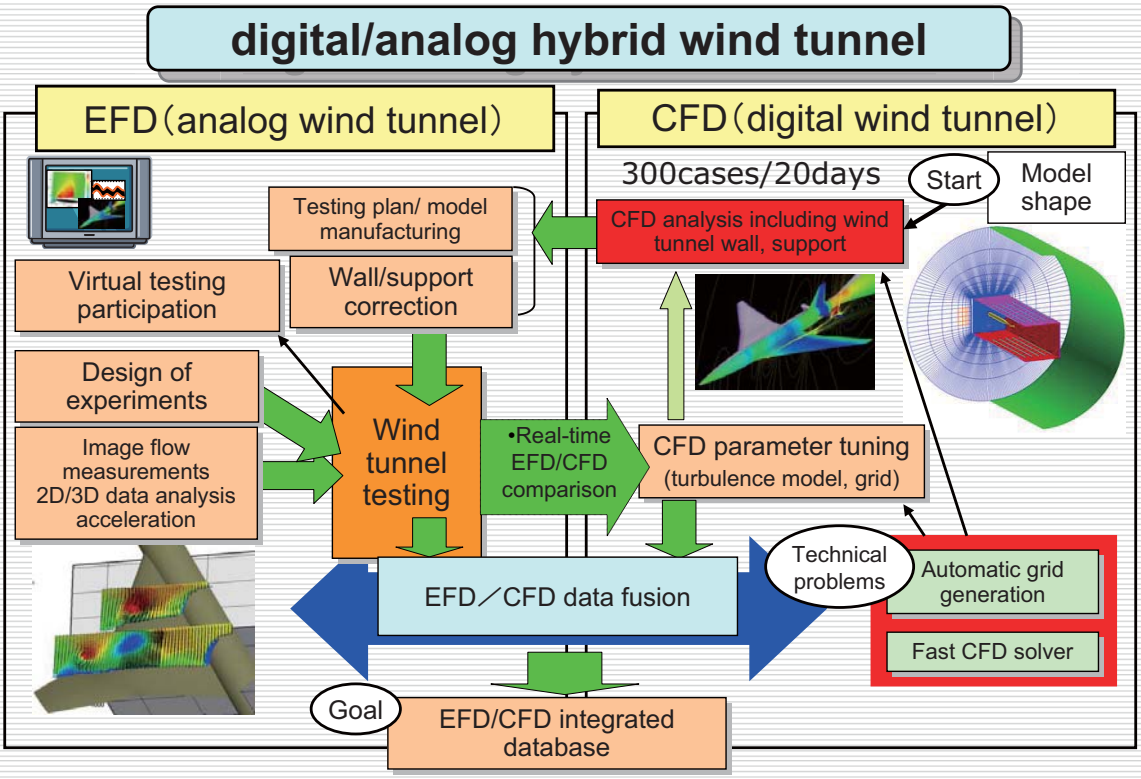
2008/02/24 Second Workshop on Integration of EFD and CFD

JAXA デジタル/アナログ・ハイブリッド風洞：デジタル風洞の開発

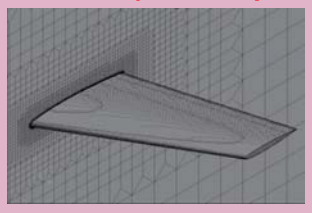
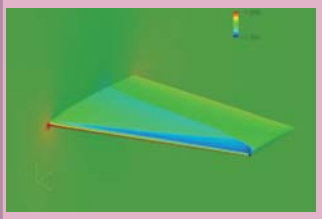
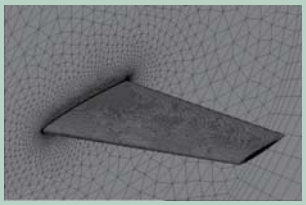
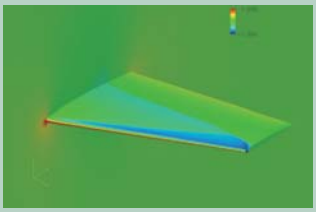
JAXA Digital/Analog Hybrid Wind Tunnel: Development of Digital Wind Tunnel

Atsushi Hashimoto, Keiichi Murakami and Takashi Aoyama
Numerical Analysis Group (NAG)
Japan Aerospace Exploration Agency (JAXA)

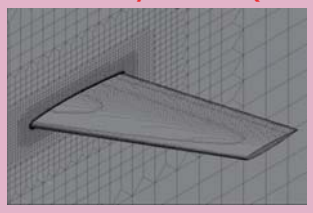
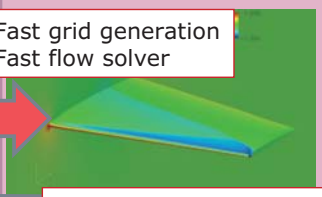
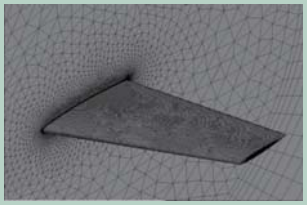
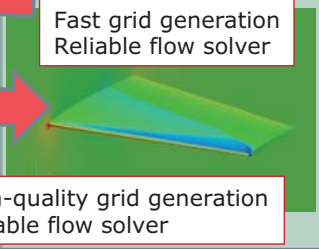
Concept of digital/analog hybrid wind tunnel



