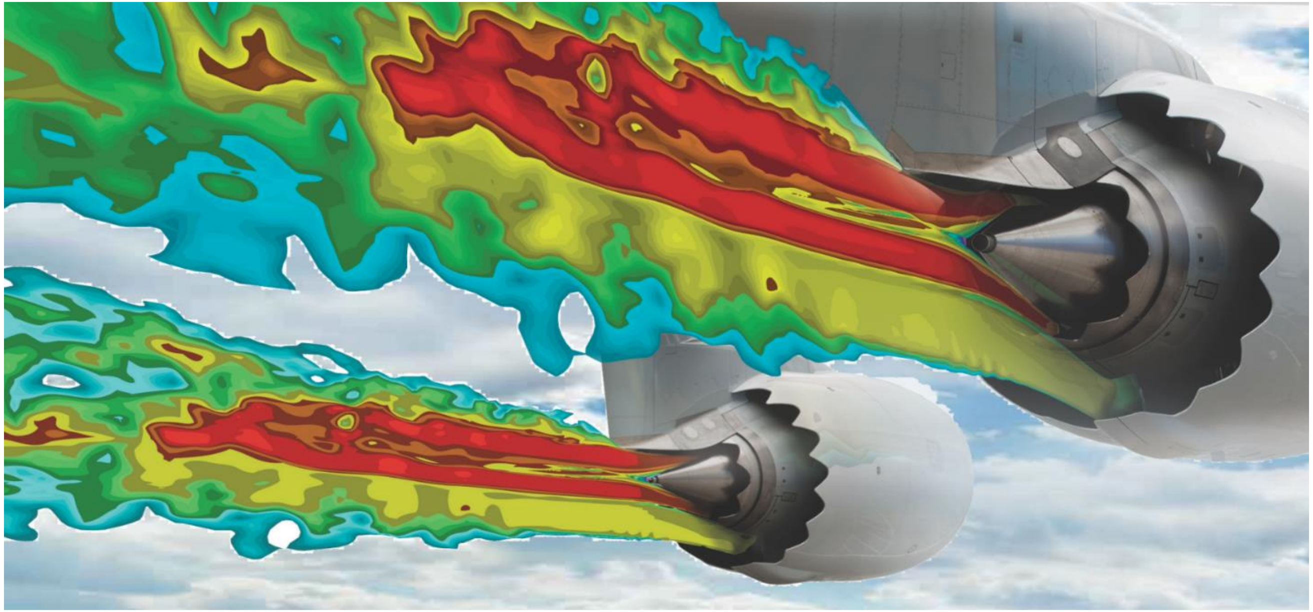
NUMERICAL SIMULATIONS OF TURBULENT FLOW USING RANS/ILES HIGH RESOLUTION METHOD



CENTRAL INSTITUTE ON AVIATION MOTORS NAMED AFTER P.I. BARANOV
JOINT SUPERCOMPUTER CENTER OF THE RUSSIAN ACADEMY OF SCIENCES

Benderskiy L.A., Lyubimov D.A., Makarov A.Yu., Rybakov A.A.

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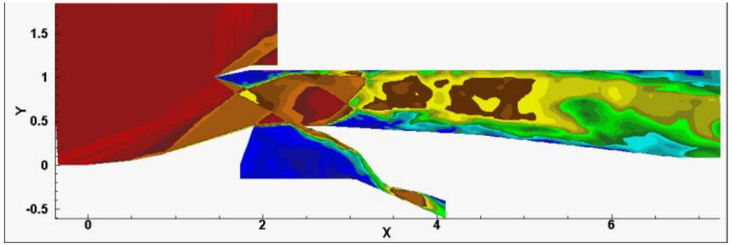
Description of solving problems

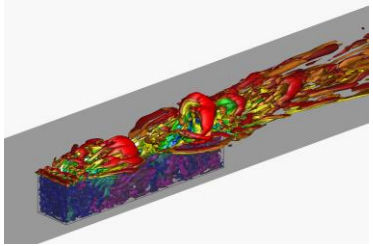
The development of competitive engines requires more accurate and more detailed description of the features of the currents in its elements

