Institute for Computer Applications in Science and Engineering

DARPA Applications Requirements for Systems Environments Meeting

November 10-11, 1997   Falls Church VA

Airframe Simulation

Manuel D. Salas

electronic version available from *goldfish.icase.e*

as anonymous ftp, file name: darpa.pdf

NASA Technology Pillars and Goals

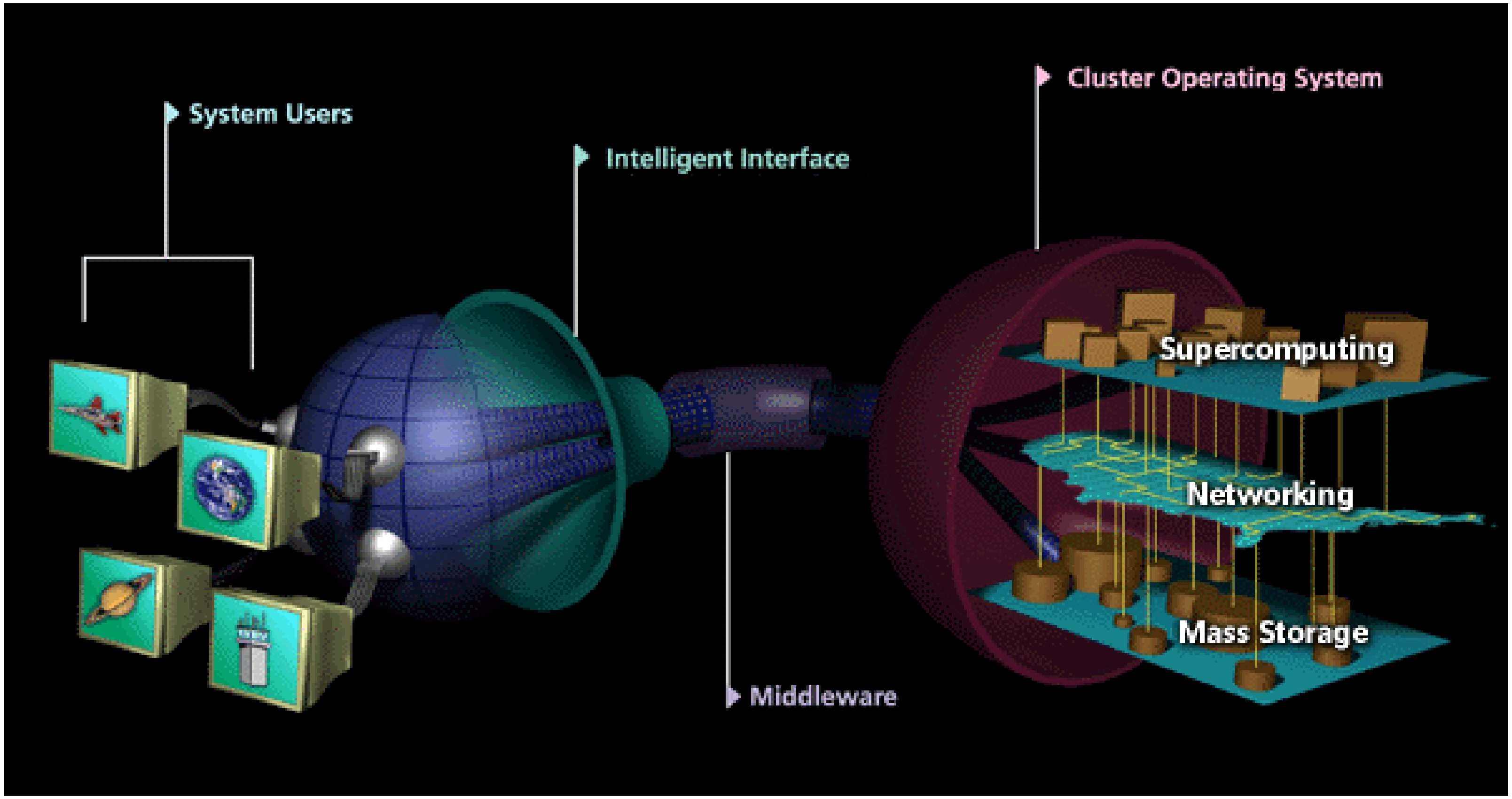
Aeronautics

☆ = CFD intensive

- Cutting aircraft accident rate by a factor of 5 in 10 years, and a factor of 10 in 20 years.
- Tripling the all-weather aviation system throughput in 10 years.
- ☆ A 3-fold cut in aircraft emissions in 10 years, and a 5-fold cut in 20 years.
- ☆ Reducing aircraft noise in half within 10 years, and by a factor of 4 in 20 years.
- ☆ Trimming cost of air travel by 25% in the next decade, and by 50% in the decade after that.
- ☆ Halving aircraft development cycle with *next-generation* design tools.
- ☆ Boosting U.S. aviation production to 10K aircraft/year in 10 years and to 20K/year in 20 years
- ☆ Cutting travel time to Far East & Europe in half in 20 years, while keeping cost fixed
- Cutting the cost of putting a pound in low Earth orbit to $1000 in 10 years.
- Further cutting launch costs to “$100’s/ pound” by 2020.

NASA's Information Power Grid

Aeronautics



Information Power Grid

- Seamless, user transparent access to all information/computing resources and data
- Management of distributed heterogeneous systems
- Dynamically reconfigurable; resources added or deleted from the operational configuration
- Extensible and scalable system capable of incorporating additional resource as budget allows.
- Testbed capability servicing and enabling critical computer science and information systems research.

IPG Program Timeline: Overview

	1997	1998	1999	2000	2001
User Visible Software					
Prototype Applications	•IDS		•AOS		•EOSDIS
Algorithmic Scalability	•100 Proc.		•1000 Proc.		•10000 Proc.
Intelligent Interface					
Data Exploitation		•Query CFD & WT data			•Query all NASA data
System Management					
Compute Nodes		•Homogeneous Metacenter			•Heterogeneous Metacenter
Storage Nodes		•Global File System			
Networks		•IPv6		•ATM QoS	
Prototype Hardware Systems					
Power Generators			•100 GF		•1000 GF?
Scalability Testbeds	•Whitney 25	•Whitney 500			•Whitney 5000
Storage Systems		•1PB, 10TB, 4TB/day			
Networks		•Fiber Ch.	•HiPPI 6400		

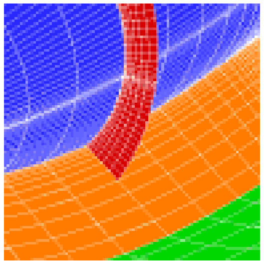
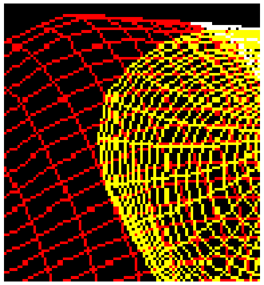
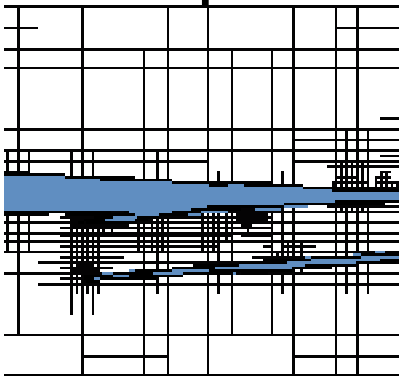
Flight Simulation Challenges

- Surface Modelling & Grid Generation
- Simulation of Complex Physics: Transition & Turbulence
- Shortening execution time
- Data visualization and knowledge extraction
- Optimization
- Multidisciplinary Interactions

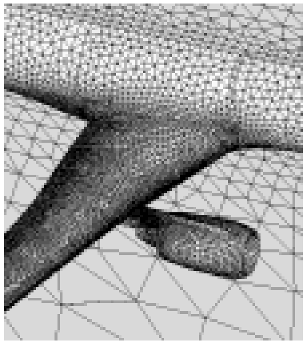
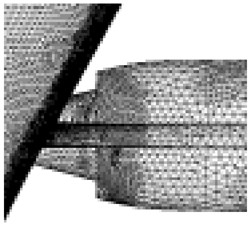
Flight Simulation Challenges
Surface Modelling & Grid Generation

