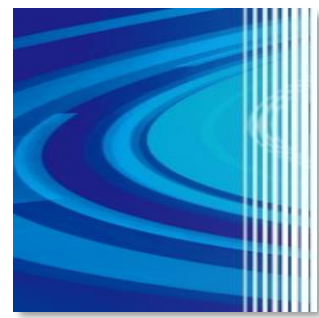# Promoting national projects

Manufacturing processes using supercomputer Fugaku

Center for Research on Innovative Simulation Software (CISS), Institute of Industrial Science (IIS), The Univ. of Tokyo is promoting national projects and is leading the research and development of advanced and applicative simulation software.

Social and scientific priority issues to be tackled by using post-K computer（8）　(2014-2019)
Development of innovative design and production processes that would lead the way for the manufacturing industry in the near future

We aim at realizing high-value-added manufacturing industries through the development and application of innovative and efficient simulation software that can maximize the capabilities and performance of Fugaku. Consequently, engineers will be able to quantitatively evaluate and optimize product concepts at an initial stage and minimize the cost and maximize the precision of the manufacturing process for the designed products.

CISS, IIS, the Univ. of Tokyo is conducting research and development in close collaboration with graduate school of frontier sciences, the Univ. of Tokyo, Kobe Univ., Tohoku Univ., Univ. of Yamanashi, Kyushu Univ., Tokyo Univ. of Science, JAXA and RIKEN.

Classification	Sub-issue	
Innovations in the design processes	Sub-issue A Research and development of multiobjective design exploration and high-performance computing technologies for design innovation	Upstream design support environment　Analysis of parameter space
	Sub-issue B Research and development of real-time real-world integrated design system for road vehicles	Automobile CAE enabling real-time/real-world analysis
	Sub-issue C Research and development of a design and evaluation system based on quasi-direct fluid-flow computations for turbomachinery	Centrifugal blower internal flow and noise analysis　Multistage centrifugal pump internal flow analysis
	Sub-issue D Research and development of core technologies to innovate aircraft design and operation	Flow analysis of single wing (K computer)　Flow analysis of actual aircraft (Post-K computer)　Element analysis/wind-tunnel test analysis　Unsteady flow simulation of actual aircraft　Actual aircraft/actual scale analysis
Innovations in the manufacturing processes	Sub-issue E Research and development of advanced press forming and welding simulators for new materials	With Post-K computer, dynamic analysis of complex nonlinear coupling phenomena is possible. Furthermore, it is possible to solve double-digit large-scale problems.
	Sub-issue F Research and development of multiscale modeling simulators for thermoplastic CFRP	CFRTP modeling process simulation (temperature/contact large deformation coupling analysis)

Program for Promoting Researches on the Supercomputer Fugaku　(2020-2022)
Research and development of innovative fluid-dynamics simulations for aerodynamical/hydrodynamical performance predictions by using Fugaku

For turbomachines and vehicles that are core of the energy industry and the transportation industry, respectively, we develop application software, by which optimal performance of HPCI (High Performance Computing Infrastructure), including Fugaku, is got and manufacturing processes are changed.

CISS, IIS, the Univ. of Tokyo is conducting research and development in close collaboration with Kobe University, the Kyushu University, Iwate University, Toyohashi University of Technology, the University of Yamanashi, and RIKEN.

Theme of experimental studies		Using application software
Theme 1 Realization of a numerical towing tank and improvement of propulsion efficiency by using energy-saving devices	Courtesy of Shipbuilding Research Centre of Japan (SRC)	FrontFlow/blue
Theme 2 Wall-resolved LES of internal flow in hydro-dynamical and leakage-flow passages of multistage centrifugal pump		FrontFlow/blue
Theme 3 Direct analysis of compressor surge		Software of DES analysis of compressible flow for turbomachines
Theme 4 Prediction of real aerodynamic performance of automobile in road conditions		CUBE
Theme 5 Prediction of automobile aeroacoustics in road conditions	Iida, Miyazawa, et. al.: Symposium on CFD2018	CUBE, FFX

Priority Issue 8 on Post-K (Fugaku) Computer

Development of Innovative Design and Production Processes that Would Lead the Way for the Manufacturing Industry in the Near Future
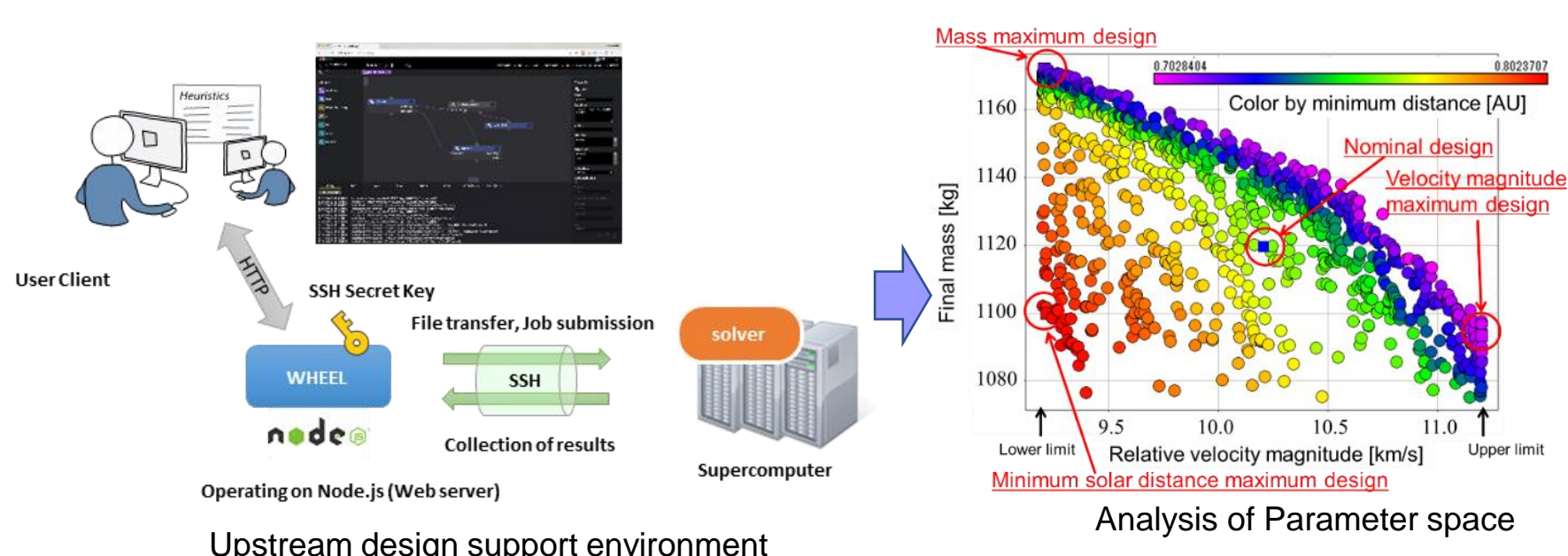
Sub-issue A:
Research and development of multiobjective design exploration and high-performance computing technologies for design innovation

Engaged institutions: JAXA, Kyushu Univ., Tohoku Univ., Tokyo Univ. of Science and RIKEN

Approach

1. Multiobjective design optimization technology development
2. High-performance computation technology development
3. Implementation on the upstream design platform

Outcome

User Client
SSH Secret Key
File transfer, Job submission
WHEEL
SSH
node.js
Collection of results
solver
Operating on Node.js (Web server)
Supercomputer

Upstream design support environment

Mass maximum design
Color by minimum distance [AU]
Nominal design
Velocity magnitude maximum design
Final mass [kg]
Lower limit
Relative velocity magnitude [km/s]
Upper limit
Minimum solar distance maximum design

Analysis of Parameter space

Approach enabling rapid computer simulations of multiple designs and selection of the optimal design parameter values.

Using new methods for utilizing supercomputer technologies that can innovatively change design methods and manufacturing processes

Achievements to date

- Calculation times have reduced via the application of new multi-objective design exploration technologies
- Research into the fundamental technologies of parallel-in-time method using the pipelined parareal method has halved the calculation time relative to the original parareal method
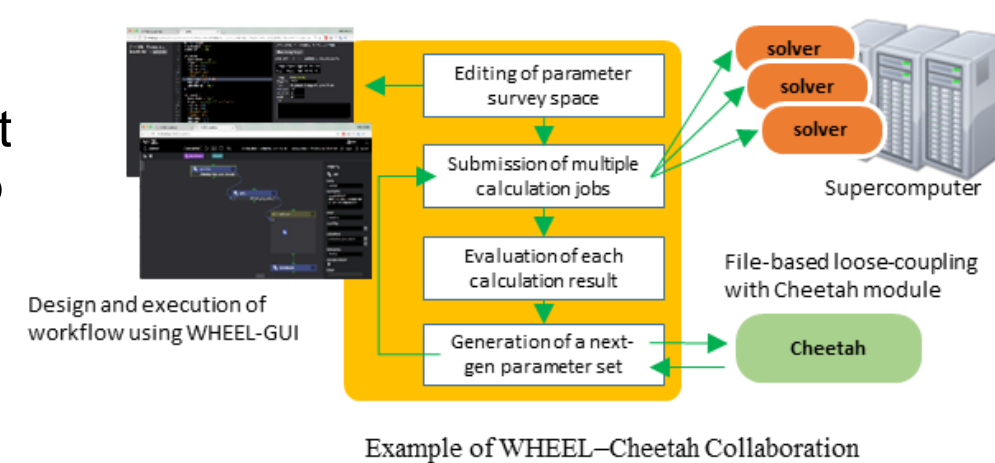- As a platform for the upstream design process, a new workflow system, called "WHEEL," has been developed