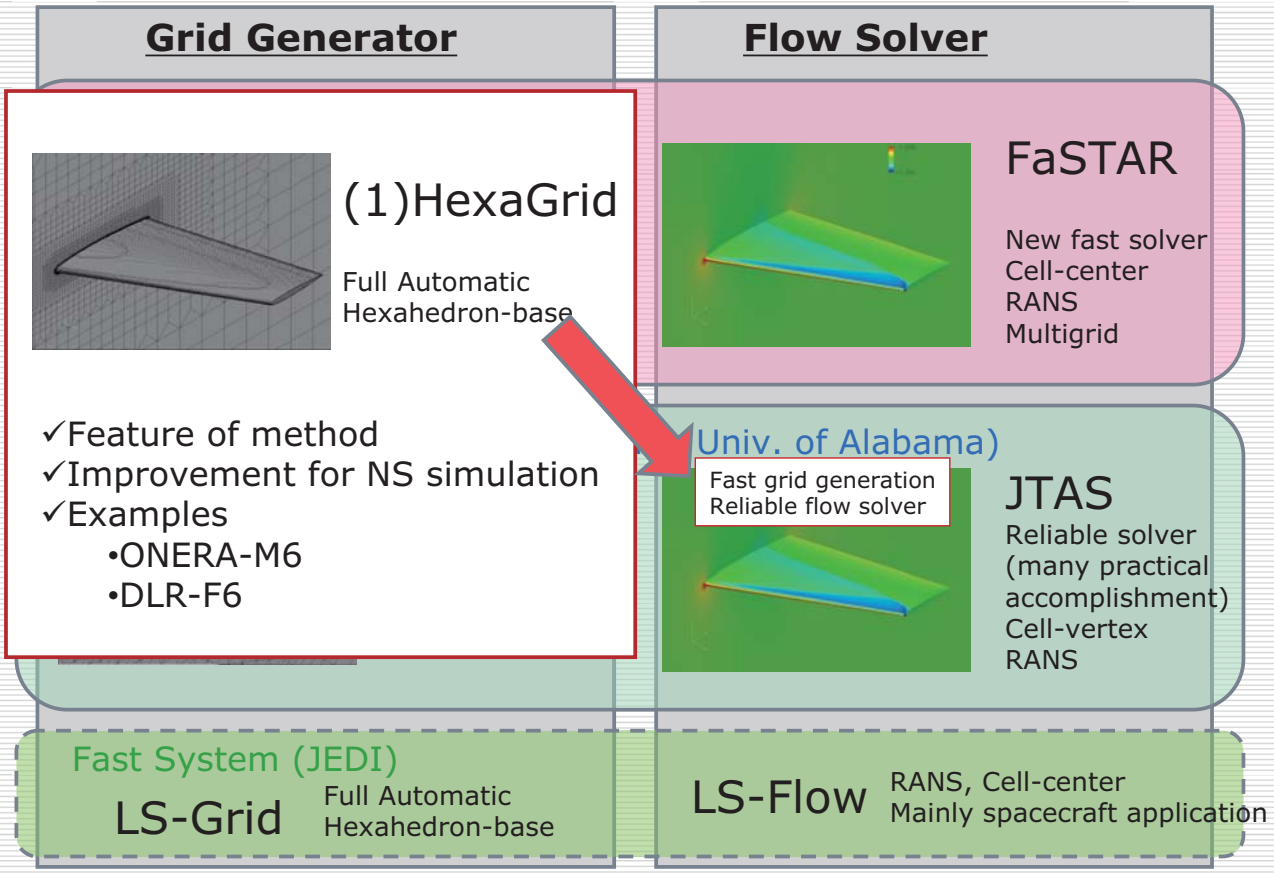
Concept of Digital Wind Tunnel

Grid Generator	Flow Solver
Fast System (NAG)	
 HexaGrid Full Automatic Hexahedron-base	 FaSTAR New fast solver Cell-center RANS Multigrid
Reliable System (APG, Tohoku Univ., Univ. of Alabama)	
 MEGG3D Semi-automatic Tetrahedron-base	 JTAS Reliable solver (many practical accomplishment) Cell-vertex RANS
Fast System (JEDI)	
LS-Grid Full Automatic Hexahedron-base	LS-Flow RANS, Cell-center spacecraft application

Concept of Digital Wind Tunnel

Grid Generator	Flow Solver
Fast System (NAG)	
 HexaGrid Full Automatic Hexahedron-base	Fast grid generation Fast flow solver  FaSTAR New fast solver Cell-center RANS ltigrid
	High-quality grid generation Fast flow solver
Reliable System (APG, Toho Univ. of Alabama)	
 MEGG3D Semi-automatic Tetrahedron-base	Fast grid generation Reliable flow solver  JTAS Reliable solver (many practical accomplishment) Cell-vertex RANS
	High-quality grid generation Reliable flow solver
Fast System (JEDI)	
LS-Grid Full Automatic Hexahedron-base	LS-Flow RANS, Cell-center Mainly spacecraft application

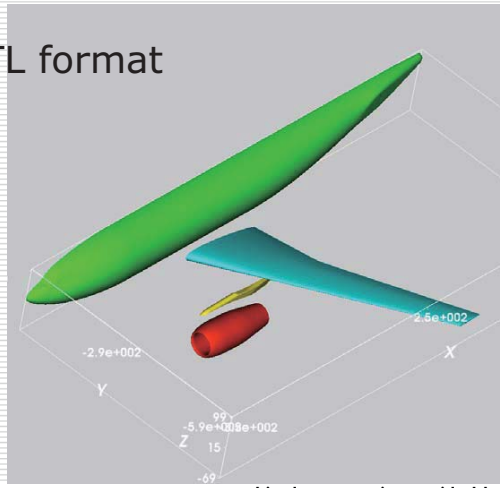
Concept of Digital Wind Tunnel



Features of HexaGrid

HexaGrid :
Automatic grid generator based on hexahedral grid

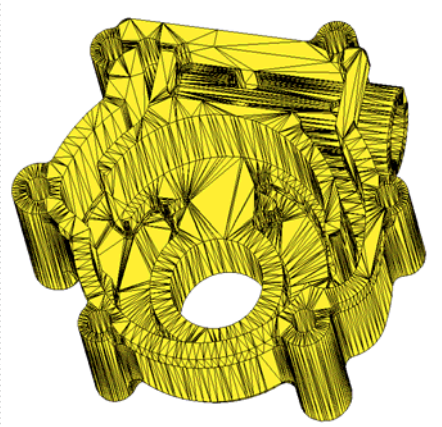
- Unstructured mesh based on Cartesian mesh
  - Handles complex geometry
  - Automatic operation (very few control parameters)
  - Fast (within minutes)
  - High quality elements (predominantly hexahedral)
- Input multi-component geometry in STL format
- Run on ordinary PC

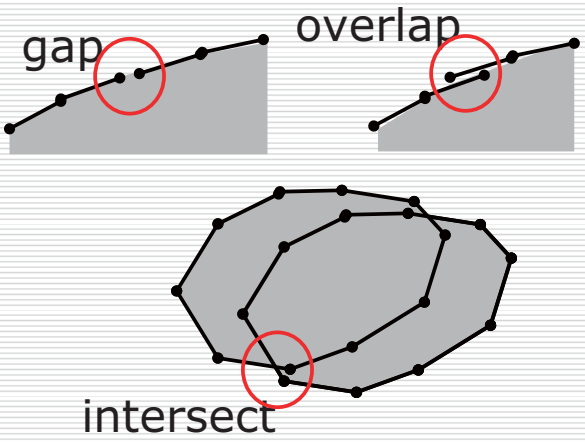


Input Data

- Triangulated surface in STL (STereo Lithography) format
  ➔ can be made by most CAD software

- Very tolerant to "dirty surface mesh"
  - Unconnected triangles ➔ non-water-tight surface is OK
  - Small gap, overlap & intersection are OK
  - Any triangle size is OK

