Computing and Visualization Relevant to Airport Capacity: Opportunities and Needs

Presented at The Conference on Capacity and Wake Vortices

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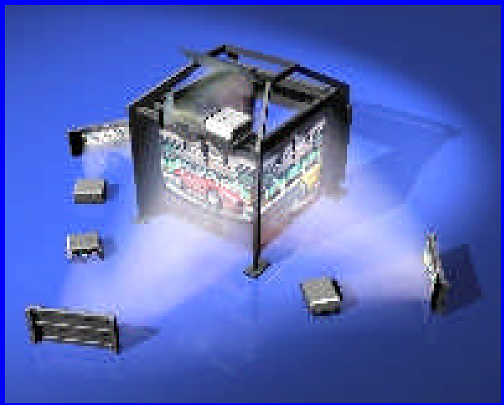

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Outline

- Airport capacity problem
- Runway independent aircraft (RIA)
- Computer, networking, and visualization trends
- Computational fluid dynamics (CFD)
- Virtual Reality (VR) systems
- Conclusions

Airport Capacity Problem

- NASA predicts that air traffic will triple by 2022
- On many airline flights, the average speed is only 60 MPH, even though the aircraft can travel at 500 MPH. The hub and spoke system is not serving airline passengers adequately.
- In the U.S., for trips less than 500 miles, it is often more convenient and faster to drive
- 98% of U.S. population lives within a 30 minute drive of a landing facility
- The U.S. has roughly 18,000 aircraft landing facilities, but 80% of all flights use only 50 airports

Airport Capacity Problem (cont.)

- National ***Aeronautics*** and Space Administration (N**A**SA)
- N*A*SA has had inadequate funding for Aeronautics for many years now (2% of total budget ?)
- Rotorcraft offer truly remarkable solutions to the airport capacity problem, yet the administration has *zeroed* out Rotorcraft funding
- Meanwhile, for the first time in history, the average speed of travel has declined

Runway Independent Aircraft

- The U.S. hub and spoke system is saturated
- Runway independent aircraft (RIA) :
  - Helicopters, tilt-rotors, gyrocopters, …
  - Use runways less than 3000 feet, tarmacs, vertiports, or GA airports
- RIA offer additional capacity without building new runways
- Current commuter aircraft account for 40% of traffic and only 20% of passengers, and they use runways
- With short takeoff and landing capabilities, capacity can be increased by 26% with existing runways
- The tools for simulating rotorcraft are about a generation behind the tools for fixed wing aircraft, due to the complexity of rotorcraft -- need more research

