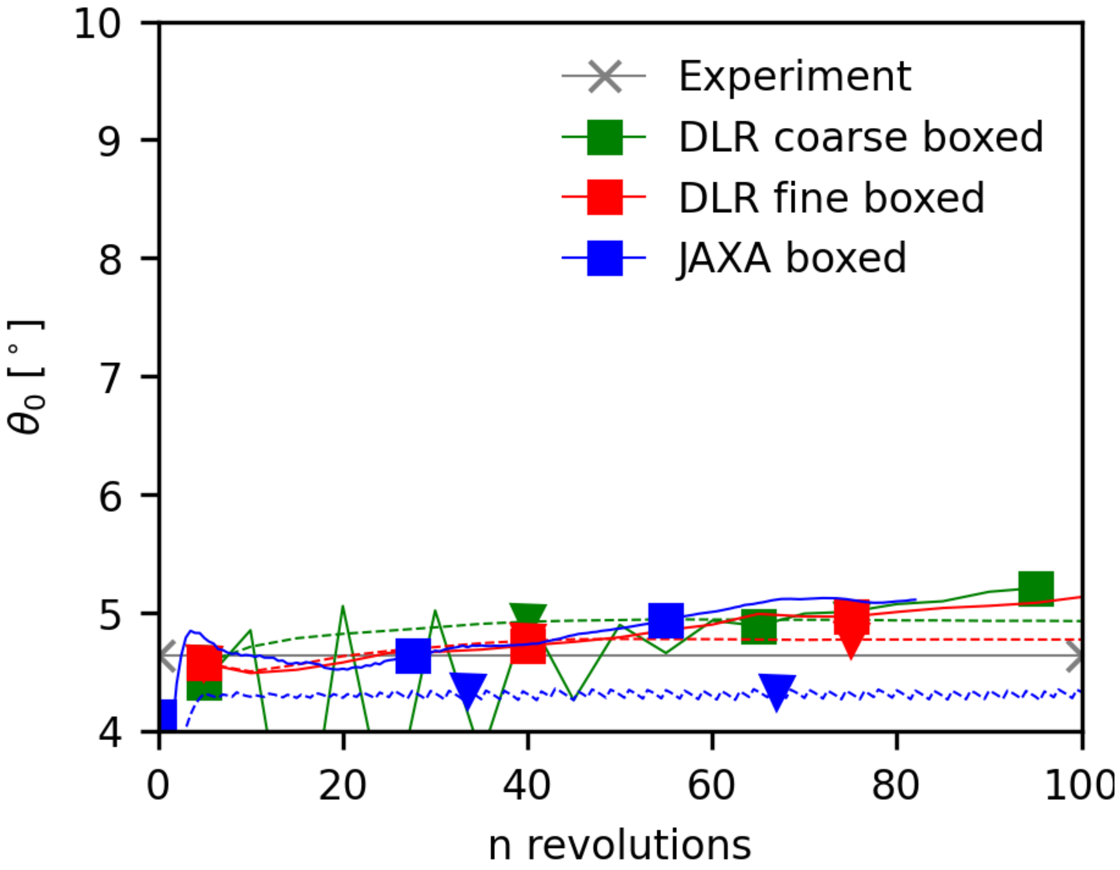
- JAXA tried to capture the wall jet through added refinement near the wall

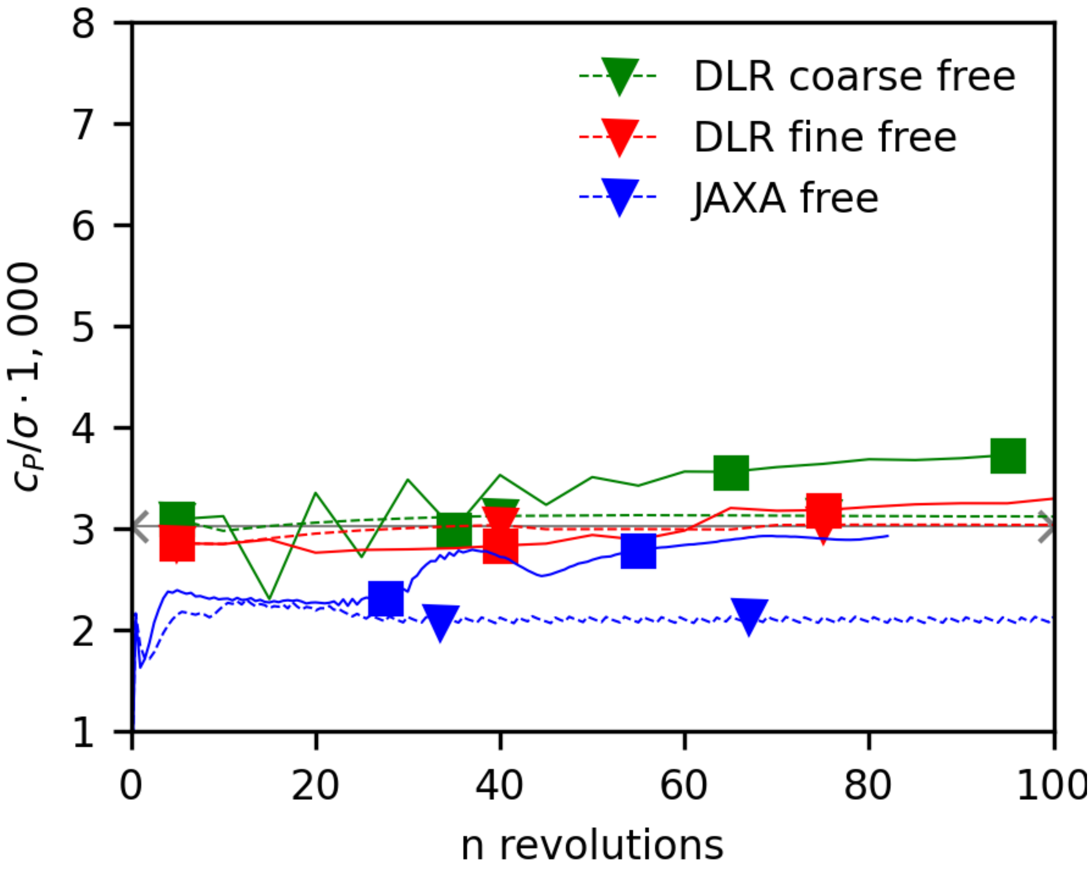
- JAXA applied an inner/outer background grid technique for the free flow to avoid issues with the farfield condition