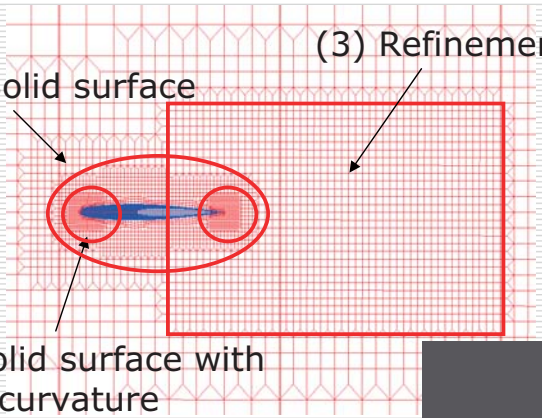




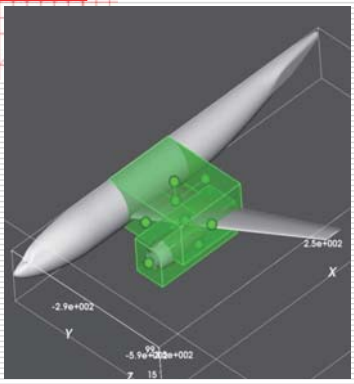
*2D illustration, the actual is 3D

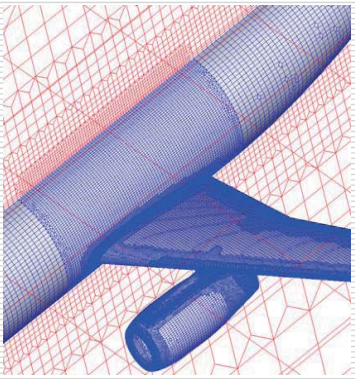
Mesh Refinement Control

- Refine the element using 3 criteria
- Each criterion has a target element size (user-defined)

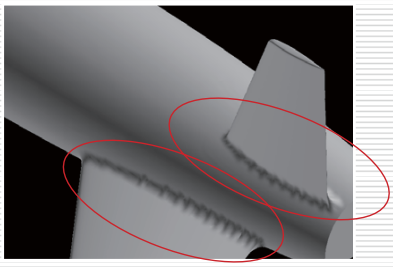


Example of Refinement box

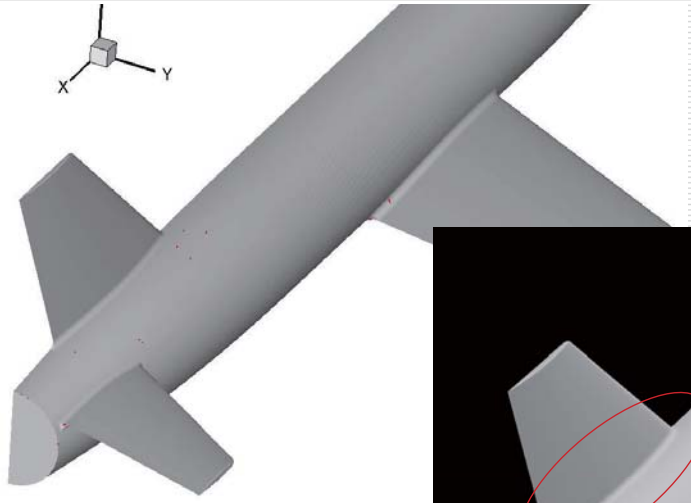




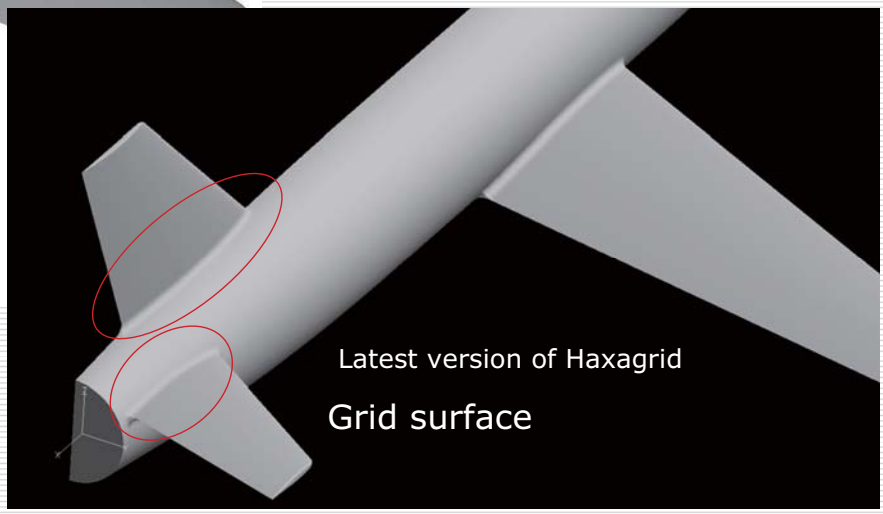
Feature capturing



Previous version of Haxagrid

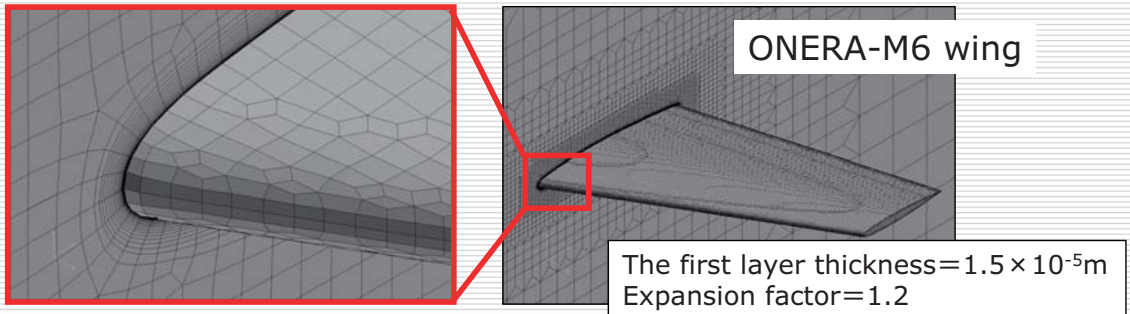


STL data

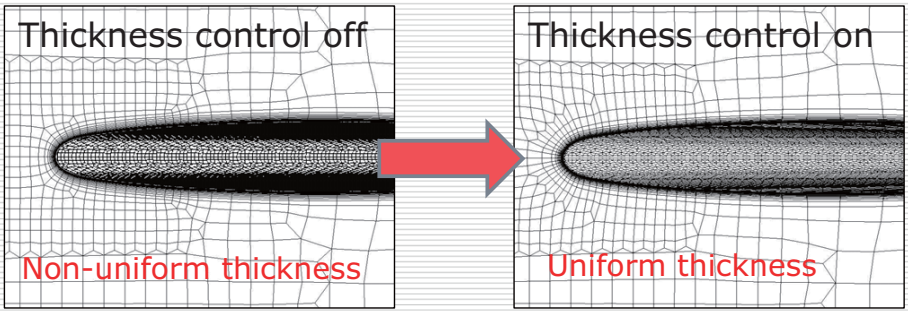


Prismatic Layer Control

HexaGrid was developed for Euler computation.
➔ Improvement of prism layer quality for RANS computation