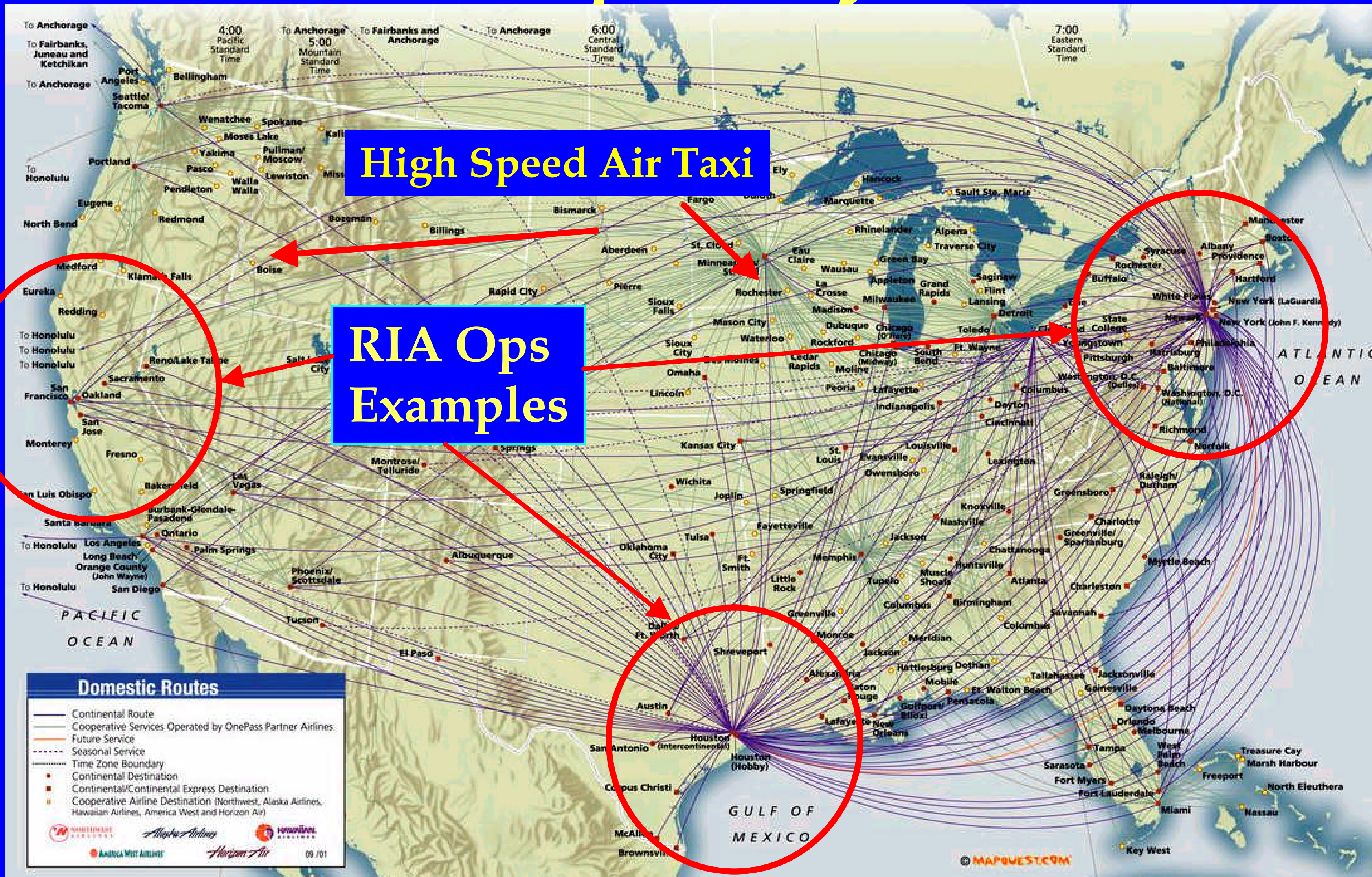
High Speed Air Taxis

- High-speed 6 passenger jets could act as "air taxis"
- For roughly airline coach ticket cost, you could fly door to door in a private air taxi
  - e.g. Eclipse Aircraft & Williams Jet engines (350 knots & 1300 nm)
- 35,000 jets could provide 30 million trips per year
- More than 100,000 corporations in the U.S. could afford one of these jets (< $1M each)

Could be especially useful for trips between moderate sized cities, which hub and spoke system does not serve well