- Structured Grids

Multi-block Overlapping Adaptive

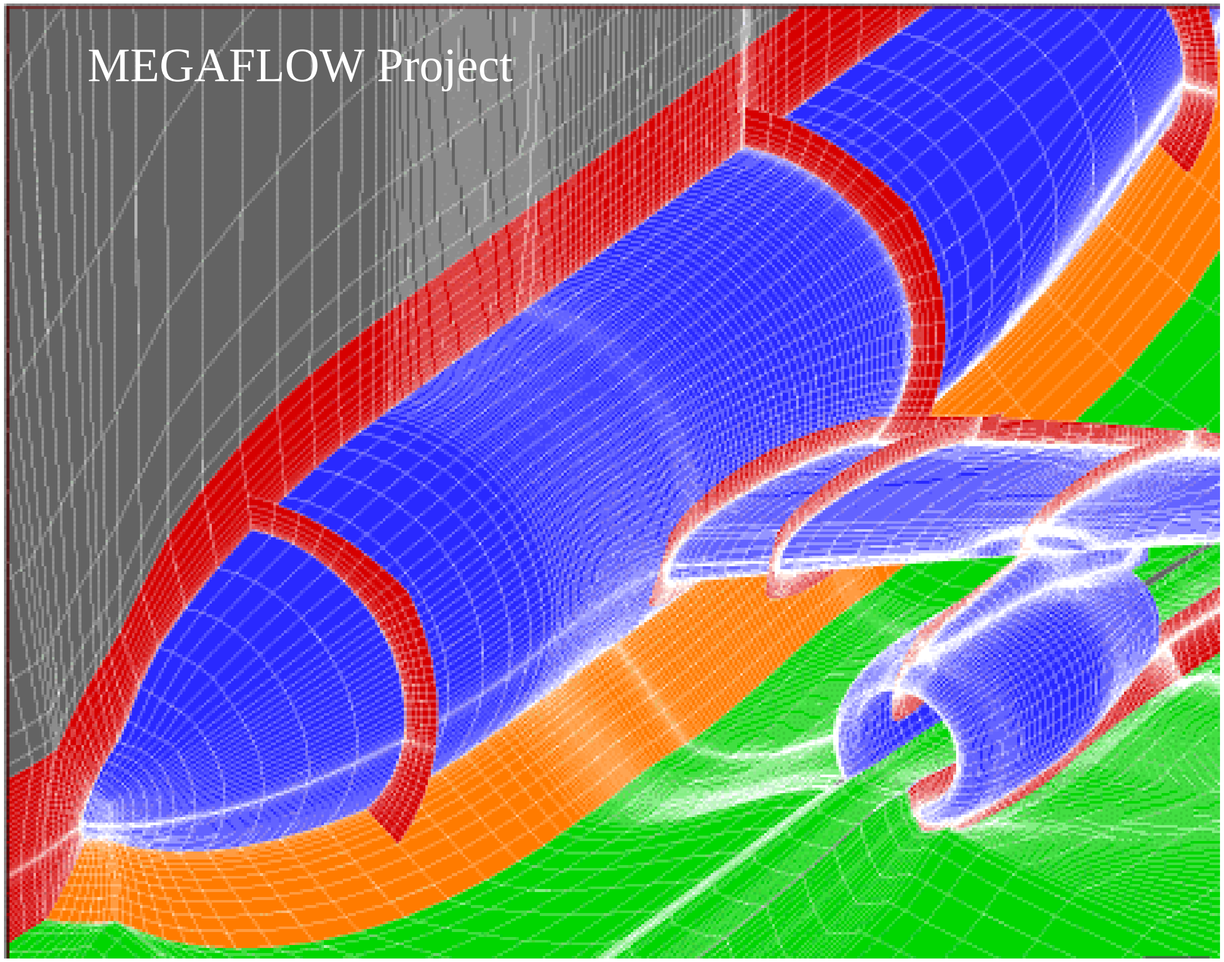
- Unstructured Grids

Adaptive

DLR-F6 Configuration

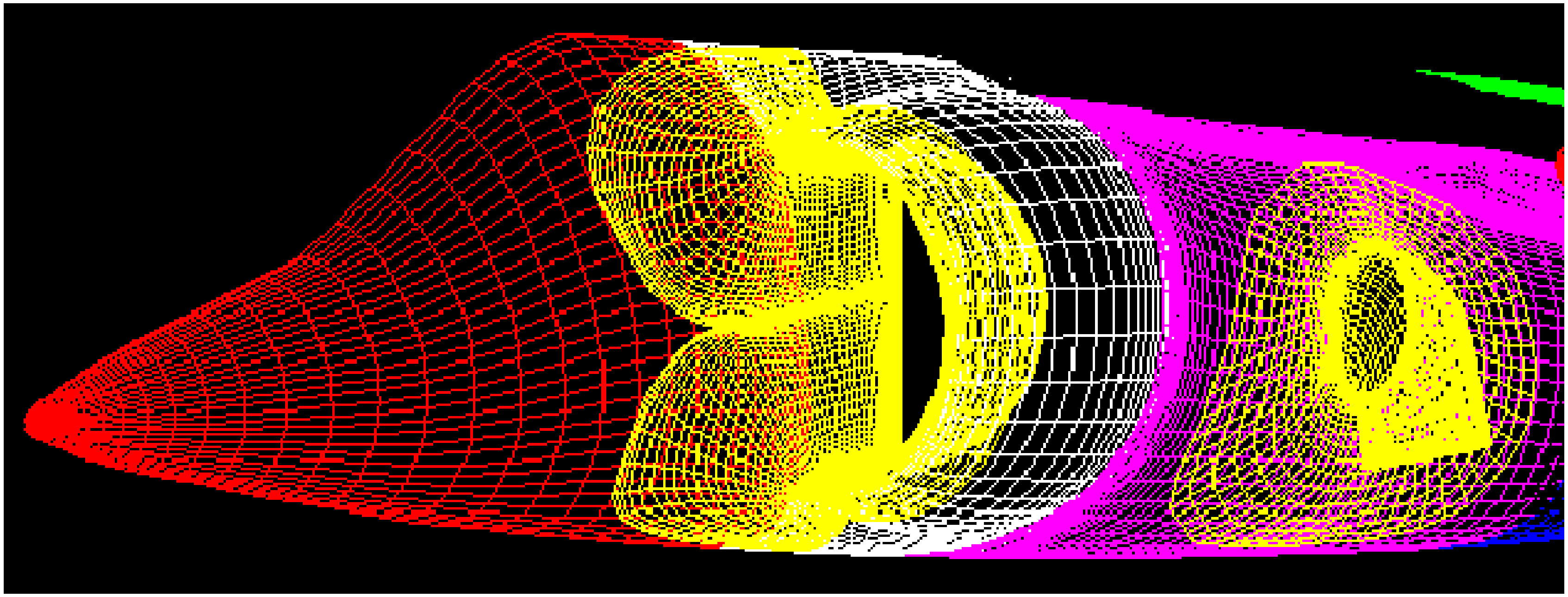
Navier-Stokes Grid with 52 blocks, 3.3M points



http://www.bs.dlr.de/sm/ea/Proj_MEGAFLOW/proj_megaflow_e.html

Overset Surface Grid for Harrier Aircraft

Calculation by M.H. Smith, K. Chawla, and W. Van Dalsem, NASA Ames



Harrier Calculation
using overset grids

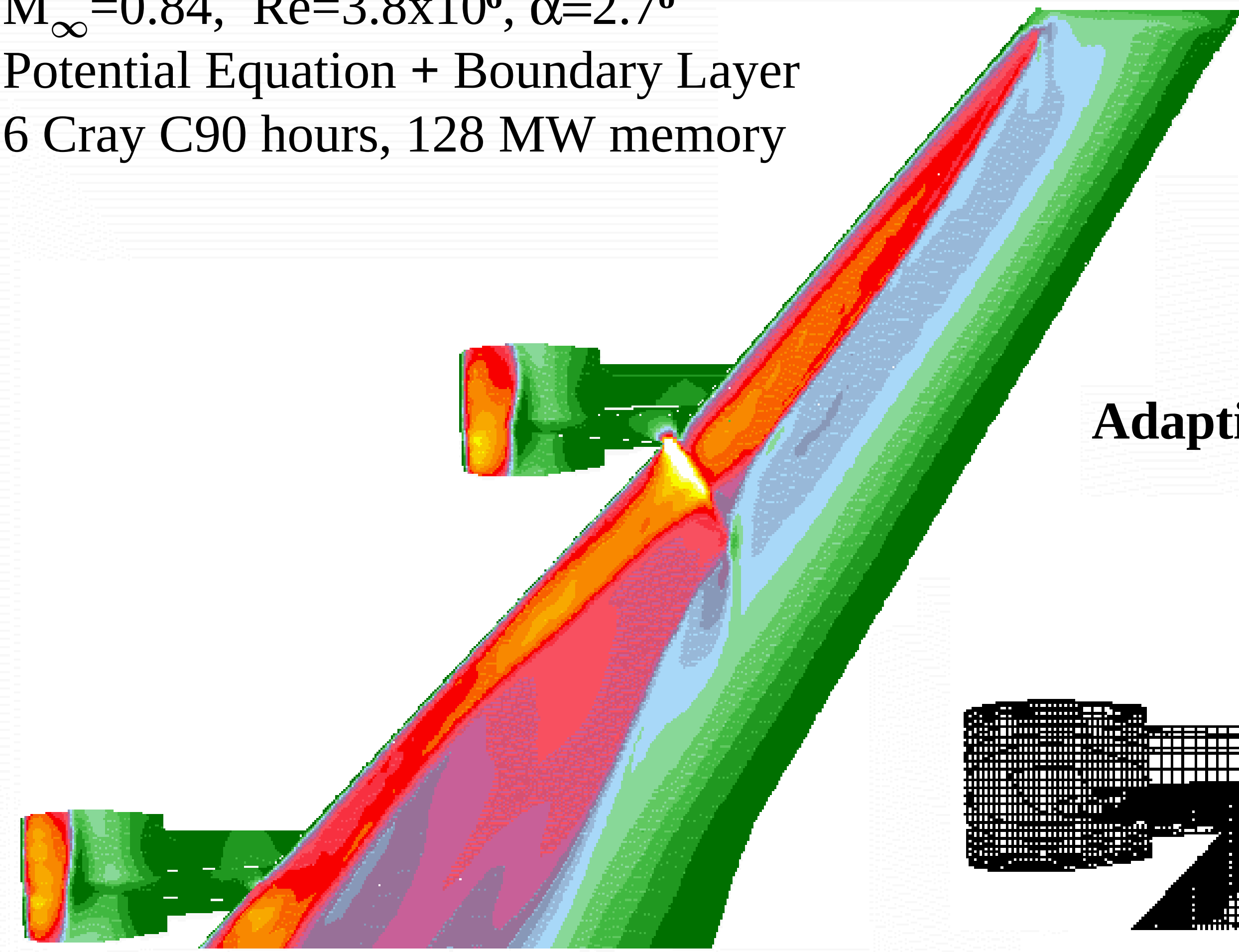
Boeing 747-200 Wing

Calculation by F. Johnson, Boeing Co.