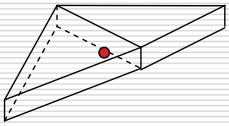


We add two control parameters;
1)Thickness of first layer and 2)expansion factor

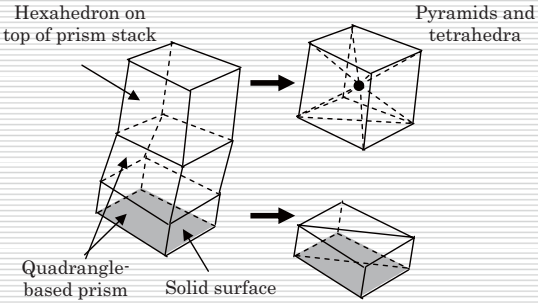


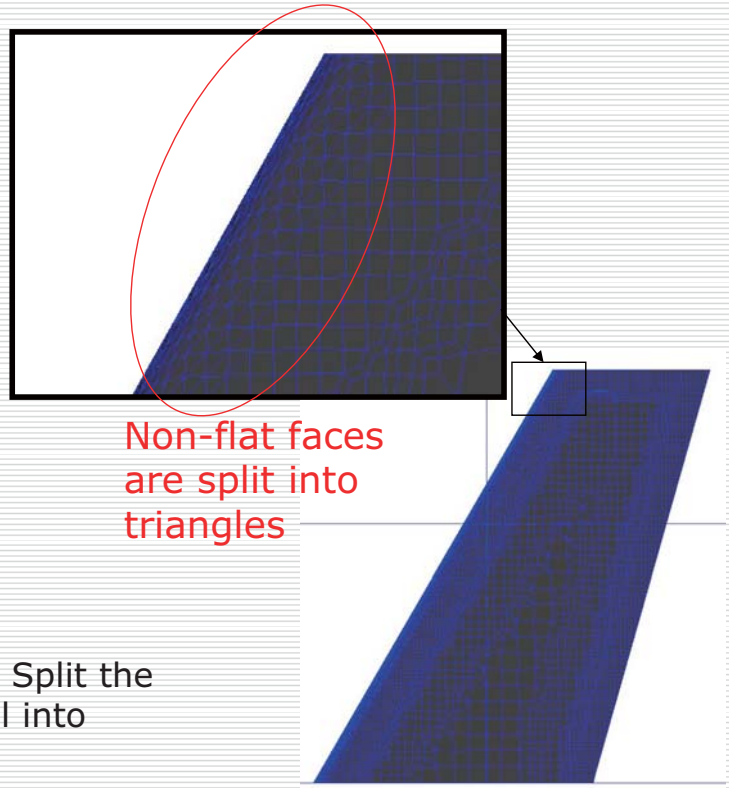
Splitting of non-flat cell

Non-flat thin hexahedral cell



Center of the cell may be outside of the cell



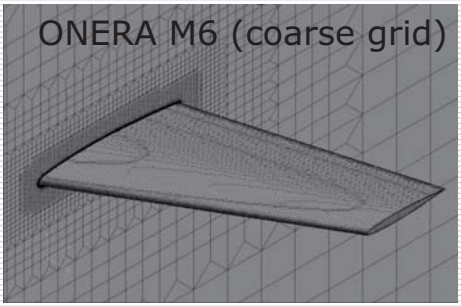


Non-flat faces are split into triangles

If rectangular face is not flat, Split the rectangle-based prismatic cell into triangle-based prismatic cell.

Grid Generation Speed

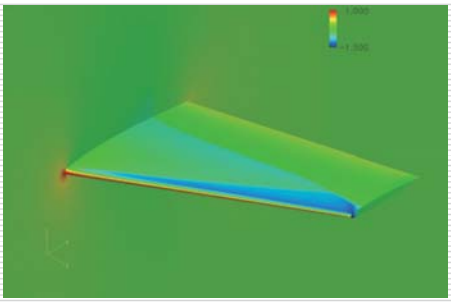
	Coarse grid	Fine grid
Cartesian level	14	15
Number of layers	30	27
Number of cells	729,173	2,232,950
Number of nodes	619,662	1,958,430
Time to generate Cartesian cells	12 sec	32 sec
Time to generate prismatic layers	19 sec	63 sec



Intel Core 2 Duo T7700 2.4GHz CPU, 2 GB memory

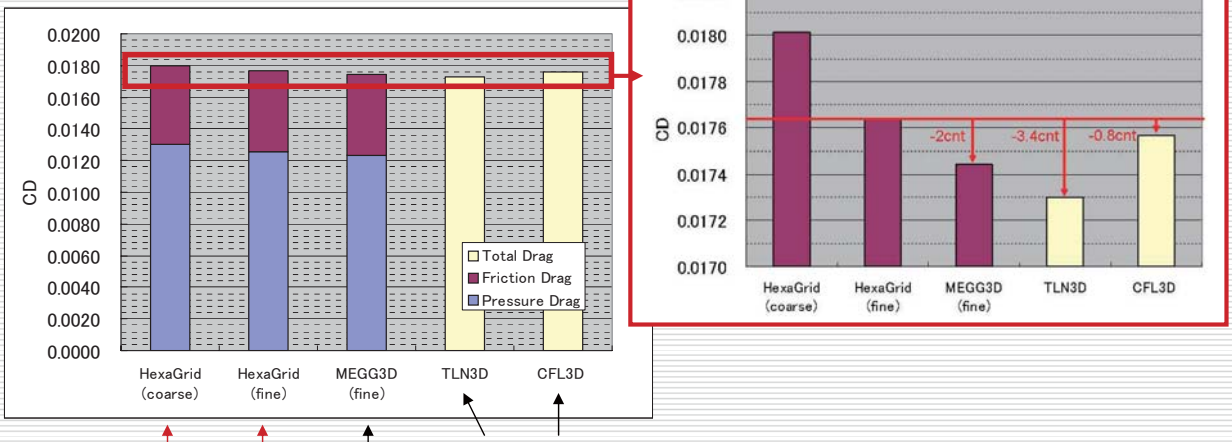
→ **Very fast grid generation**

Validation (ONERA M6)



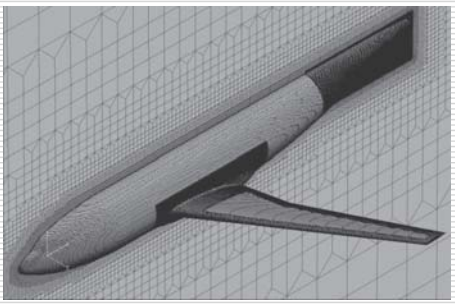
Comparison of drag coefficient with other results

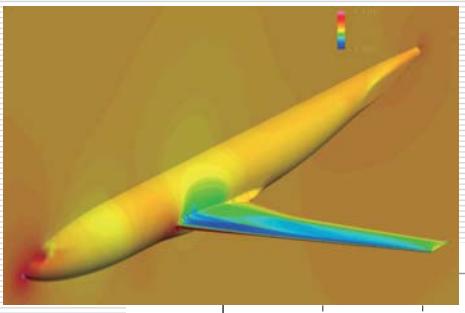
Good agreement was obtained



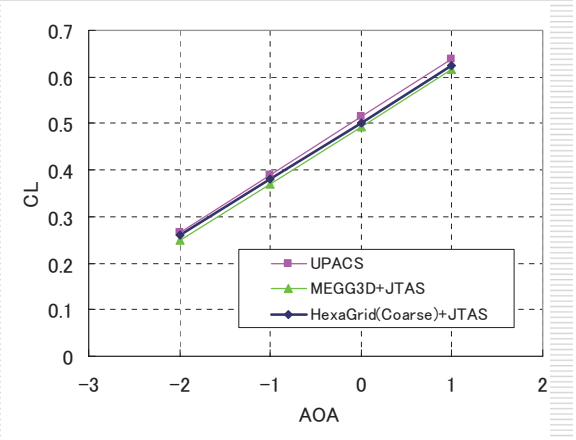
HexaGrid MEGG3D Structured grid (Bonhaus、AIAA 1990)