Ref.: "Free Flight" by James Fallows

Hub and Spoke System & RIA



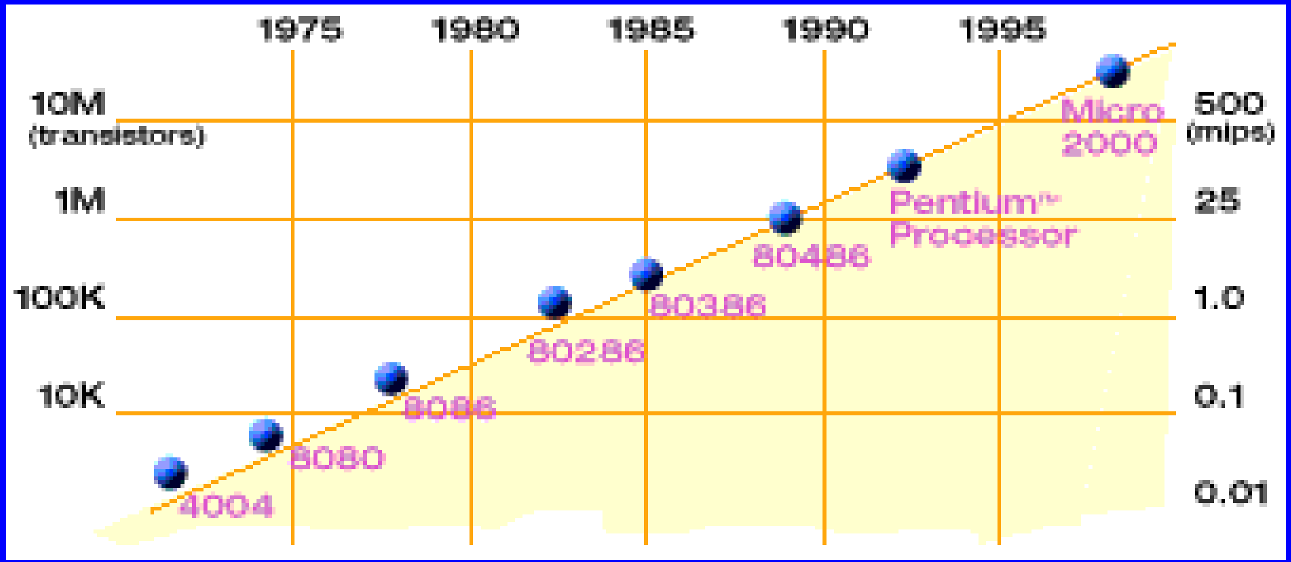
Computers, Networks, and Visualization

- **Computers, networks, and visualization can play many roles in solving capacity problem**
- **Computing power :**
  - **Better simulations for design (aero, noise, propulsion, …)**
  - **Operations research for route planning**
  - **Air traffic control**
  - **Information processing & intelligent systems**
- **Networks**
  - **Massive data can be sent (Gigabits per second)**
  - **Wireless networking becoming common (11 Mb/sec.)**

- **Visualization**
  - **Stereographics: Virtual reality & Augmented reality**
  - **Wearable monitors**
  - **Retinal scanning**

Moore's Law

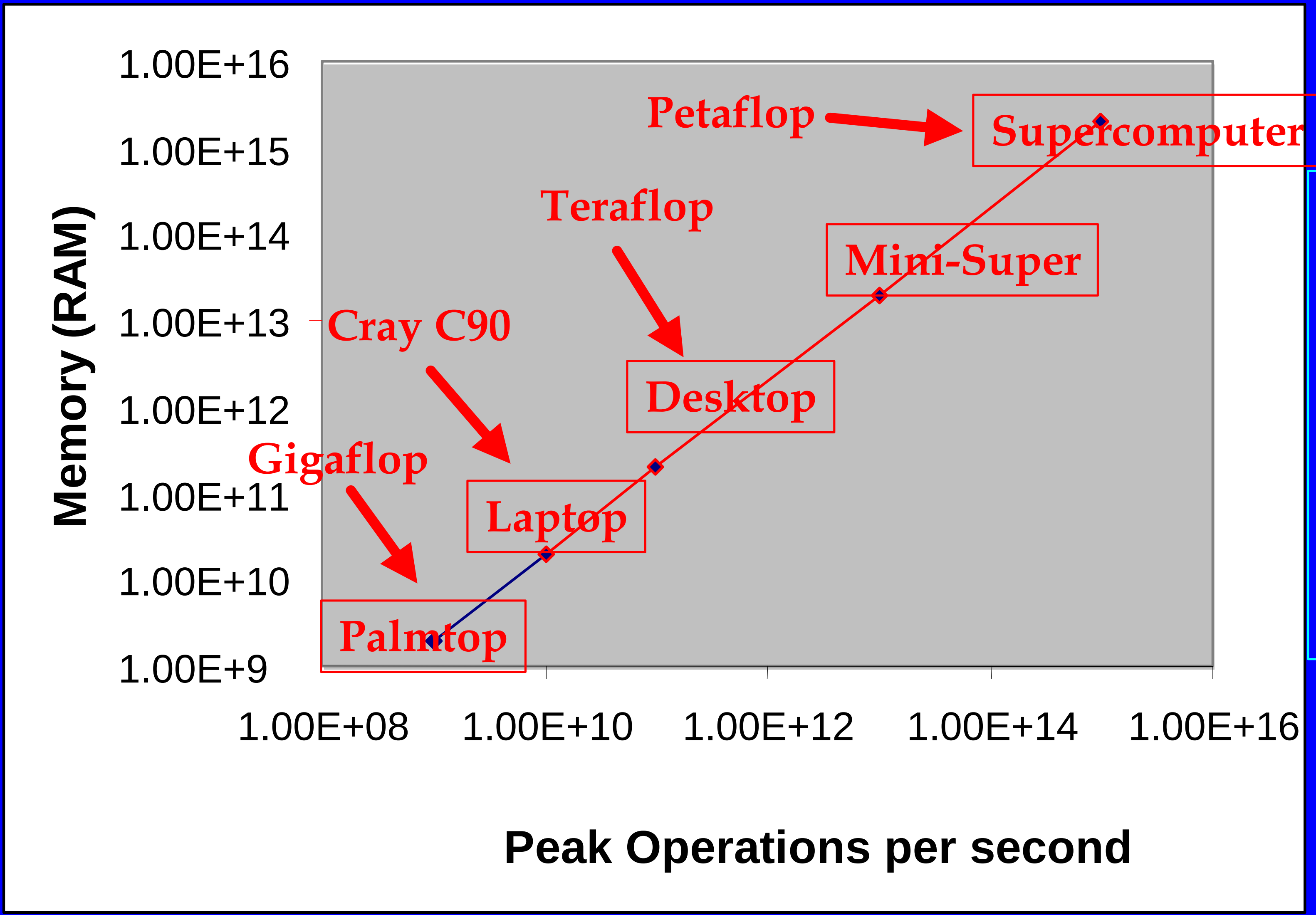
- Computer power doubles every 18 months (with cost constant)
  - 100 times faster every 10 years
  - 100,000 times faster every 25 years
  - Dictates revolutionary changes, not evolutionary



