BARAM : Virtual Wind-Tunnel System for CFD Simulation

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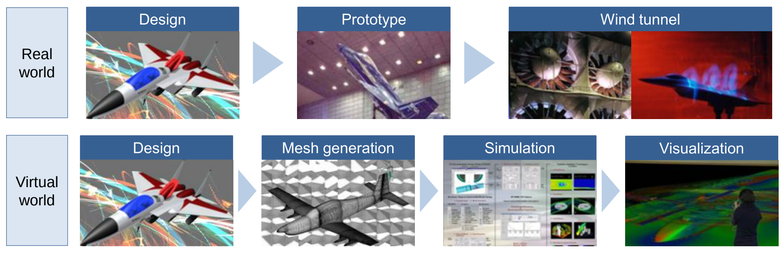
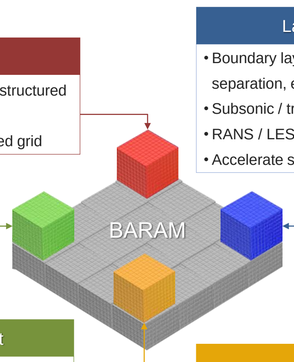
Overview



Mesh generation
- (Semi) automatic generation of structured grids and unstructured grids
- Support of multiblock, overlapped grid

Large scale simulation
- Boundary layer / laminar flow / transition / separation, etc.
- Subsonic / transonic / supersonic flow
- RANS / LES / DES
- Accelerate simulation codes using GPUs

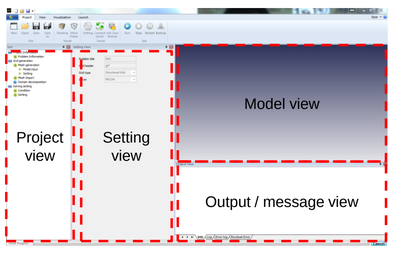


Integrated environment
- Manage user, simulation history, simulation data, etc.
- Launch applications and monitor their execution status
- A pluggable architecture provides a standardized interface for new components

Visualization
- Real-time visualization & analysis of large-scale simulation dataset
- Support of scalable, immersive environment

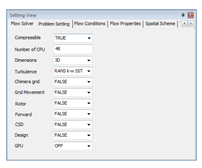
Integrated environment

- Application control
  - Users can launch, monitor and terminate all applications that constitute BARAM in the integrated environment
  - Supports submission of batch jobs to remote cluster
  - Messages from applications running on remote hosts/clusters are forwarded to the integrated environment in real-time

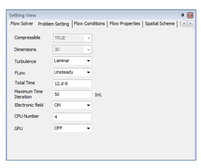


UI Layout

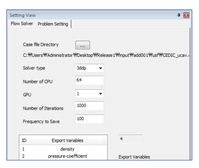
- Simulation interface
  - Multiple simulation codes can be integrated into the environment
  - Provides user interfaces to specify the amounts of computing resources needed, initial & boundary conditions and other parameters that affect simulation



Generic CFD solver (KFLOW)

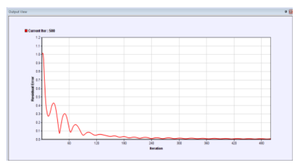


Hypersonic simulation (SNUFLOW)



Commercial solver (FLUENT)

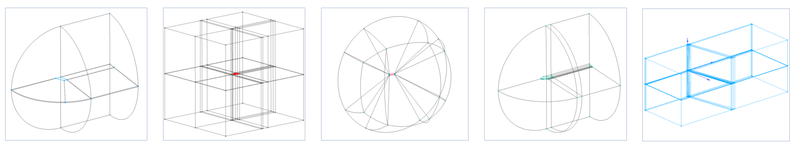
  - Once a batch job is scheduled to run, it becomes possible to monitor residual to check whether the simulation is getting closer to the solution



- Management tools
  - User, history and meta information of simulations, etc.

