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R2Wall:
From wall-resolved to wall-modeled LES

PRACE 14th call

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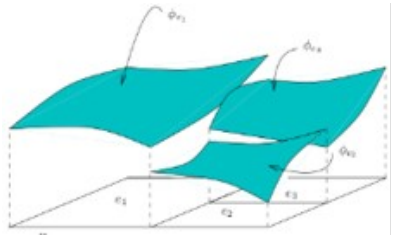
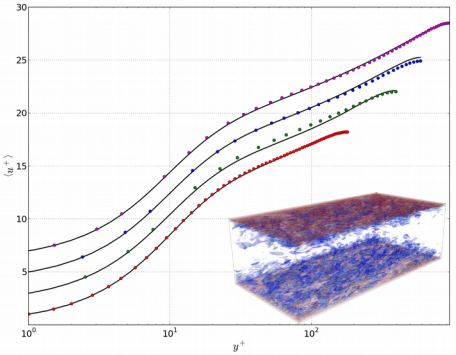
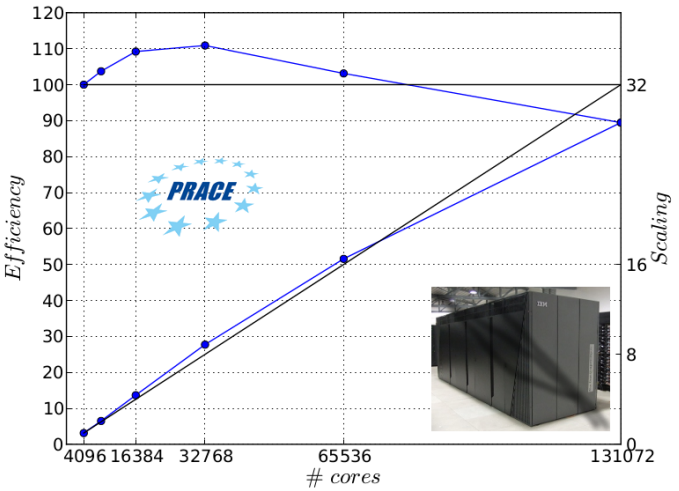
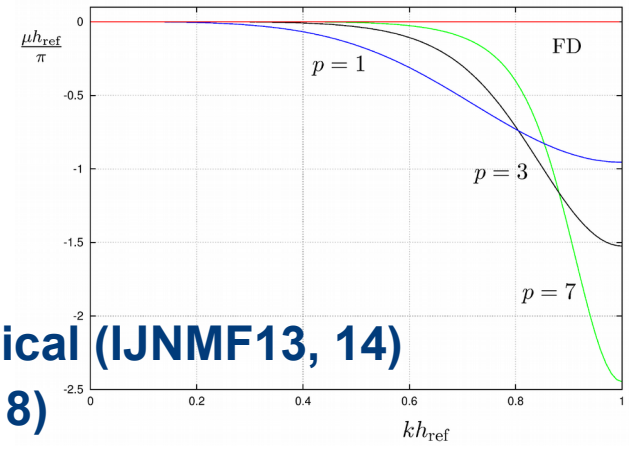
Argo - discontinuous Galerkin method (DGM)

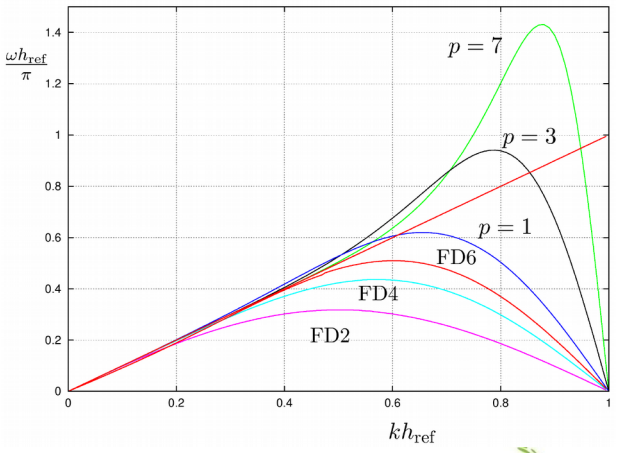
- **Hybrid FEM – FVM**
  - FEM per element
  - Internal BC/Riemann
  - Stable for hyperbolic systems
  - Conservative
- **High accuracy**
  - order of accuracy (p+1)
  - low dissipation/dispersion
  - on unstructured mesh
- **Efficiency**
  - matrix-matrix operations
  - scalability (MPI/OpenMP)
- **Implicit LES**
  - Sharp cut-off ~ SGS
  - Extensive validation canonical (IJNMF13, 14)
  - Wall models (PoF17, FTaC18)