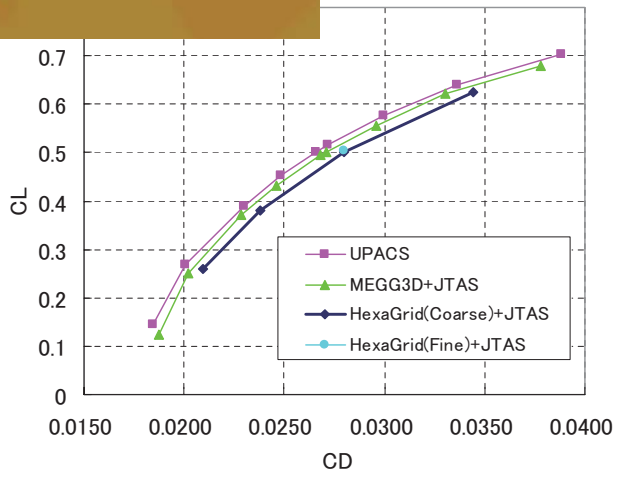
Validation (DLR-F6 FX2B)





HexaGrid agrees with other results. The difference is 10-15 counts



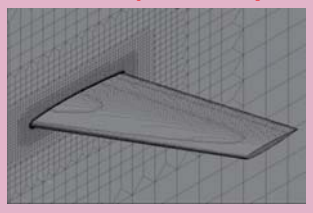


UPACS, MEGG3D+JTAS (Murayama et al., AIAA 2007-258)
Number of grid: 9.3M(UPACS), 10.0M(MEGG3D), 4.5M(HexaGrid)

Concept of Digital Wind Tunnel

Gridgen
(structured & Unstructured Grid)

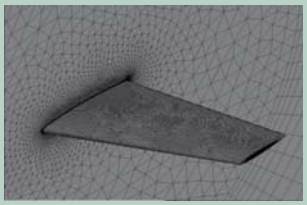
Fast System (NAG)



HexaGrid

Full Automatic
Hexahedron-base

Reliable System (APG, Toho[illegible]un



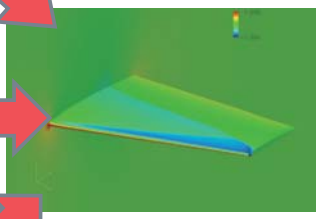
MEGG3D

Semi-automatic
Tetrahedron-base

Fast System (JEDI)

LS-Grid Full Automatic Hexahedron-base

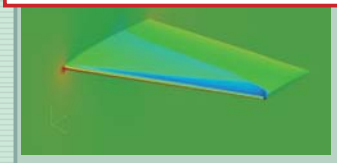
Flow Solver



(2)FaSTAR

New fast solver
Cell-center
RANS
Multigrid

✓Concept, Target
✓Configuration, Plan
✓Examples



Reliable solver
(many practical accomplishment)
Cell-vertex
RANS

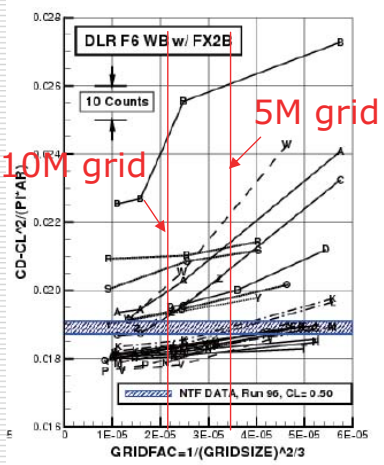
LS-Flow RANS, Cell-center
Mainly spacecraft application

Target of FaSTAR

FaSTAR (**FAST** **A**erodynamic **R**outines)
We develop a new code from scratch.

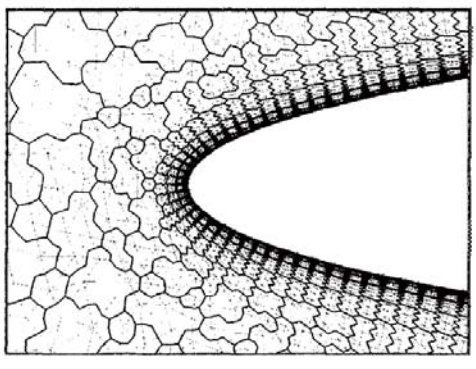
Target: 300cases/20days
(300cases =1/5 of a wind tunnel test campaign)
→1 hour/case, 100CPU, 10M Grid

≒1.5 hour, 96CPU, 15M Grid (NSU3D, Mavriplis)



Third Drag Prediction Workshop(DPW3)
Vassberg, AIAA 2008-6918

Convergence acceleration technique
(Multigrid method, GMRES) is necessary.



Agglomeration Multigrid (NSU3D)

FaSTAR configuration(1)

FaSTAR (FAST Aerodynamic Routines)

MEGG3D, HexaGrid
Gridgen(structured & unstructured grid)

↓

Pre-Process
- Data structure conversion
- Surface area, Volume
- Reordering
- Cell quality check

↓

Solver
- Flow solver (using minimum data)

↓

Post-Process
- Visualization data

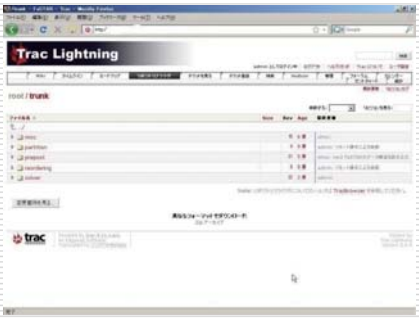
↓

Aerodynamic force
Visualization (Fieldview, Tecplot)

Separation of process
Compact design → Improvement of development efficiency and maintenance

Development tools
- ✓Subversion
- ✓Trac
- ✓Doxygen

Development based on coding rule



Trac Lightning

FaSTAR configuration(2)

Employed Schemes

Governing Equation: Euler, Thin layer/Full N-S
Discretization: Cell base
Data Structure: Face base
Reordering: Cuthill-Mackee
Flux: Roe, HLLE, AUSM+
Turbulence model: SA, SST
Convergence acceleration: Agglomeration Multigrid, Krylov method (GMRES)
Grid Partition: Zoltan (METIS)
Parallel library: MPI