- Flow separation, unsteady flows, flows with mixing layers.
- Traditional RANS methods with models of turbulence poorly describe such types of flows.
- The use of RANS/ILES-methods allows to describe current flows and to obtain additional information about flow (pulsations of pressure, temperature, velocity, noise) as compared with RANS methods.
- The use of RANS/ILES methods requires the use of a detailed mesh and a small time step for the explicit resolution of vortices. To get results in a short time, super computers are required.

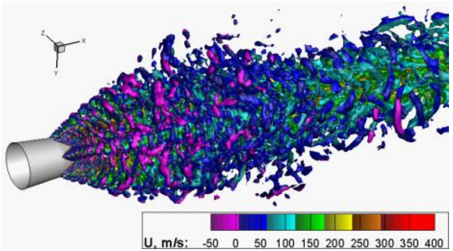
Air intake



Cavities and niches



Jets and nozzles

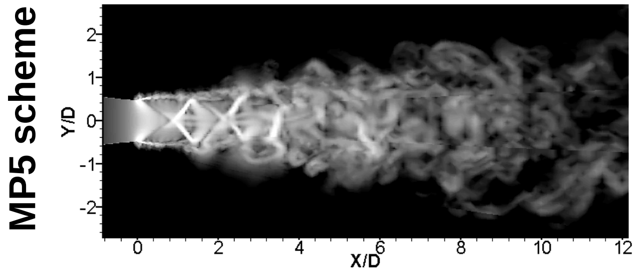


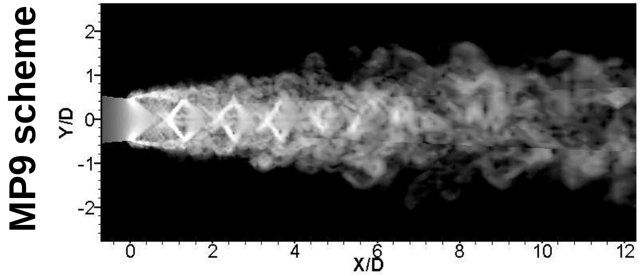
Main features:

- Roe`s flux difference splitting method.
- Monotonicity-preserving scheme MP9 [A. Suresh, H.T. Huynh, JCP 1997, V.136, P.83-99] with upwind 9th-order approximation in smooth regions for calculating flow parameters on cell faces. It makes possible to calculate supersonic flows with shocks without modification of the method.
- LES with implicit SGS-model (ILES): the scheme viscosity performs a function of a subgrid scale (SGS) model.
- In ILES region, the distance in dissipative term of Spalart–Allmaras turbulence model is changing:

$$\tilde{d} = d, d \le C_{ILES}\Delta_{MAX} \qquad \nu_t = \nu_{tRANS}$$

$$\tilde{d} = 0, d > C_{ILES}\Delta_{MAX} \qquad \nu_t = 0$$





Lyubimov D.A. *High Temperature*, Vol. 50, No. 3, pp. 420-436., 2012.

