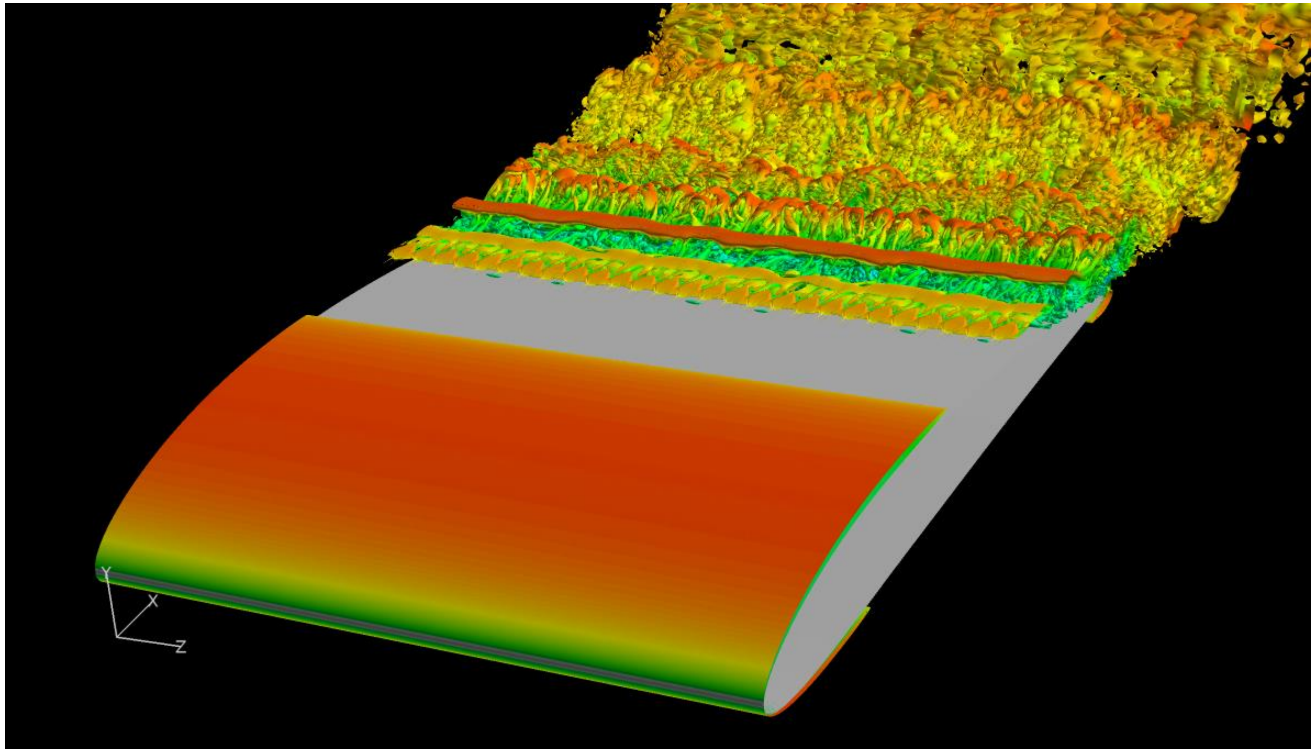
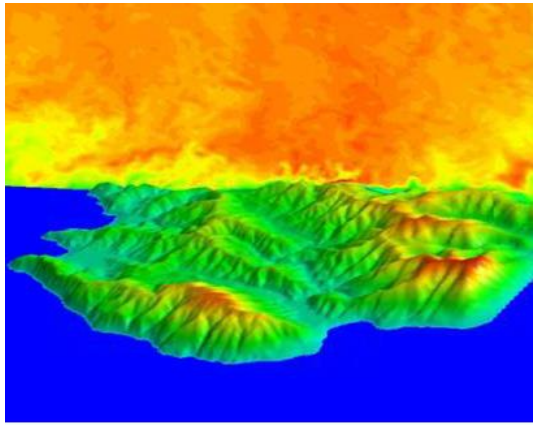
High Performance Computing in Wind Turbine Aerodynamics

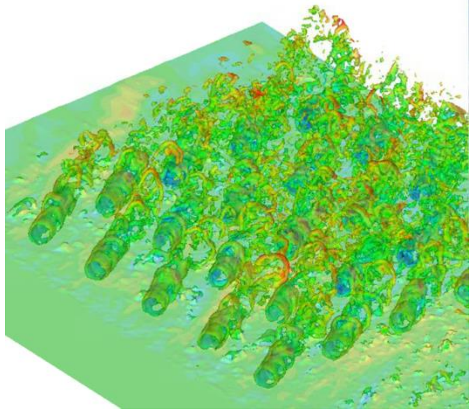
Niels N. Sørensen
Aerodynamic Design, DTU Wind Energy

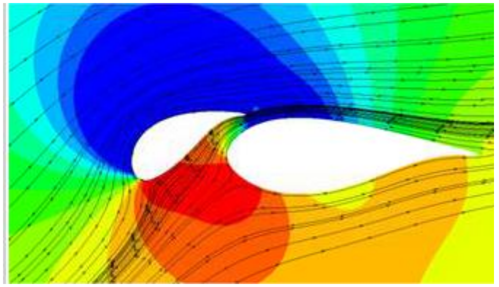


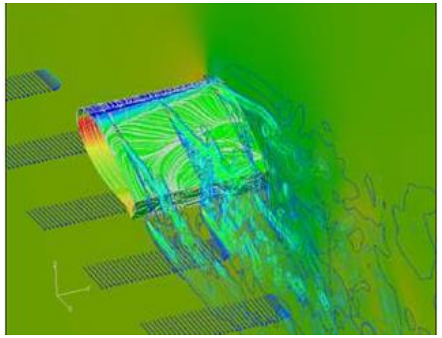
Applications

- Aerofoil aerodynamics
- Rotor aerodynamics
- Wake aerodynamics
- Wind farm flow
- Atmospheric boundary layer flows
  - Terrain
  - Atmospheric stability
  - Forest