Using adaptive discretization for real-number design variables, the calculation time has been reduced by ~70%

Hyper Volume (HV)
Calculation time reduced by ~70%
Calculation time: 1/3
SD(2 ~ 8 digit)
2-digit
4-digit
6-digit
8-digit
Number of solution evaluations
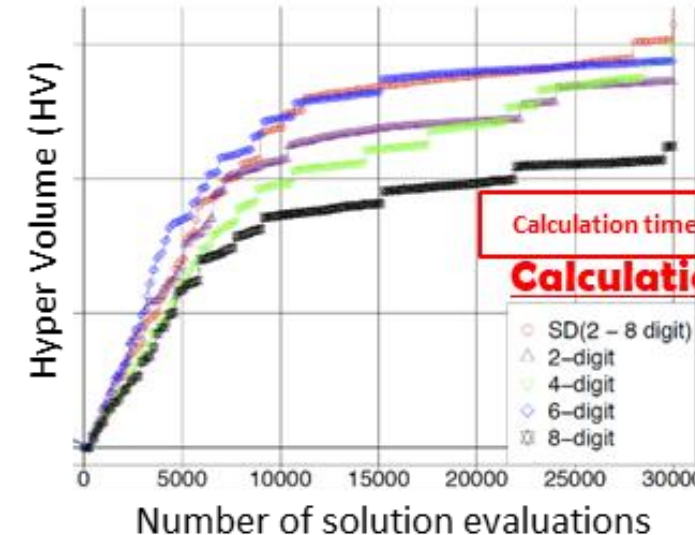
Effect of adaptive discretization on the optimization history of Mazda benchmark problem.

Workflow system for capacity computing using different applications

- Development of a versatile editor, that facilitates the setup of design variables
- Cooperation with Cheetah multi-objective design exploration system

Editing of parameter survey space
Submission of multiple calculation jobs
Evaluation of each calculation result
Generation of a next-gen parameter set
solver
Supercomputer
File-based loose-coupling with Cheetah module
Cheetah
Design and execution of workflow using WHEEL-GUI
Example of WHEEL–Cheetah Collaboration

Software to be developed

Multiobjective design optimization app, high-performance computation apps, and upstream design platform

Sub-issue B:
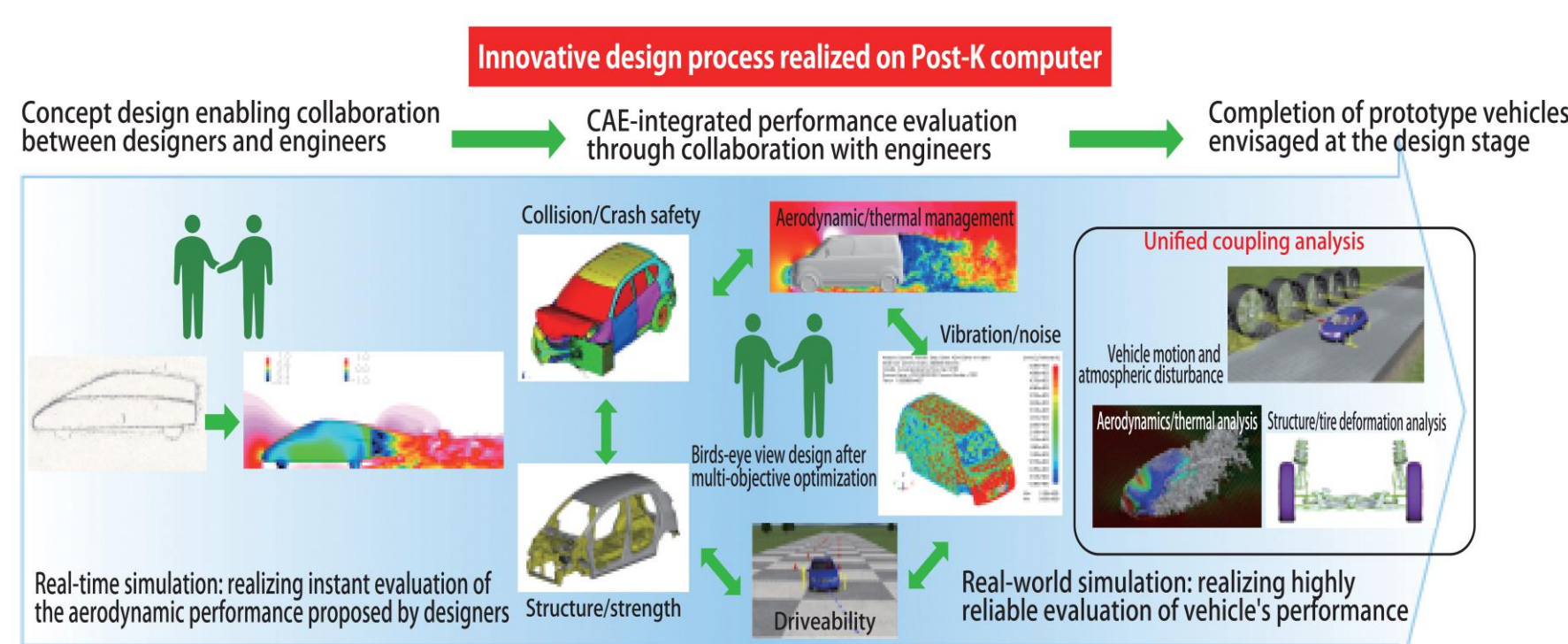### Research and development of the real-time real-world integrated design system for road vehicles

Engaged institutions: Kobe Univ., Univ. of Yamanashi and RIKEN

Approach

1. Development of real-time simulation technology
2. Development of real-world simulation technology

Outcome

High-speed analysis enables designs in which designers and developers can collaborate easily and efficiently. Furthermore, through integrated coupling analysis, it is possible to perform general performance evaluations during upstream design as well as produce a multipurpose design that straddles the various stages of development.


Innovative design process realized on Post-K computer

Concept design enabling collaboration between designers and engineers → CAE-integrated performance evaluation through collaboration with engineers → Completion of prototype vehicles envisaged at the design stage

Collision/Crash safety
Aerodynamic/thermal management
Unified coupling analysis
Vibration/noise
Vehicle motion and atmospheric disturbance
Birds-eye view design after multi-objective optimization
Structure/the deformation analysis
Aerodynamic/thermal analysis
Structure/strength
Driveability

Real-time simulation: realizing instant evaluation of the aerodynamic performance proposed by designers
Real-world simulation: realizing highly reliable evaluation of vehicle's performance
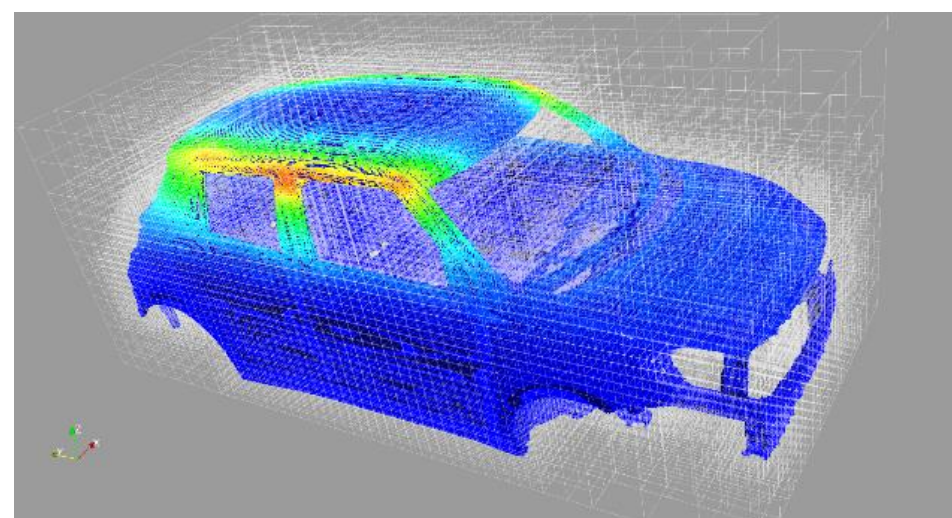
Achievements to date

- Turnaround time (TAT) for a real vehicle aerodynamic analysis reduced to ≤ 24 h by increasing the speed of preprocessing and core kernel of the developed program
- Development of a basic program for a Euler structural analysis, a compressibility analysis, and a six-degree-of-freedom moving boundary analysis

The aerodynamics of a real vehicle with a complex configuration can be analyzed ten times faster than before
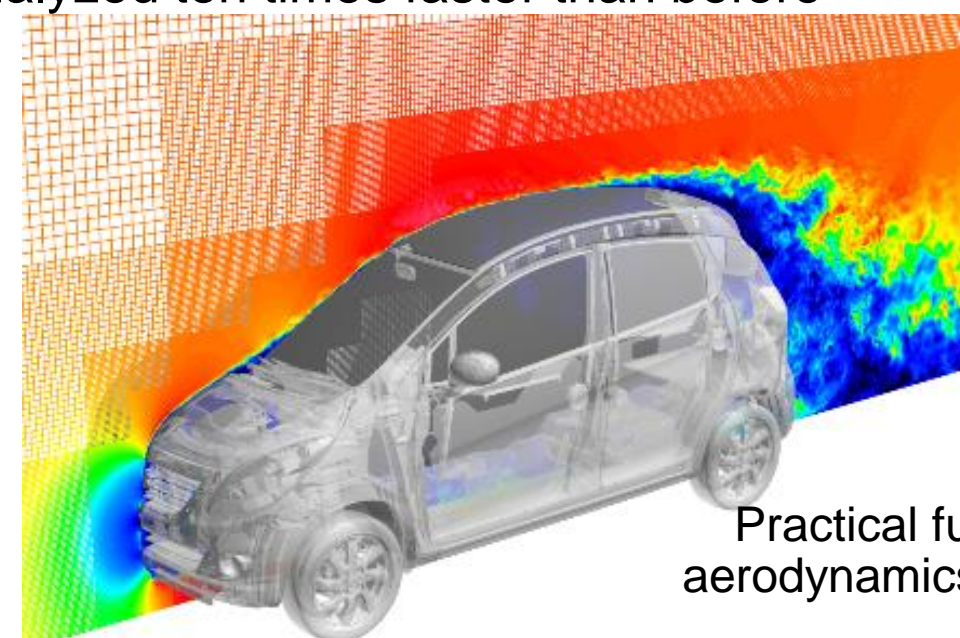
Practical full-vehicle aerodynamics simulation

Development of a Eulerian structure-fluid unified coupled scheme. A thin-plate structure can be modeled using the particle method.