Mesh generation

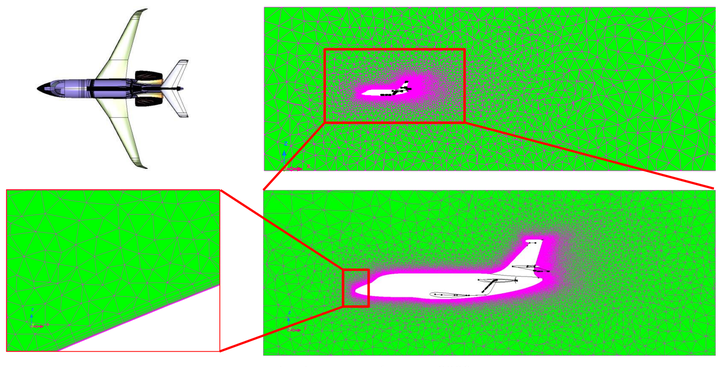
- Semi-automatic generation of structured grids
  - Provides generic, predefined templates for various types of models(airfoil, delta wing, generic wing-body, etc.), which drastically reduce manual works in mesh generation
  - Supports generation of multi-block, overlapped grid



2-cube | 3-cube | 5-cube | UCAV | Wing-body

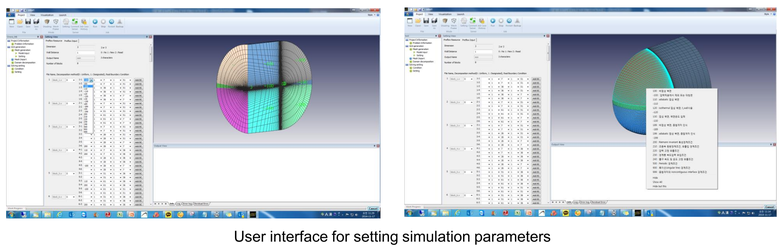
Predefined templates for generating structured grid

- Automatic generation of unstructured grids



Unstructured grid of Falcon 2000

- After generating meshes, users can browse individual block and set boundary condition in an interactive manner within the integrated environment

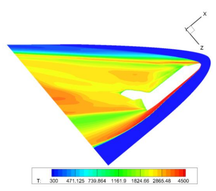


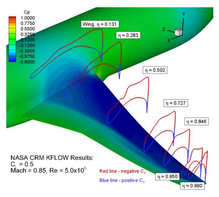
User interface for setting simulation parameters

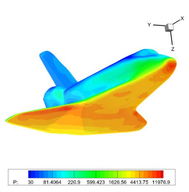
CFD simulation

Multiple simulation solvers

- Currently, there are 2 proprietary simulation codes integrated into BARAM, and it is also possible to add new solvers on demand
  - **KFLOW**
    - ➢ Generic solver for various types of CFD problems
    - ➢ Supports multi-block, overlapped structured grid
    - ➢ RANS / LES / DDES turbulence models are implemented. As for DDES, we applied γ-Re_θ transition model with consideration of a cross-flow effect
    - ➢ GPU accelerated version is available
  - **SNUFLOW** is a solver specialized for hypersonic CFD simulation
    - ➢ Supports multi-block, overlapped structured grid
    - ➢ GPU accelerated version is available

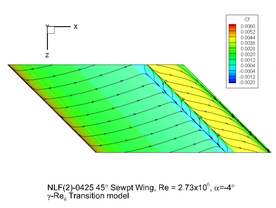


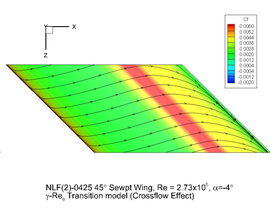


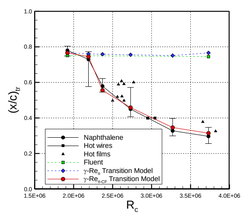


Case study

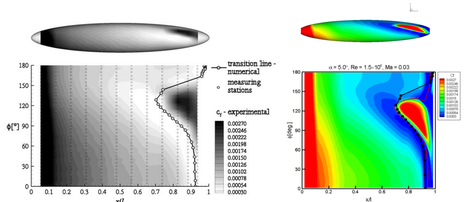
- Transition point distribution of NLF(2)-0425 Swept Wing
  - ➢ Applied modified γ-Re_θ transition model that considers cross-flow effect for precise prediction of transition point distribution



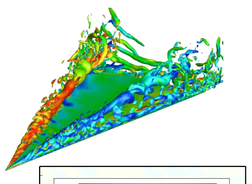


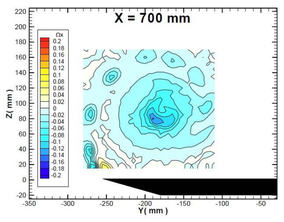


- Transition flow around a prolate spheroid
  - ➢ Reynolds number : 1.5 x 10^6
  - ➢ Mach : 0.03
  - ➢ Angle of attack : 5.0º, 10.0º