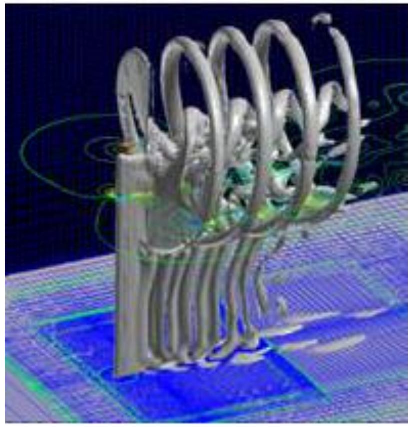


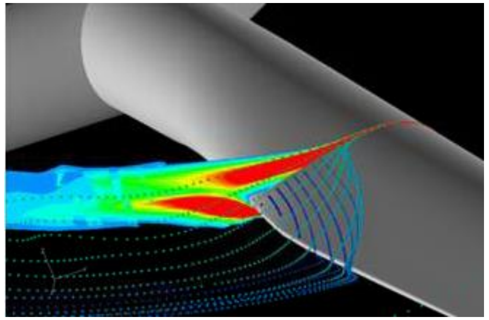






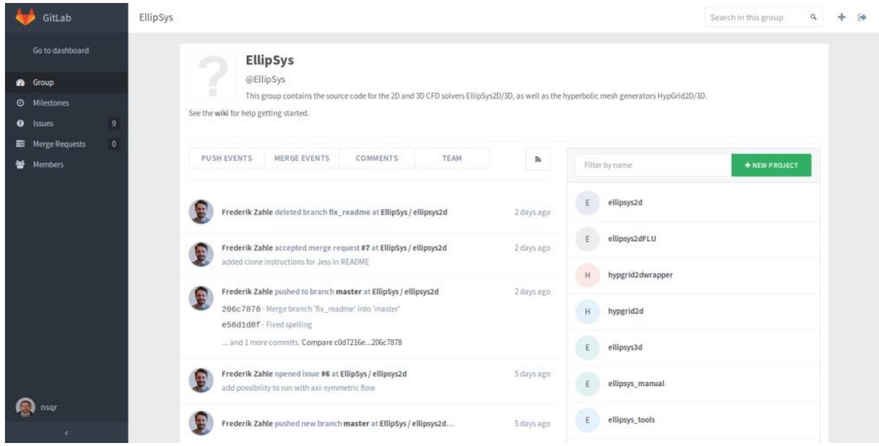
EllipSys2D/3D

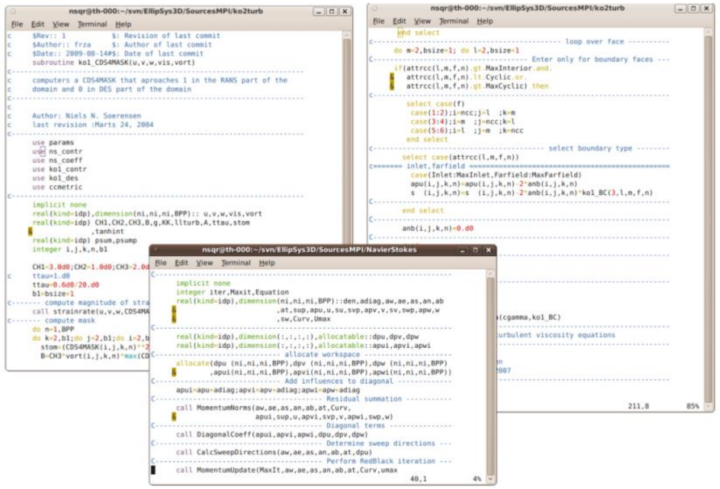


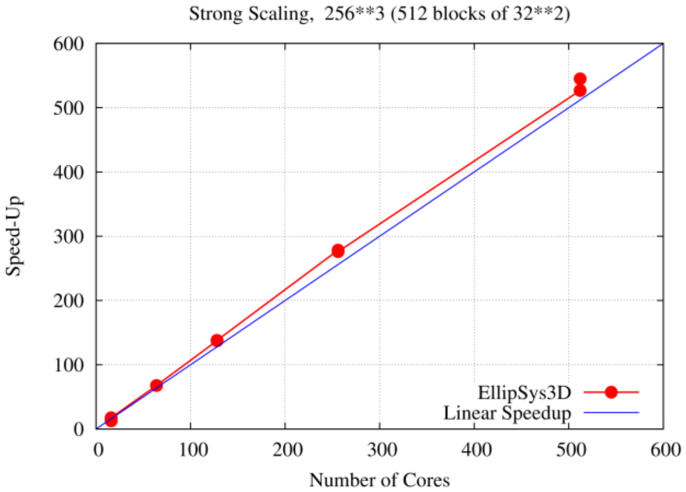


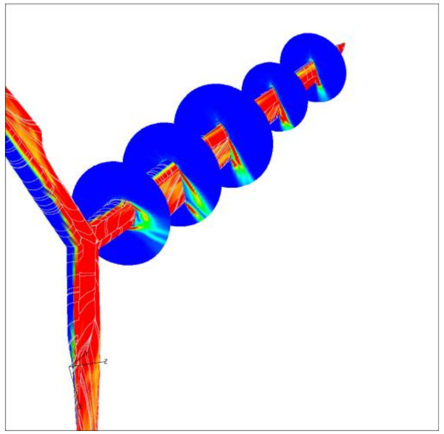
EllipSys2D/3D

GIT Repository

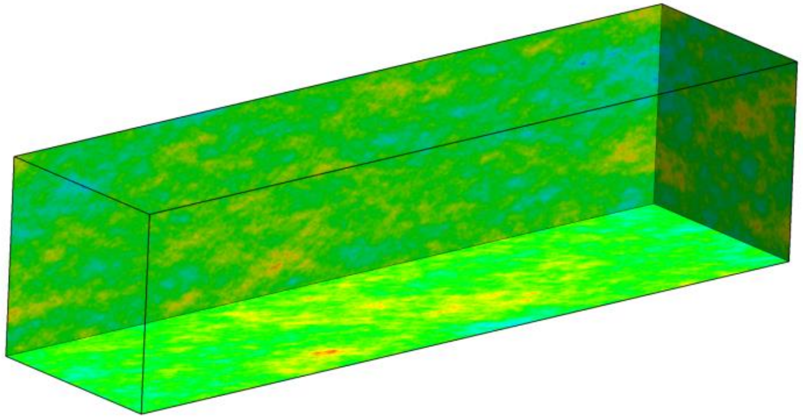


