Numerical Wind Tunnel(NWT) and CFD Research at National Aerospace Laboratory

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Abstract

National Aerospace Laboratory(NAL) of Japan is the only one national research institute for aerospace engineering and services in Japan. NAL is a forerunner of supercomputer development and utilization in Japan. Since 1993, NAL has developed NUMERICAL WIND TUNNEL (NWT) consisting of parallelly connected 166 vector processors with Fujitsu and has been providing substantial power resources to the scientists and industries since 1993. This paper describes the background of NWT development, present status and CFD researches being made on NWT.

1.Background

National Aerospace Laboratory (NAL) of Japan is the only one government research institution belonging to Science and Technology Agency for the research of aerospace engineering and services of major R&D facilities such as lowspeed/ transonic/ supersonic/ hypersonic wind tunnels and computer systems for national and civil programs of JAPAN.

In the past, NAL has developed large scale computer systems which are necessity for aerospace technology research but not available as a ready-made commercial machine. Such includes FACOM230-75APU, the first Japanese supercomputer of vector processor type in the 1970's.

The present major computation server "NUMERICAL WIND TUNNEL(NWT)" was developed jointly with Fujitsu based upon NAL feasibility studies on NUMERICAL SIMULATOR II Project. The NWT started operation service for end users on February 1, 1993.

2.NUMERICAL SIMULATOR II

Present NAL NUMERICAL SIMULATOR II system consists of
- NWT (computation server, 166 Processing Element(PE)'s, details described bellow),
- Fujitsu NWT-FEP(Unix UXP FEP, 63.8MIPS x2, 256 MB),
- Fujitsu VP2100 (MSP Server and file server, 63.8MIPS, 512MB),
- Large-Scale External Storage(magnetic disks 360GB, CMT 483 GB and MOdisks 500 GB),
- CRAY YMP M92(visualization server 333 MFLOPS x2, 8GB),
- Intel PARAGON XP/S25 336Nodes(for MPP type computation research, 25.2 GFLOPS, 10.5GB)
  PARAGON XP 32Nodes

and networks(Hippi800 Mbps, FDDI 100Mbps, ethernet10 Mbps) connecting GWS(SGI Onyx, Titan2, Indigo2, etc.),WS's and PC's located among the office rooms in the headquarters and Chufu campus. The NS II is also accessible from outside of NAL thru the Internet, etc.

3.UMERICAL WIND TUNNEL

NWT is a unique parallel vector machine

consisting of 166 Processing Elements(PEs), 2 Control Processors(CP) and Crossbar Networks (421MB/sx2x168). Each one of PEs is itself a high level supercomputer with vector unit, scalar unit and main memory of 256MB(4PEs with 1GB) and peak speed of 1.7 GFLOPS. The architecture is similar to Fujitsu VP400. The PE uses GaAs tips Thus total peak performance is 280GFLOPS and main memory capacity of 44.5 GB.

Use of specially dedicated NWT-FORTRAN enables end-user make parallelized scientific computing very easy. NWT-FORTRAN uses parallel directives for automated parallel compiling upon FORTRAN77Ex. A single PE job runs using standard FORTRAN77ex. Simply addition of directives to where parallelization of DO loop is required makes parallelized code and users don't need any knowledge of message-passing tools. Thus any conventional fortran user can make full use of NWT within one week. And NWT was able to operate fully soon after the installation. Standard UNIX Parallel libraries: PVM, MPI and PARMACS are also available.

4.Performance of NWT

4.1. Linpack and 3D N-S Benchmark

Latest NWT performance test shows:

LINPACK benchmark test 229.7GFLOPS using 167 PE's

3-D Navier-Stokes solver 150.4 GFLOPS using 166 PE's

This was reported on Dongarra's Report.

1993 configuration(144 PE's) showed

LINPACK benchmark test 170.4 GFLOPS

3-D Navier-Stokes solver 116 GFLOPS

Benchmarked NS Solver is "NS3D" using TVD Implicit Approximate Factorization Scheme with 512x420x280 grid points.

For practical applications of CFD codes, a direct simulation of turbulence computation for 512^^3 was made. This computation required 24 hours using 128PEs and attained more than 90 GFLOPS. Other application includes hypersonic thermo- aerodynamic analysis for the design of "HOPE" Japanese unmanned space reentry vehicle, transonic civil transport aerodynamic analysis with fanjet engines, aeroelastic interaction flow analysis of transonic transport wing, flow analysis of centrifugal compressor, design of bowed stacking turbine blades, etc.

4.2. Gordon Bell Prize Awards

Development of NWT and various applications of CFD on NWT was awarded "Gordon Bell Prize (Honorable Mention)" at SUPER COMPUTING'94. It should be reffered that HOPE configuration was designed based upon CFD. A lot of NWT hours were dedicated to this design computation in the past years.