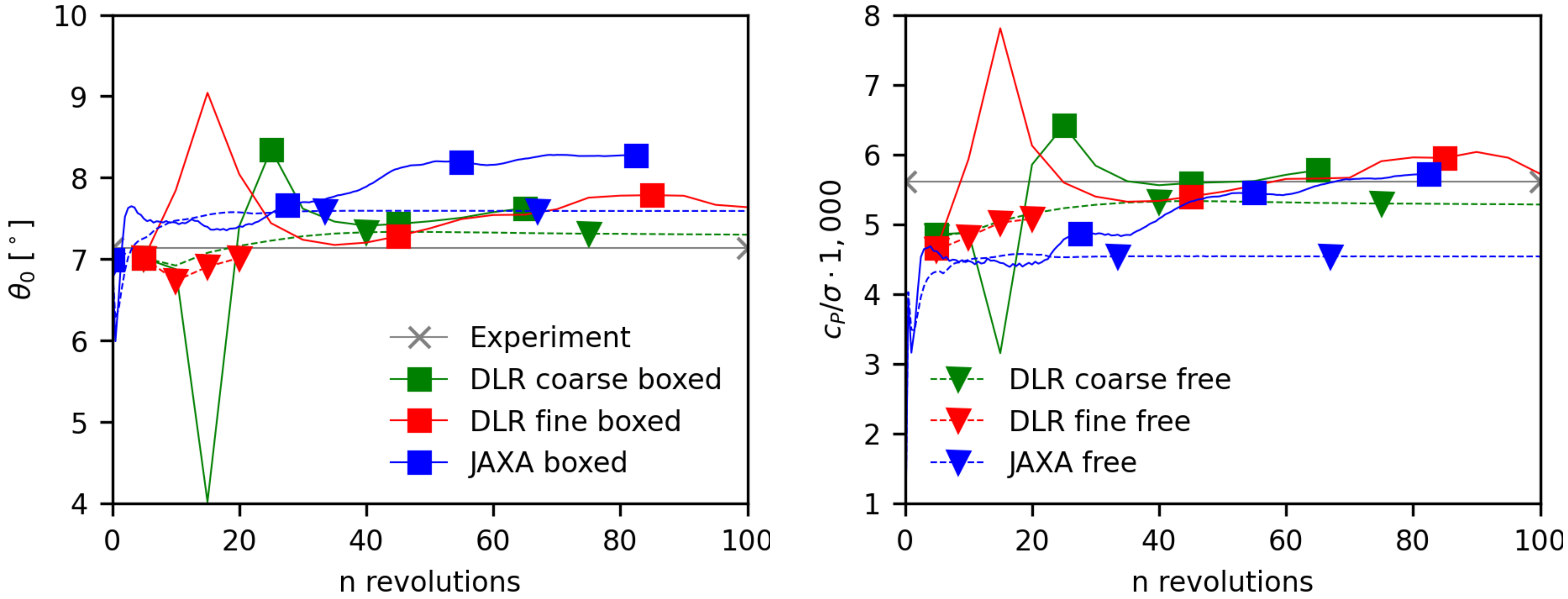
Results – Trim convergence – T=2kN / c_T/σ = 3.54/100





- Trim convergence for free flight significantly better than for boxed flow
- Expected drift observed

Results – Trim convergence – T=3.6 kN / c_T/σ = 6.37/100



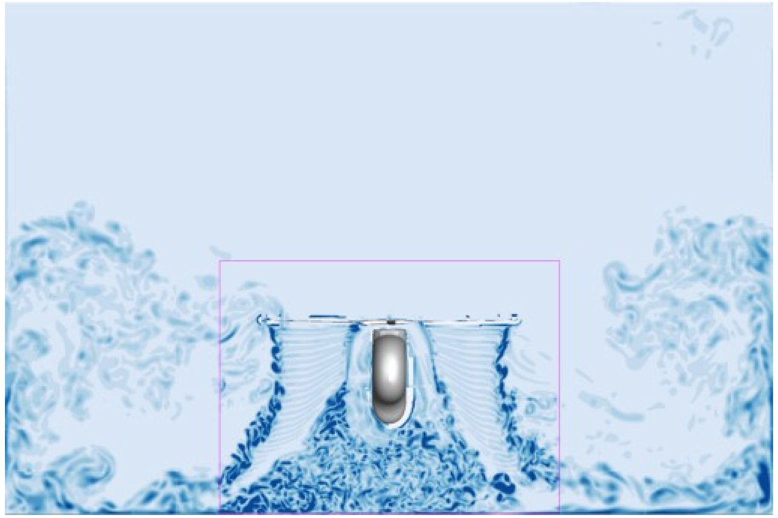
- DLR Fine grid issues with comprehensive code – recovered on the fly
- Faster convergence for boxed flow due to higher speeds

Results – Vertical Velocity Evolution – T=2.0 kN / c_T/σ = 3.54/100

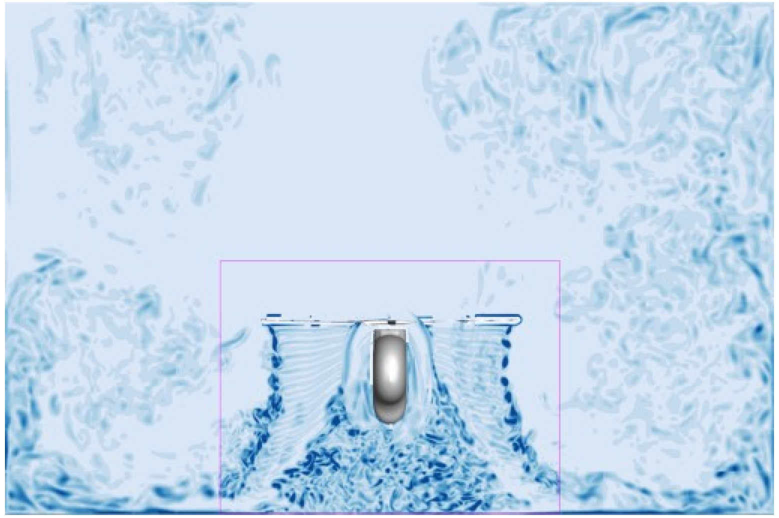
- Flow not fully developed after 65 revolutions
- After 80 revolution roughly doubled estimated cycle time
- 100 revolutions shows little change and only grown chaos