Unified coupled analysis of automobile thin-plate structure and fluid.

provided by SUZUKI

Software to be developed

CUBE(Complex Unified BCM)

http://www.postk-pi8.iis.u-tokyo.ac.jp/

東京大学生産技術研究所
Institute of Industrial Science, The University of Tokyo

Priority Issue 8 on Post-K (Fugaku) Computer

Development of Innovative Design and Production Processes that Would Lead the Way for the Manufacturing Industry in the Near Future

Sub-issue C:
Research and development of a design and evaluation system based on quasi-direct fluid-flow computations for turbomachinery

Engaged institutions: The Univ. of Tokyo and Kyushu Univ.

Approach

1. R&D of an Ultra-high Speed Flow Analysis Solver
2. R&D of a quasi-direct calculation method to reduce computation costs drastically
3. R&D of turbo device/optimized design system

Outcome

For all types of turbomachinery, including high-pressure pumps and hydro-turbines, we can achieve high-precision predictions of internal flows, performance and reliability that can replace the loop tests. Furthermore, we will realize multi-purpose optimal design of turbomachinery through quasi-direct computations. The developed applications, in addition to turbomachinery, can be applied to most fluid-related products (e.g., ships).
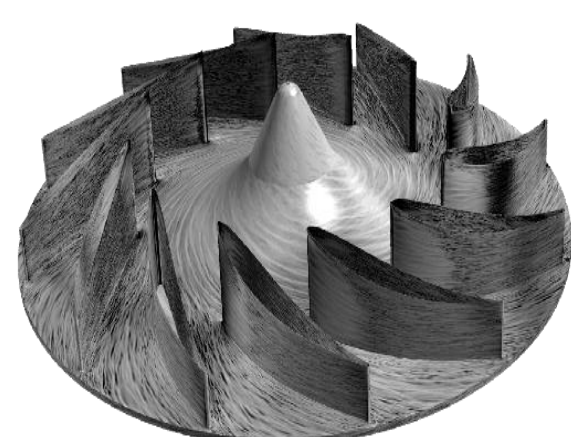
Centrifugal blower internal flow and noise analysis
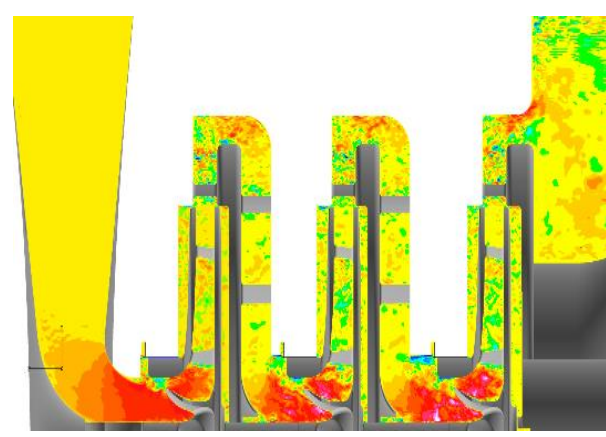
Multistage centrifugal pump internal flow analysis

Assist in enhancing the competitive advantages of the industry by improving the performance and reliability of turbomachinery

Achievements to date

■ The use of FFB has the potential to make calculations 100 times faster on supercomputer Fugaku (post-K)
■ Development of a prototype program based on Lattice Boltzmann Method (LBM)

Development of speed-up technic and the example of benchmark test using the technic
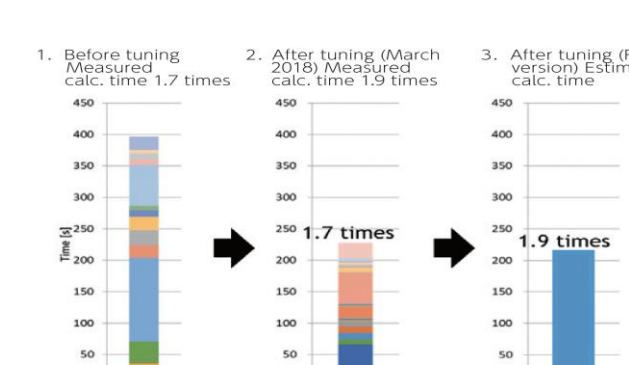
Estimation of performance of FFB flow solver with multi-vectors
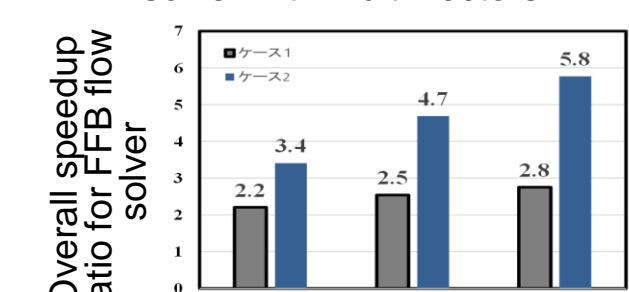
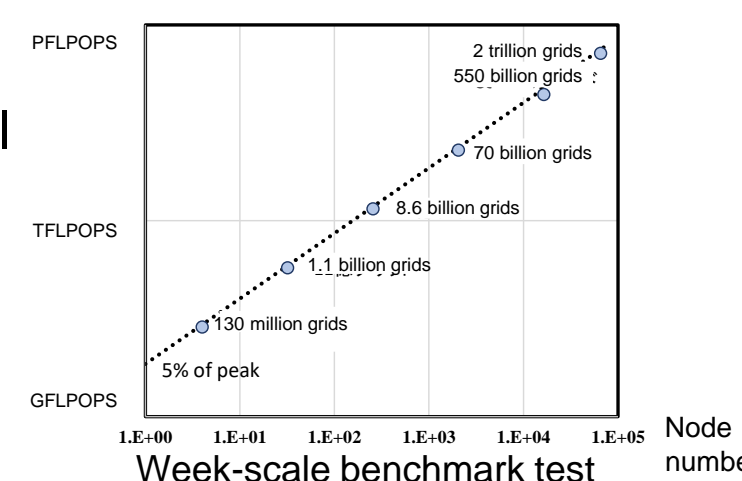Estimation of speedup ratio for overall FFB flow solver $\left(\sum_{i=1}^{i=5} \frac{\alpha_i}{R_i(n)} \right)^{-1}$

Simulation of self-navigation test
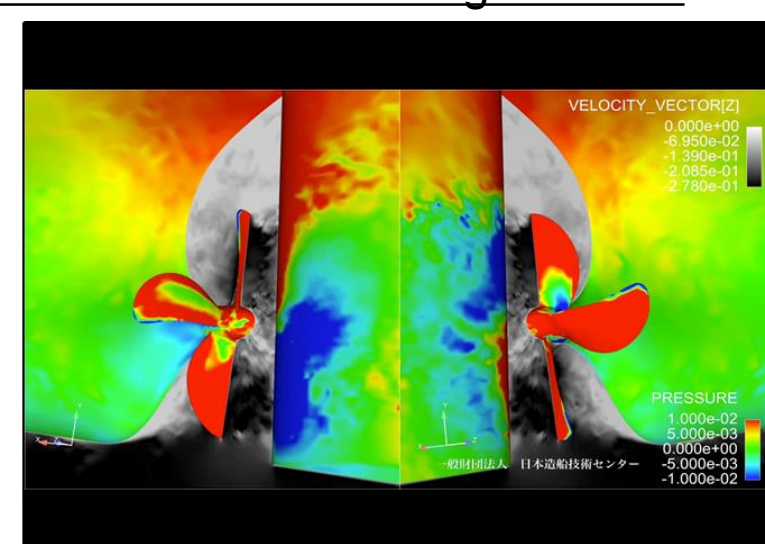
Pressure distribution on ship surface (color) and velocity distribution of the ship center section (black and white)

Courtesy of Shipbuilding Research Centre of Japan (SRC)

Measurement of the computational speed and validation of the computational accuracy have begun for the developed prototype LBM program

Week-scale benchmark test

Software to be developed

Ultra-large-scale incompressible/compressible LES analysis software (FrontFlow/blue)
Software to perform direct LBM calculation of aeroacoustical/hydraulic noise generated from turbomachinery (FFX)

Sub-issue D:
Research and development of core technologies to innovate aircraft design and operation