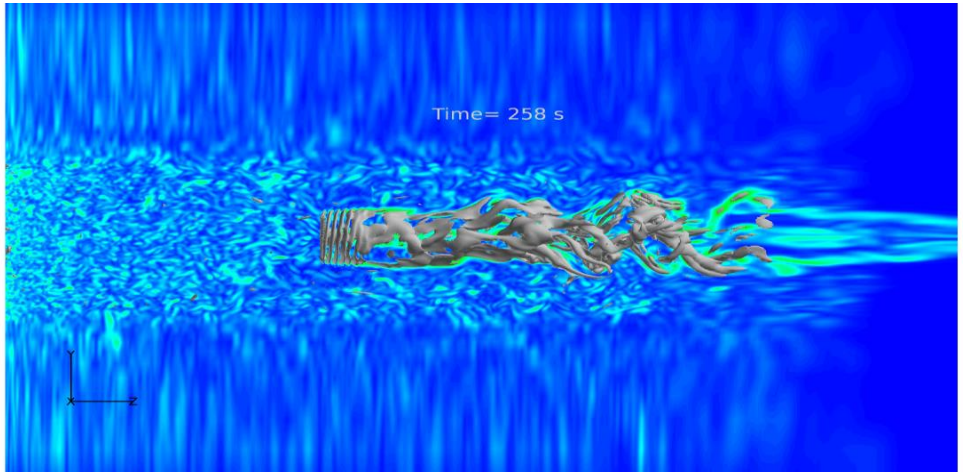


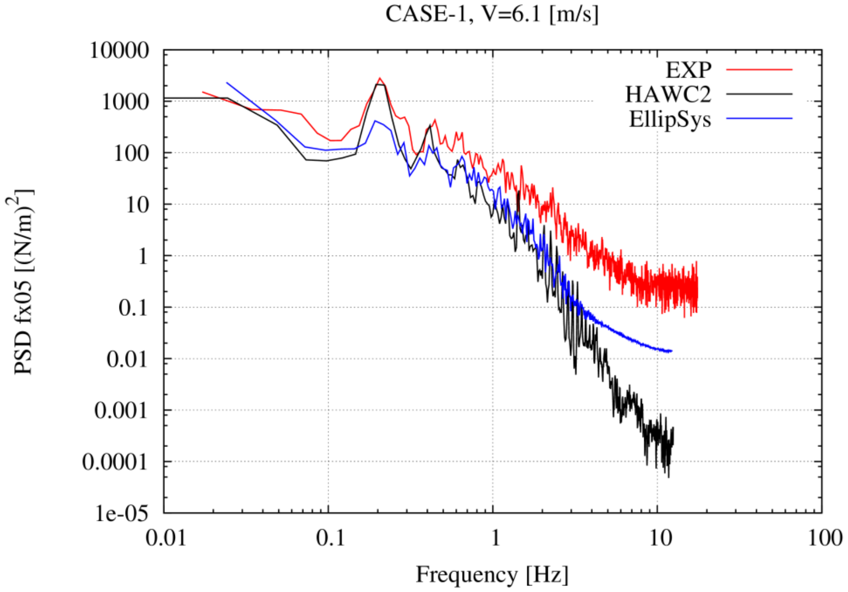




Rotors in Turbulent Inflow







Grid Size 32 Mill.

Comp. Requirement: 72 hours on 506 Cores

Free form optimization

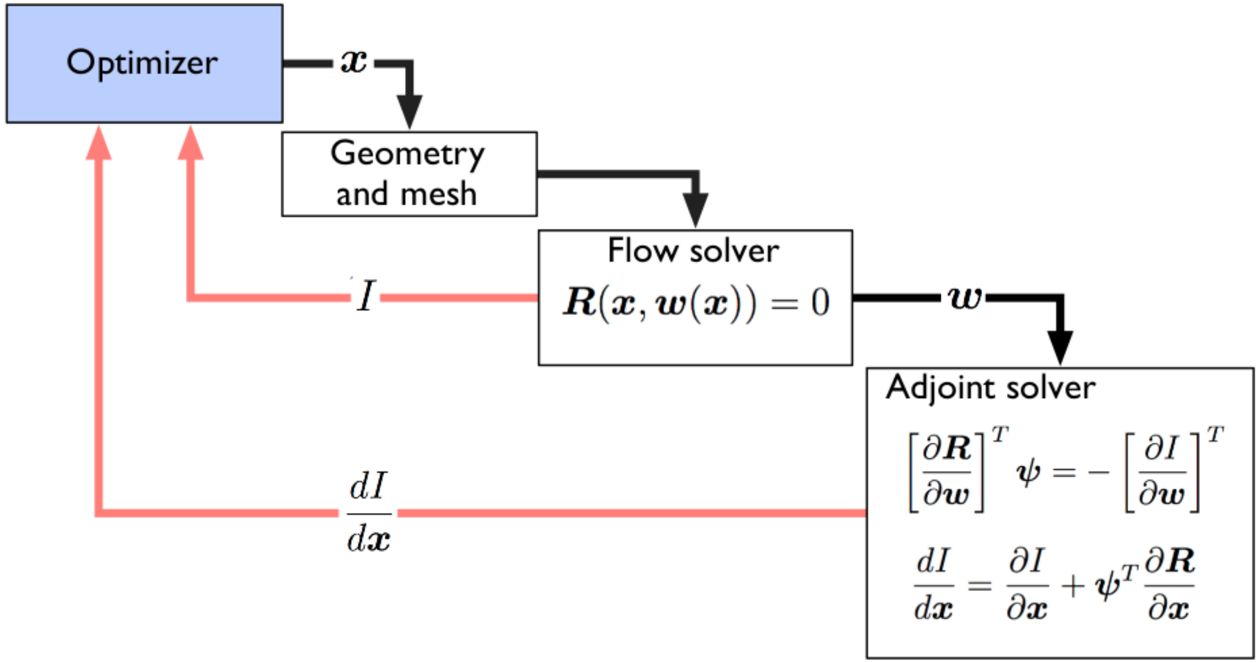
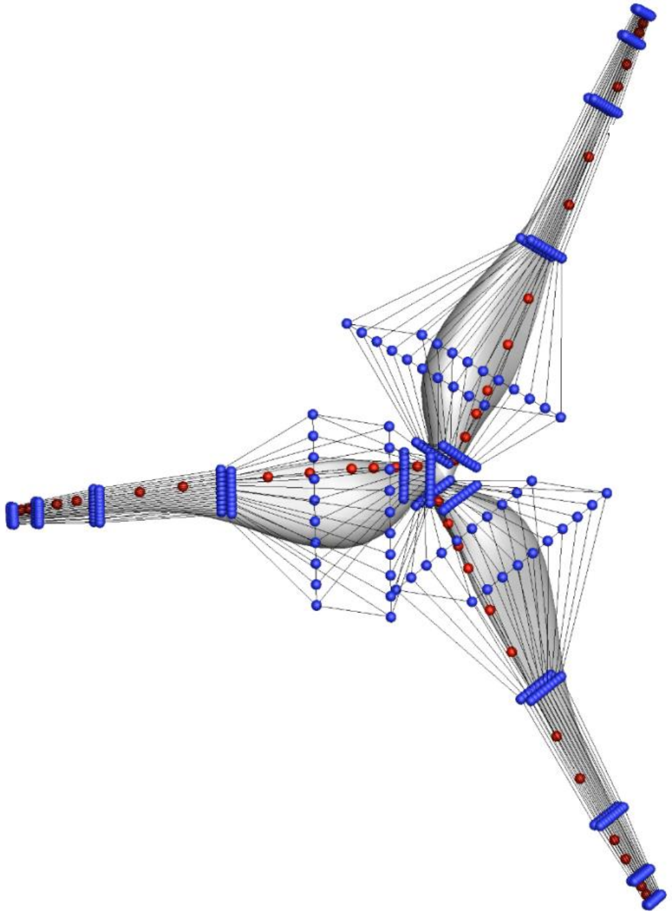
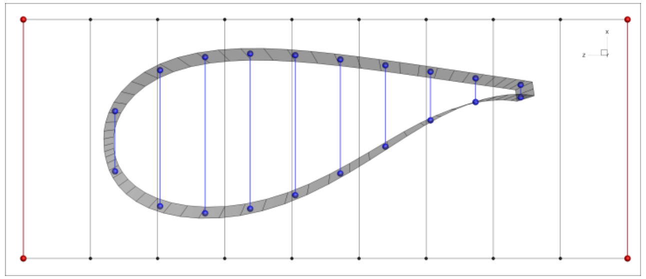