History of code development

Serial Fortran code

10^5-10^6 cells
1 core
~month

2011 year

Add simple OpenMP for basic cycles

Light tuning of OpenMP

10^6 - $4{\cdot}10^6$ cells
6-16 cores
two weeks - month

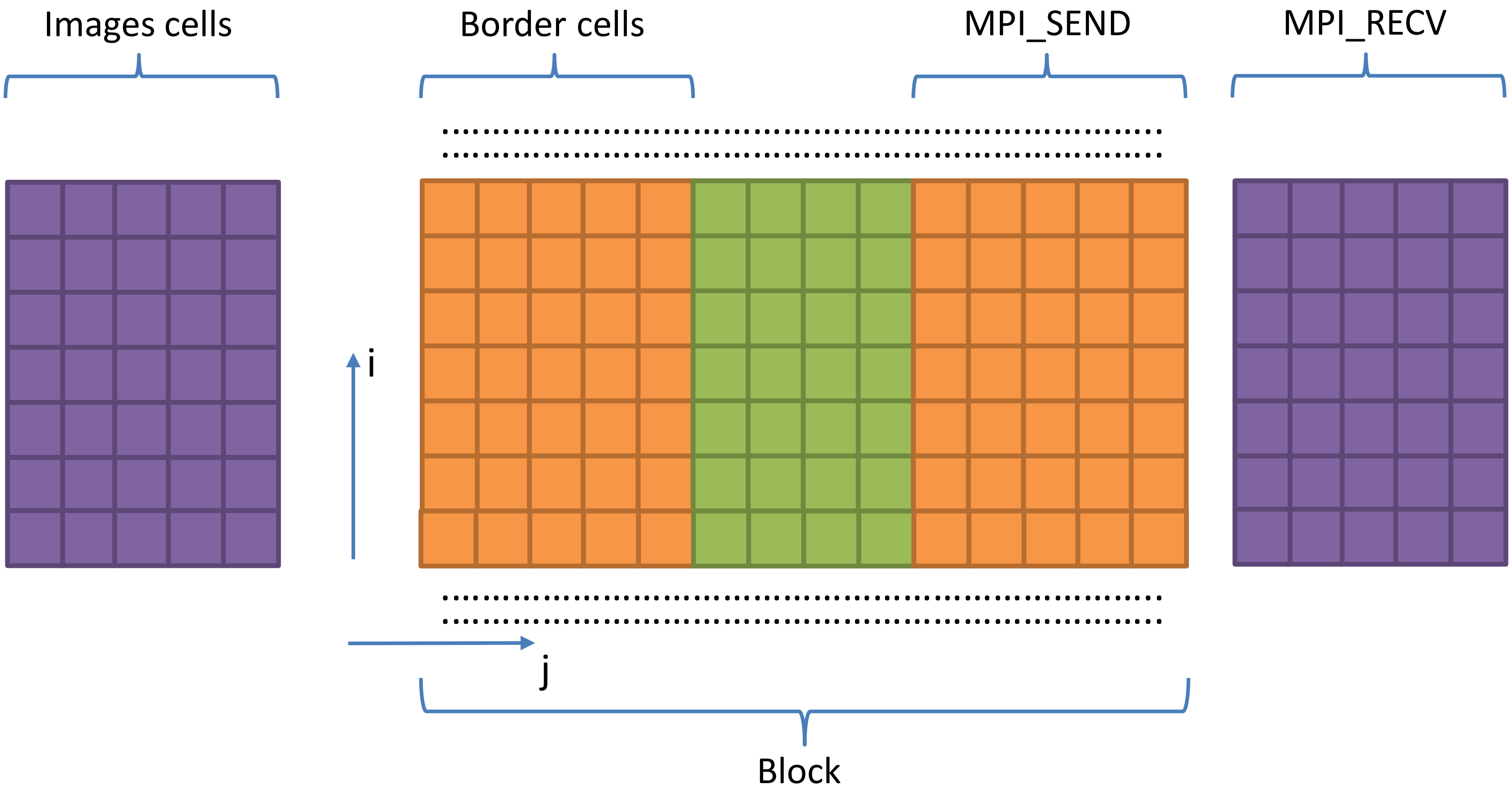
2016 year

Add MPI (MPI + OpenMP)