Engaged institutions: JAXA, Tohoku Univ. and Tokyo Univ. of Science

Approach

1. Development of high-speed/high-accuracy turbulence flow analysis technology applicable to take-off/landing and the detailed configuration of actual aircraft
2. Flight control based on a non-linear flight dynamics model

Outcome

It will be able to predict flight status, such as take-off and landing, with high accuracy, which has not been possible until now, we can now perform precise aircraft design and safer flights that were difficult using previous methods.
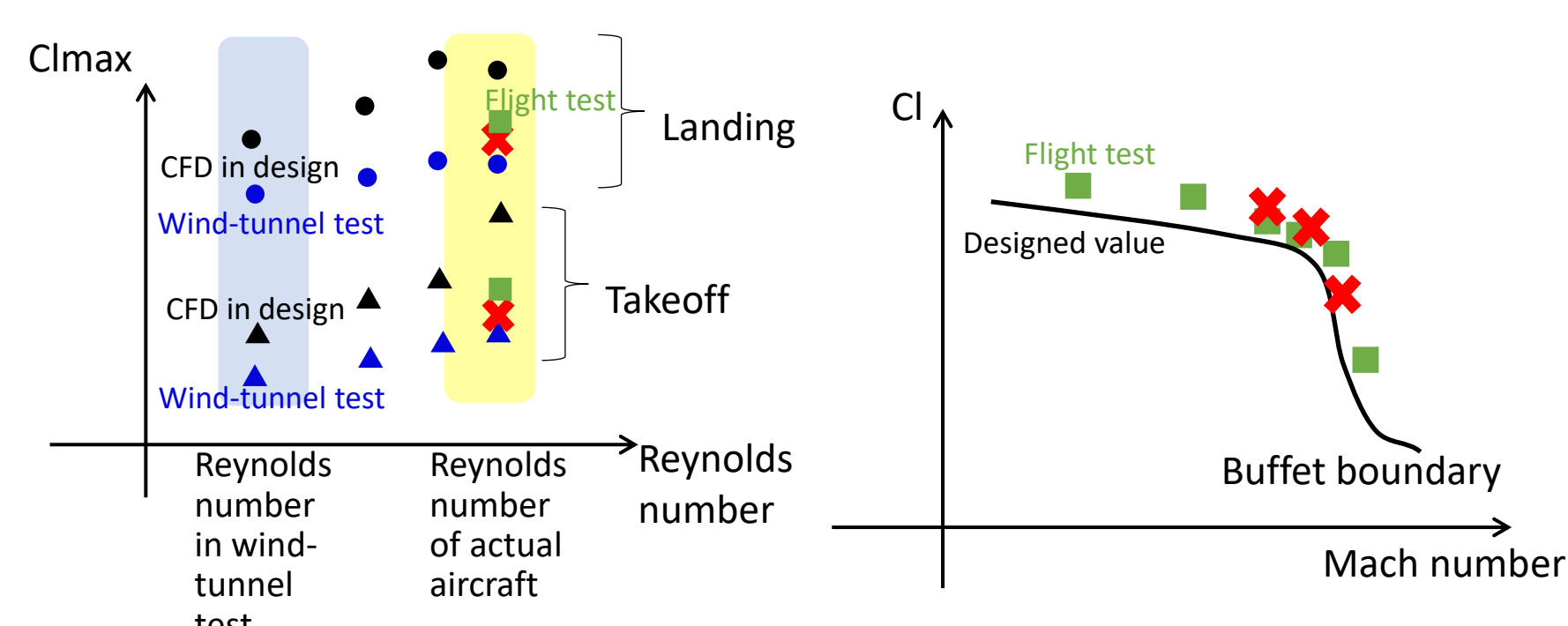
Prediction of maximum lifting capacity during landing and takeoff
→Considerably improve the commodity value of aircraft

Prediction of flight boundary
→Enabling the partial replacement of flight tests with CFD calculations

Software to be developed
FFVHC-ACE

Achievements to date

■ Wall model has been newly implemented in CFD program and transonic buffeting phenomena has been successfully predicted using the same program
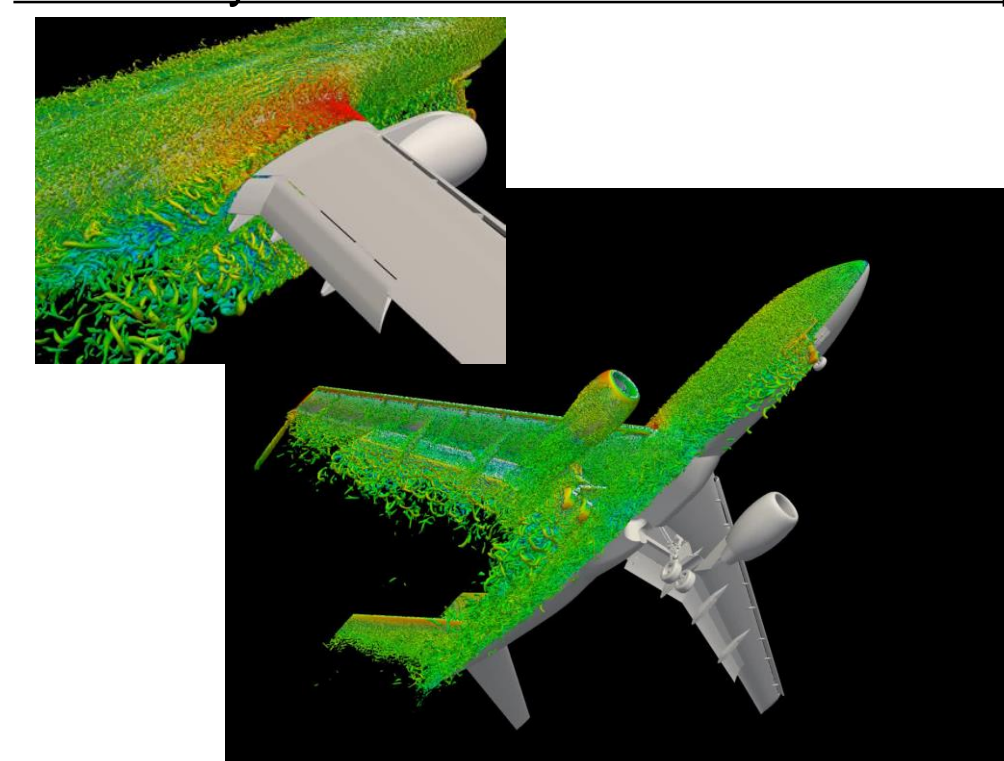■ Test analysis for actual aircraft with complex configurations have been performed

Test analysis of transonic buffet and low speed stall phenomena

OAT15A supercritical airfoil
$M_\infty = 0.73$
$\alpha = 3.5$deg
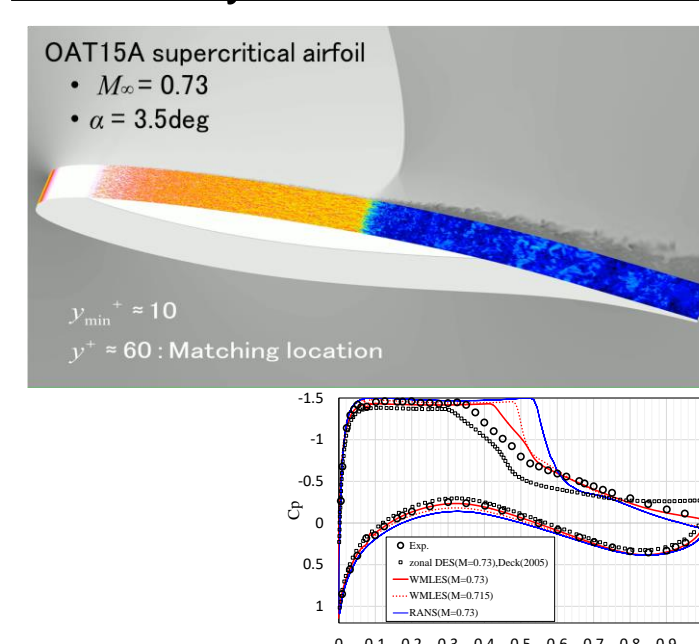
Transonic buffet phenomena of a single airfoil

Low speed stall of a single airfoil

Test analysis for actual aircraft with a complex configuration

-JAXA High-Lift Model
- Approximately 4.5 billion grids,
Hierarchical number of lattices = 7
(solid: 1.4 billion grids)
- 1024 node@FX100

http://www.postk-pi8.iis.u-tokyo.ac.jp/

Priority Issue 8 on Post-K (Fugaku) Computer

Development of Innovative Design and Production Processes that Would Lead the Way for the Manufacturing Industry in the Near Future

Sub-issue E:
Research and development of an advanced press forming and welding simulator for new materials

Engaged institution: The Univ. of Tokyo (Graduate School of Frontier Sciences)

Approach

1. Development of a parallel iterative method for large-scale analysis of assembly/contact problems
2. Development of a large-scale strong coupling method for thermos-elastoplastic problems with phase transformation
3. Development of a welding analysis method that considers spring-back during press forming

Outcome

Through our development of accuracy enhanced technologies in welding process, we are contributing to increasing reliability and reducing time in the manufacturing process.

Permanent deformation predictions for entire mast assembly for a jib climbing crane

Jib climbing crane   Mast section
(http://www.iuk.co.jp/howto/t_crane.html)

The mast panel models, one of our target problems, assembled by the multiple arc welding paths.