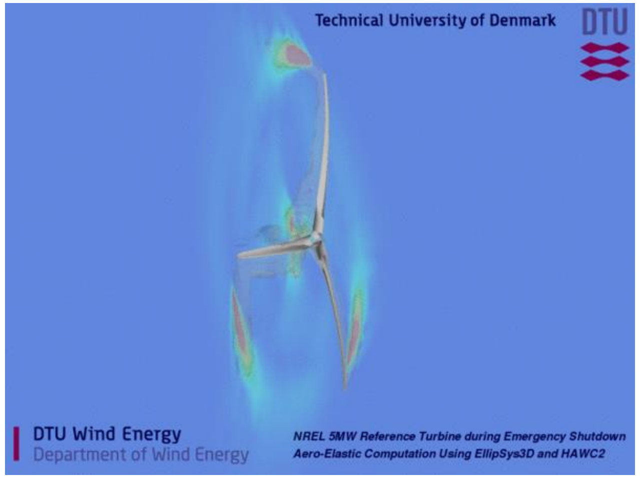
Figure 3: Aerodynamic shape optimization procedure.



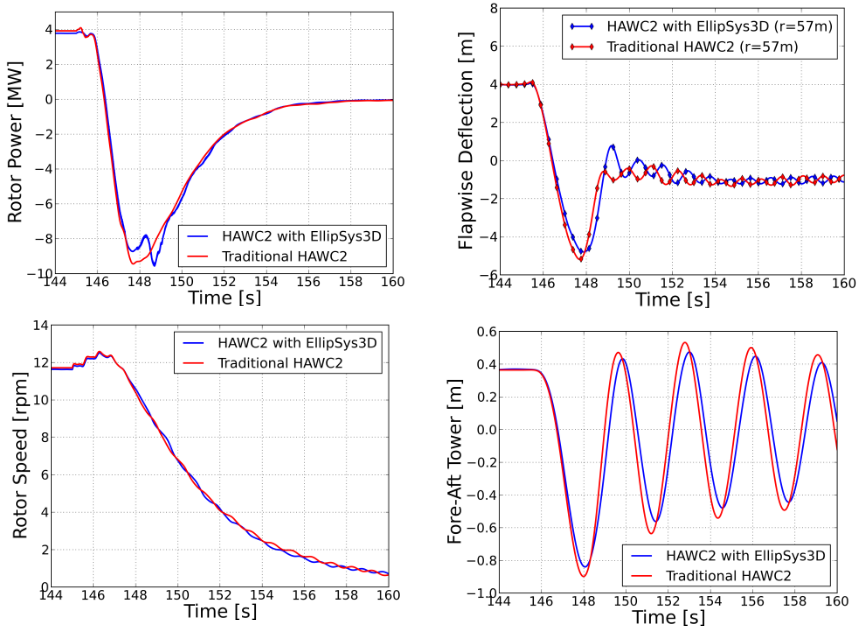


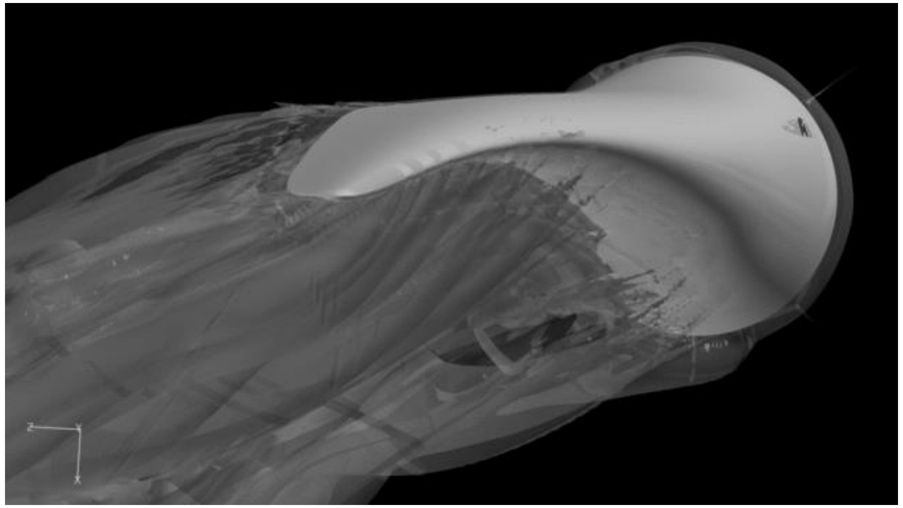
Rotor aerodynamics: Fluid-structure interaction