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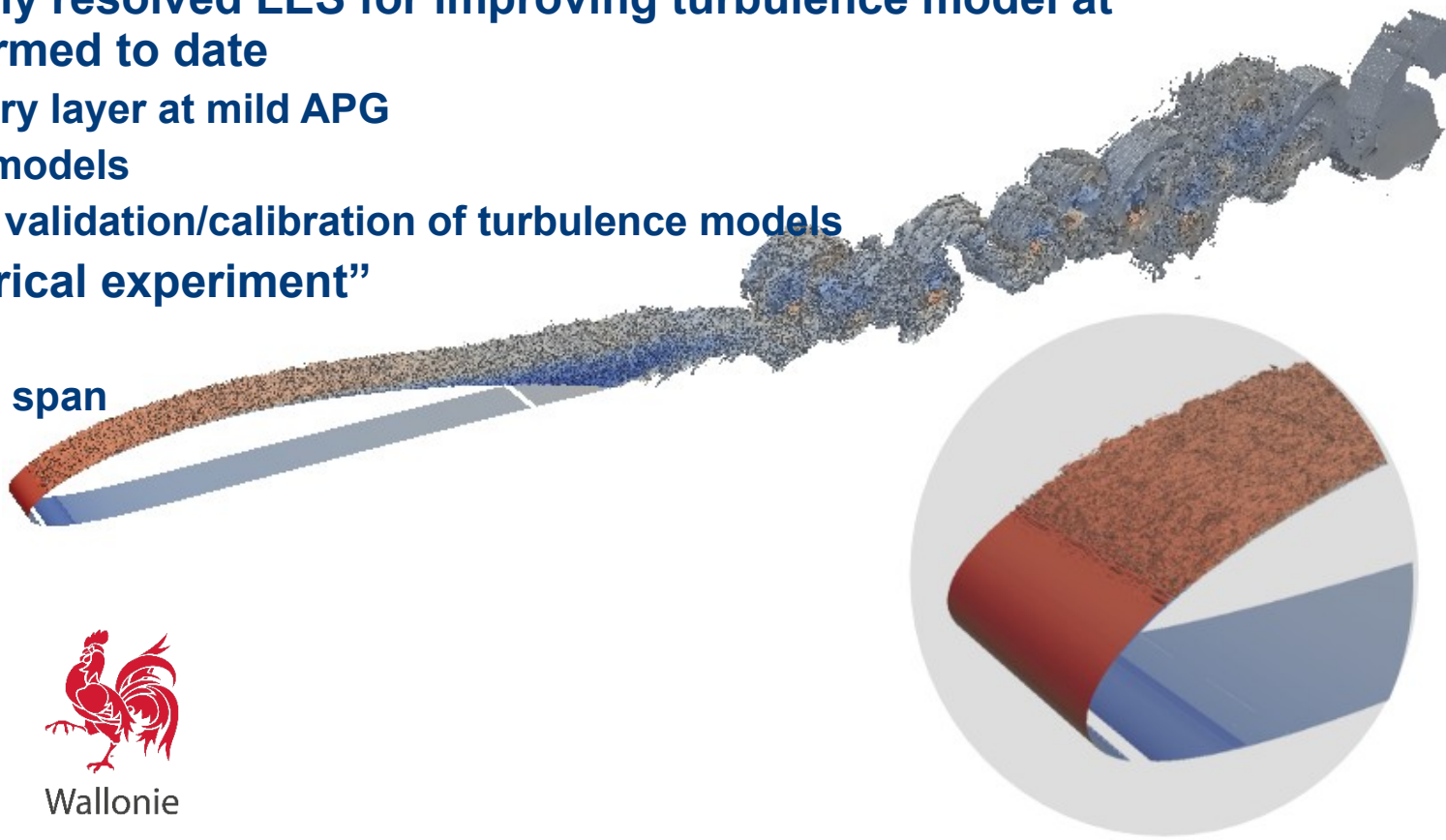
R2Wall – 14th PRACE Call, Jülich Supercomputing Centre