Survey of well-known CFD code

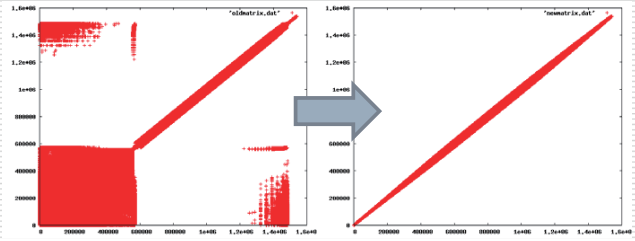
JTAS
NSU3D
BCFD
EDGE
UG3
USM3D
FUN3D

FaSTAR data structure

Cell
↑ face2cell
Face
BD Face

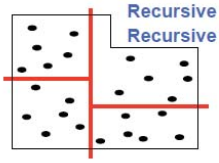
Almost all loops are written in face loop.
- ➢Gradient
- ➢Flux
- ➢LU-SGS sweep

Cuthill Mackee reordering
=Hyperplane reordering
(speed up by 20%)

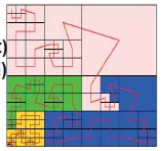


Domain Partition

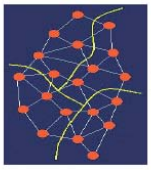
Zoltan toolkit includes the following methods



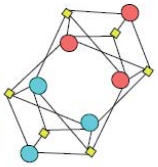
Recursive Coordinate Bisection (Berger, Bokhari)
Recursive Inertial Bisection (Taylor, Nour-Omid)



Space Filling Curves (Peano, Hilbert)
Refinement-tree Partitioning (Mitchell)



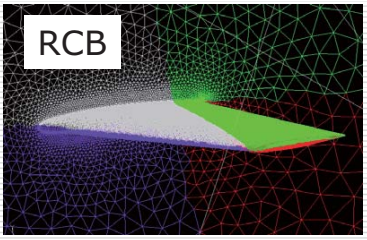
Graph Partitioning
ParMETIS (Karypis, Schloegel, Kumar)
Jostle (Walshaw)

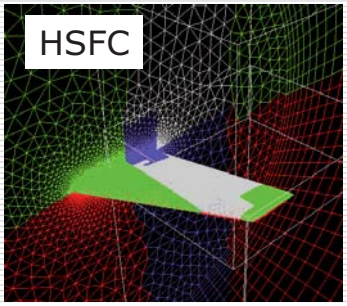


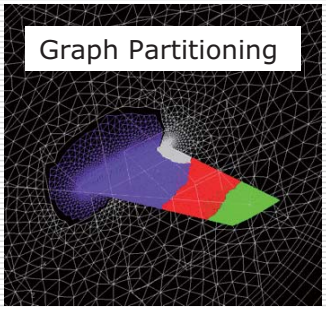
Hypergraph Partitioning & Repartitioning
(Catalyurek, Aykanat, Boman, Devine, Heaphy, Karypis, Bisseling)
PaToH (Catalyurek)

(Zoltan tutorial)

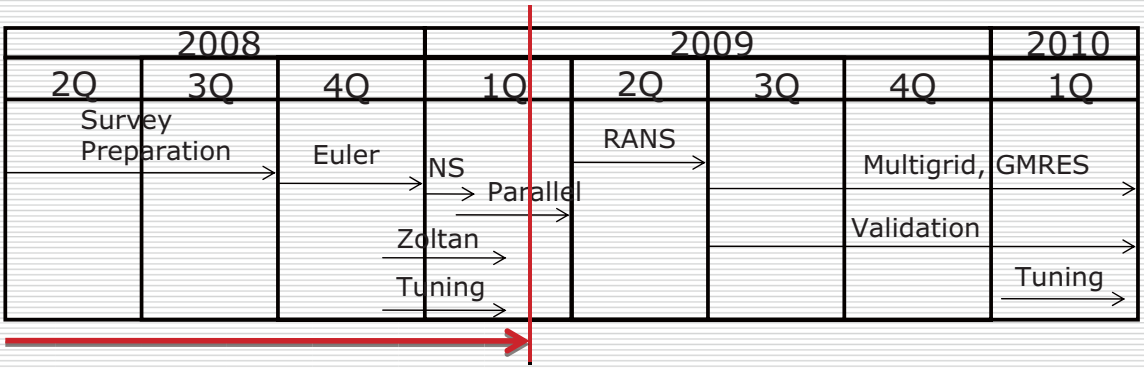
Examples of partitioned grids



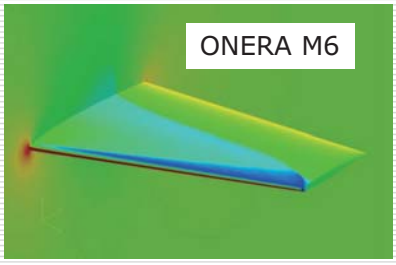


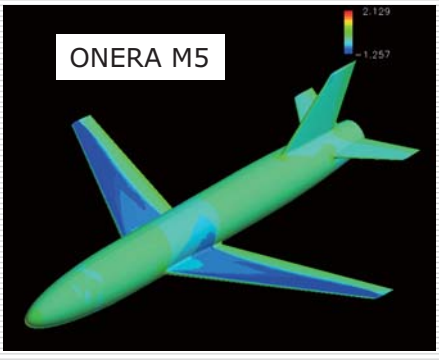


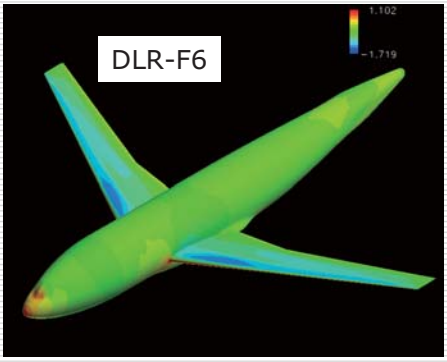
Plan



Preliminary results using FaSTAR(Euler)
FaSTAR achieves 1.1GFlops on 1CPU of JSS (11% of theoretical peak performance)



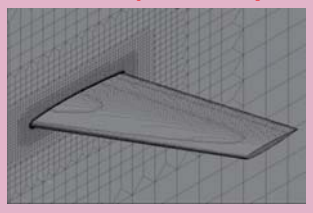




Concept of Digital Wind Tunnel

Grid Generator

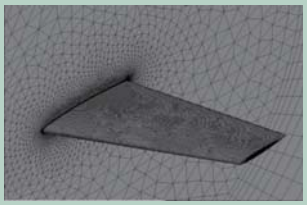
Fast System (NAG)



HexaGrid

Full Automatic
Hexahedron-base

Reliable System (APG, Tohoku U[illegible] Univ. of Alabama)



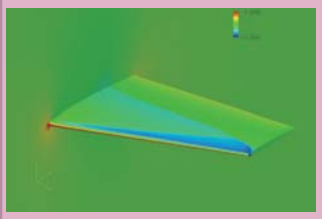
MEGG3D

Semi-automatic
Tetrahedron-base

Fast System (JEDI)