- Using EllipSys3D and HAWC2 for aero-elastic simulations
  - Validating standard aero-elastic simulation
  - Applied to cases where simpler models are not valid



Emergency shutdown

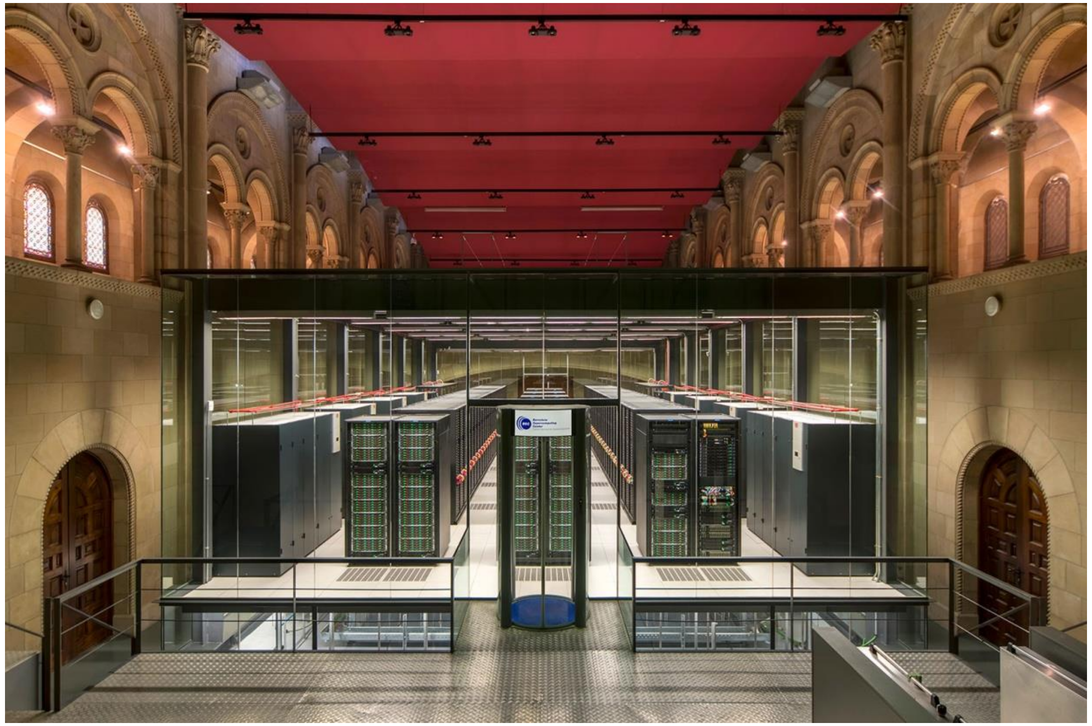




Standstill vibrations

The large scale computers of today

Mare Nostrum 4, Barcelona Super Computing Centre, PRACE



The general-purpose block has 48 racks with 3,456 nodes
Each node has two Intel Xeon Platinum chips, each with 24 processors.
A total of 165,888 processors and a main memory of 390 Terabytes.

Acceleration of the EllipSys code

The acceleration of EllipSys is based on:

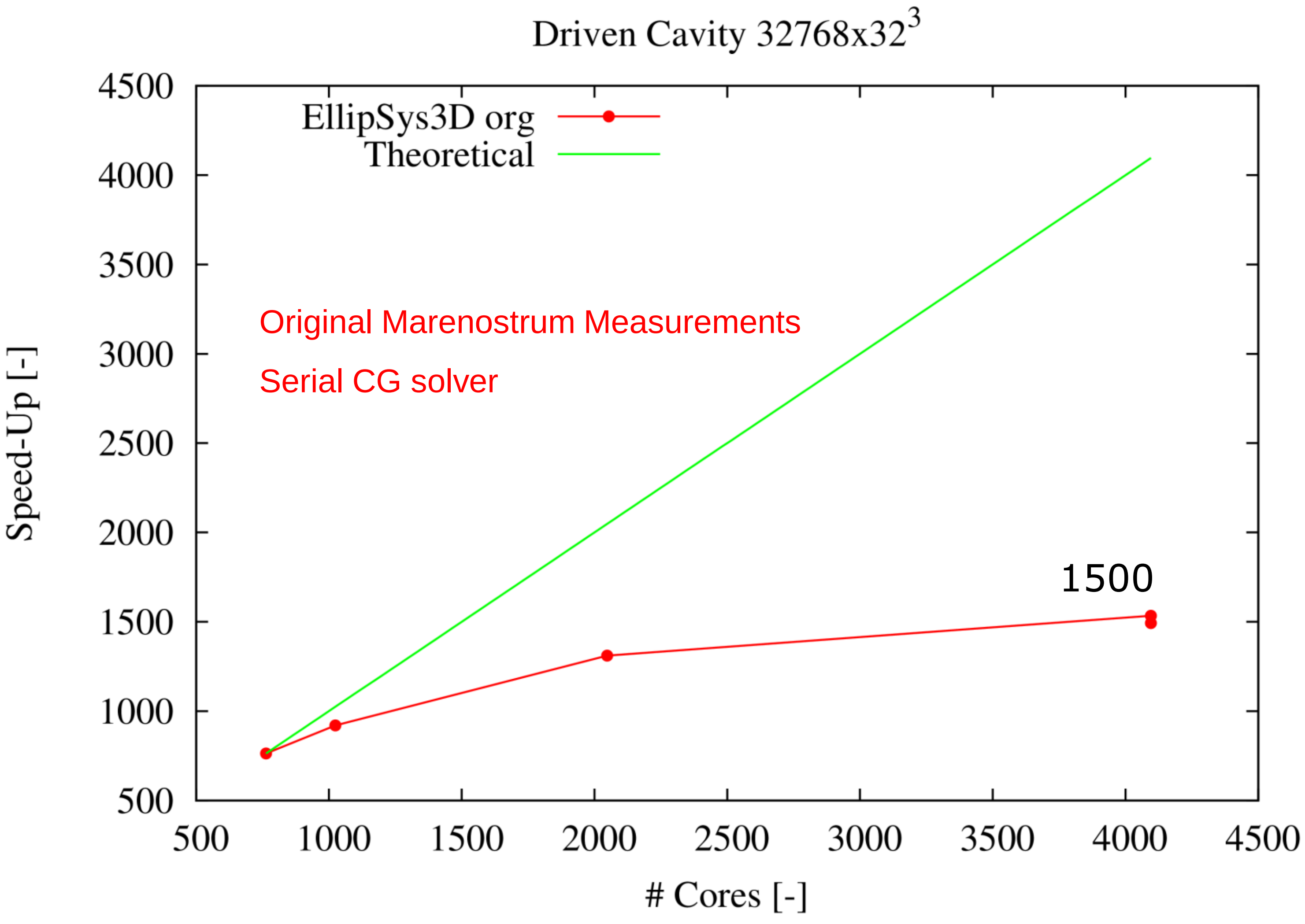
- Careful implementation, sweep directions, loops, cache optimization, minimize active arrays, effective storage,….