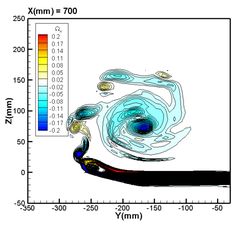


- Vortex breakdown of a delta wing at high angle of attack
  - ➢ Reynolds number : 1.56 x 10^6
  - ➢ Mach number : 0.0706 (U_∞=24 m/s)
  - ➢ Angle of attack : 27º

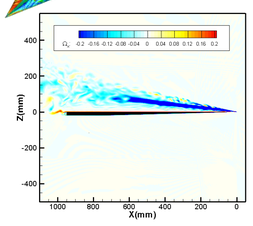




Experiment data

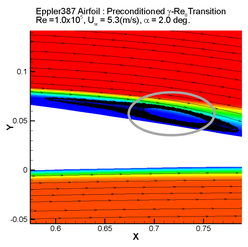


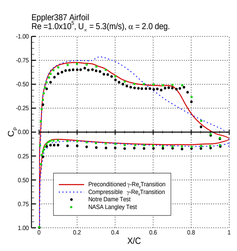
BARAM (KFLOW)



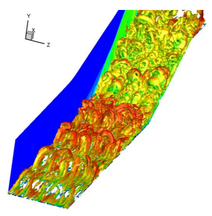
Vortex breakdown location

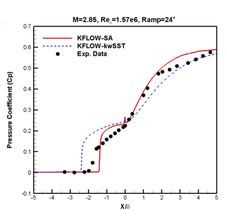
- Low Reynolds number transition simulation
  - ➢ Eppler 387 airfoil
  - ➢ Reynolds number : 1.0 x 10^5
  - ➢ U_∞ = 5.3m/s
  - ➢ Angle of attack : 2.0º, 11.0º, 14.0º





- Supersonic compression corner flow
  - ➢ Reynolds number : 1.57 x 10^6
  - ➢ Mach number : 2.85
  - ➢ Turbulence model : S-A, k-w SST
  - ➢ Ramp : 8º, 16º, 20º, 24º





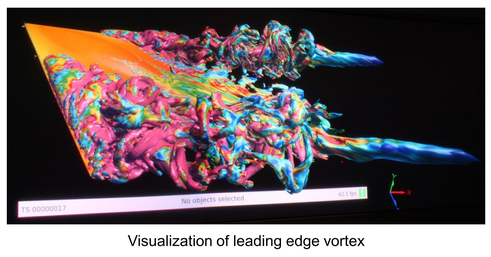
- Blade vortex interaction
  - ➢ Hart-II rotor blade

Background grid	177 x 761 x 761 (102.5M)
Blade grid (c x s x n)	321 x 103 x 49 (1.62M)
Inner background spacing	0.05c
Azimuth angle increment	0.2

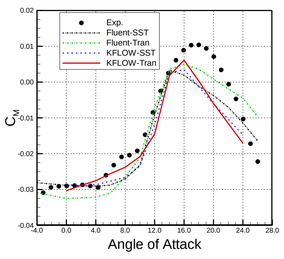
Accelerating simulation codes with GPUs

- Ported proprietary simulation codes to GPU
  - Analyzed profile information of the simulation codes to identify most time-consuming routines and modified them to run on GPUs
  - Achieved 60% speed up in simulation of UAV with 100+ million grid cells

	Model	Time(sec)	Speedup
CPU only	Intel Xeon E5-2650 v2 x 112 sockets	2239.9	1.00
GPU + CPU	Intel Xeon E5-2650 v2 x 112 sockets NVIDIA Tesla K20 x 56 GPUs	1396.7	1.60