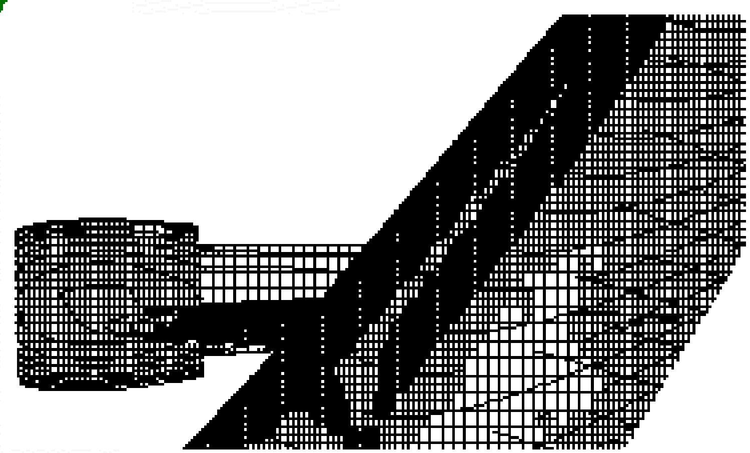
$M_\infty = 0.84$, $Re = 3.8 \times 10^6$, $\alpha = 2.7^o$

Potential Equation + Boundary Layer

6 Cray C90 hours, 128 MW memory



Adaptive Structured Mesh



CFD Structured Grid Process Time

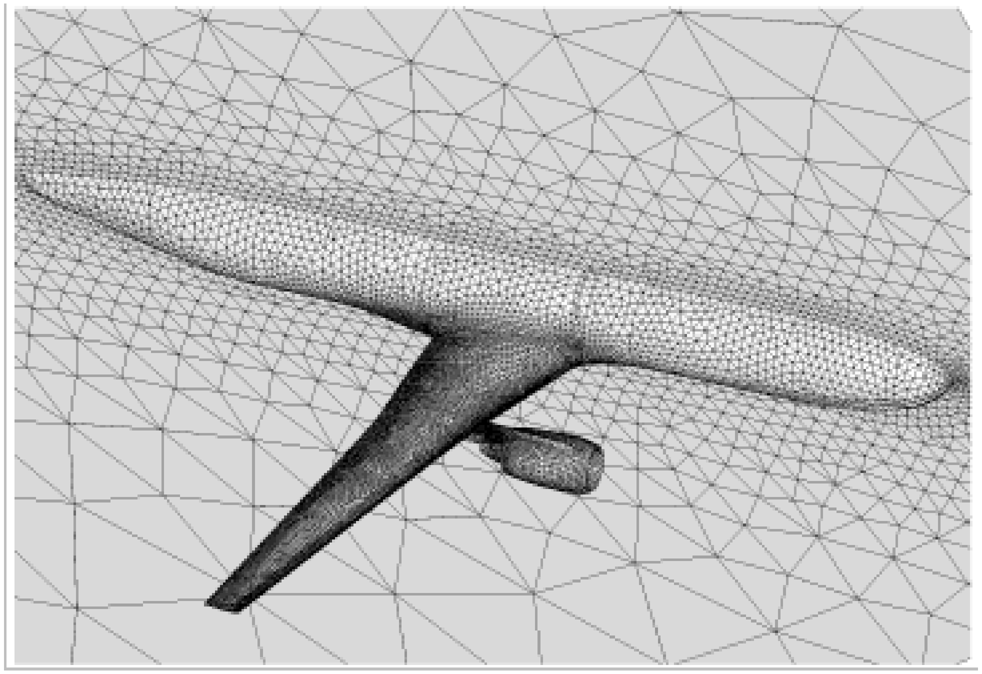
Based on C-17 flap down computation with 30M points. NASA Ames' AST High Lift Program.

process	time in days	
CAD to surface definition	45	16%
Surface definition to surface grid	90	32%
Surface grid to volume grid	65	24%
Boundary interfaces for multiblock	25	9%
One computation	30	11%
Study computation	21	8%
Total	**276**	

C-17 Wind Tunnel Model

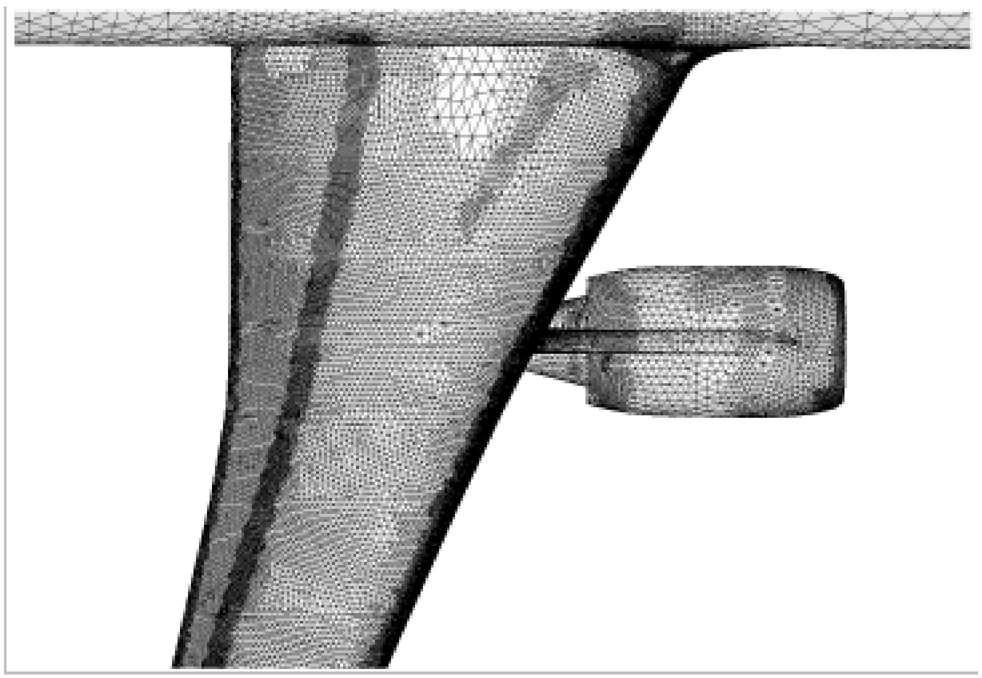
Unstructured Grid

D. Mavriplis, ICASE



Adaptive Unstructured Grid

D. Mavriplis, ICASE



Flight Simulation Challenges
Simulation of Complex Physics

- Laminar to Turbulent Transition
- Turbulence Simulation

    Turbulence Modelling

        model all scales of turbulence

    Large Eddy Simulation

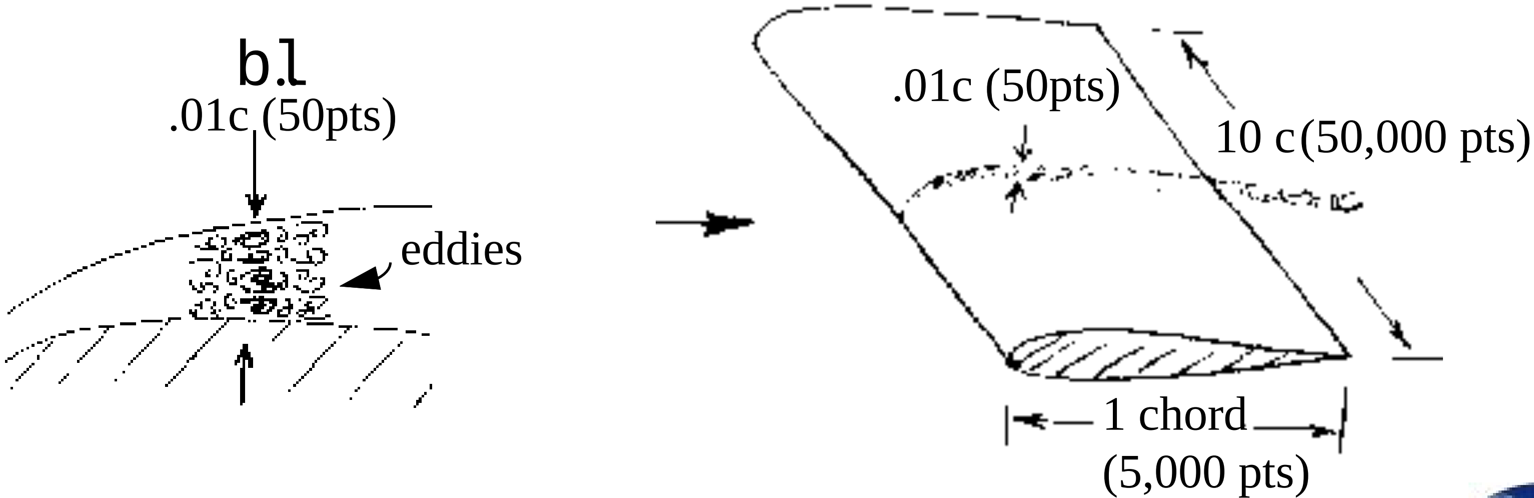
        resolve numerically only *large* eddies, model the smallest scales