An trial to extend the applicapability of NWT to the other discipline was made in 1995:QCD(Quantum Chromo Dynamics), an elementary particle simulation of physics. This simulation achieved 178 GFLPOPS and was awarded 1995 Gordon Bell Prize Award. 1996 Gordon Bell Award was given again to the 3D cascade flow simulation which showed 111 GFLOPS on 3D NS solver[1-3].

4.3. Move Time Overhead

The communication(move) time among PEs were measured using NS3D code with 1 million grid points. On 1 PE job, move time percentage is of course 0. Upto 16 PE job, move time remains less than 3%. On 32 PE job move time is 5%. Since this example job is small enough to be put on 1 PE, the relative ratio of move time to the total operation time becomes large as PE number is increased. On NWT, we suggest users to use minimum PEs for their jobs so that memory use on each PE should be maximum. This reduces move time overhead.

4.4. NWT job statistics

NWT JCL for MSP users and similar jcl-shell scripts for UNIX users are provided. The user submit their job using these macros on NWT FEP and FEP-WorkStations. The job class is specifyed by job class name:

Unnn where nnn is 001 to 164

for 256MB memory standard PE jobs or

Lmmm where mmm is 001 to 004

for Large 1GB memory PE jobs. The nnn and mmm specifys the total number of requested PE's. Maximum job step computer time limit is 5 hours. By continueing GO steps, user can can extend total time further to any ammount.

Here the computer time means similar concept of CPUTime on non-parallel machine, i.e., computer time 5 hours means all of the requested PE runs 5 hours.

In average, monthly processed job numbers are approximately 10,000 to 13,000 jobs. 1 PE jobs shares about 40 %. 2-15 PE jobs and 16-31 PE jobs shares about 20 % respectively. 64-128, 128-162 jobs occupy the rest. The parallel use seems relatively small in these statistics. However, job number times used PE number statics show different aspects. In average 70,000 to 80,000 PExTime/month is used. About 40% of PExTime is by U064-127 jobs. 16-31PE jobs shares about 30% and 1 PE jobs only shares 10%. Very large job class using 128-162 PEs only use 2-3 %. The share of L class is small.

Each disciplines share of Computer time use changes significantly from year to year because of on-going project use and otehr reasons. Recent statistics show fluid dynamics research and aeroengine research shares about 30%. Aircraft aerodynamics and space development research shares about half of previous fields. These includes use by industries and universities. NAL provides NWT for research cooperations and other government ministry's naional projects.

5.CFD Researches

CFD researches are conducted among a number of divisions and most of researches are inter-division joint works. The research will be classified into four major fields[4].

5.1.Aircraft Aerodynamics CFD

High Speed Civil Transport(HSCT) research program has started in 1995. Supersonic high L/D aerodynamic design and LFC will make full use of CFD. Preliminary SST configuration CFD analysis and sonic boom analysis are made(Figure 1). Transonic transport simulations are also made(Figure 2).

In the aeroelasticity and flutter simulation, 3-d transonic wing unsteady aerodynamics analysis coupled with aeroelastic structure dynamics code has been made for a transonic transport wing(Figure 3). SST wing application is underway.