Note:
A new major airport takes roughly 20 years to complete !

- An inexpensive computer will ***exceed human intelligence*** by 2020 ... and there will be billions of them all connected together. A parallel computer could have 10,000 times more computing power than a human brain.

Year 2025 Computers (10^4 factor)

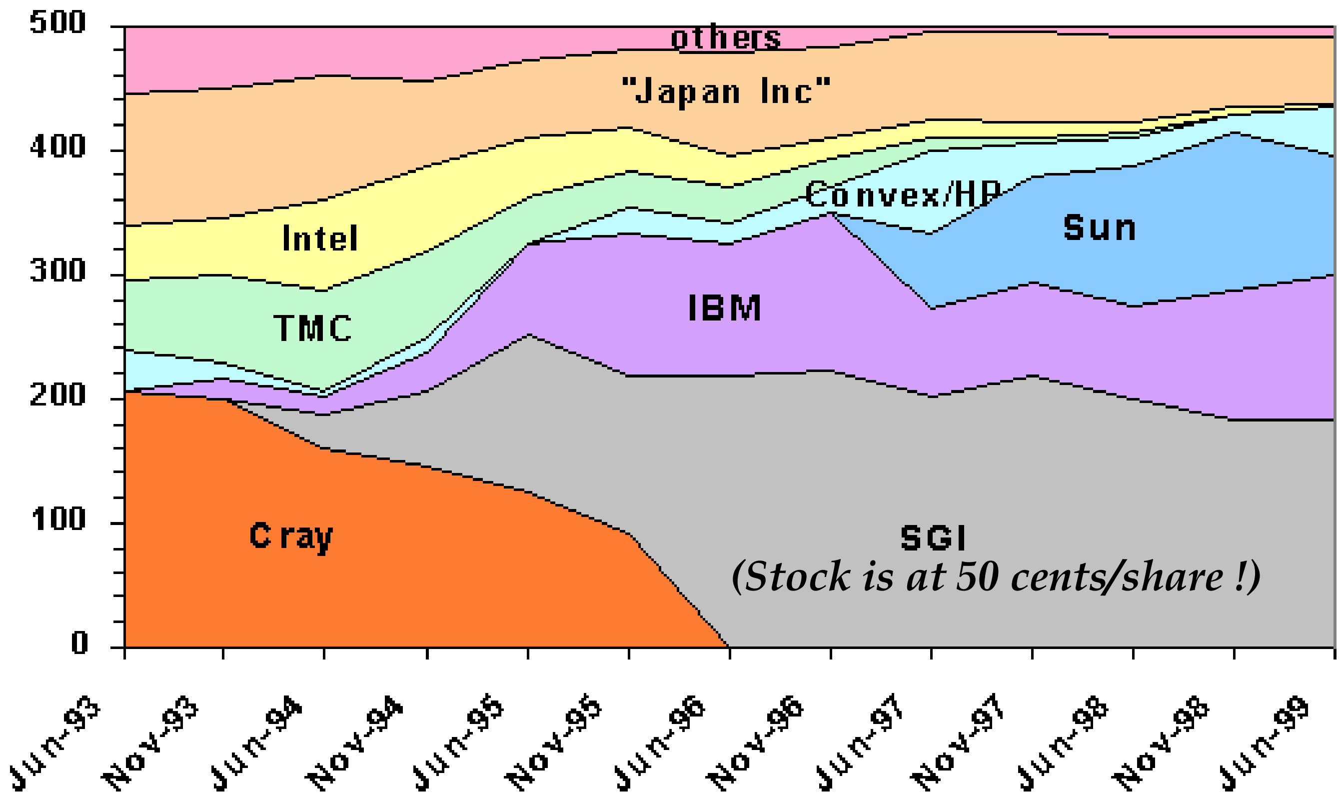


Full Aircraft LES CFD will require roughly this level of computing power. Grid point requirements scale with Re**2