Results – Vortex Strength Evolution – T=2.0 kN / c_T/σ = 3.54/100

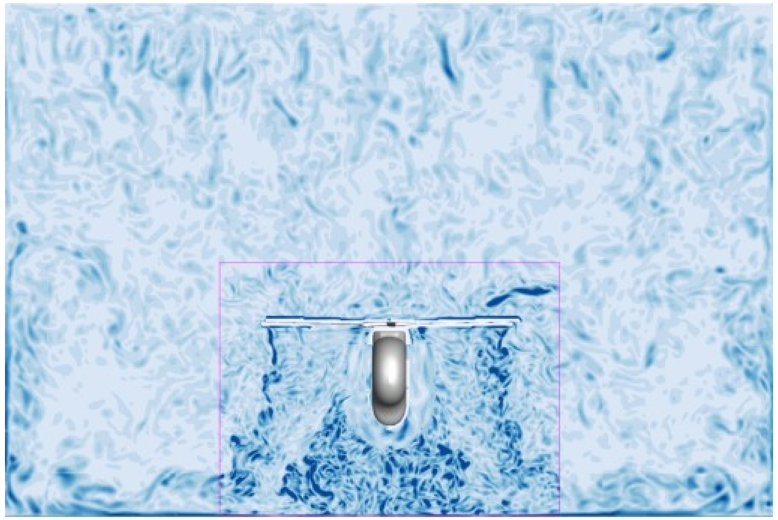
65 revolutions



80 revolutions



100 revolutions

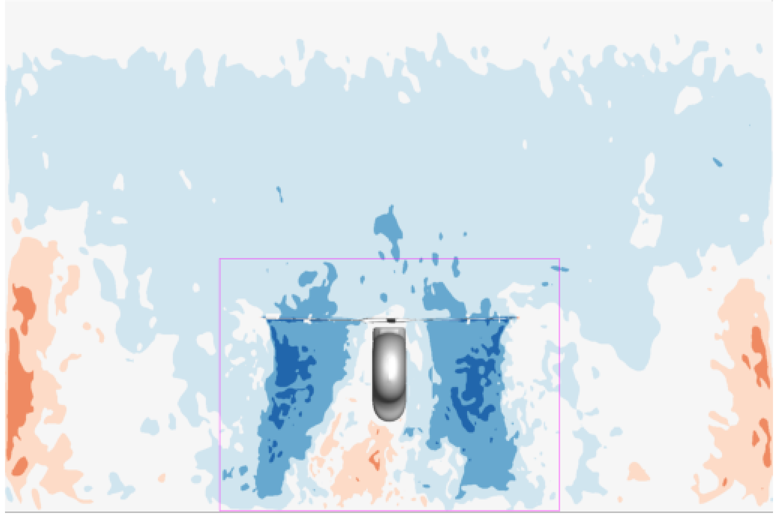


- Boxed not filled with secondary structures above the wall after 65 revolutions
- 80 revolutions first secondary structures found at the hall ceiling
- 100 revolutions the ‘periodic’ case, yet only increasing chaos due to adding energy