    Direct Numerical Simulation

        resolve numerically all scales of turbulence

Estimate of CPU time to compute the boundary layer (b.l.) on a wing using LES

- assume eddie size resolved is 1/5 of b.l. thickness
- assume 10 mesh points needed to resolve 1 eddie
- use same mesh in all directions
- assume b.l. thickness 0.01c and wing aspect ratio of 10, then 12.5×10^{9} mesh points are needed to resolve the b.l.

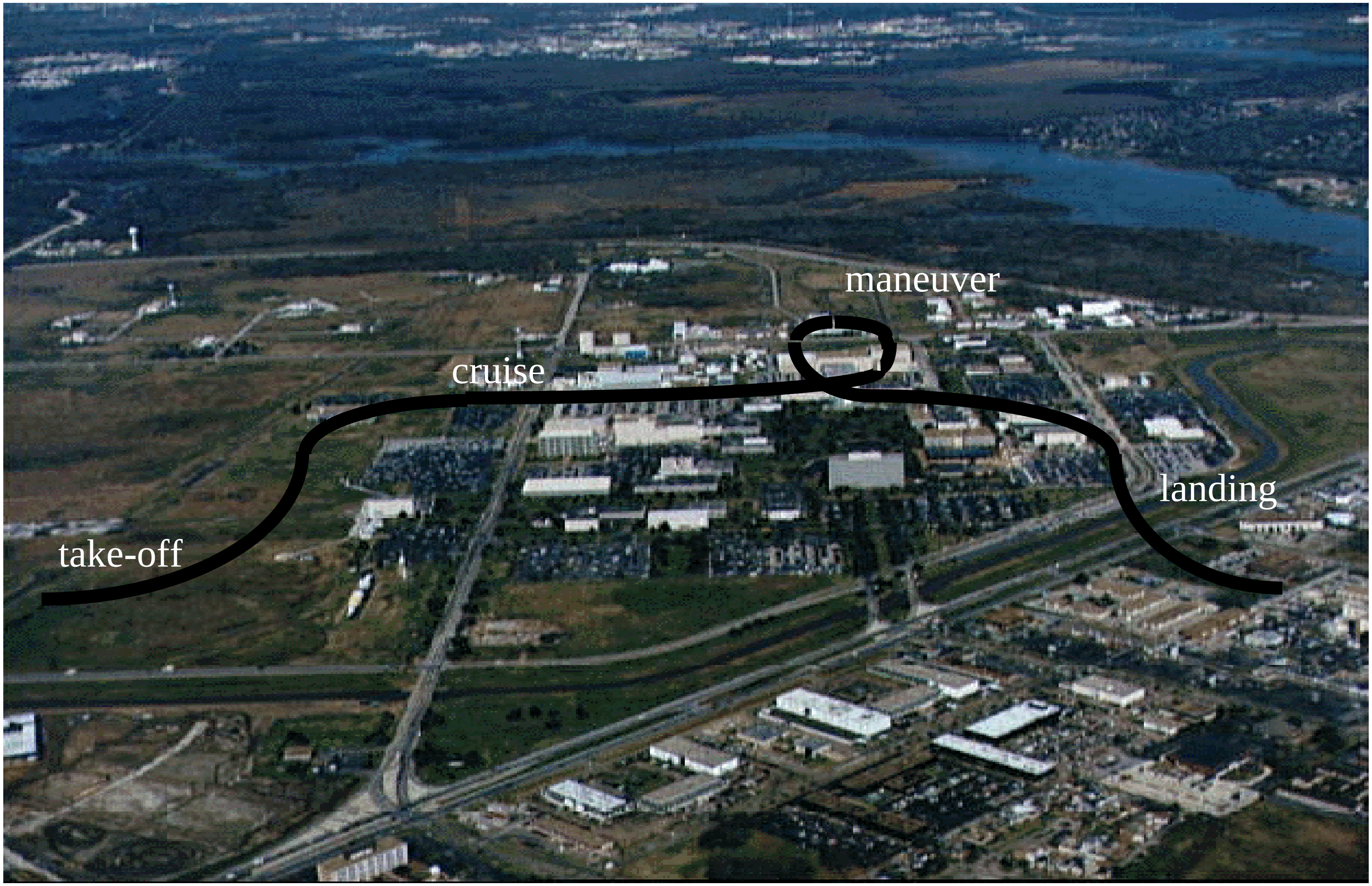


Estimate of CPU time to compute the boundary layer (b.l.) on a wing using LES

- assume algorithm uses 5,000 flops/mesh point/iteration
- assume time step of order required for a wave to pass a mesh interval ($\Delta t \sim \Delta x$) and a total time required for waves to travel 3 chords, then 15,000 time steps are required
- assume teraflop performance, then CPU time is given by:

$$5{,}000 \times 12.5 \times 10^{9} \times 15{,}000 / 10^{12} = 260 \text{ hours}$$

Flight Regimes



Flight Regimes

- **take-off**

  low mach number, but compressible, large regions of separated flow, possibly unsteady, complex geometry

- **cruise**

  attached flow, steady, weak shocks, applied CFD today

- **maneuver**

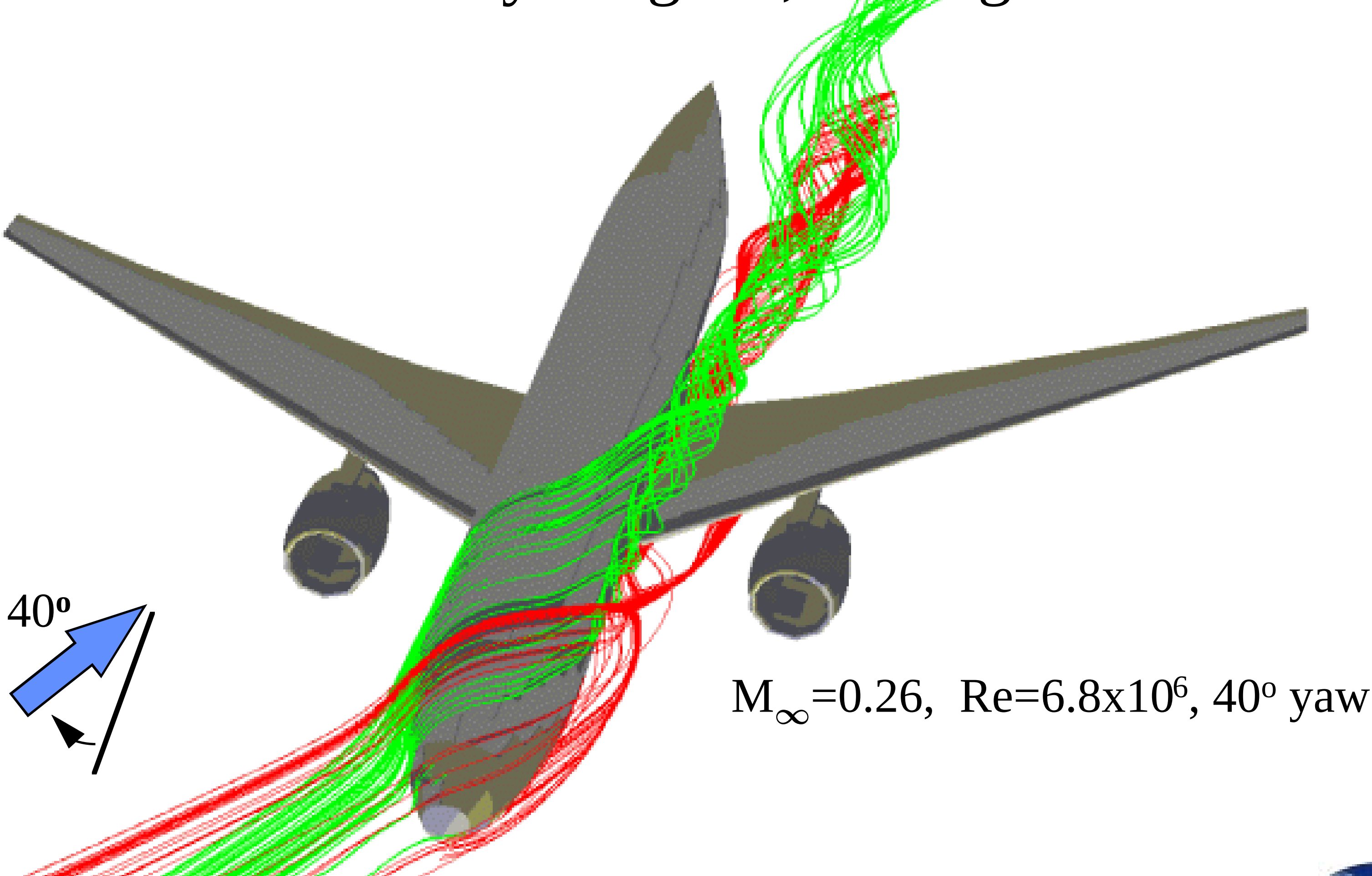
  unsteady, separated flow, possible buffet (structure-flow interactions), complex geometry, full configuration

- **landing**

  low mach number, but compressible, large regions of separated flow, possibly unsteady, complex geometry

Simulation of Complex Physics
Side Wind Simulation

Calculation by Jong Yu, Boeing Co.