Wall-resolved LES of NACA4412 near stall at Re=1.6 million

- **Part of PhD A. Frère – Wall shear stress modeling strategies for LES**
  - **FirstDocA doctoral project @ UCLouvain**
  - **Previously : Frère et al. PoF17 & FTaC 18**
- **Goal: near DNS/ highly resolved LES for improving turbulence model at higher Re than performed to date**
  - **Analysis of boundary layer at mild APG**
  - **Calibration of wall models**
  - **Open data base for validation/calibration of turbulence models**
- **Reproducible "numerical experiment"**
  - **No inlet turbulence**
  - **Periodicity 1 & 10% span**



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ÉCOLE POLYTECHNIQUE DE LOUVAIN

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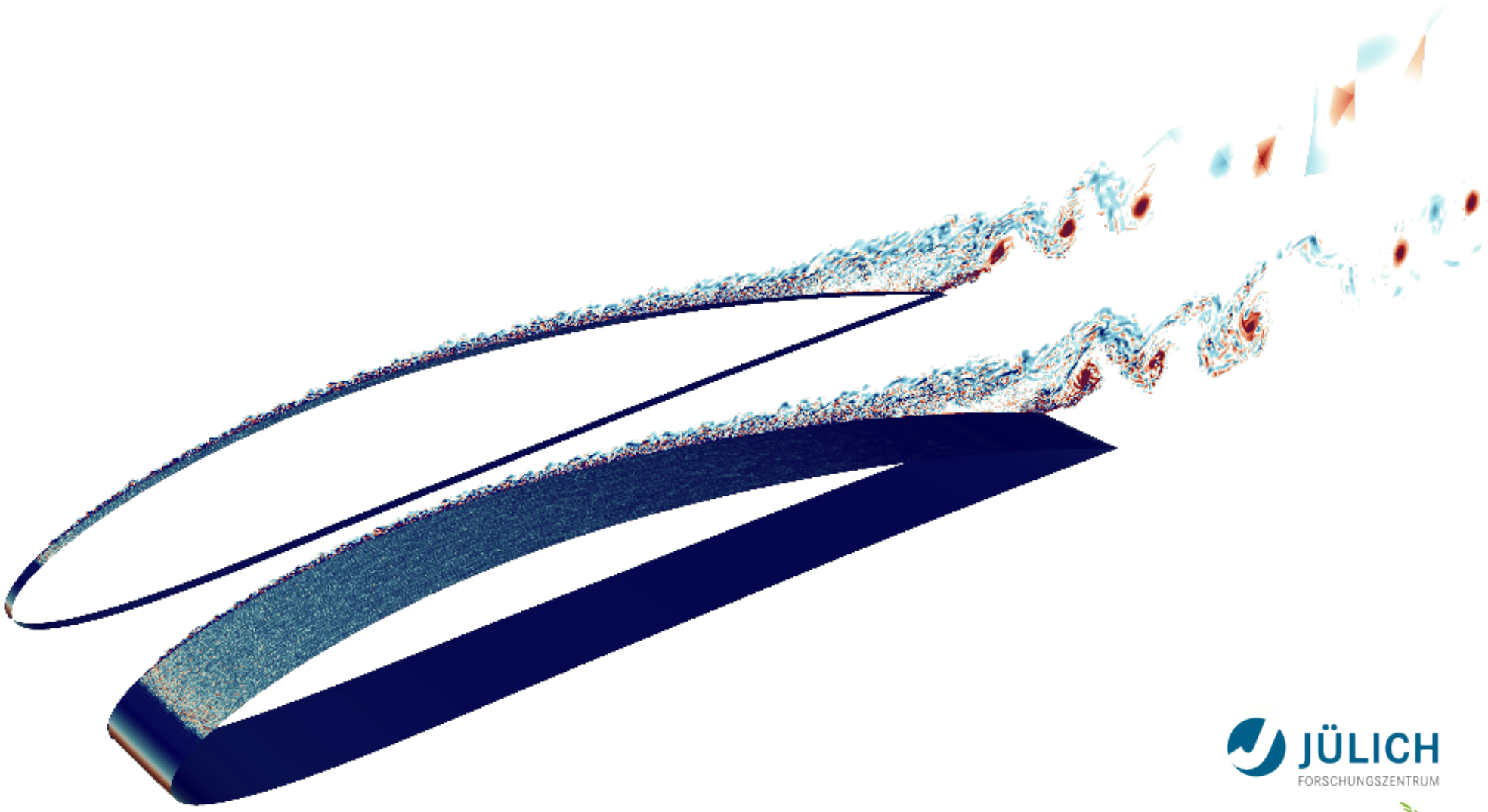
Calibration of wall-modeled LES on NACA4412