A pre/post application has been developed that can comprehensively handle a series of manufacturing processes from the press process to the welding process as a workflow.
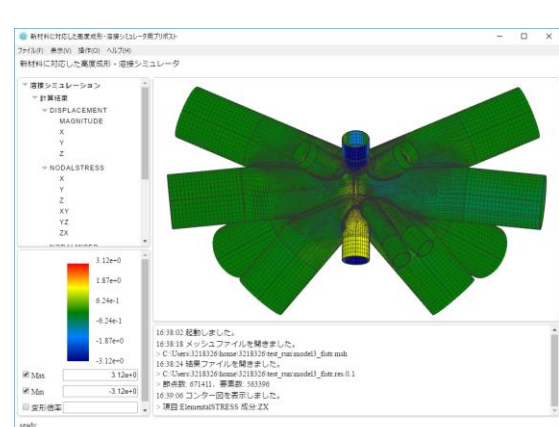
The development of simulator that can solve the large-scale heat analysis and thermal elastic-plastic problems with high resolution FE mesh, enables the more accurate prediction of permanent deformations in a welding process

Software to be developed
FrontISTR

Achievements to date

■ Prototype code for the advanced press forming and welding simulator has been developed.
■ A pre/post processor has been developed and enhanced its functionality to handle a series of simulations for thermomechanical coupled analysis.
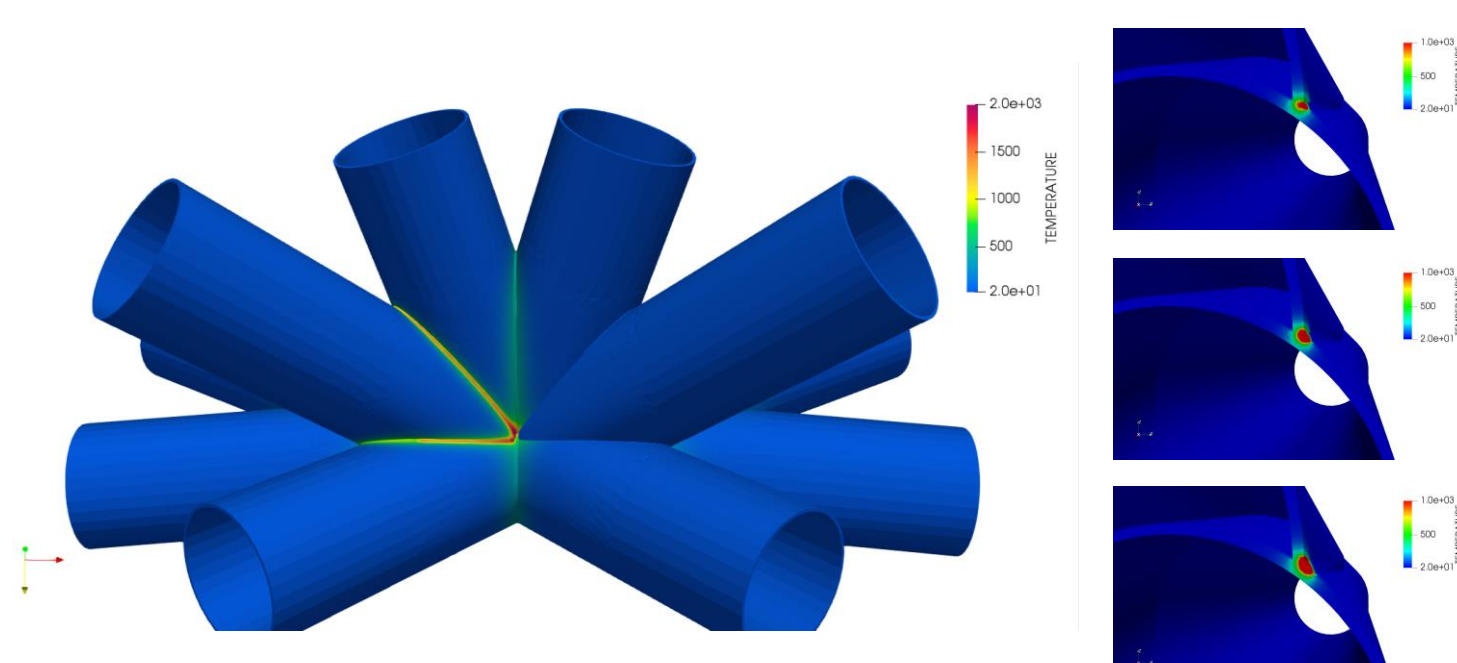
The operation of a code based on thermomechanical monolithic coupled formulation was confirmed, and its accuracy was verified.
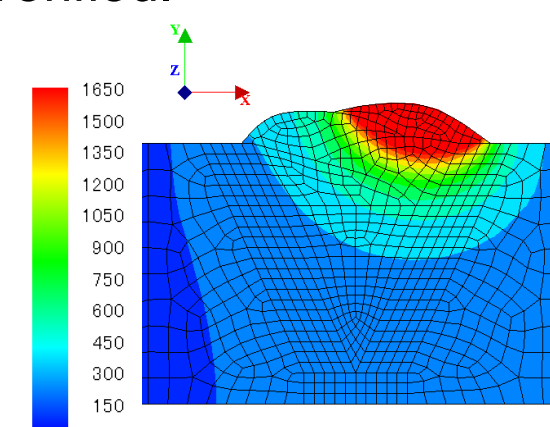
Temperature distribution on the central section of a specimen after sixth welding paths.
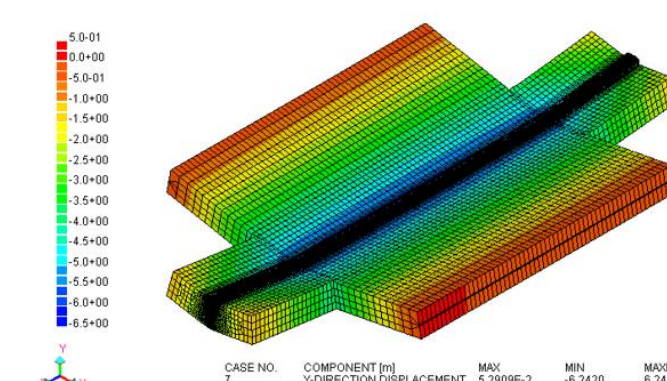
Vertical displacement distribution in the analysis domain after sixth welding paths

The arc welding process of the mount part of large-scale telescope. Temperature distribution by heat injection of 90 welding paths, required to join 16 pipes.

Sub-issue F:
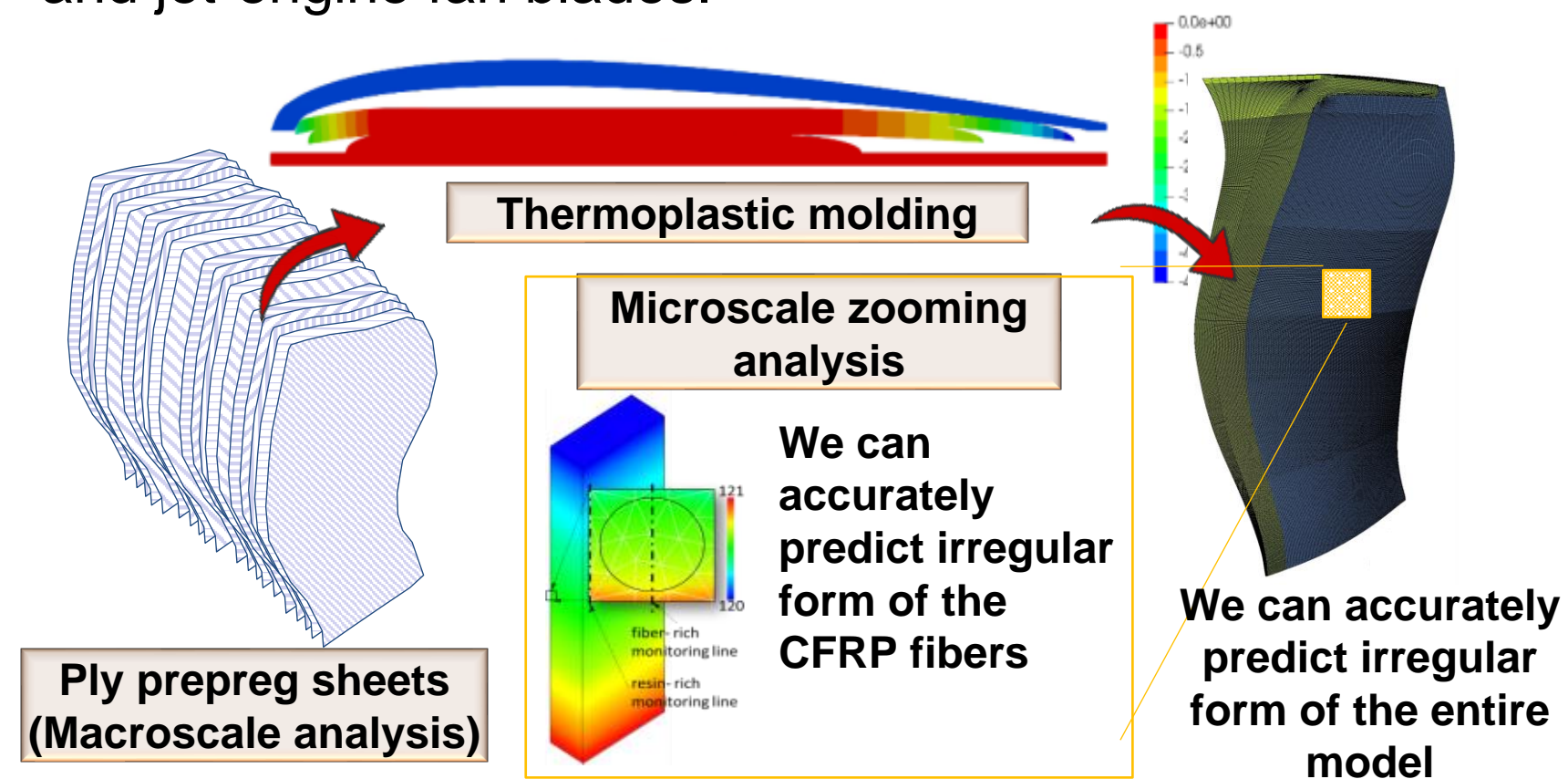### Research and development of multiscale modeling simulators for thermoplastic CFRP

Engaged institution: The Univ. of Tokyo

Approach

1. Development of a microscale thermoplastic simulator for zooming analysis
2. Development of a macroscale thermoplastic model through multi-scale development
3. Development of a macroscale thermoplastic molding simulator

Outcome

The improved CFTRP product design considers tolerance of errors that occur during the manufacturing process and enhances transportation devices such as automobile bodies and jet-engine fan blades.