Simulation of Complex Physics
Side Wind Simulation

- calculation used 9.6 million points, 28 blocks
- 550 MW memory (in-core)
- 32 hours to compute on single Cray C90 cpu
- multigrid calculation used 300/400/400 fine/medium/course cycles
- code is multi-tasked for Cray, turn around time one or two days
- Small geometrical changes require 2 or 3 days for grid generation

Flight Simulation Challenges
Shortening execution time

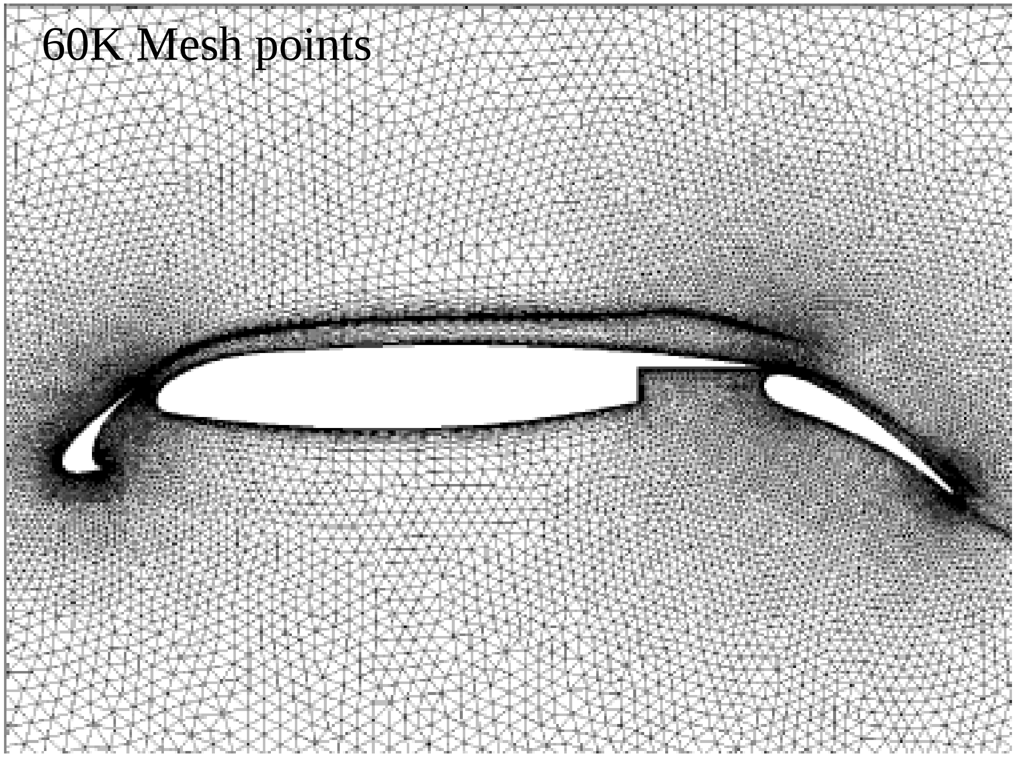
- Algorithm Improvements
  Preconditioning
  Multigrid
- Parallelization

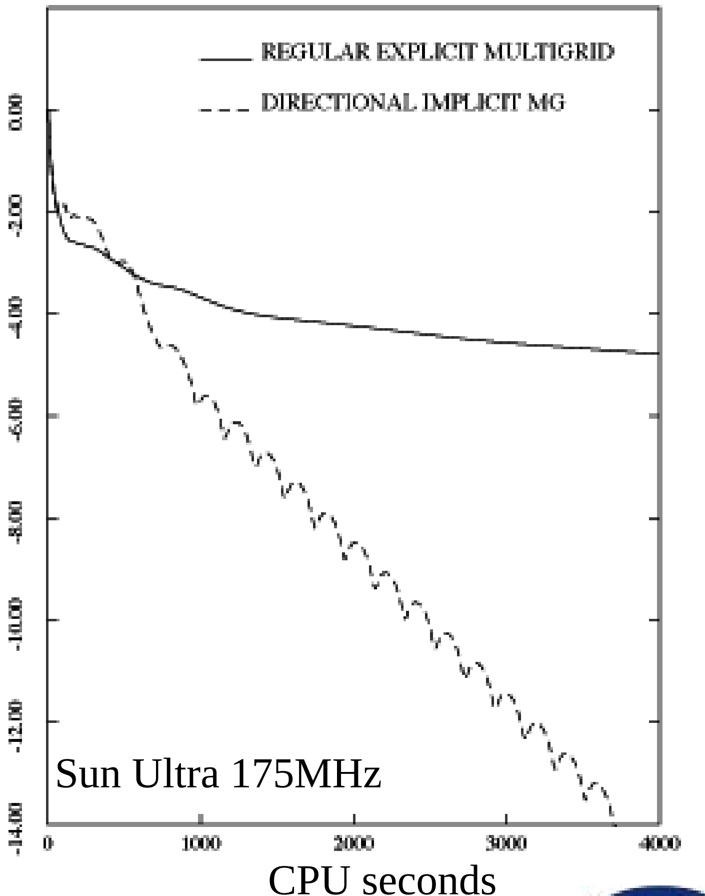
Shortening Execution Time

3 Element Wing

2D Unstructured Grids, Navier-Stokes

Calculation by Mavriplis, ICASE



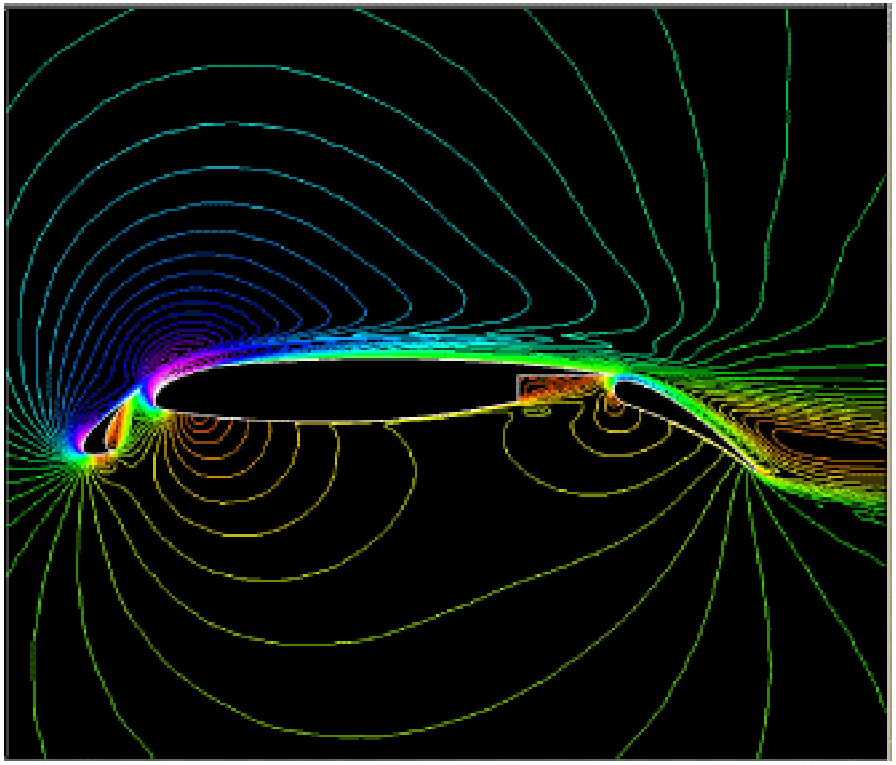


Shortening Execution Time

3 Element Wing

Unstructured Grids, Navier-Stokes

M_∞=0.2, Re=$1x10^6$, α=16^o



Shortening Execution Time

ONERA M6 Wing Test Case

Parallel Implicit Pseudotransient Newton-Krylov-Schwarz
3D Unstructured Grid Euler Eqs. (FUN3D Code) Parallelized with PETSc
Calculation by David Keyes ODU/ICASE and associates