Program improvement

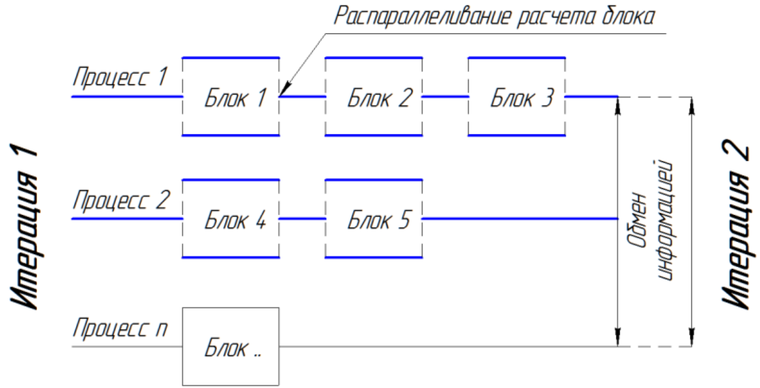
$4{\cdot}10^6$ - $100{\cdot}10^6$ cells
up to 100 nodes
up to 1600 cores
four days – month

Block structure

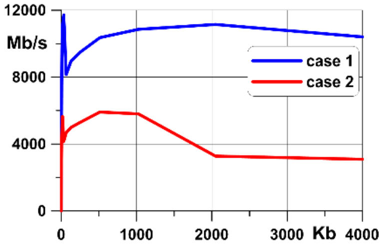


MPI realization in code

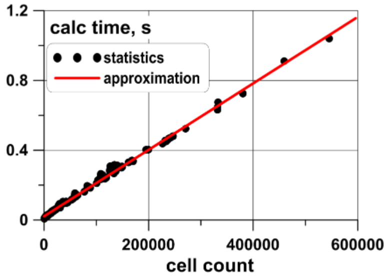
Scheme of parallelization



Theoretical model for speedup prediction

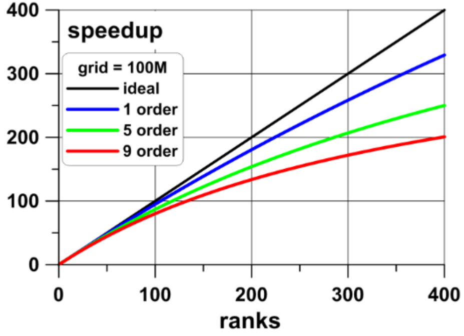


Real speed of data transfer

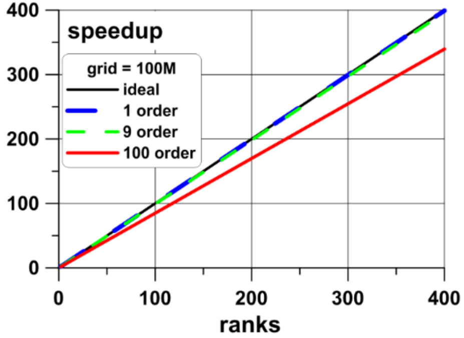


Real calculating time statistic

Expected theoretical effect



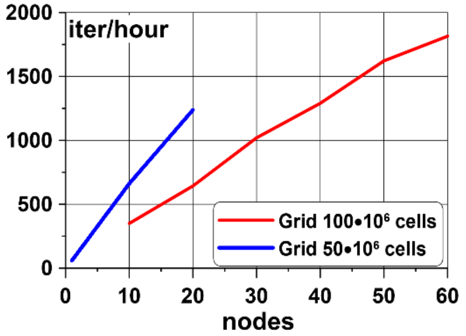
Sequential exchange



nonblocking sends

Speed tests on Intel Xeon

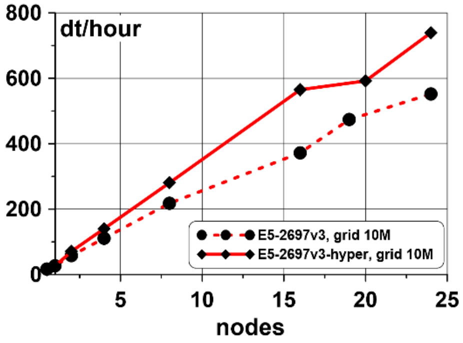
First result



Speed test on model grids

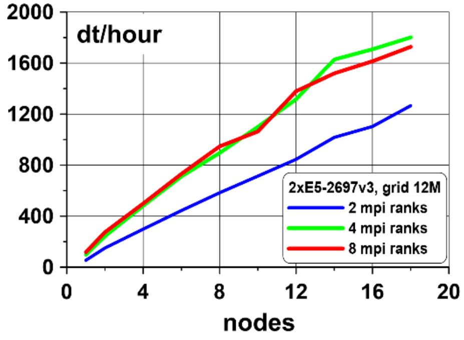
- 2 mpi rank on node (2xE5-2690)
- 16 treads on one rank (hyperheading)