- Domain decomposition (Parallelization)

- Multi-grid solution of pressure Poisson equation

- Grid sequencing

Driven Cavity, $32768x32^3$

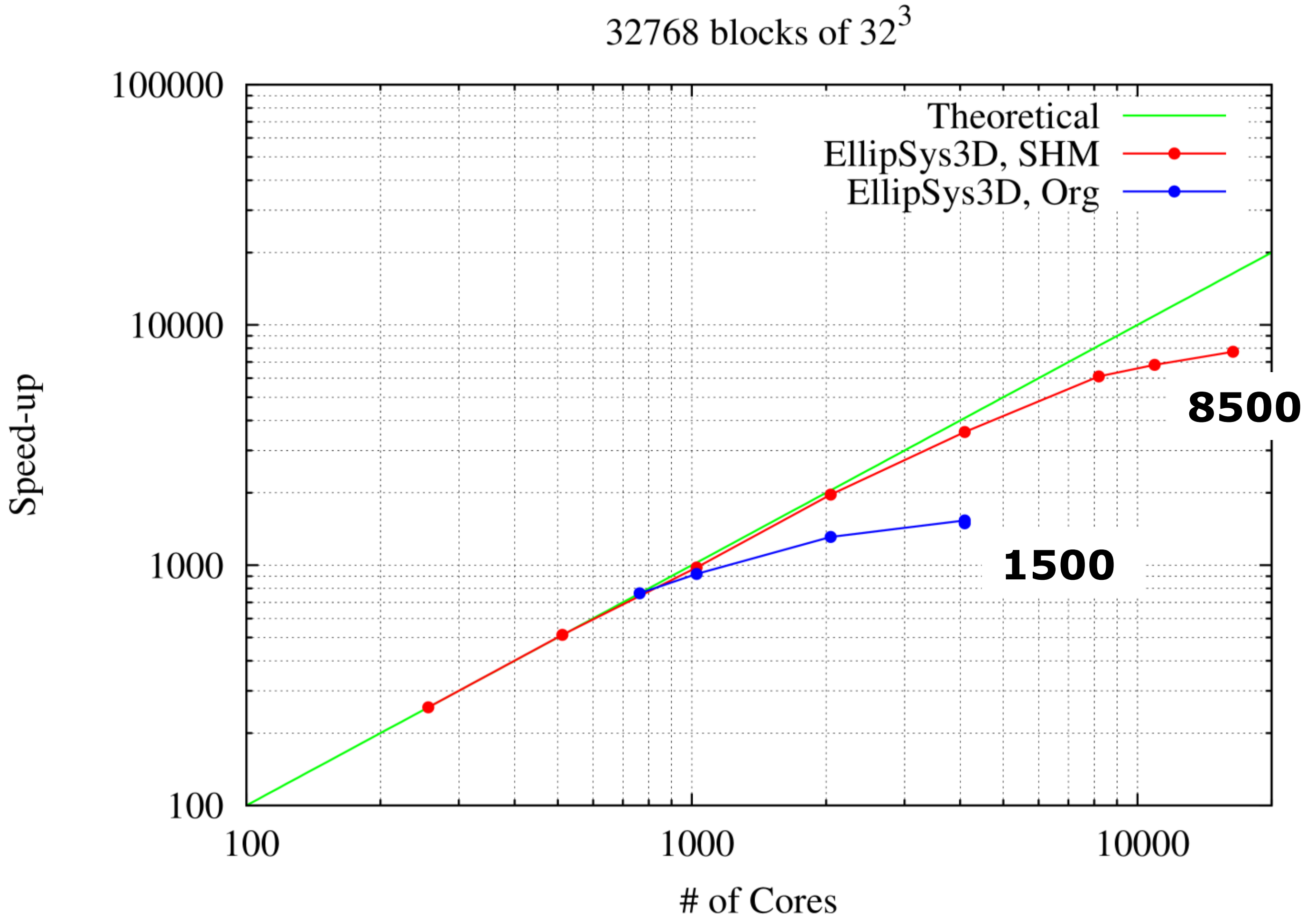


- Failed to work with large block nr.
- Slow startup time (~1 hour)
- Fail to scale above 4000 Cpu's

Techniques Applied

- Shared Memory Parallel Coarse Grid (SHM-CG) Solver
  - MPI-MPI model
- Shared Memory Aware Gather/Scatter of the CG problem
  - MPI-MPI model
- CG size of 1 cell and 7 MG levels

Driven Cavity, 32768x32^3



Work for nr. blocks > 32000

Startup problems solve

Speed-up: 1500 => 3800 @ 4096 Procs.

Efficiency: 37% to 92% @ 4096 Procs.