Span effects: 1% (CEN) – 10% span (JSC)



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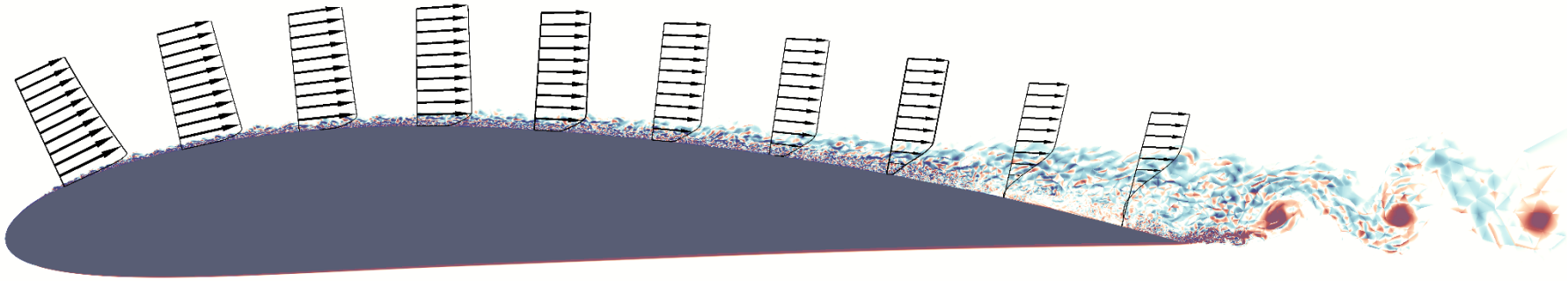
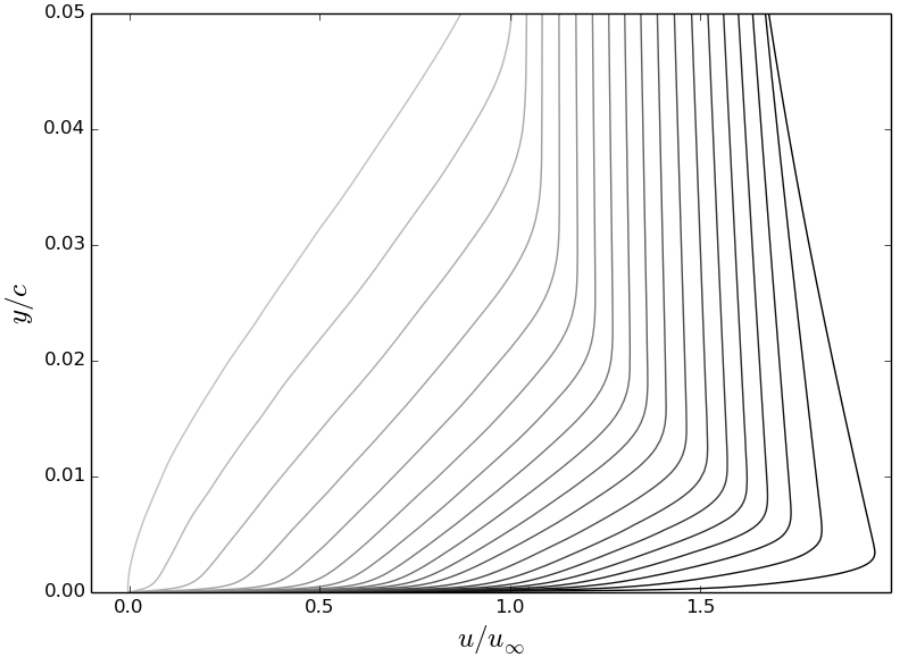
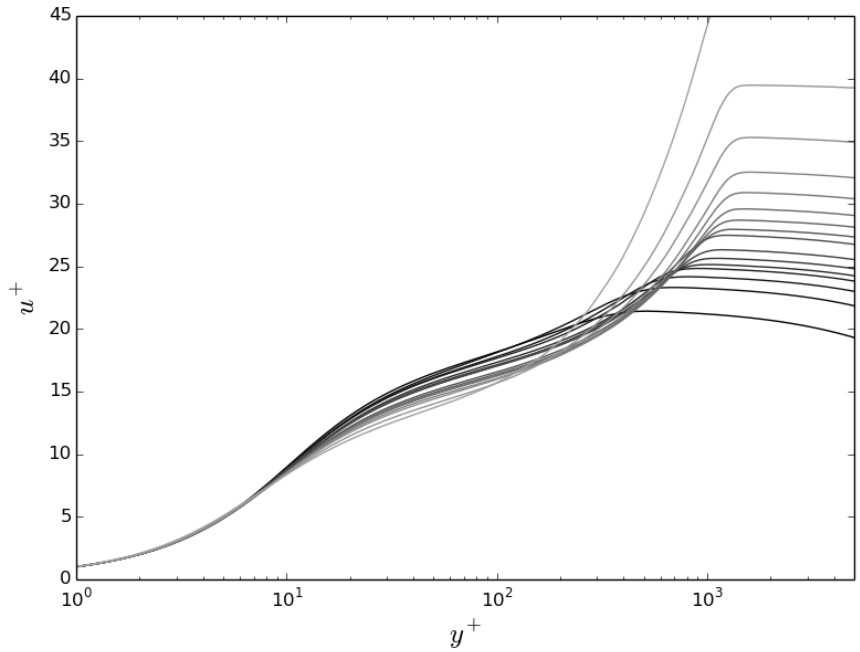
Calibration of wall-modeled LES on NACA4412

Detailed analysis of boundary layer – velocity profile







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- ***Criteria***
  - ***novelty and timeliness of the science proposed;***
  - ***ambition, adventure and transformative aspects;***
  - ***appropriateness of the proposed methodology.***
- ***Reviewer 1***

  "Typically, DNS of separated flows for similar configurations are possible for Reynolds numbers not exceeding 100,000 while the actual flows of engineering interest have Reynolds numbers in the range between 0.5 and 2 million. The authors propose simulations at Re=1.6 million, i.e., in the range of interest in practical applications.

  …

  I expect that the combination of the realistic Reynolds number, an accurate numerical solver, and tested LES method will produce a very valuable database for those who work in the area of separated flows around turbine blades and airfoils."