Thermoplastic molding

Microscale zooming analysis

We can accurately predict irregular form of the CFRP fibers

We can accurately predict irregular form of the entire model

Ply prepreg sheets (Macroscale analysis)

Development of multiscale manufacturing process simulator
→ Design and manufacturing of components made of thermoplastic CFRP are optimized to afford a competitive advantage to Japanese manufacturing

Software to be developed
FrontCOMP

Achievements to date

■ Development of a macroscale thermoplastic molding simulator based on a macroscale thermoplastic model through multi-scale development
■ Development of a microscale forming process simulator to accurately predict the properties of thermoplastic CFRP
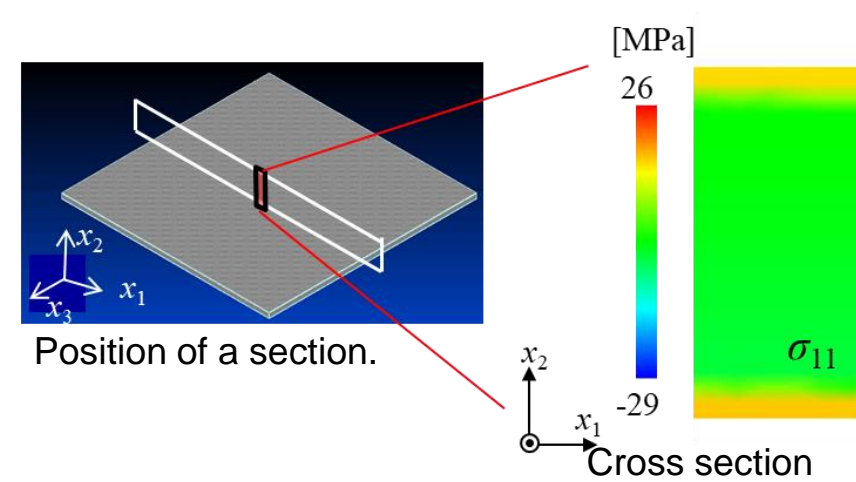
Execution of forming process simulation of CFRTP of test piece for developing fan blade of jet engine by hyper parallel computer of K computer class

Verification by using eight ply prepreg sheets.

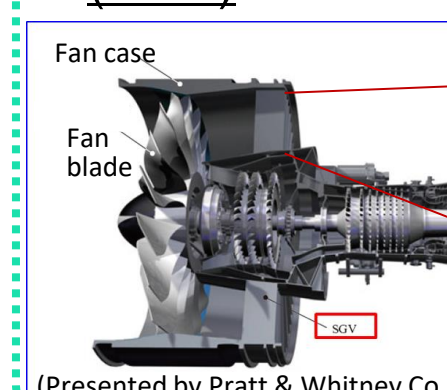Specimen : eight ply prepreg sheets
100 × 100 × 1.4 [mm]

Measurement setup

Position of a section.
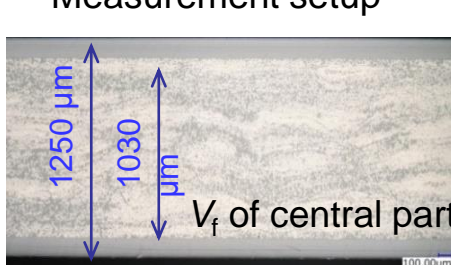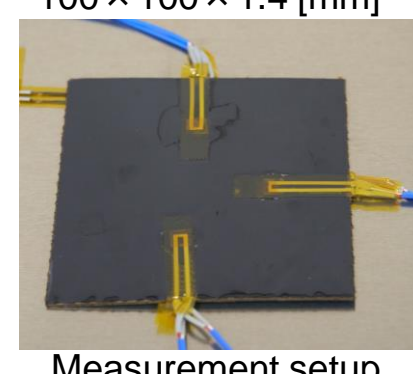
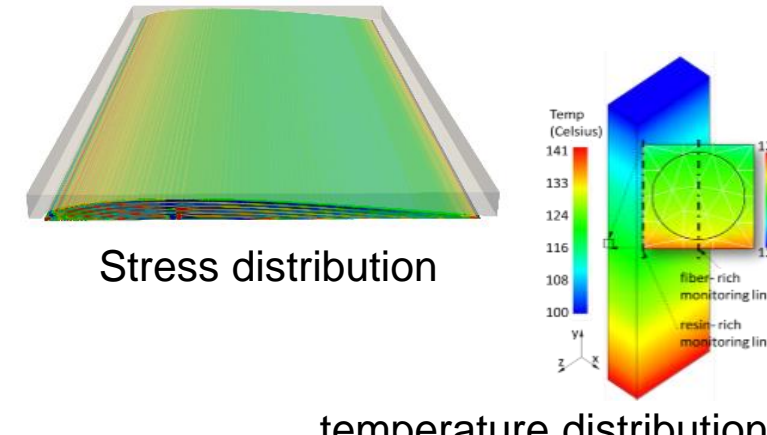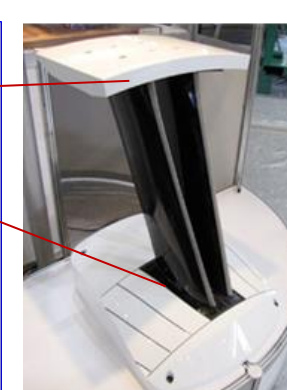Cross section of eight ply prepreg sheets

V_f of central part : 60.0 %

Calculated Stress Distribution

Calculation for thermoplastic molding Structural Guide Vane (SGV)

Fan case
Fan blade
[Presented by Pratt & Whitney Co.]

Stress distribution

temperature distribution

http://www.postk-pi8.iis.u-tokyo.ac.jp/

Research and Development of an Innovative Fluid-Dynamics Technologies

Program for Promoting Researches on the Supercomputer Fugaku

Research and development of innovative fluid-dynamics simulations for aerodynamical/hydrodynamical performance predictions by using Fugaku

Theme 1

Realization of a numerical towing tank and improvement of propulsion efficiency by using energy-saving devices
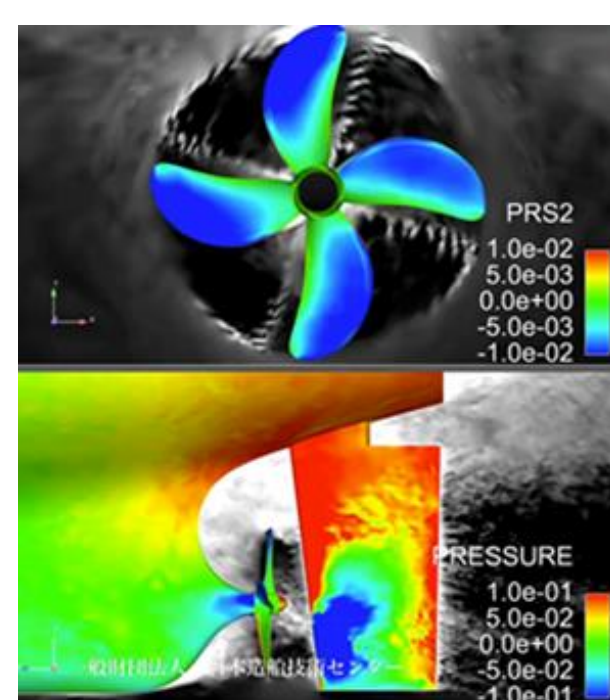
Benchmark calculation for replacing self-propulsion tests (Courtesy of SRC)

Engaged institutions: Shipbuilding Research Centre of Japan (SRC) , The Univ. of Tokyo, et al.