- Tetrahedral grid with 2.8 M vertices, 11M unknowns solved on Cray T3E-900 (450MHz) at NERSC
- 83% efficiency on 512 nodes relative to 128 nodes
- 32.1 Gflop/s on 512 (compared to 255 Gflop/s for dense LINPACK matrix (order 80K) on same 512 configuration)

# procs.	# its.	exec time hours	speed up	Mflop/s per proc.	total Gflop/s	overall effic
128	164	1.68	1	66.7	8.5	----
256	166	0.90	1.87	64.8	16.6	93%
512	171	0.50	3.34	62.6	32.1	83%

Flight Simulation Challenges
Data visualization and knowledge extraction

- **Dataset Trends**
  - Increasing size: 100's MB -> 100's GB / timestep
  - Time-dependent: 1000's of timesteps
  - Complex grids: 3D, unstructured, adaptive, multi-block, overset
  - Multidisciplinary: fluids + structures + propulsion + thermodynamics

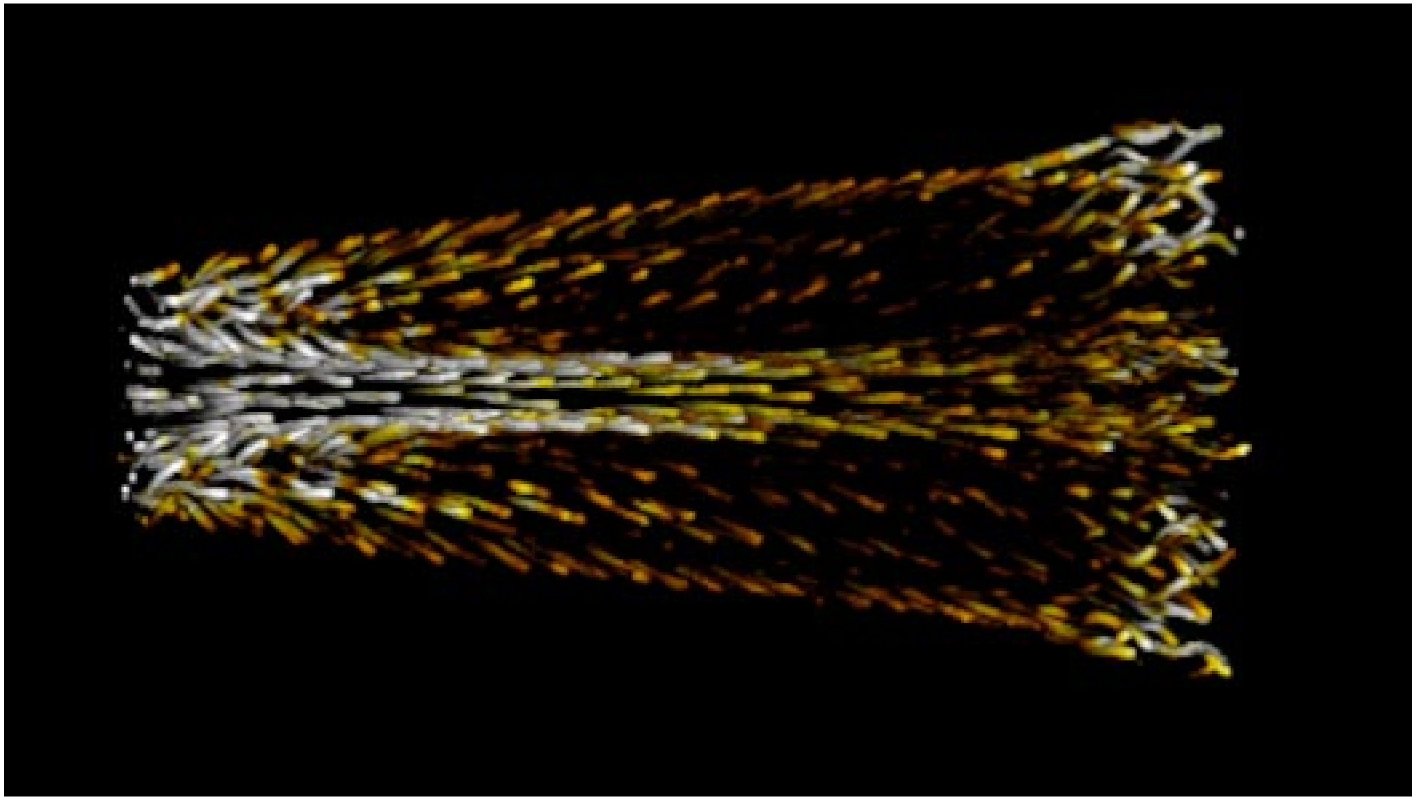
- **Visualization Challenges**
  - Managing large data
  - Finding what's important
  - Navigating in high-dimensional spaces (e.g., MDO)

Data Visualization and Knowledge Extraction

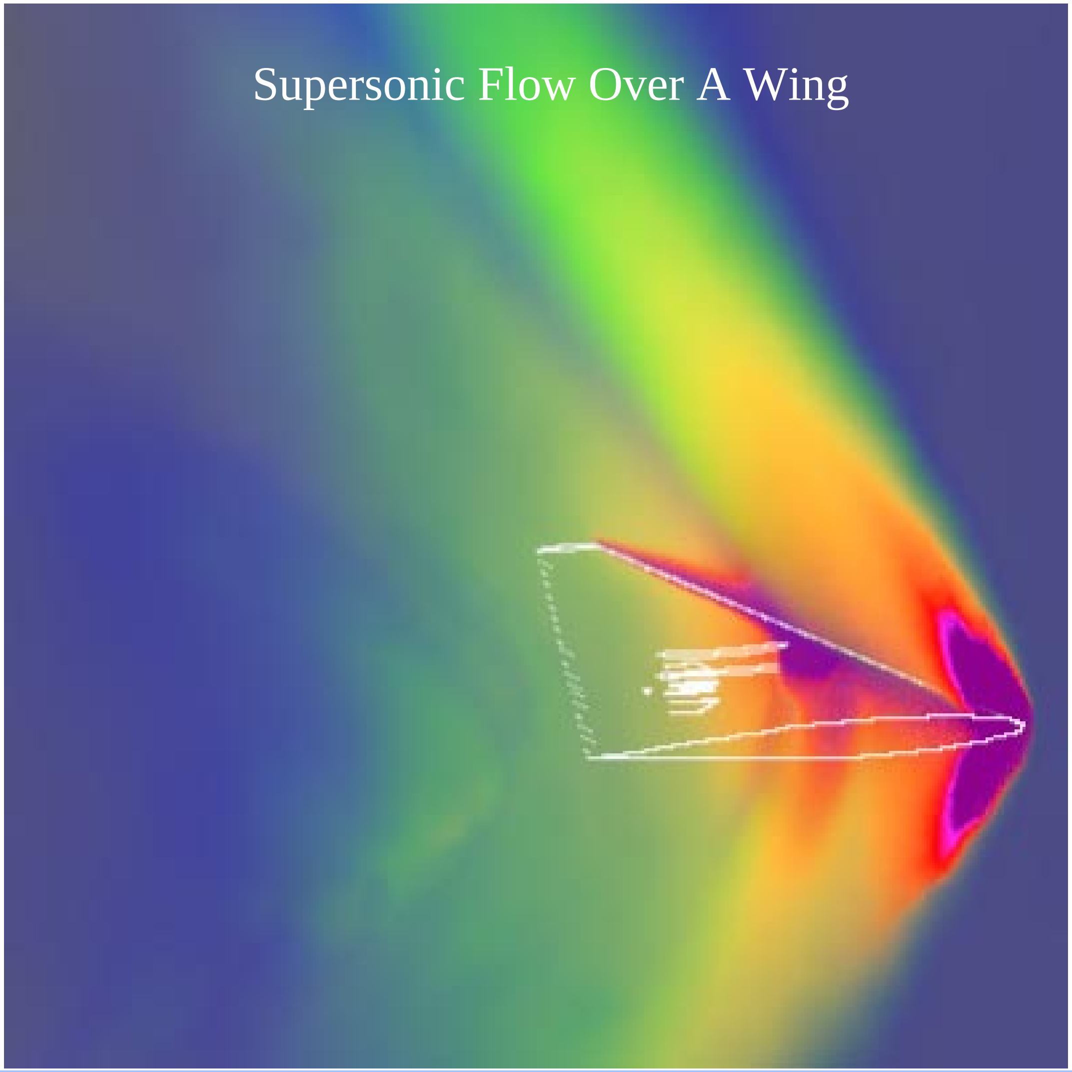
- **Software Strategies**
  - Parallel visualization and rendering methods
  - Decimation, compression, multi-resolution methods
  - Automated feature identification and extraction
  - Networking protocols: quality of service, performance guarantees

- **Hardware Strategies**
  - High-end visualization servers
  - Higher resolution displays
  - Immersion and VR
  - Networks: higher bandwidth, lower latency, less congestion