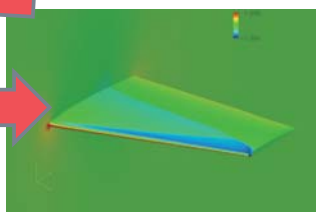
LS-Grid Full Automatic
Hexahedron-base

Flow Solver



FaSTAR

New fast solver
Cell-center
RANS
Multigrid



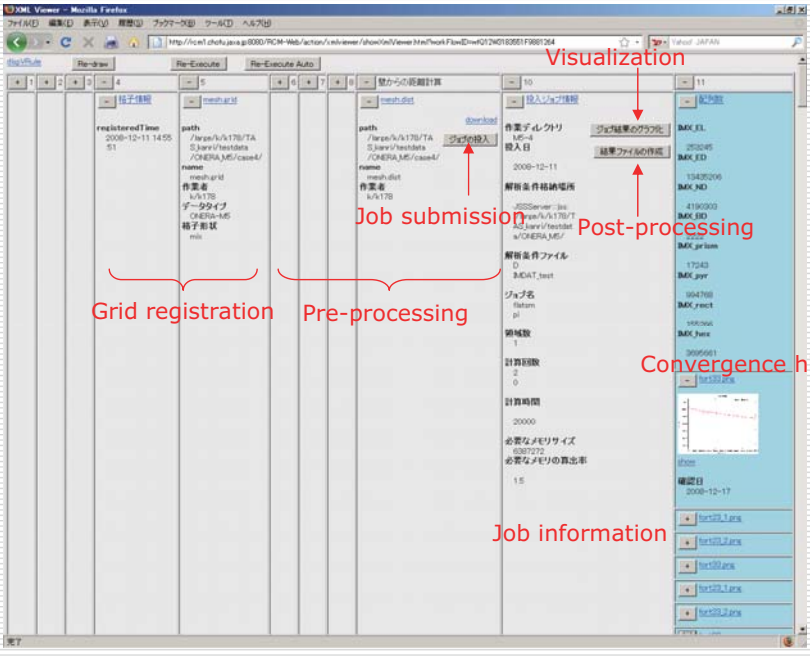
(3)JTAS

Reliable solver
(many practical accomplishment)
Cell-vertex
RANS

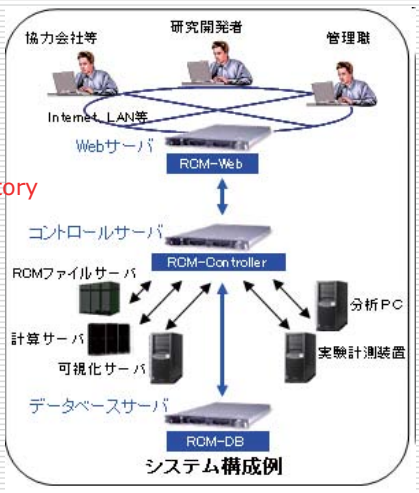
✓Installation of RCM portal
✓Whole wind tunnel simulation
(Porous wall modeling)

RCM portal system

HexaGrid+JTAS workflow system



RCM(**R**&D **C**hain **M**anagement) is a middleware integrating web server, control server, and database server.

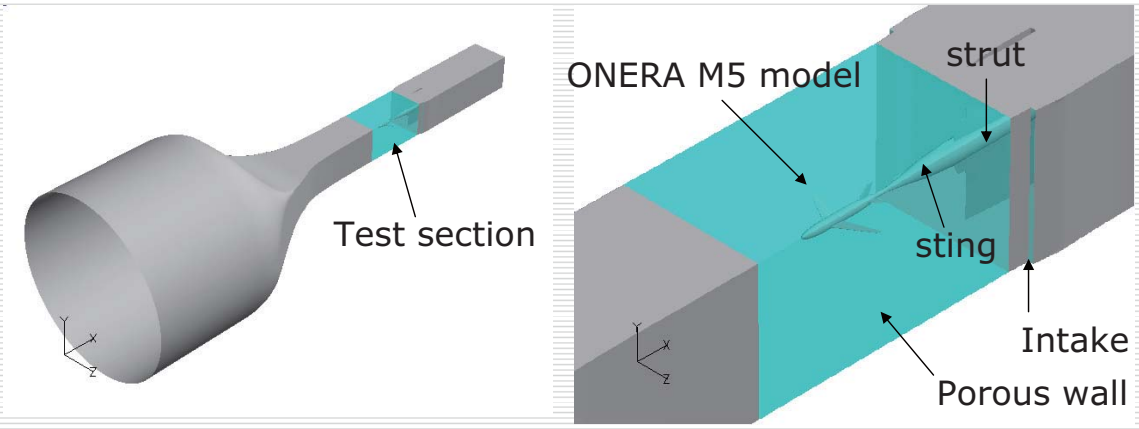


http://www.i4s.co.jp/rcm/rcmabs.html

✓User can make registration of grid and result data.
✓User can search the data using the database.
✓User can submit and monitor jobs from the web.
✓User can visualize the result from the web.

Quatre-i science

Transonic wind tunnel simulation

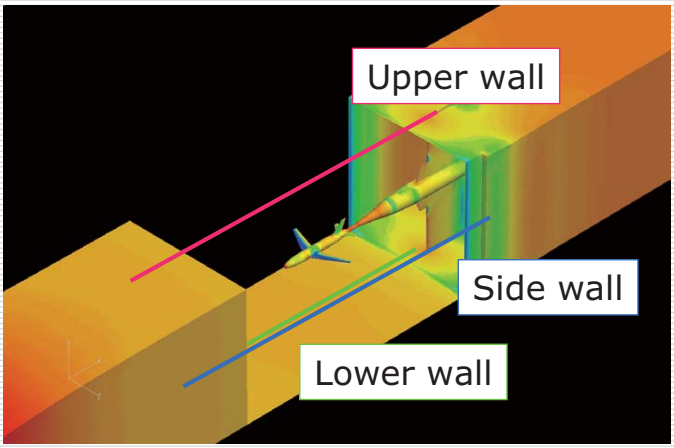


Experimental conditions: M=0.84, AoA=0deg
Re=1.67x10^6 (Re is based on MAC)

Computational conditions
inflow conditions: $P_0/P=1.58$, $T_0/T=1.14$
Outflow condition: $P_{out}/P=1.05\sim1.10(?)$
We have to adjust the outflow pressure to make M=0.84 flow at the test section.

1. Solid wall computation
2. Porous wall computation (modified Harloff model)

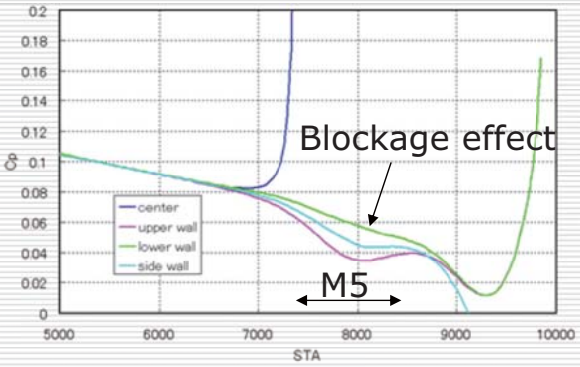
Transonic wind tunnel simulation



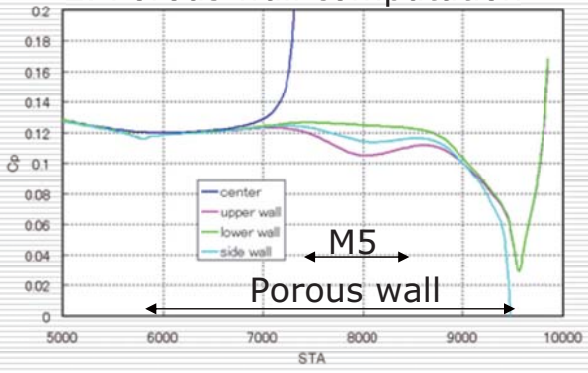
Porous wall effect can be reproduced using the Harloff model.