NI_f	NI_c	$Nprocs$	$Nr.Points$
64	2	131072	34.0×10^9
64	4	16384	4.2×10^9
48	3	16384	1.8×10^9
32	2	16384	536.0×10^6
16	2	2048	8.4×10^6

Example 1:
DNS of airfoil at Re=40.000

Grid: 18112x32^3 = 593 mill. points

Wall clock per time-step (8 sub-iterations) @ 1 CPU = 33750 seconds ~9 hours

Wall clock per time-step (8 sub-iterations) @ 625 CPU's = 54 seconds

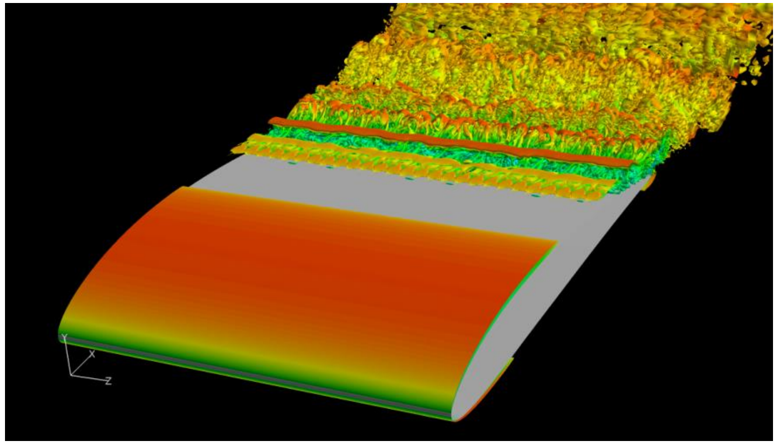
Wall Clock per time-step (8 sub-iterations) @ 9056 CPU's ~ 4 seconds

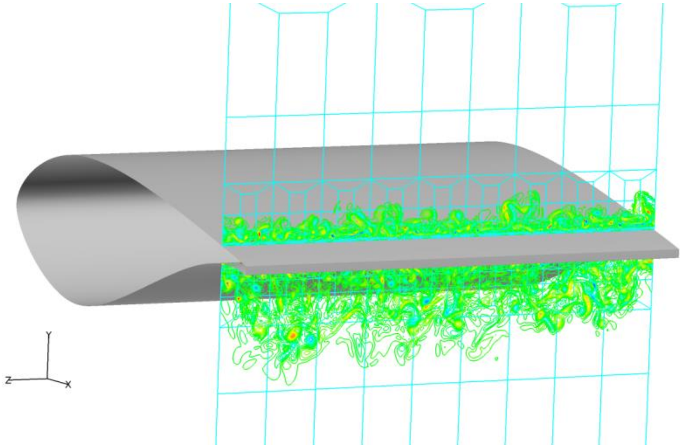
Necessary nr. of time-steps for periodic state ~ 20.000 corresponding to:

~ 20 years on 1 CPU

~ 12.5 days on 600 CPU's or

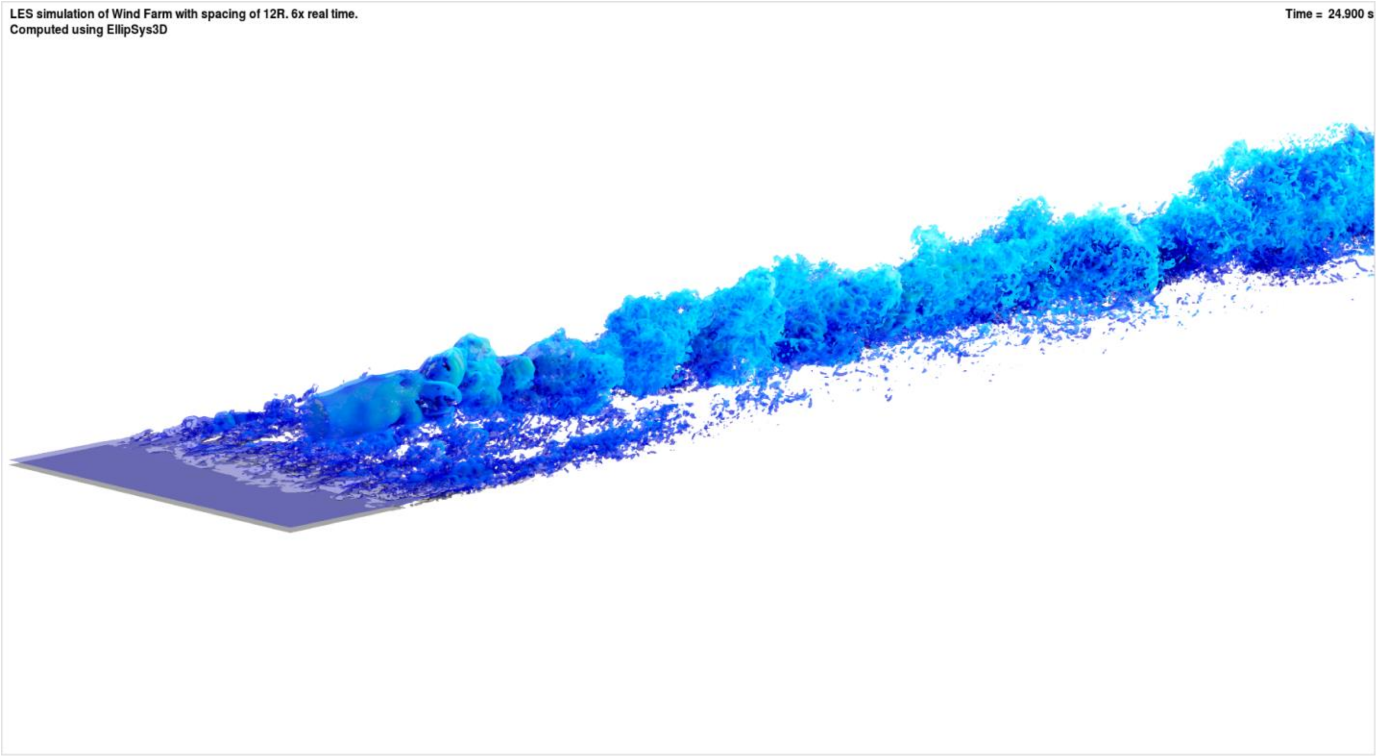
~ 1 day on 10.000 CPU's or





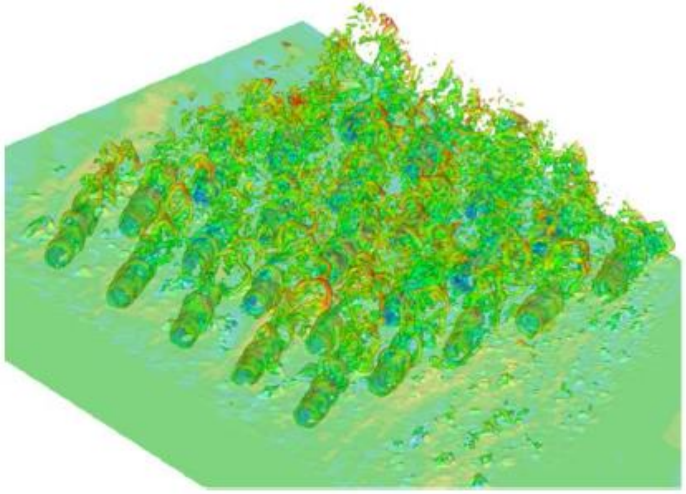
Example 2:
Wind turbine wake/wake interaction

- Mesh points: 327 million (640 Blocks of 80^3)
- Domain size (200R x 20R x 20R) using (3200 x 320 x320) points
- Wall clock per time-step (2 sub-iterations) @ 640 CPU's: 9 seconds
- A full simulation with spin up and statistics will take ~ 350.000 time-steps at a given wind speed
- This corresponds to:
  - 560.000 hours @ 1 CPU ~64 years
  - 875 hours @ 640 CPU's ~36 days
  - 148 hours @ 10.000 CPU's ~6 days

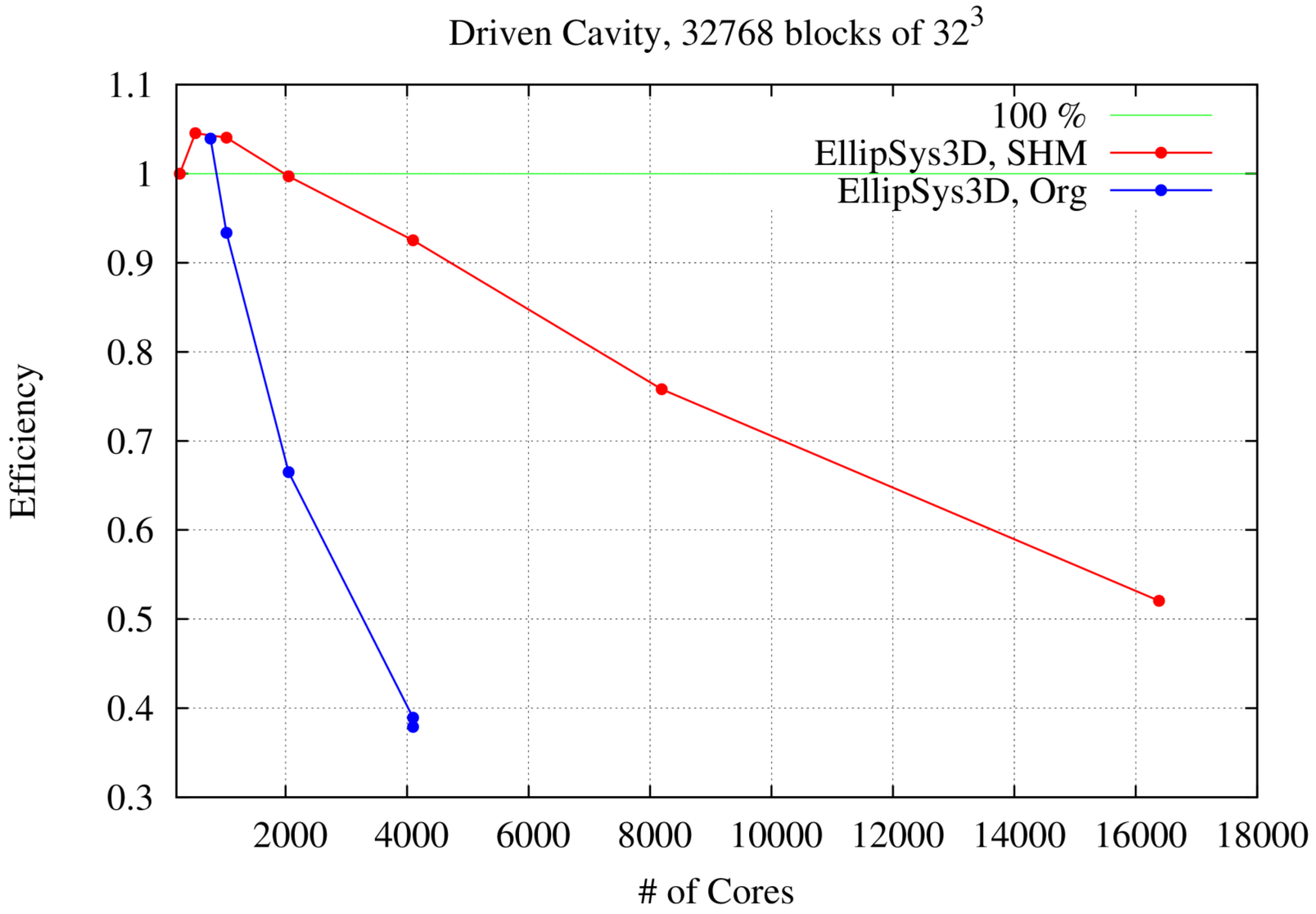


Conclusion

- A new improved version of the EllipSys have been developed exploring a MPI-MPI concept of shared memory.
- The solver now works with ~30.000+ blocks in an efficient way.
- We now scale beyond 10.000 processors :-)
- We are ready to utilize the massive parallel computers of the near future



Efficiency



Driven Cavity, 32768 blocks of 32^3
100 %
EllipSys3D, SHM
EllipSys3D, Org
Efficiency
# of Cores
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2000
4000
6000
8000
10000
12000
14000
16000
18000