The using application: FrontFlow/blue

Theme 2

Wall-resolved LES of internal flow in hydro-dynamical and leakage-flow passages of multistage centrifugal pump
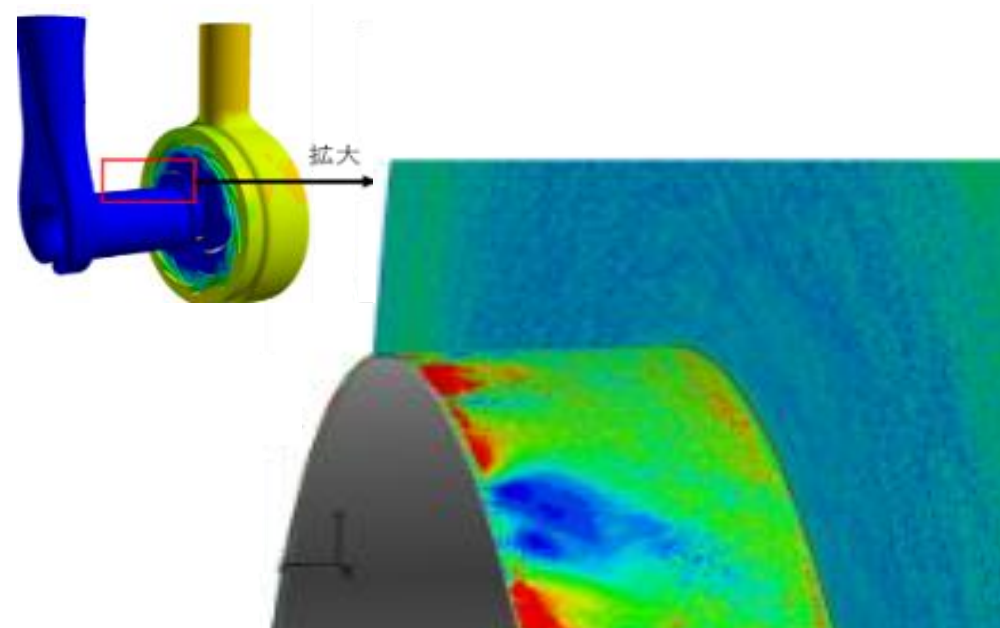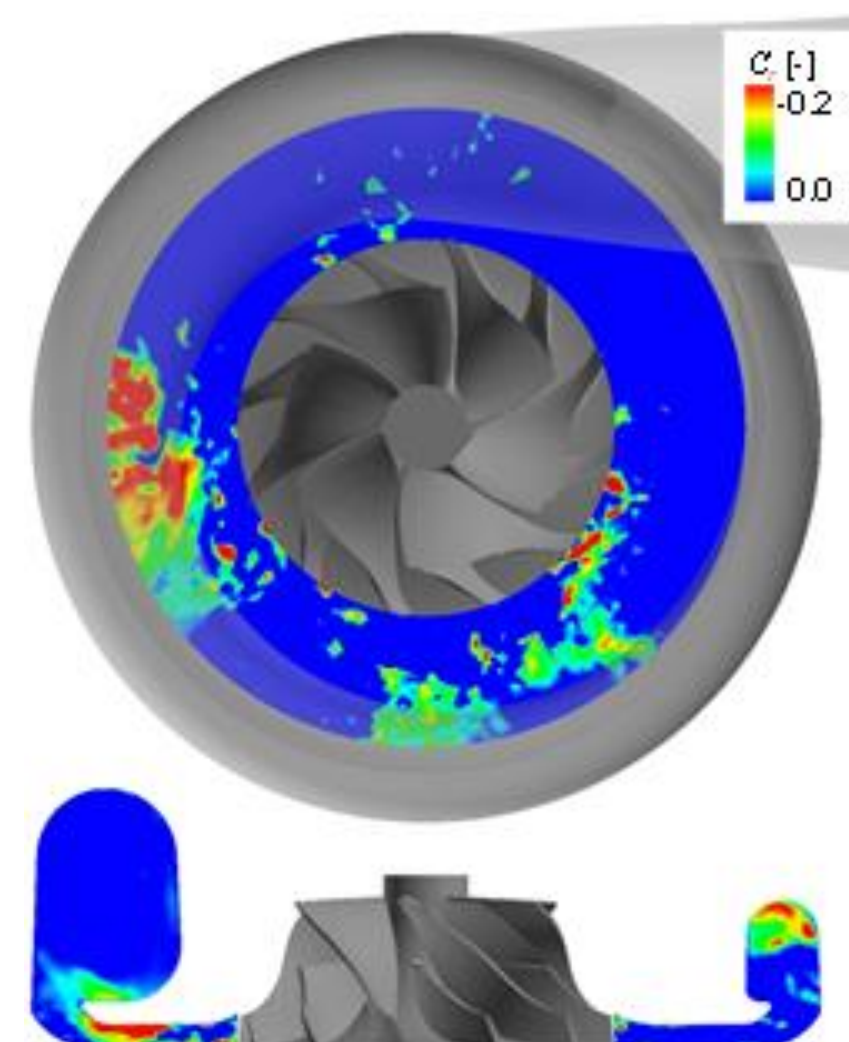

Wall-Resolved large-eddy simulation of internal flow around the stenopeic structure of single-stage centrifugal pump

Engaged institutions: Ebara Corp., Hitachi, Ltd., Kyushu Univ., The Univ. of Tokyo, et al.

The using application: FrontFlow/blue

Theme 3

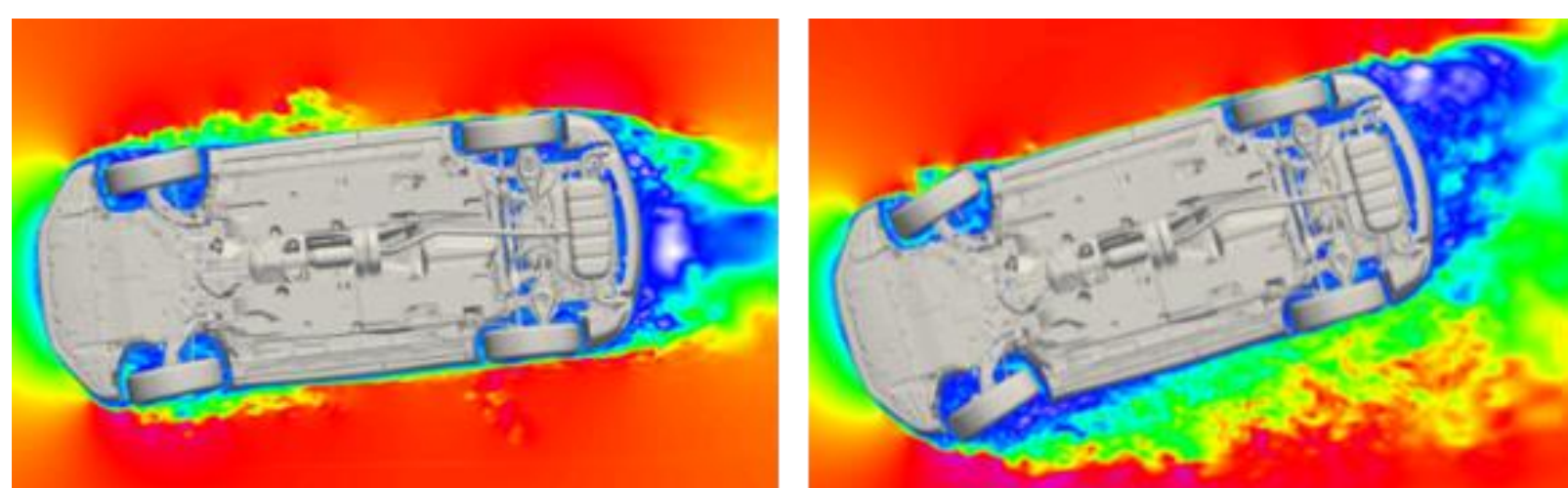Direct analysis of compressor surge

Velocity distribution of flow of rotating stall

Engaged institutions: Kyushu Univ., et al.

The using application: software of DES analysis of compressible flow for turbomachines

Theme 4

Prediction of real aerodynamic performance of automobile in road conditions
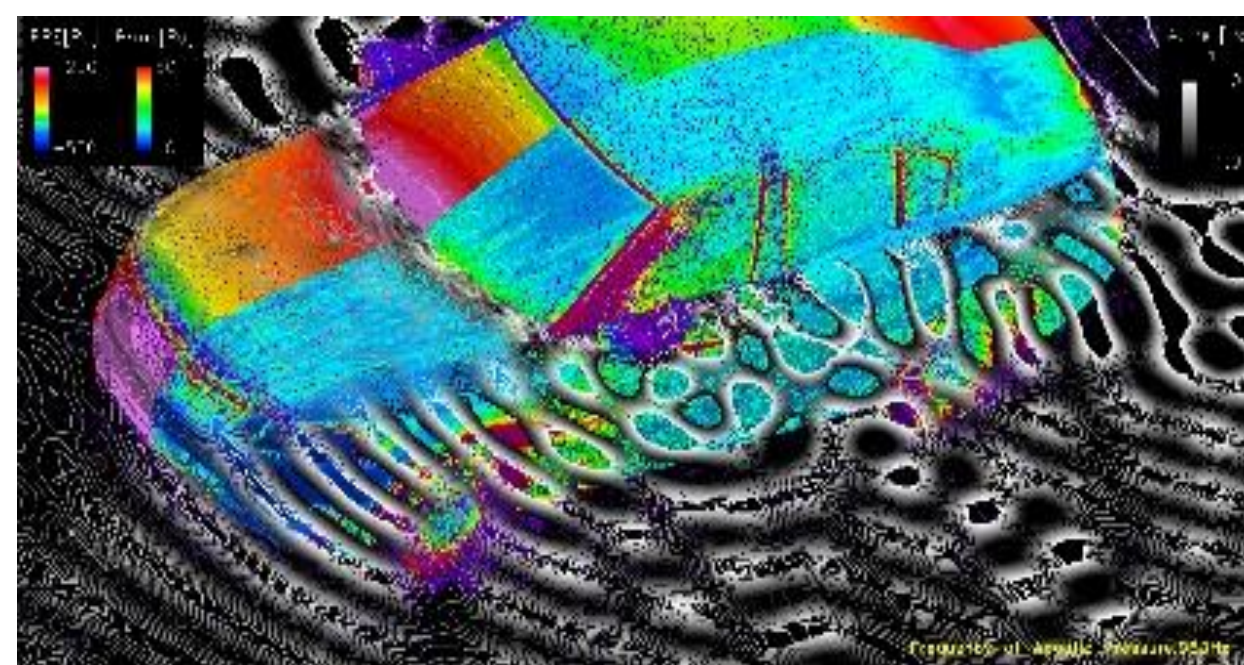

Real-world simulation coupled aerodynamics and vehicle running motion

Engaged institutions: Kobe Univ., Univ. of Yamanashi, RIKEN, et al.