Supercomputer Companies

(there are almost none left)

Manufacturer



PC Clusters (Beowulf)

(COTS supercomputers)

COst effective COmputing Array
(COCOA II)

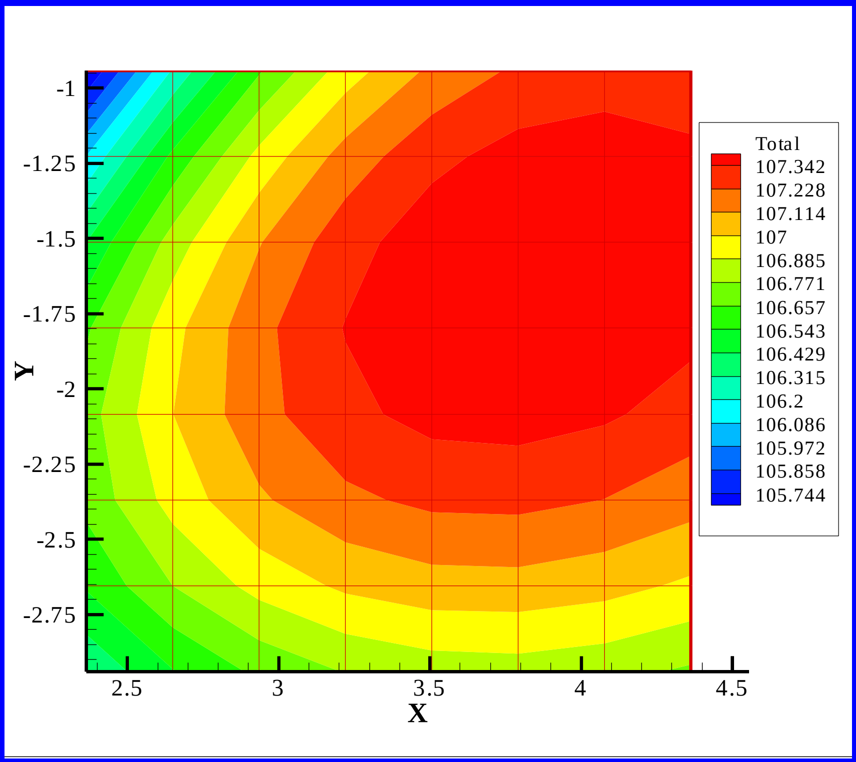
42 Pentium III 800 MHz
512 MB RAM each (21 GB RAM)
42 Fast Ethernet ports
2 HP 2324 24-port switches
RedHat Linux with MPI
F95 Compilers
GNU C compiler

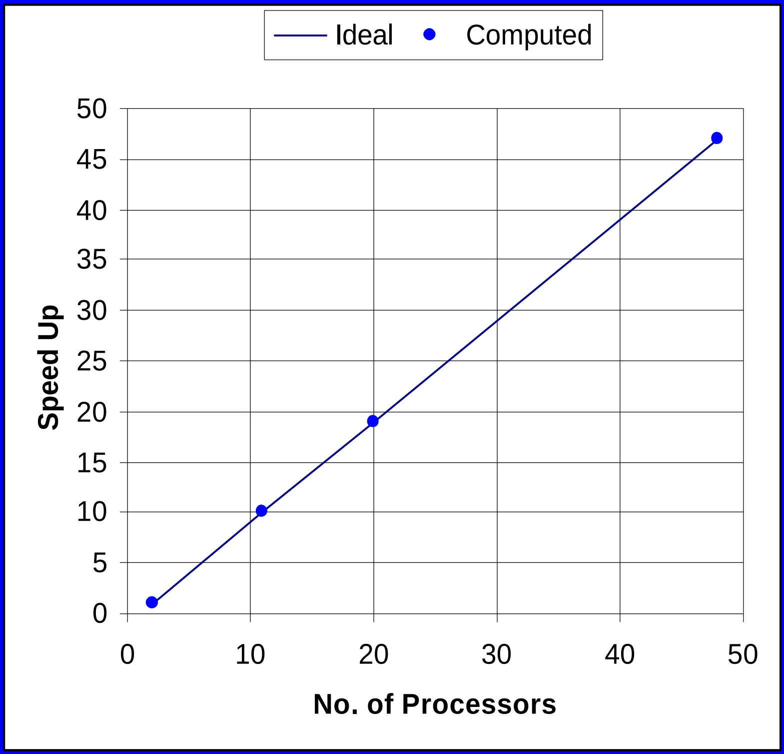
http://cocoa.ihpca.psu.edu

32 gigaflops peak speed
$50,000

Sandia Labs has a machine with 9000 PC processors (ASCI Red)