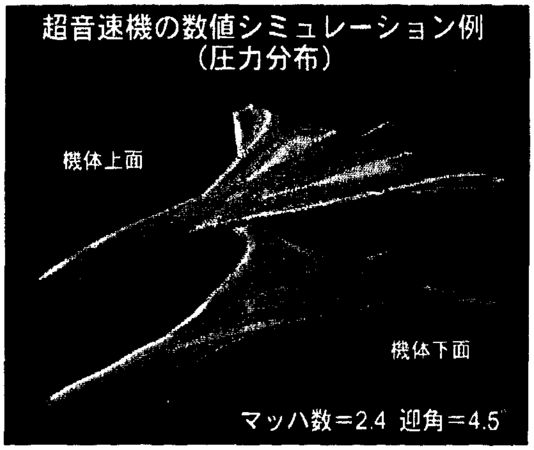

Figure 1. SST simulation

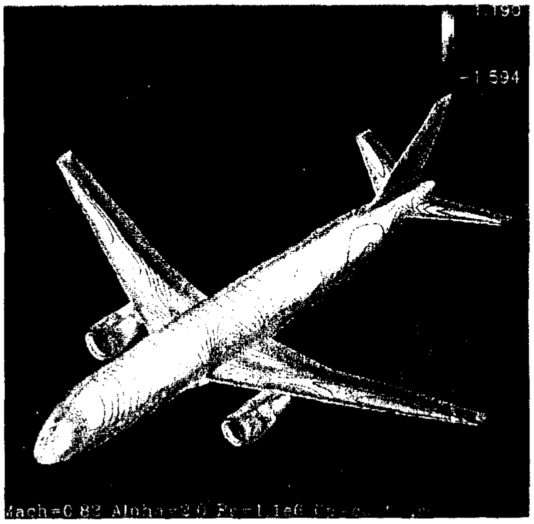

Figure 2. Civil transport

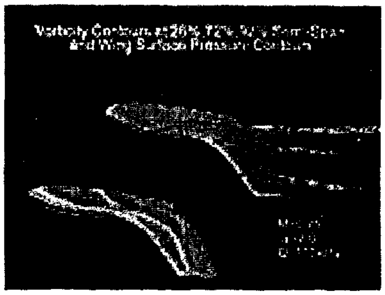

Figure 3. Transonic main wing flutter simulation

5.2. Space Development CFD

CFD has been the only aerodynamics design tool for hypersonic flow problems encountered in the design of Japanese HOPE project. NWT was fully used to obtain aerothermodynamic characteristics of hypersonic and transonic ranges in the design of configuration. HYFLEX: a reentry test vihicle for HOPE project also used CFD analyses(Figures 4,5). Chemically reacting real flow simulation was made to compare with reentering HYFLEX hypersonic flow in black-out phase. Hypersonic wind tunnel test data obtained from various wind tunnels served as the CFD evaluation data. In this regards, domestic and international meeting for hypersonic CFD code validations has been held in the past and will be in future as well.

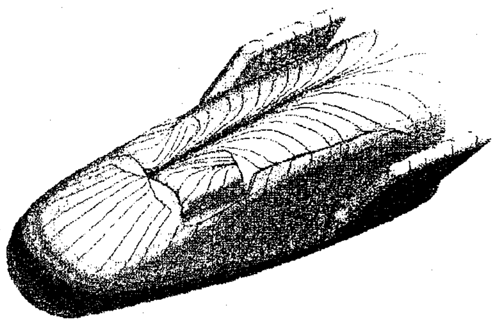

Figure 4. HYFLEX analysis

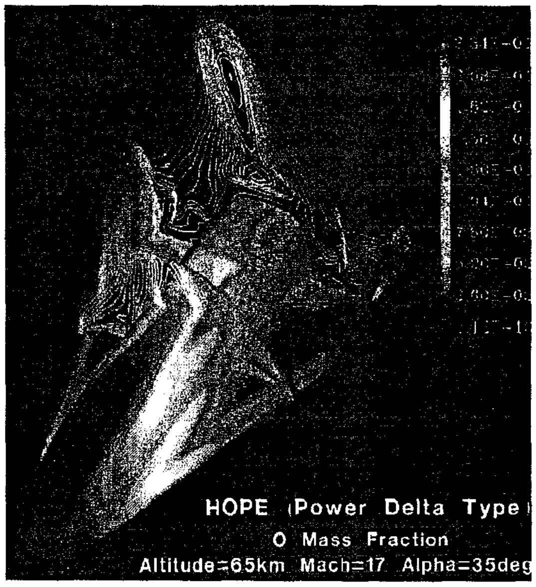

Figure 5. HOPE simulation

Scram jet engine flow simulation and fuel combustion analysis are also made. Spaceplane configuration CFD analysis in supersonic range are also made.

5.3. Aeroengine CFD

In the aeroengine CFD, code development for various flow regimes are made. These are closely promoted with Japanese high speed jet engine development programs. A fewexsamples will be shown in the paper such as integrated flow simulation of high-bypass ducted fan shroud and fan in transonic range. Multistage compressor full-circle rotor and stator interacting 3-d blades simulation with inclusion of distorted flow, accurate tip-clearance flow analysis of 3-d blade, 3-d stacked turbine blade design, combustor