Visualization of leading edge vortex

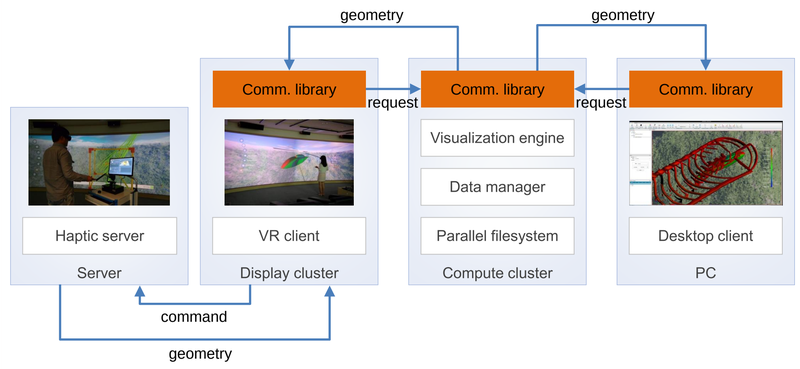


Angle of Attack

Visualization

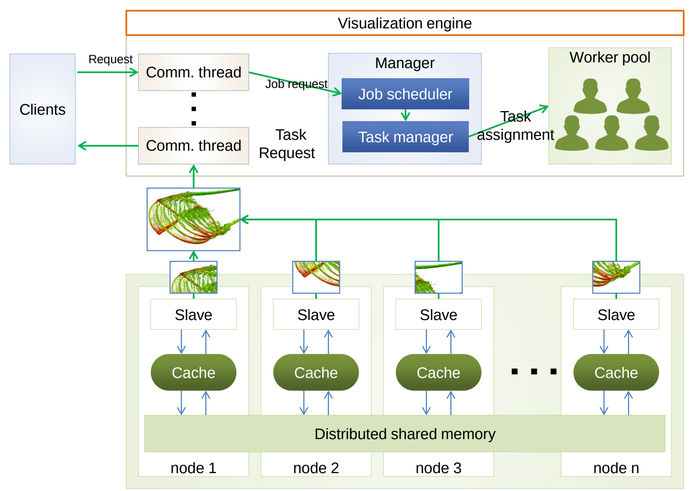
Overview

- Visualization system consists of several components, most of which are implemented as parallel programs to run on large-scale clusters
  - **Data manager** : reads simulation dataset into memory and feed the dataset to the visualization engine
  - **Visualization engine** : receives command from clients and extracts geometries from the dataset. Also, it is responsible for sending the geometry back to the client
  - **Communication library** : lets visualization clients communicate with visualization engine running on a separate cluster. Supports both infiniband and ethernet.
  - **Visualization client for the immersive environment** : supports various input devices and scalable display systems.
  - **Visualization client for desktop PC** in case immersive display is unavailable



Data manager and parallel visualization engine

- Data manager is based on Global Arrays toolkit, which gathers local memory of each node to make a virtual, large memory pool with single address space
  - Applications don't have to care about whether data is located in local memory or should be fetched from remote host
- Visualization engine consists of a set of communication threads, a job manager and a pool of workers



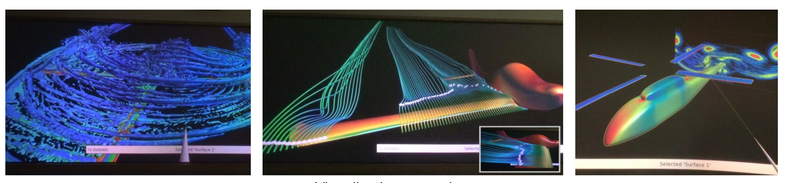
- Visualization engine makes use of application level caches to reduce number of fetches from external nodes as possible

Tool	EnSight	ParaView	BARAM
Slice	1.5	1.79	1.80
Iso-surface	4.8	10.11	2.12
Streamline	79.74	-	71.02
Pathline	3906.91	-	85.12
Iso-surface animation	307	274	2.12

Performance comparison chart (sec)

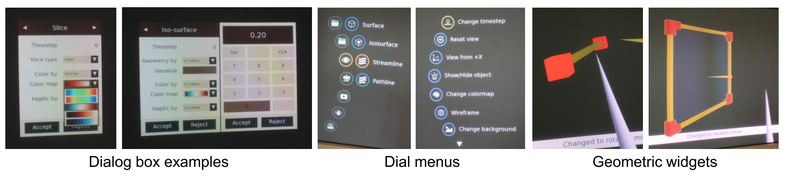
Visualization client for immersive environment

- Visualization client receives geometries from the visualization engine and displays them on screen
  - Uses VR Juggler for managing I/O devices and OpenSceneGraph for rendering



Visualization examples

- Widget library for VR application
  - Basic widgets : frame, label, button, drop box, keypad, message box, etc.
  - Dial menu : corresponds to the main menu of desktop applications
  - Geometric widgets : line, sphere, plane, cube → used to specify orientation and size of slices, how to arrange seed points for streamline, etc.



Dialog box examples | Dial menus | Geometric widgets

- Usability test
  - Performed usability tests against dozens of students and researchers, most of them major in CFD
  - SUS(System Usability Scale) test result shows that users think BARAM is more usable than other commercial visualization software

		BARAM	EnSight
Effectiveness	# of requests for help	2	12
	# of manipulation errors	5	6
Efficiency	Time taken for a single test (sec)	53.22	74.21
	Time taken for all tests(sec)	638.8	1136.65
Satisfaction	SUS score	69.5	44.5