Data Visualization and Knowledge Extraction
Hot jet flow



Data Visualization and Knowledge Extraction



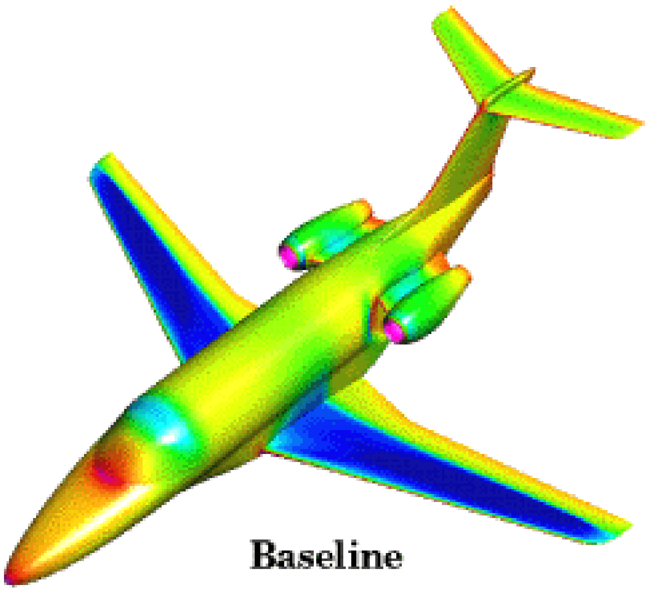
Flight Simulation Challenges
Optimization

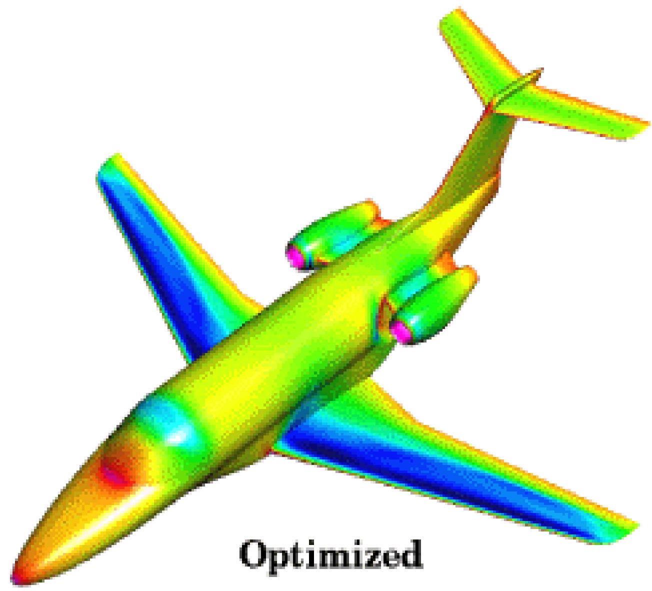
- Theory for Navier-Stokes is under development. Optimization for structural mechanics better understood.
- Could require repeated (100s or 1000s of runs) application of discipline codes
- Finding *global* minimum remains a research problem

Optimization
Transonic Business Jet

Calculation by James Reuther, RIACS

M_∞=0.82, C_L=0.35





Optimization

Transonic Business Jet

- Mesh uses Wing-Body-Nacelle-Pylon-Empennage-Geometry, 240 blocks, 5.8 Million cells
- Goal: redesign wing to improve aerodynamics at design point starting from a *generic* configuration
- 108 design variables at 5 wing stations and 55 geometric constraints
- "optimized" configuration attained 21.5% drag reduction in 5 design cycles

Optimization

Transonic Business Jet

Computational Statistics

- Single Navier-Stokes analysis used 5.8M cells and 300 multigrid cycles on an IBM SP2 with 32 processors. Wall clock time 2 hours.
- 5 design cycles on IBM SP2 with 32 processors required 28 wall clock time hours.

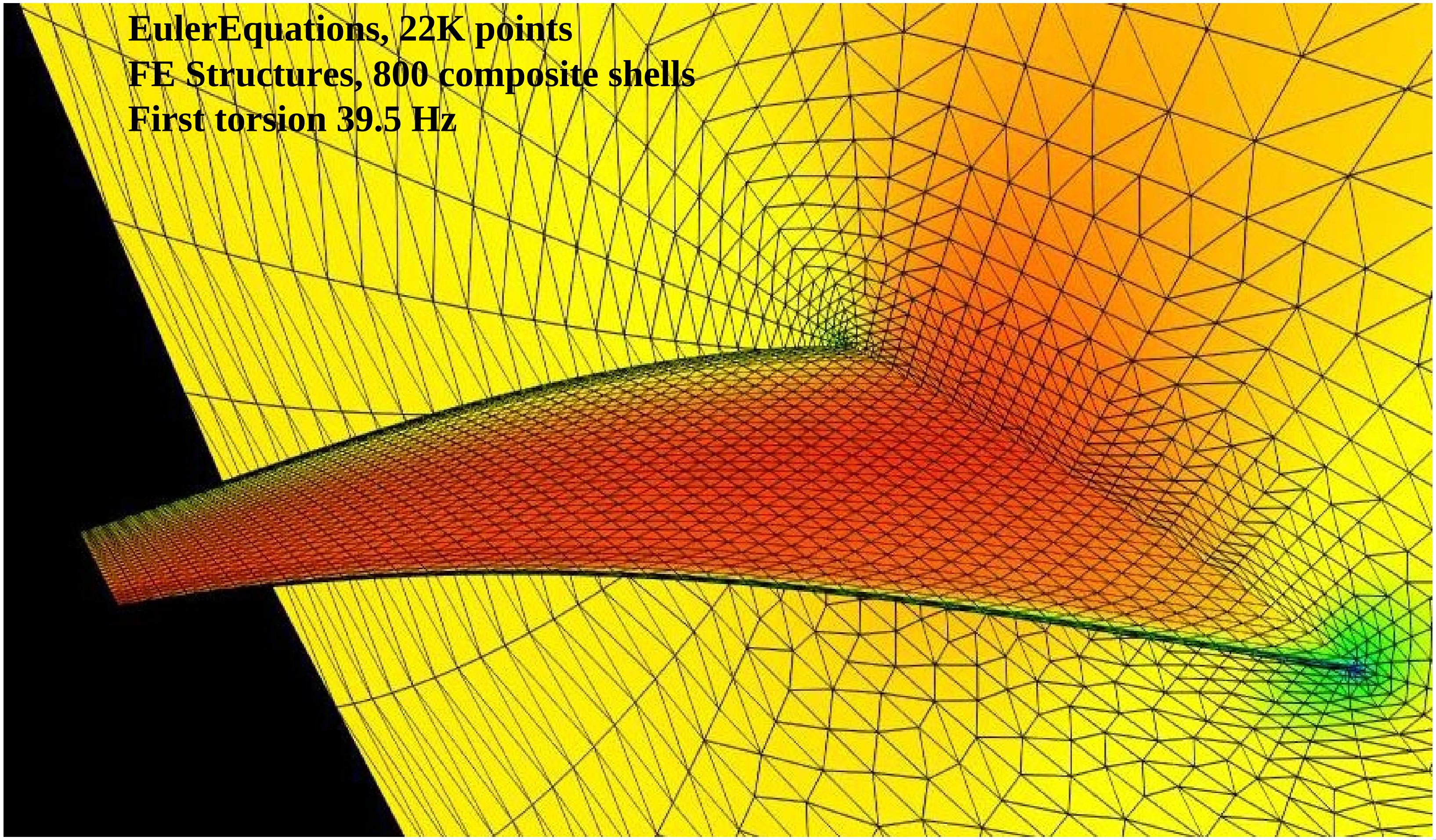
	cpu (hours)	#/design	# of designs	time (hours)
Flow analysis	1 -1.5	3	5	21
Adjoint analysis	.5-1.0	1	5	5
Mesh & gradient	.3	1	5	1.5
total cpu time				**28**