- ***Reviewer 2***

  "The proposal is interesting, its biggest novelty is the fact that provides LES result of a NACA airfoil at AOA=1 and a large Reynolds of 1.6M. The research is timely, as Wall-modelled LES is important as in configurations of industrial interest (with large Reynolds), LES alone is very expensive as a lot of effort is spend in solving the viscous sub-layer. There has been a long tradition of using wall-functions to model the shear stress at the first node close to the wall, the problem is what happens when the boundary layer separates and how the model behaves.

  The strength of the proposal lies in the use of well-defined "numerical experiment" (BC, geometry, etc.), compared to expensive wind-tunnel testing. The generated database that can be used to develop new WMLES models, investigate separation effects or three-dimensional effects.

  …

  The final simulation would probably be one of the largest database of NACA (existing large scale DNS are about Re=0.4M with 3.2 B grid points)."

Scientific review
Impact

- ***Criteria***
  - ***relevance of the research proposed for the development of the research area ;***
  - ***any commercial or societal application and if the research would be transferable to other scientific disciplines;***
  - ***appropriate routes and resources have been identified for dissemination and knowledge exchange.***
- ***Reviewer 1***

"The ultimate success of the proposal will be in the dissemination of the database and how different groups interact with it. This of course, is very difficult to judge a priori. The authors have derived an adequate Impact plan based on the High-Order CFD Workshop (that they co-organize) and journal publication. In principle, the database could be used for a decade or so before computer progress makes new simulations cheaper. In this aspect, the proposal has a relatively long-life and it will add value to the European research portfolio.Still, the proposal is scarce on details how this will be managed apart from the website. Maybe hosting researchers? Where is going to be the database published."

"I am confident that at least one or two journal publications should come out of the project and several conference papers. ... The acceptance of a paper there will be based on new effects discovered by the simulations (not just the fact that is a big simulation). To my knowledge the authors have not identified the new "science" that can come up from these simulations (which, from the engineering point of view, are very interesting)"

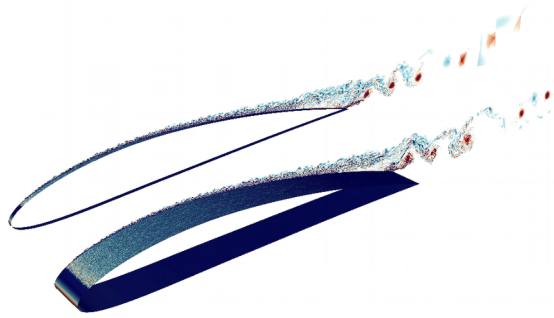
- ***Reviewer 2***

"Expected impact of the proposed research will be twofold:

- *(1) creating an accurate database of flows that can be used by engineers concerned with design of turbomachinery components, efficiency of wind turbines, flight stability of UAV's, ...*
- *(2) improving existing wall models for LES and potentially developing new models that could impact numerical simulations of not only engineering flows but also of environmental flows responsible for weather, climate, and spreading of pollutants.*

Several publications from the proposed research in good quality journals is highly likely."

- **Span/resolution convergence**
- **extrapolation ~ 1% span → credible estimates**
  - **Computational cost**
  - **Resolution**
  - **Statistical averaging**