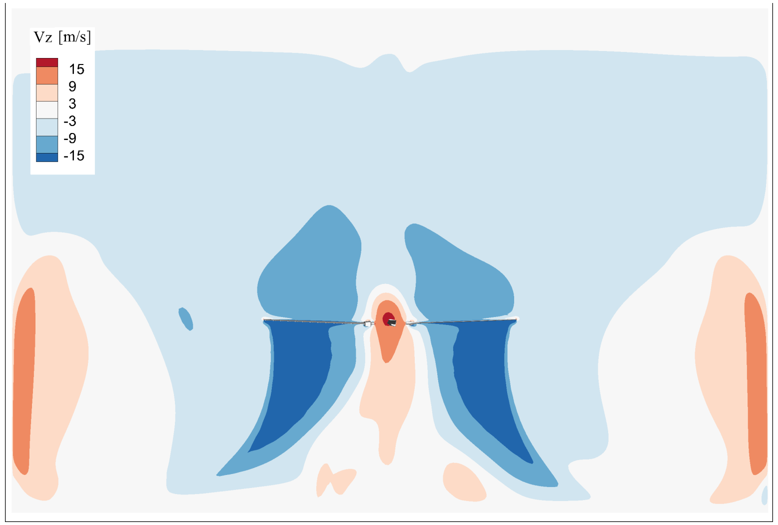
DLR

Results – Vertical Velocity – T=2kN / c_T/σ = 3.54/100

DLR fine grid

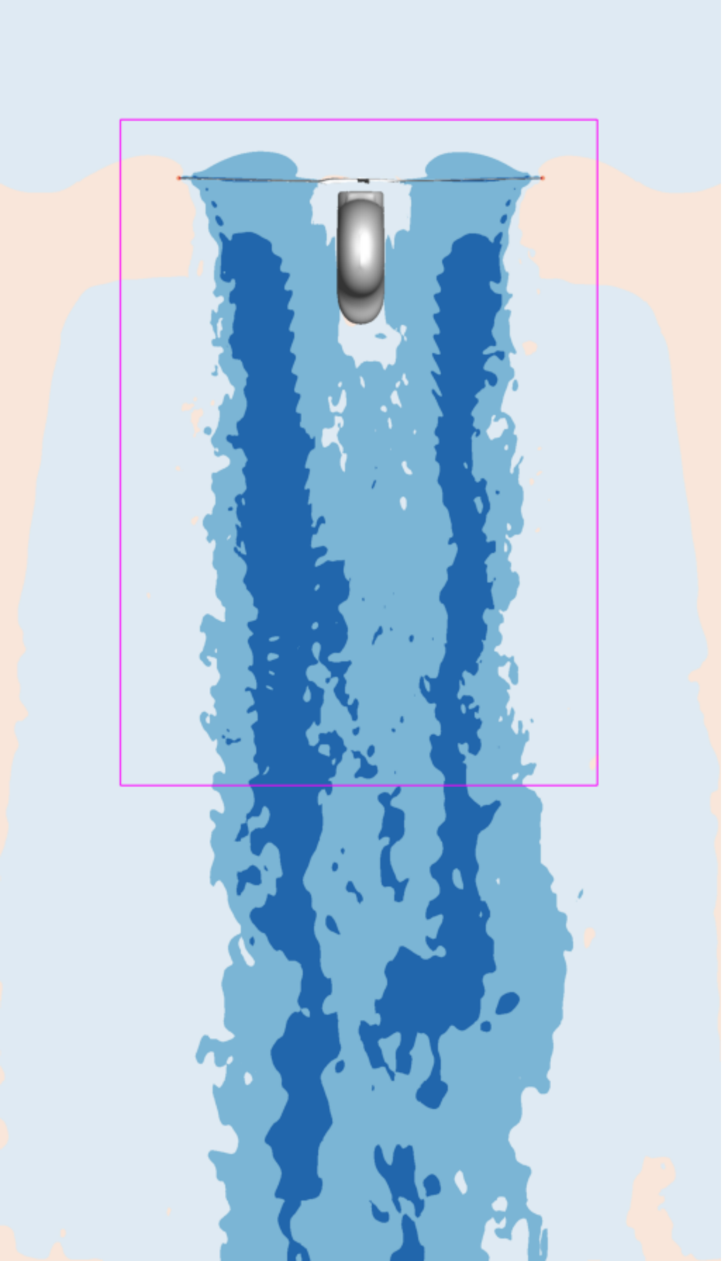


JAXA grid



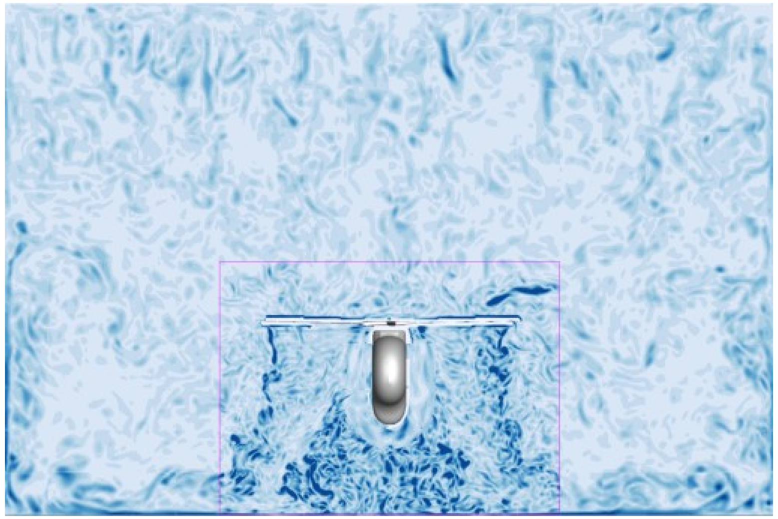
- General flow velocity distribution similar between DLR and JAXA
- In ground, but also re-circulation observed
- Difference between JAXA & DLR
  - DLR has a more jagged velocity distribution
  - JAXA has an upwash in the hub region – root vortex is not blocked by hub as for DLR (simplified hub and fuselage block this)