The using application: CUBE

Theme 5

Prediction of automobile aeroacoustics in road conditions

Analysis of broadband sound produced by door mirror
(Iida, Miyazawa, et. al.: Symposium on CFD2018)

Engaged institutions: Toyohashi Univ. of Tech., Kobe Univ., RIKEN, The Univ. of Tokyo, et al.

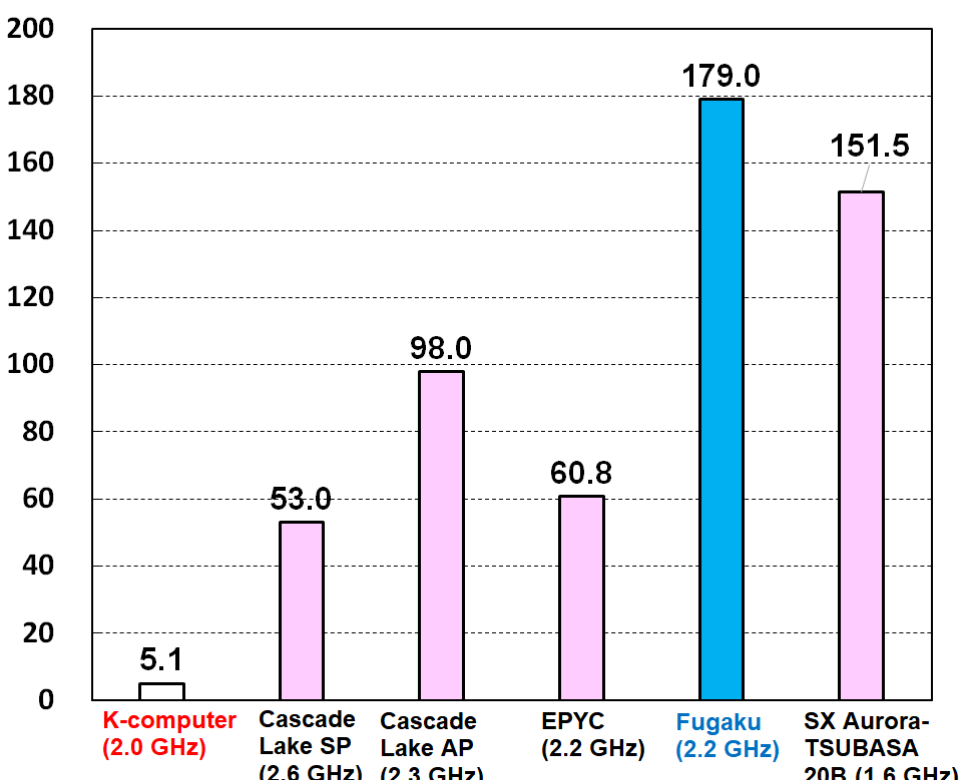The using application: CUBE, FFX

Results of speed up of the LES analysis software, FrontFlow/blue

To realize numerical towing-tank tests by substantially shortening the time to the solution, FrontFlow/blue (FFB) has been fully optimized so as to achieve maximum possible sustained memory throughputs with three of its four hot kernels.
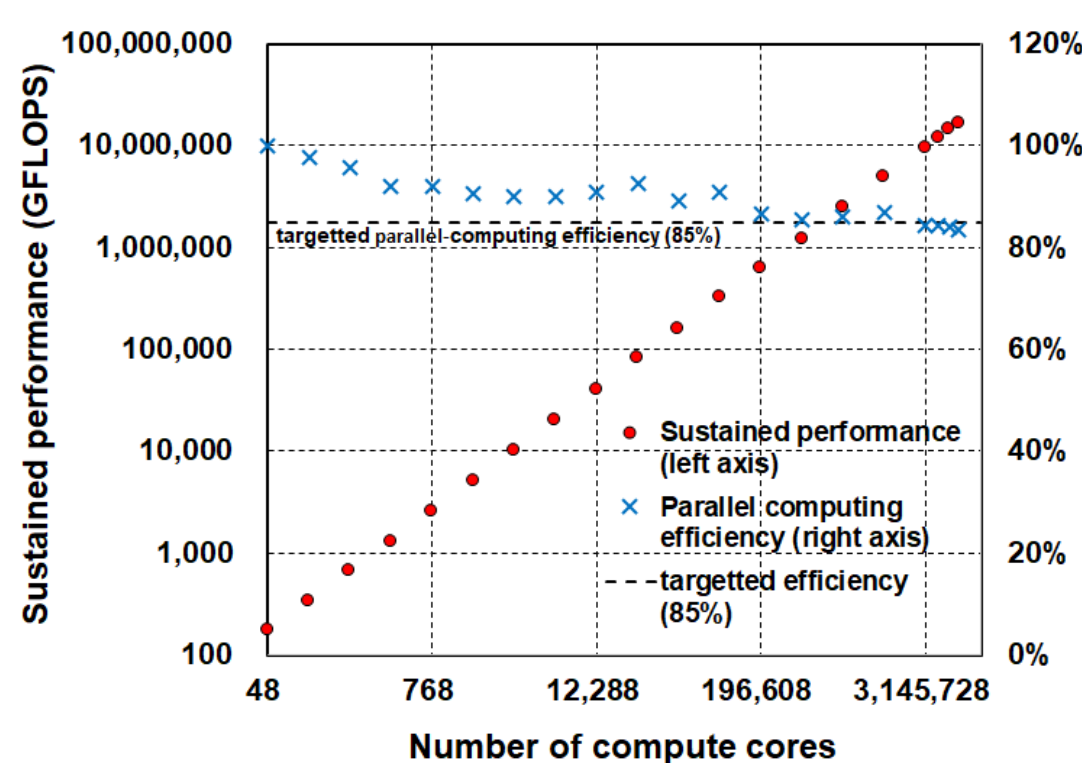
→The Gordon Bell prize paper:

"Toward Realization of Numerical Towing-Tank Tests by Wall-Resolved Large Eddy Simulation based on 32 billion grid Finite-Element Computation", C. Kato, Y. Yamade, K. Nagano, K. Kumahata, K. Minami, T. Nishikawa
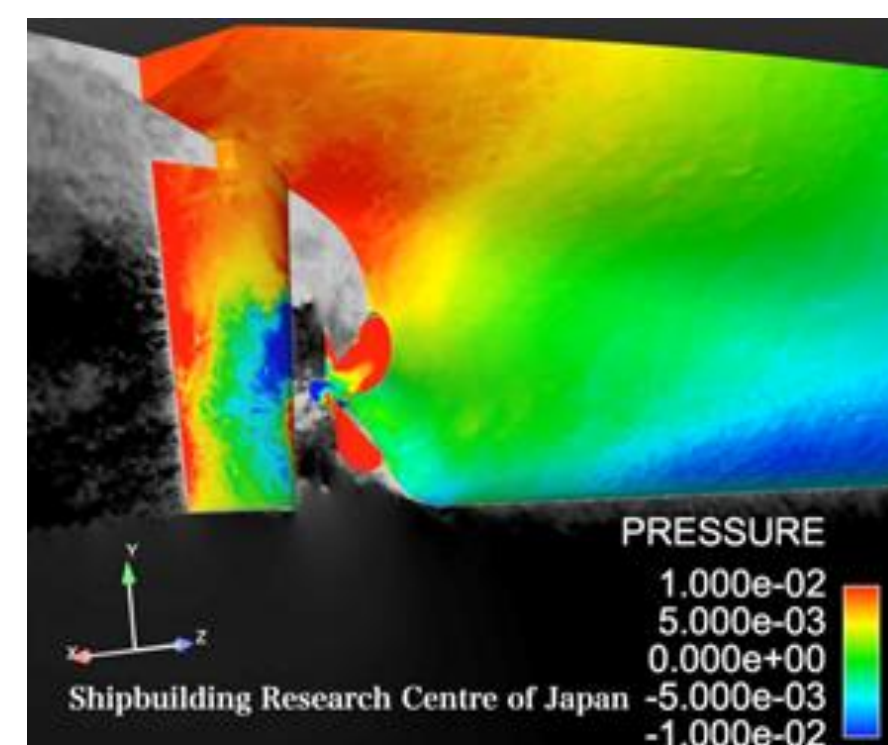

Sustained single-node performance of FFB run on various CPUs

Parallel-computing performance of FFB run on Fugaku in weak-scale benchmark test

Computed instantaneous distribution of static pressure in TBL for self-propulsion test of KVLCC2 vessel.

※The results presented in this paper were obtained in the evaluation environment in the trial phase of the supercomputer Fugaku. They should not be regarded as guaranteeing the computation performance, power-consumption rate and/or any other attributes of supercomputer Fugaku at the start of its full operation.

http://www.fugaku-pj.iis.u-tokyo.ac.jp/