Hypertreading test



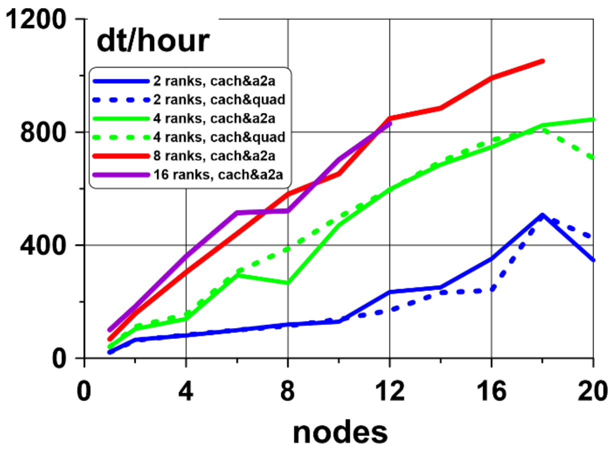
- 2 mpi rank on node (2xE5-2697v3)
- 28 treads on one rank (hyperheading)
- 14 treads on one rank (with out hyperheading)
- 1.2-1.5x with hyperheading

Rank count test

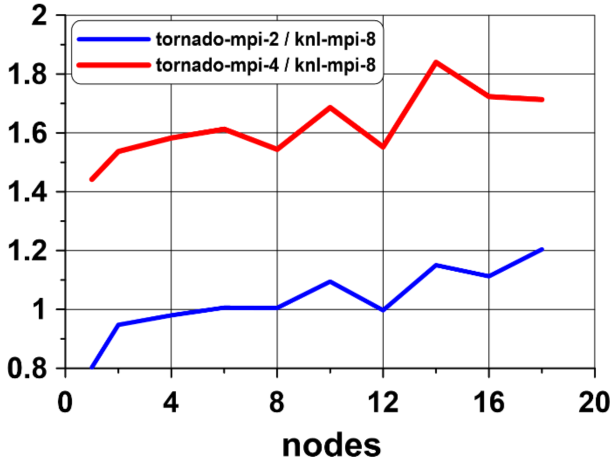


- 2, 4, 8 mpi rank on one node (2xE5-2697v3)
- 56 treads on node (hyperheading)
- 1.6x for 4 mpi ranks on node

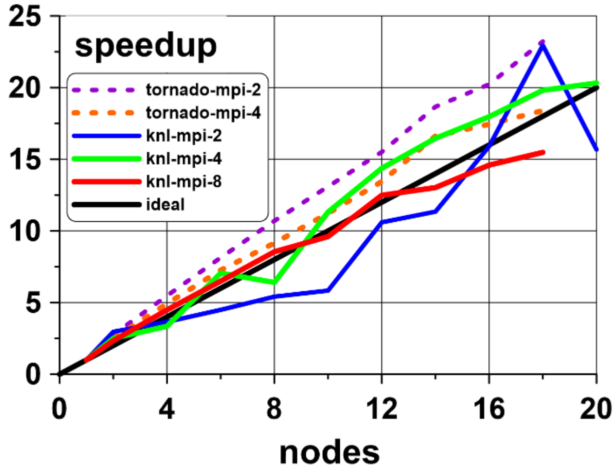
Speed tests on 2nd generation Intel Xeon Phi (KNL)