DLR fine grid

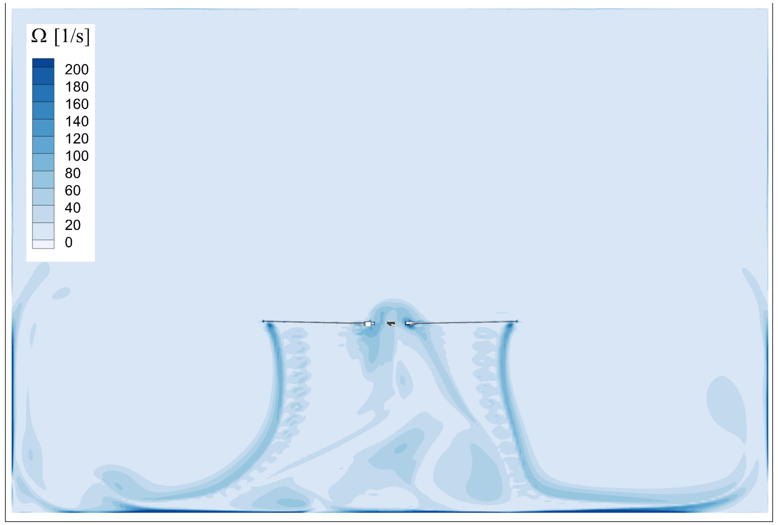


Results – Vortex Strength – T=2kN / c_T/σ = 3.54/100

DLR fine grid

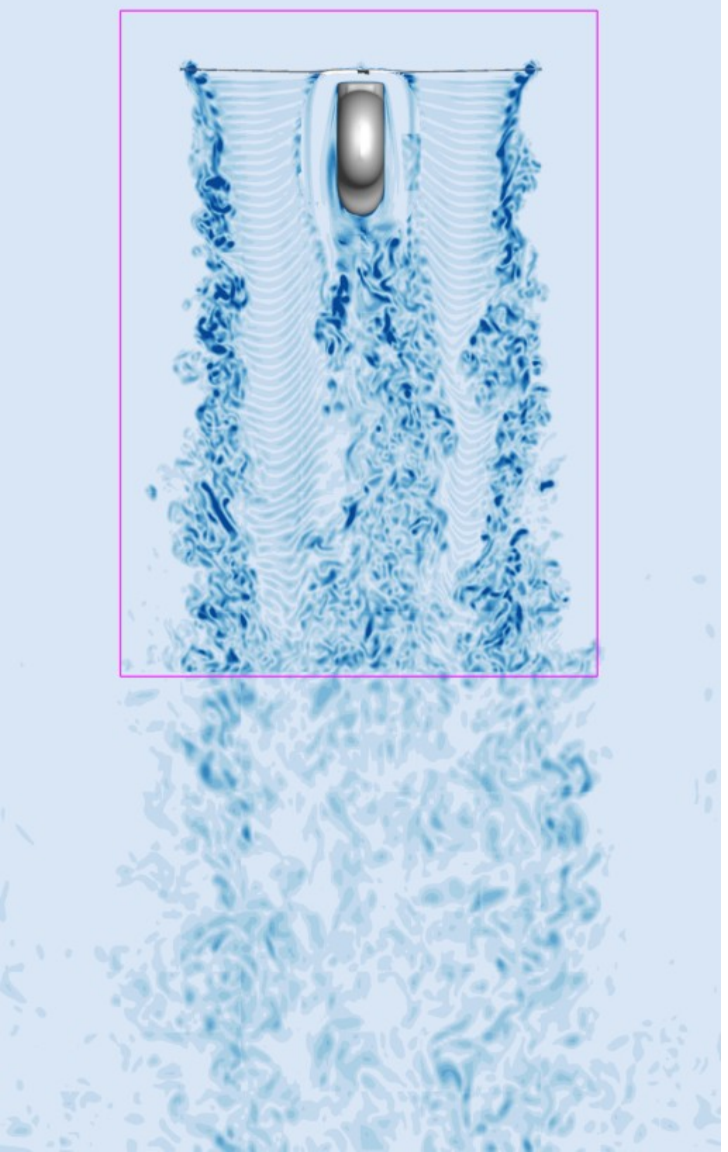


JAXA grid



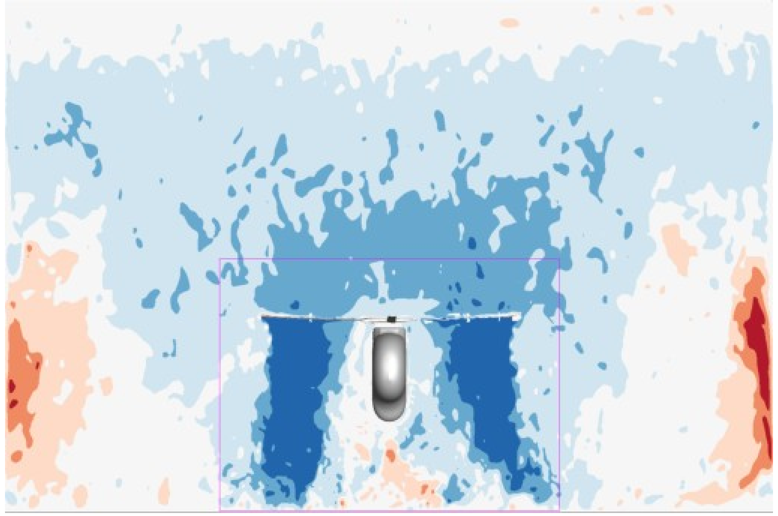
- Primary vortices resolved by both partners
- Many more secondary vortices for DLR
  - Reason is the application of DDES with slightly finer grid spacing

DLR fine grid

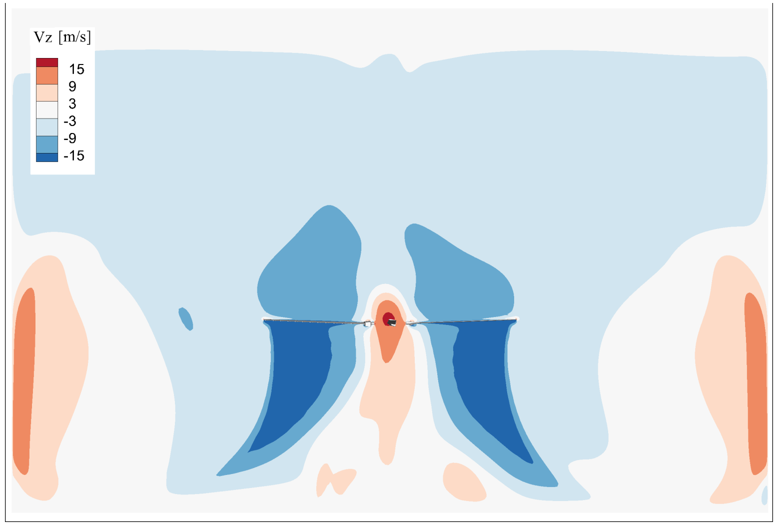


Results – Vertical Velocity – T=3.6 kN / c_T/σ = 6.37/100

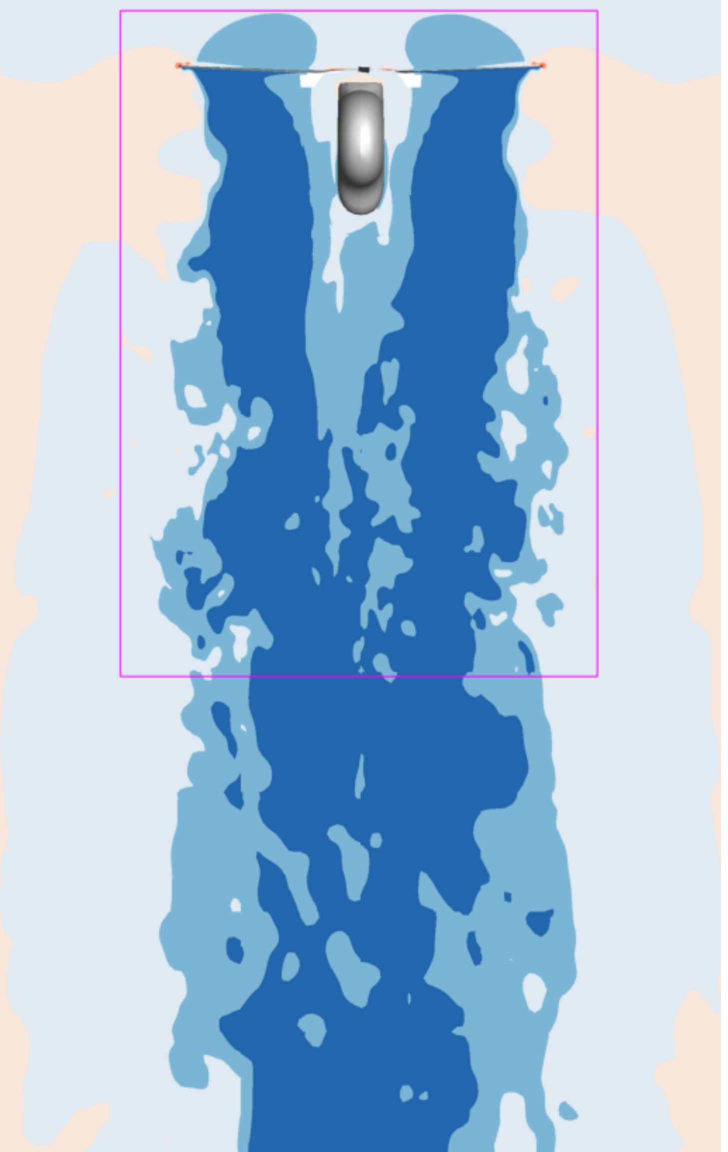
DLR fine grid



JAXA grid



DLR coarse grid

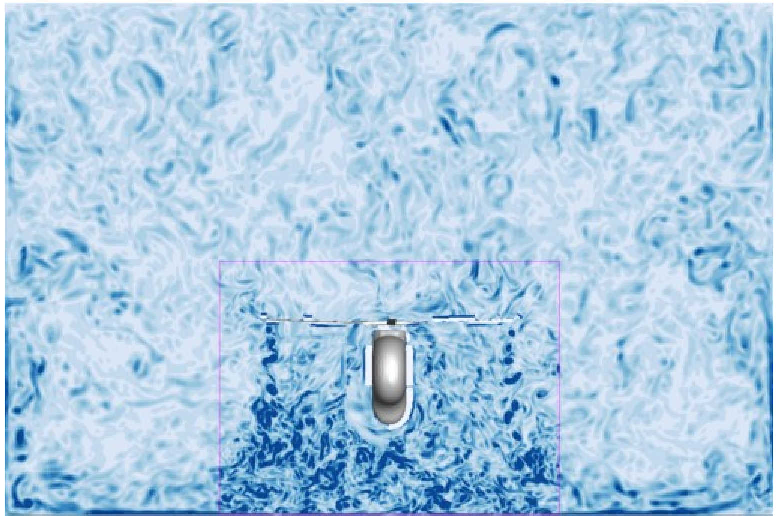


- The differences among the partners remain similar for the higher thrust
- Both partners capture the same trend, that as expected, the velocities increased and in particular the re-circulation effect becomes stronger