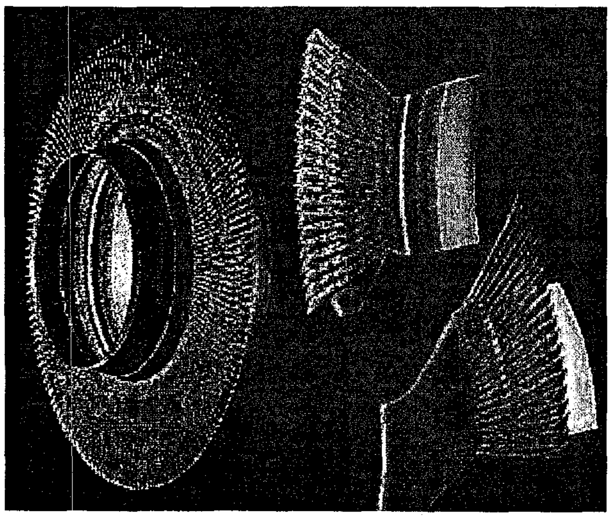

Figure 6. 160 blade cascade flow

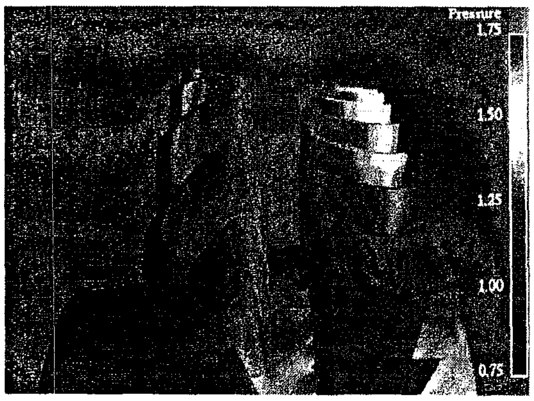

Figure 7. Compressor stage analysis

analysis to reduce NOX emission, intake flow analysis of HSCT vehicle and nozzle flow for HSCT engine(Figures6,7).

5.4. Fluid Dynamics Science

NAL is also making research in the field of fundamental fluid dynamics such as turbulence which is very important for the construction of practical application CFD for aerospace flow problems. Most ambicious CFD simulation is 512 ^3 cube computation of Turbulence(DNS) using FFT. NWT can process these case within about 24 hours using 128 PE's. Recent results show that "worms", i.e., locally concentrated high vorticity tubes , were observed(Figure 8).

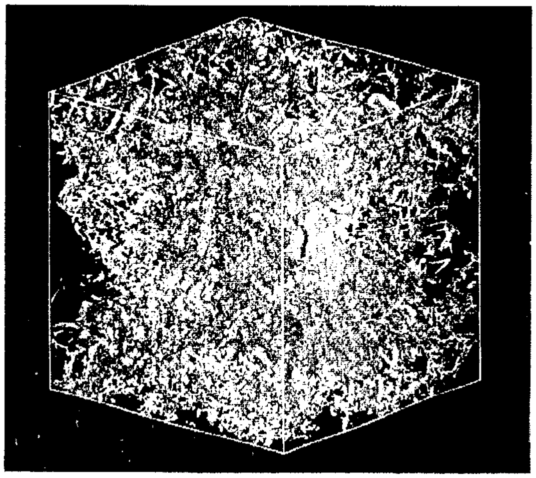

Figure 8. 512 cube DNS

Simulation of transition of shear flow into turbulence are made for a rectangular duct flow heated from bottom at Reynolds number 220.

Channel flow transition at Reynolds number 10^4 was also made. Compressible turbulence simulation is also made which shows eddy-shocklets for a compressible isotropic turbulence in a cube with rms Mach number of 1. Compressible mixing layer simulation is also made and shows the compressibility effect of supressing spreading of shear layer(Figure 9).

Also other than these categories, scramjet and rocket engine CFD researches are made at Kakuda Research Center of NAL. Kakuda uses their own supercomputer: NEC SX4 since this year and they do not use NWT in most cases, their topics are not reffered here.

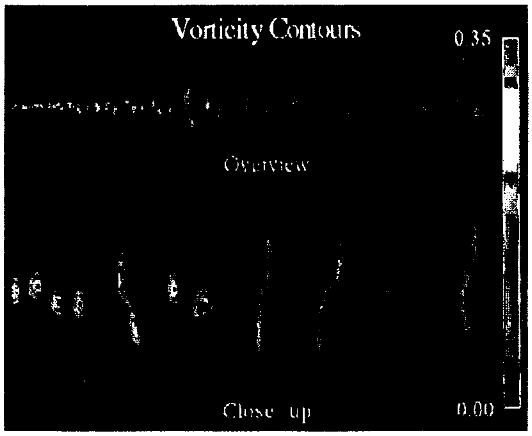

Figure 9. Compressible shear layer DNS

6. Future

The practical application CFD developed shows excellent results for the design of Japanese aerospace development projects. However, as the CFD design tool progresses, the more detailed and accurate analysis and design will be requested. The present CFD using Time averaged Navier-Stokes equations will not be appropriate in some cases and may need LES and DNS. Even with TANS, turbulence models and grid refinement will not be sufficient enough to get high quarlity flow characteristics. Present NWT capability will not be powerful enough to meet with these future demands. Several Tera FLOPS machine fitted to CFD application should be developed together with computer designers.

References

[1] Miyoshi, H., et.al., Development and achievement of NAL NWT for CFD Computations, Proc. SUPERCOMPUTING'94, November, 1994.
[2] M.Yoshida, et.al., QCD Simulation on NWT, CD-ROM Proc.SUPERCOMPUTING'95, December, 1995.
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[4] NAL Numerical Simulator II 1996 Brouchure, April, 1996.