Flight Simulation Challenges

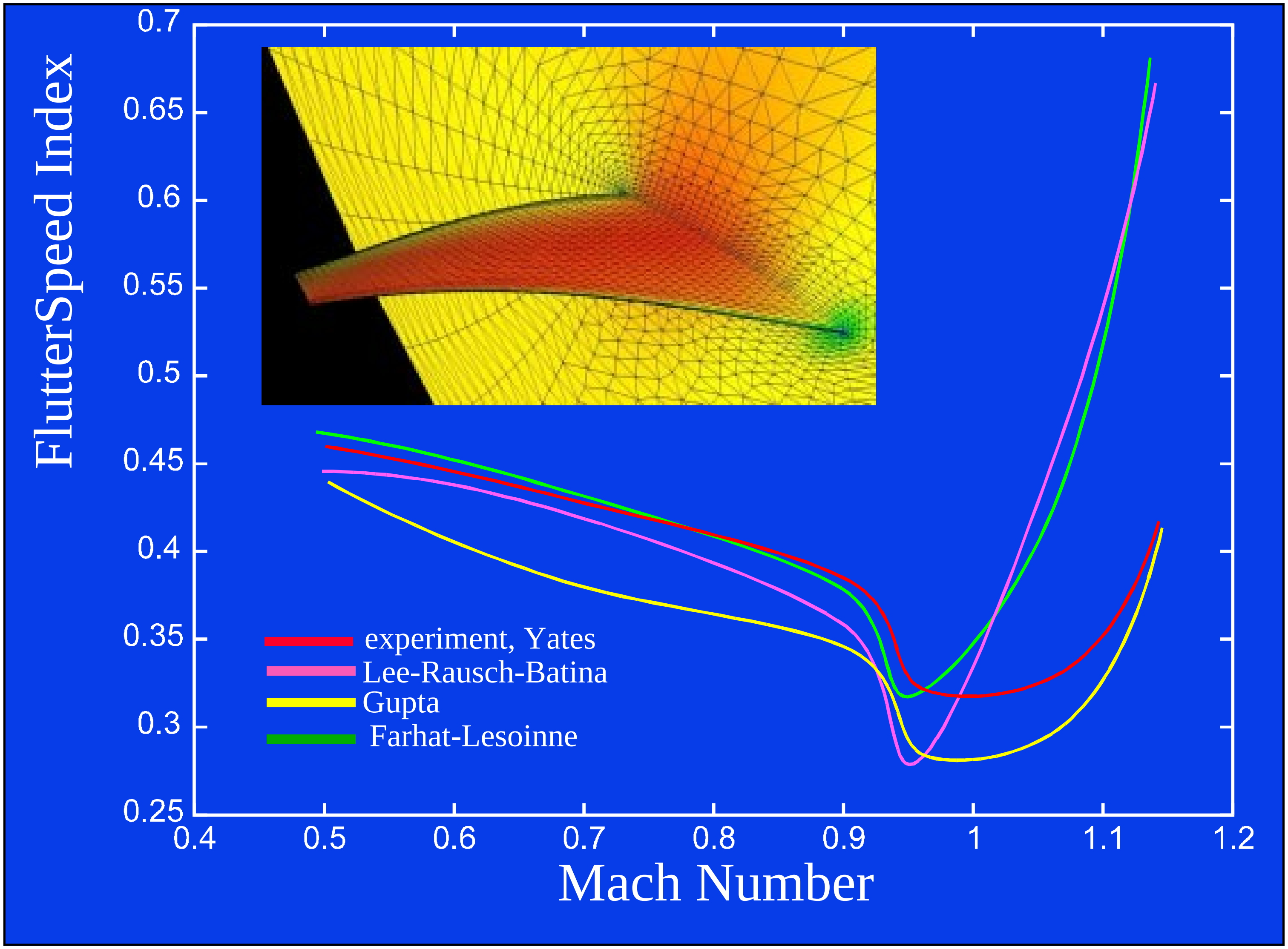
Multidisciplinary Interactions

Aeroelastic Simulation of the AGARD 445.6 Wing

Computation by Charbel Farhat, Univ. of Colorado



Aeroelastic Simulation of the AGARD 445.6 Wing



Aeroelastic Simulation of the AGARD 445.6 Wing

- Gupta, 45K points, $\Delta t=0.0000425$
- Lee-Rausch-Batina, 261K points, $\Delta t=0.0001$

- Farhat-Lesoinne, 22k points, $\Delta t=0.002$

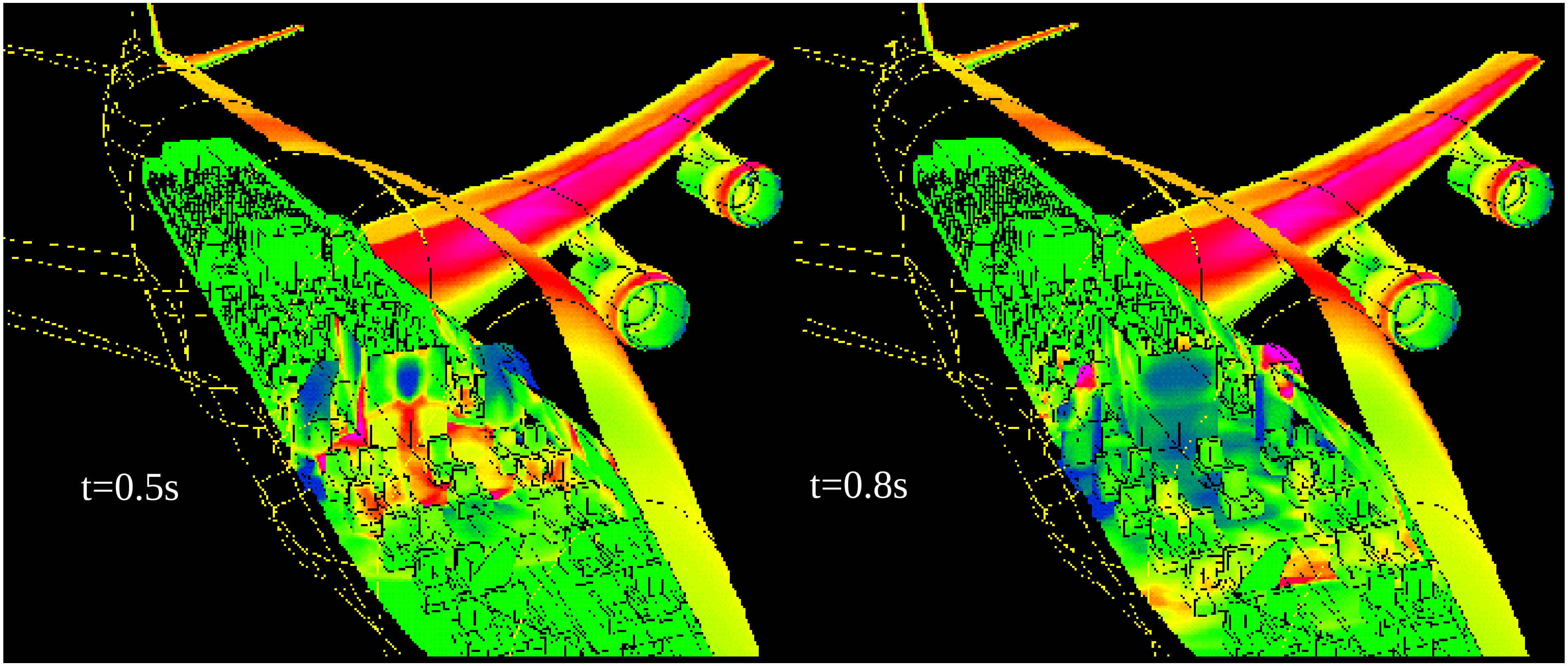
Computation Statistics

IBM SP2 with 4 processors, simulation of 0.25 secs

	Basic Algorithm	Modified Algorithm
#time steps	1000	100
fluxes, (per t.s.)	1136.3, (1)	493.2, (5)
cpu time secs	11752.6	2451.9

Simulated Explosion inside Boeing 747

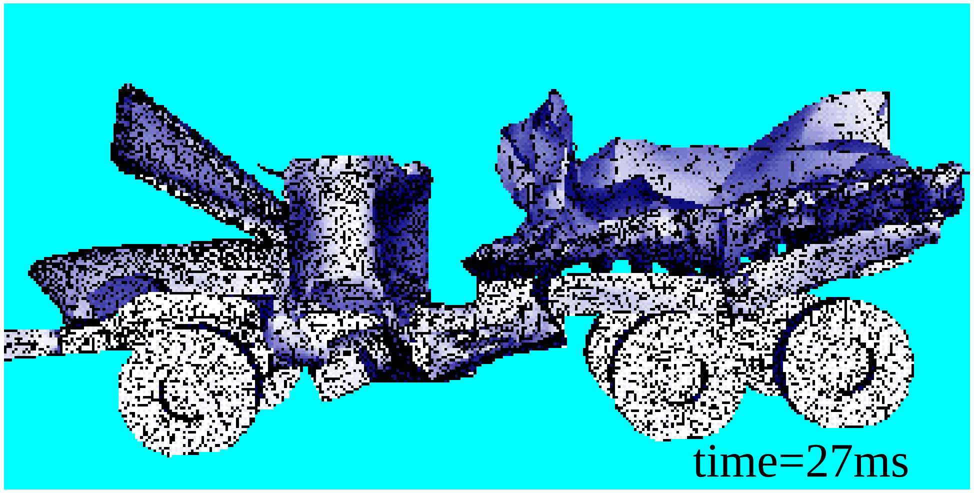
Calculation by Rainald Lohner, GMU
using Euler Eqs. and Unstructured Grids



Shock impact on a truck

Coupled CFD & CSD Simulation

Calculation by SAIC-GMU-GA



Research Opportunities in Computational Sciences

- Computational Tools Integration
- Interactive Navigation
- Experimental/Computational Integration

Computational Tools Integration

- Large number of tools exist for geom modeling,grid generation, adaptive refinement, partitioning, automatic differentiation, linear & non-linear solvers, I/O, visualization
- With few exceptions, these tools do not work together, mainly because of incompatible data structures
- A common data structure for all tools would not provide good performance

Interactive Navigation

- Large-scale computations, particularly in multidisciplinary design and optimization,can benefit form interactive visualization and steering: navigation
- However, frequency and data volume exchange must be such as to provide navigation without reducing high-performance execution

Experimental/Computational Integration

- Experimental and computational methods have disadvantages: experiments can be costly, some quantities cannot be measured directly, experiments limited by interference,...;computations limited by model accuracy, resolution, computational power,...
- Seamless, real-time, integration of experiments and computations, each supporting the other's weak area