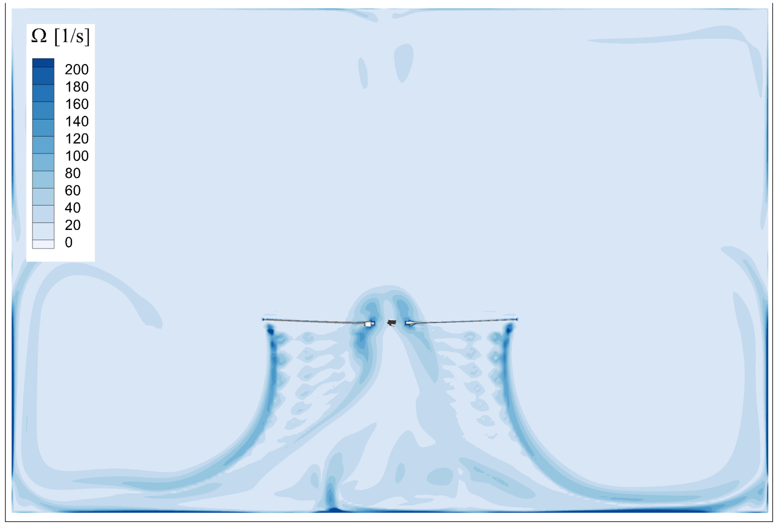
DLR JAXA

Results – Vortex Strength – T=3.6 kN / c_T/σ = 6.37/100

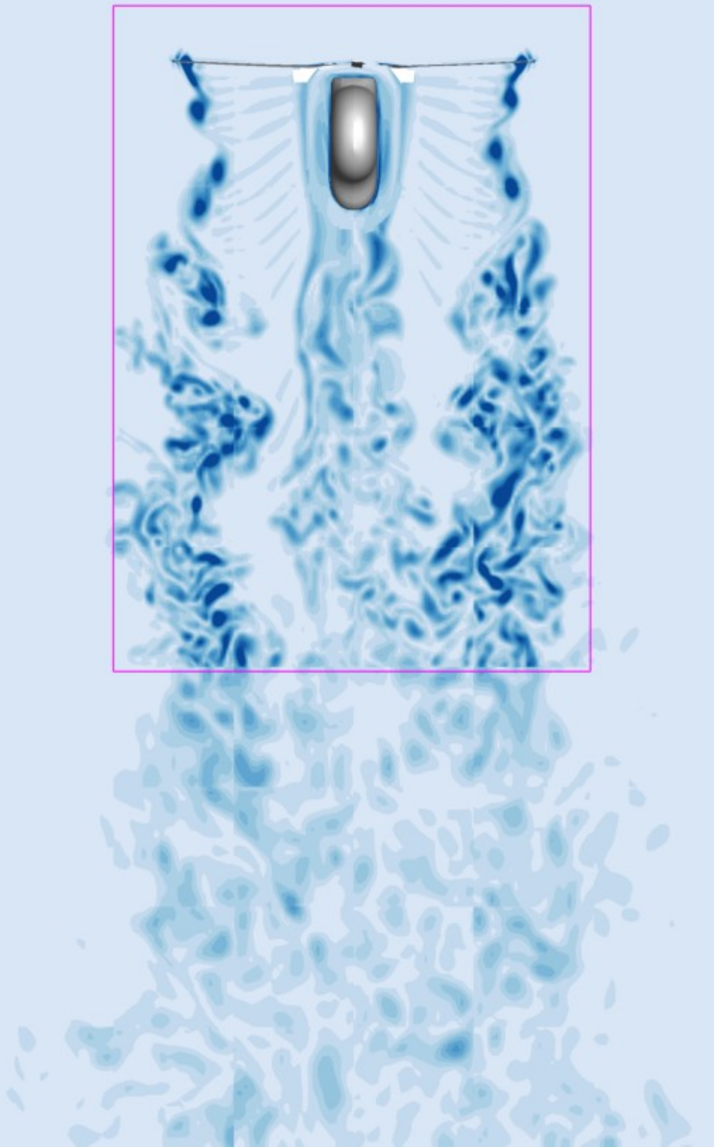
DLR fine grid



JAXA grid

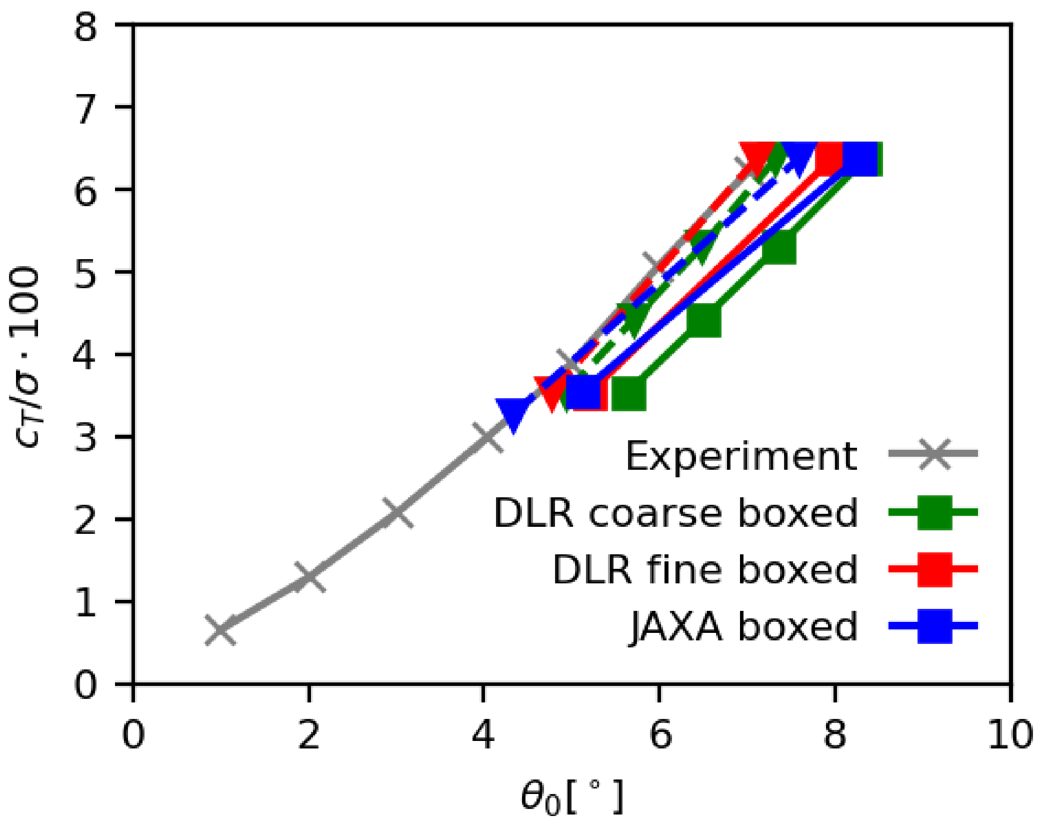


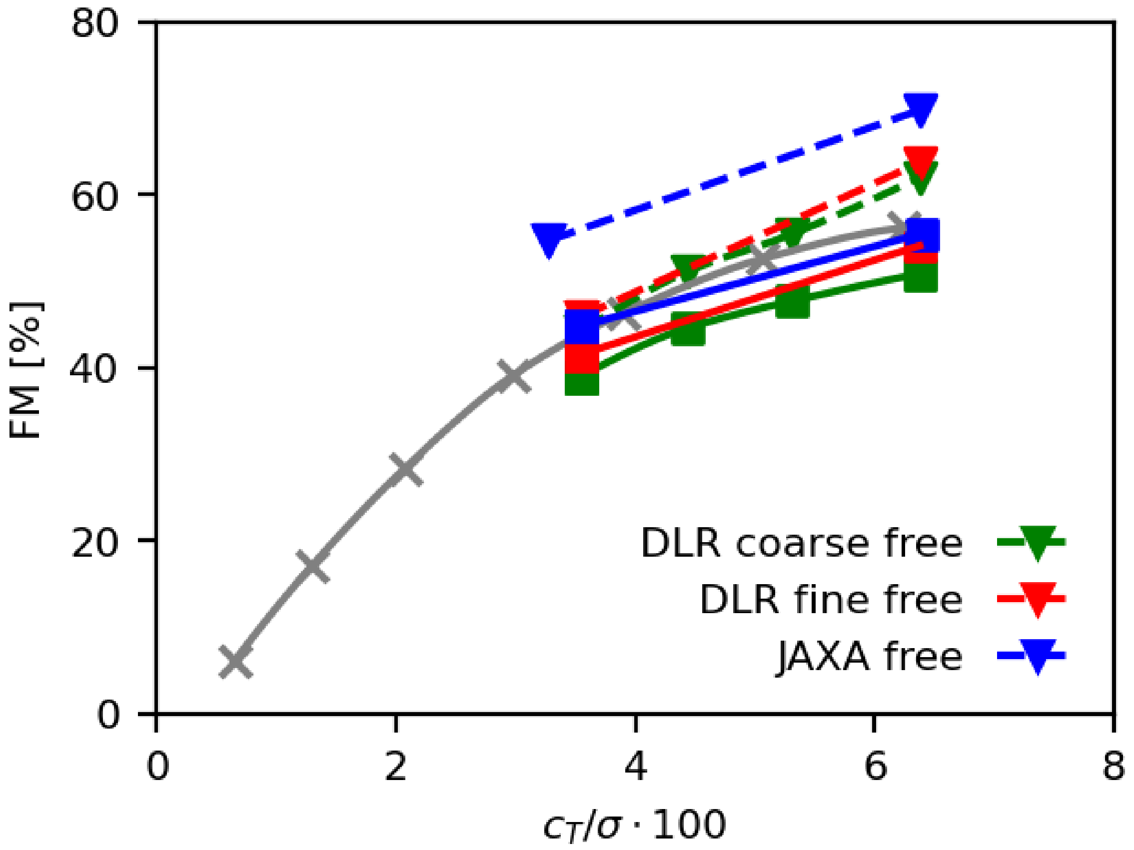
DLR coarse grid



- The strength of the primary and secondary vortices increased with thrust