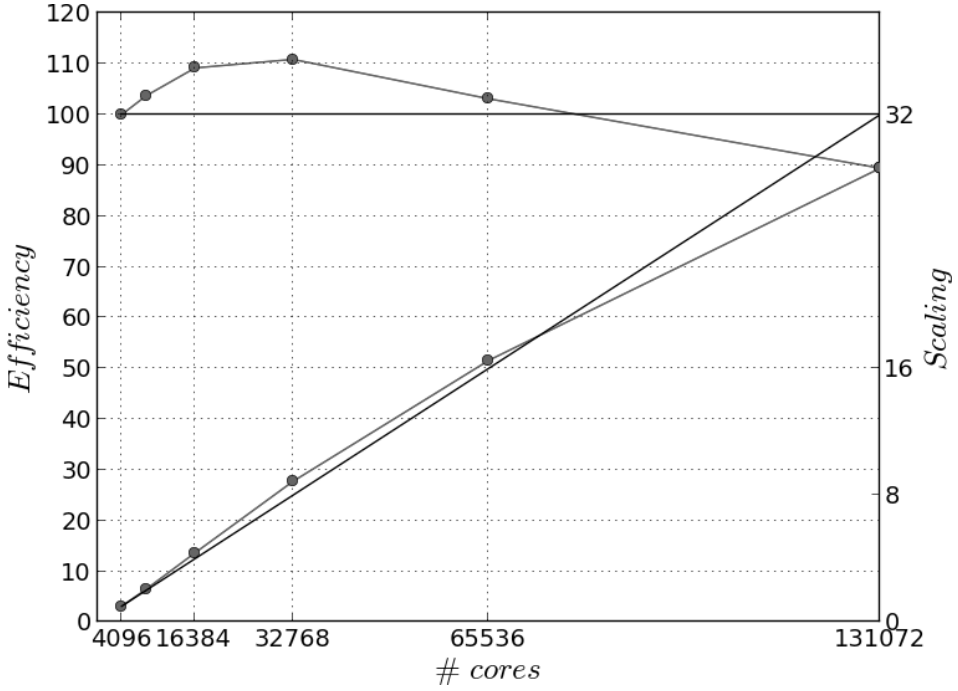


Run type	dofs/run	# Runs	convective time	# Steps /Run	Walltime /Step	# CPU cores	Total core hours /Type Run
WP1 A grid coarse - span=5% chord	80Mio	1	10	40k	6e-3	8192	1.9M
WP1 B grid medium - span=5% chord	226Mio	1	10	50k	8e-3	16384	6.7M
WP1 C grid fine - span=5% chord	640Mio	1	10	60k	6e-3	65536	22.6M
WP2 A grid medium - span=1% chord	45Mio	1	10	50k	7e-3	4096	1.3M
WP2 B grid medium - span=10% chord	453Mio	1	10	50k	8e-3	32768	13.3M
Total							45.9M

- **Gantt**
  - **gradual consumption of ~ 1/12 per month**
  - **logical follow-up of simulations**
    - Improved resolution ifo results
    - Reuse of coarse as starting point for fine computations

		hCPU (mio)	M1			M4			M7			M10		
WP1	A: grid coarse - span=5% chord	1.9												
	B: grid medium - span=5% chord	6.7												
	C: grid fine - span=5% chord	22.6												
WP2	A: grid best WP1 - span=1% chord	1.3												
	B: grid best WP1- span=10% chord	13.3												
Post processing + paper + website		-												

- **Prerequisite !!**
- **Scalability/efficiency**
  - **On requested machine**
  - **Use case: strong / weak scaling?**
  - **Optimal use of architecture**
    - MPI/OpenMP, accelerators
    - Sufficiently large proportion of machine
  - **All used code features**
    - I/O
    - Analysis of results



- **Work flow feasible ?**
  - **Libraries & tools available / compilable ?**
  - **Data transfer ? Estimation of disk space ?**
  - **Alternatively co-processing available ?**
  - **Checkpoint ?**

Conclusions

- **Technical review is prerequisite**
  - **Extensive performance data on all aspects**
  - **Includes full work flow**
  - **Demonstrate feasibility**
    - **to be prepared long time in advance**
    - **preparatory access on requested machine**
- **Scientific review**
  - **Reviewer = specialist/practitioner/competitor in your field !**
    - Scientific relevance to be demonstrated extensively w/ literature
    - Justification of computational time wrt to other codes !
    - Justify use of models, … by similar examples in literature
  - **Full disclosure & dissemination**
    - Reproducibility → verification of results
    - Database → verification and further exploitation
  - **Technical relevance**
    - Impact on competitiveness of industry ? Relation to EU work programme ?
    - Long term perspectives ?