Streamwise pressure distribution becomes flat.

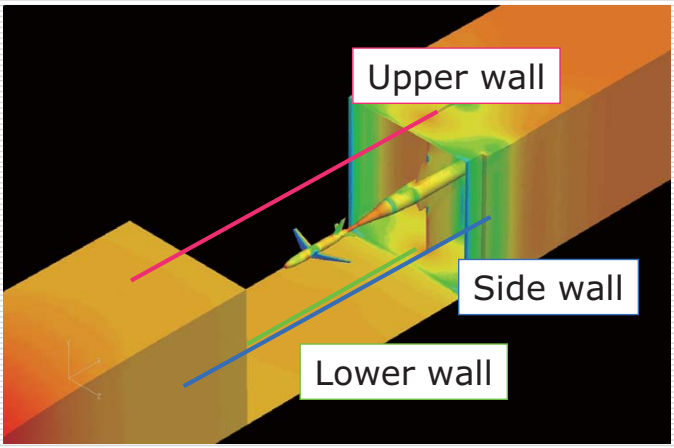
1. Solid wall computation



2. Porous wall computation

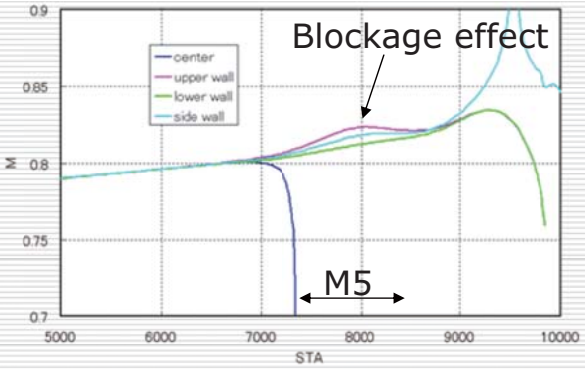


Transonic wind tunnel simulation

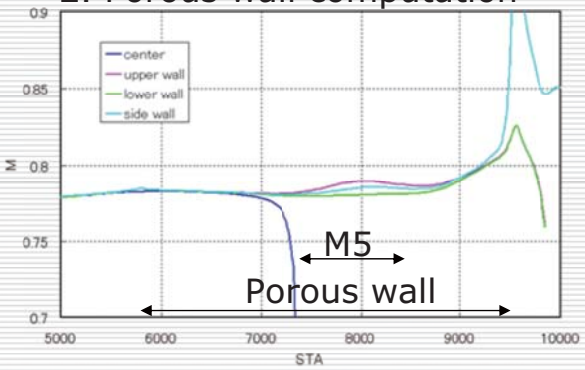


Mach number computed with isentropic relation

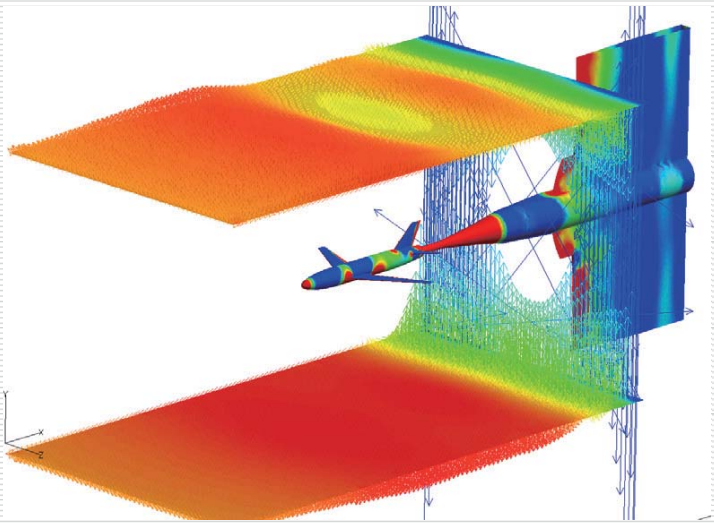
1. Solid wall computation



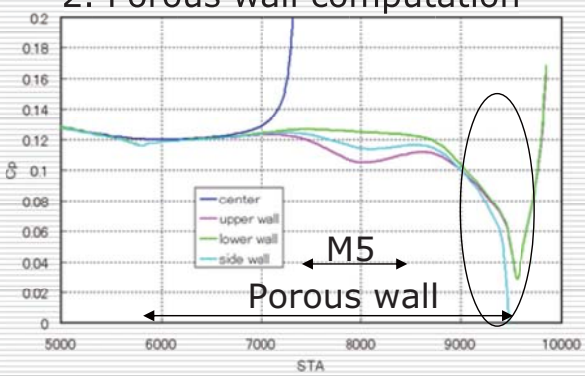
2. Porous wall computation



Transonic wind tunnel simulation



2. Porous wall computation

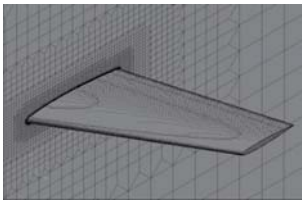


Velocity through the porous wall.
Inflow velocity is faster at the end of porous wall.

This inflow may interfere the downwash from the model.

Concept of Digital Wind Tunnel

Grid Generator



(1)HexaGrid

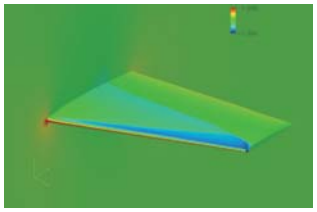
Full Automatic
Hexahedron-base

✓Feature of method
✓Improvement for NS simulation
✓Examples
- •ONERA-M6
- •DLR-F6

Fast System (JEDI)

LS-Grid

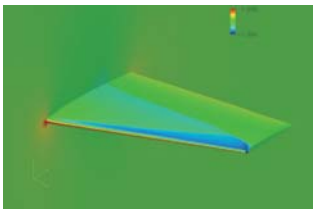
Full Automatic
Hexahedron-base



(2)FaSTAR

New fast solver
Cell-center
RANS
Multigrid

✓Concept, Target
✓Configuration, Plan
✓Examples



(3)JTAS

Reliable solver
(many practical accomplishment)
Cell-vertex
RANS

✓Installation of RCM portal
✓Whole wind tunnel simulation
(Porous wall modeling)