KNL speed test



Compare speed on KNL and Xeon

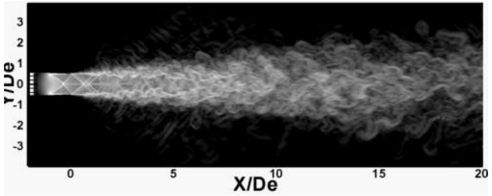


Speedup on KNL and Xeon

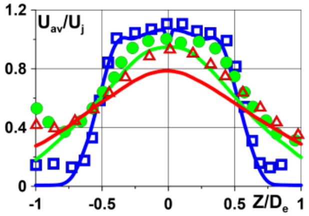
- One KNL have same speed as 2xE52697v3 with 2 mpi rank per node and is inferior in performance 1.6 times compared to one Xeon node with 4 mpi ranks for our task.
- Linear speedup for 20-60 nodes.

Examples of calculations

Propagation of a supersonic jet

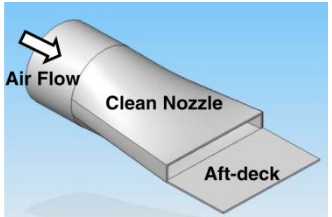


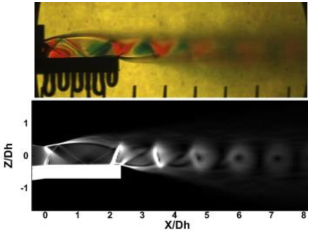
Field of $\log|grad\rho|$



comparison with experiment

Supersonic jet from a rectangular nozzle

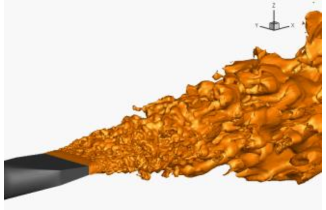


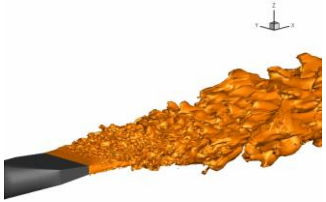


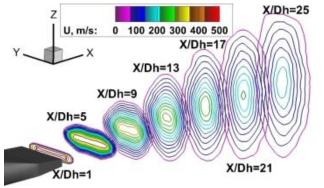
The geometry of the nozzle and comparison with experiment

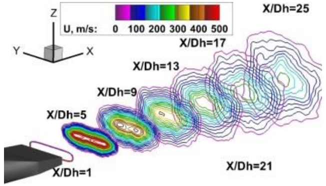
without aft-deck

With aft-deck



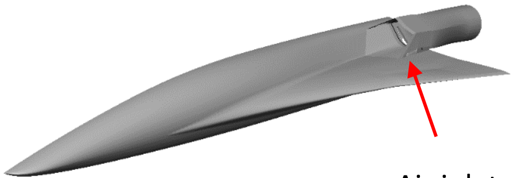




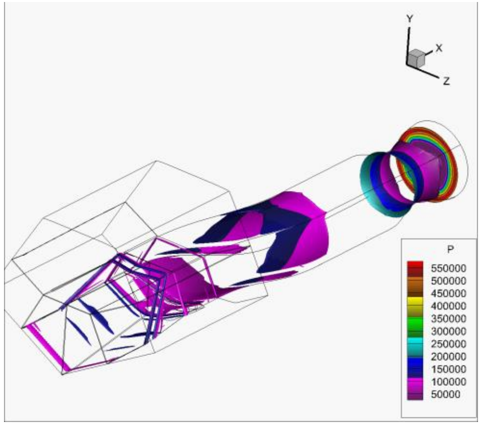


The effect of turning the axes of the jet

Supersonic business aircraft



Air inlet



Flow inside the air intake device

Conclusion

Now:

- RANS/ILES high resolution code is parallelized for calculations on supercomputers
- The method is successfully used in fundamental studies of turbulence, acoustics and in solving the applied problem of modeling physical processes in aerospace engines

Planned:

- Improvement of the calculation method
- Increase the speed of code on modern processor architectures