- The box is therefore filled with many ‘worms’ in contrast to the plain free stream flow

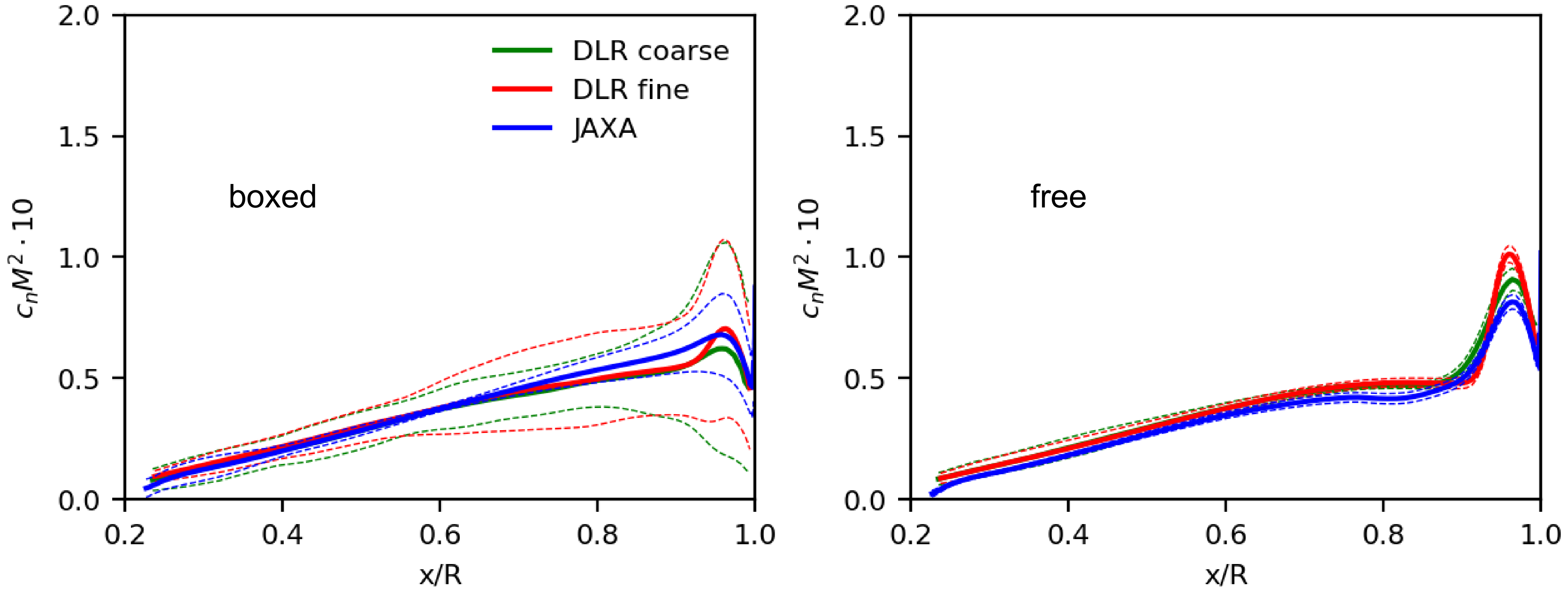
Results – Performance





- The collective is higher for boxed flow over free flow. The DLR coarse grid needs even more (num. Diss.)
- Figure of Merit is lower for the boxed flow. Agreement with experiment is good with offset -

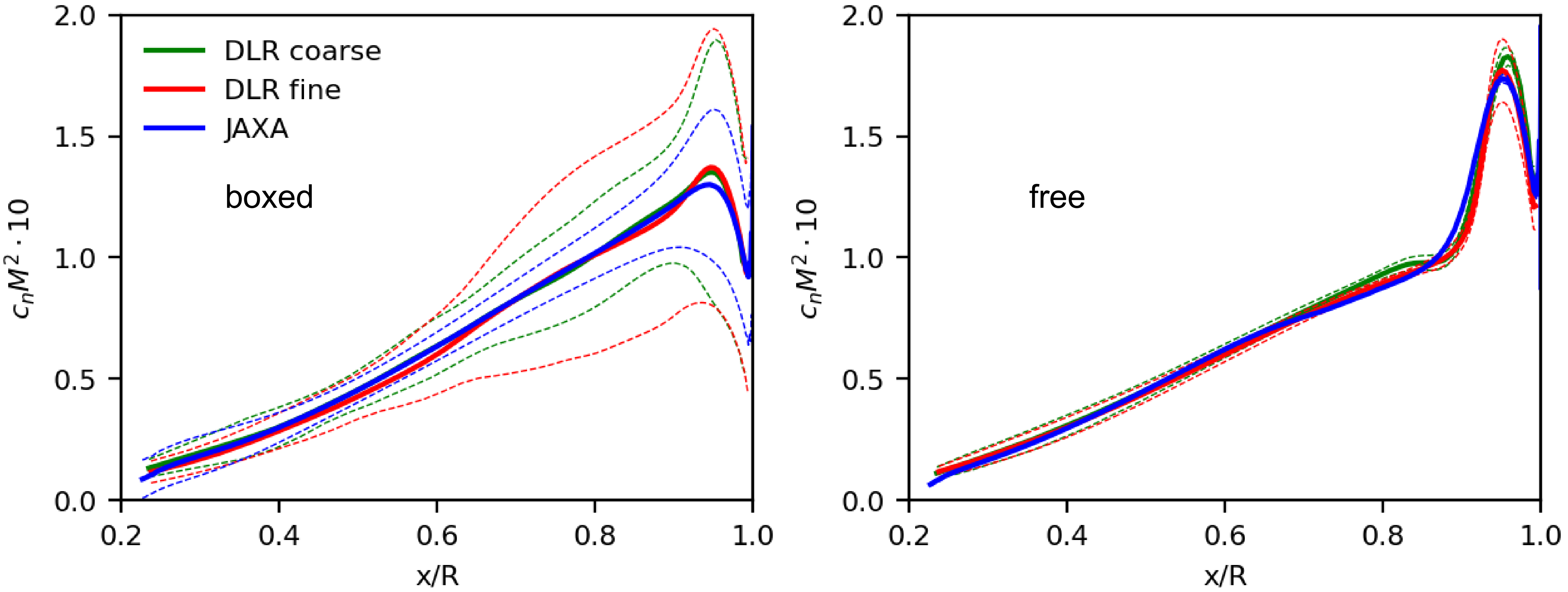
Results – Loads – T=2kN / c_T/σ = 3.54/100



- Dashed lines show 2 x standard deviation (95% interval) added to mean normal force.
- Boxed flow has noticeable greater deviation and lift distribution appears more like a climb than a hover case

DLR JAXA

Results – Loads – T=3.6 kN / c_T/σ = 6.37/100



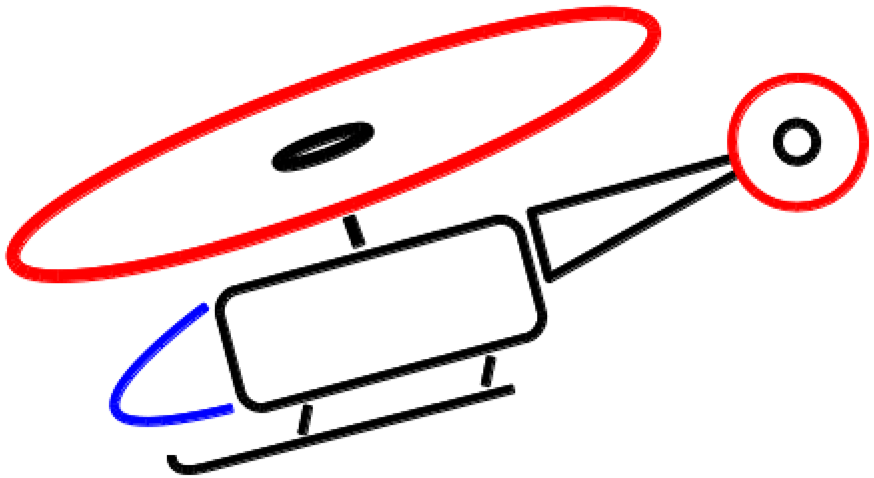
- Standard Deviation grows analogue to the overall thrust
- DLR has greater deviation in both case → a) DDES instead URANS and b) fuselage is included

Summary

- Simulation of hovering rotor in a box: investigation of the flow phenomenon in the pre-test hall at DLR Braunschweig
- Literature research revealed little existing research on that, among the first
- ‘Common’ sense results observed: lengthy runtimes confirmed with momentum theory, re-circulation found as expected
- Boxed flow more difficult to trim (latency), it will likely be better to run at fixed pitch angles rather than trim the rotor. Then interpolate results
- Runtimes of over 3 months – recommend a Cartesian solver (only curvilinear structured applied here)

International Design Workshop on Rotor Blade Optimization (InDeWo) after ERF on Friday, September 8th , 09:00-14:00 German time (UTC+1)

- Extension of JOD-ROC open to anybody
- HART II as baseline rotor
- Participate and share results with us
- Online spots still available!
- Contact Gunther.Wilke@dlr.de
  +49 176 226 33 857



DLR JAXA