Parallel Wopwop SpeedUp

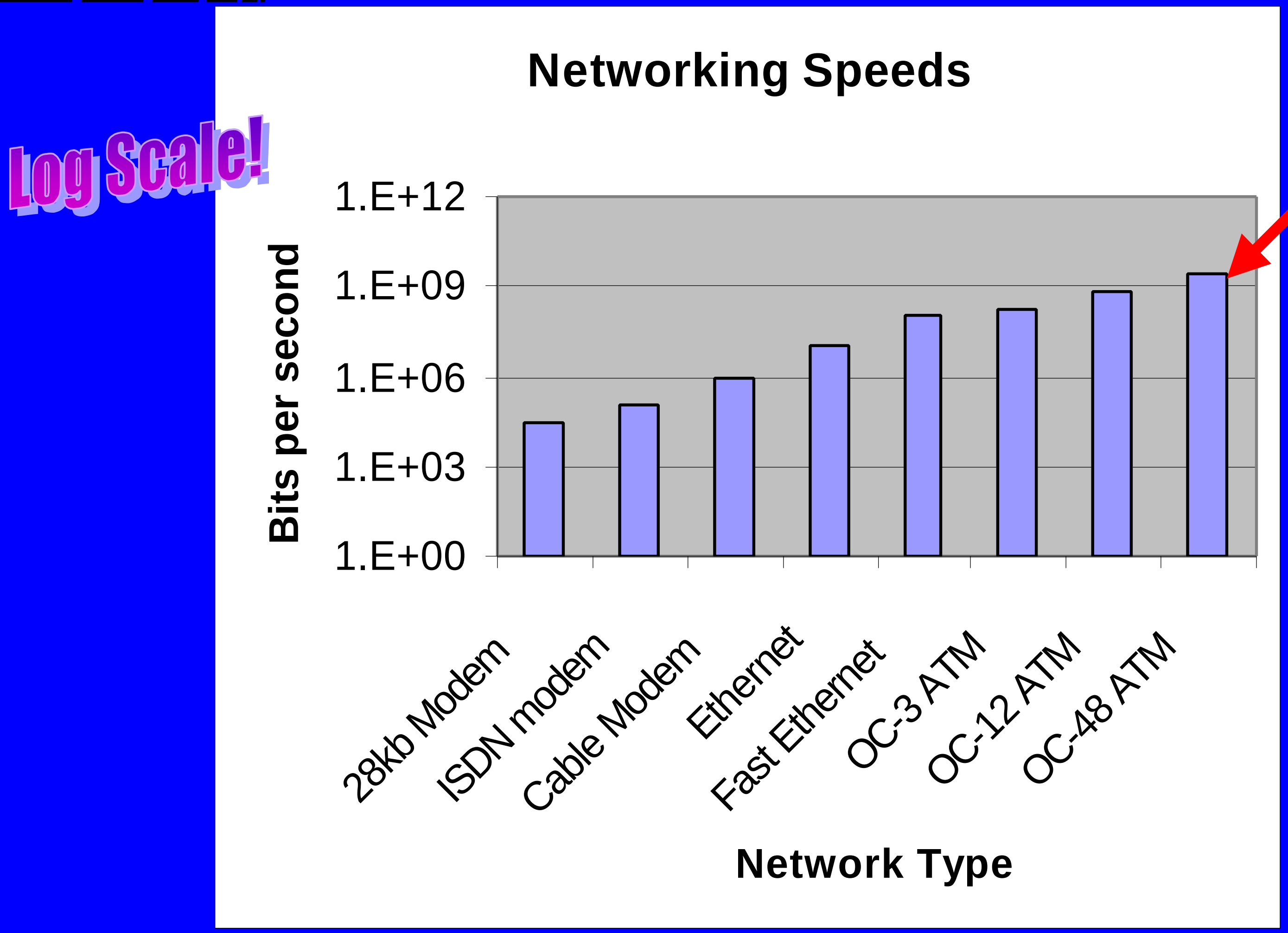




400 Observer Locations computed using COCOA Cluster.

1 Processor: 4700 sec. 48 Processors: 127 sec.

Parallel computers aren't just for CFD, large scale design studies (and Monte Carlo) work well too.



Could send entire encyclopedia in 10 seconds

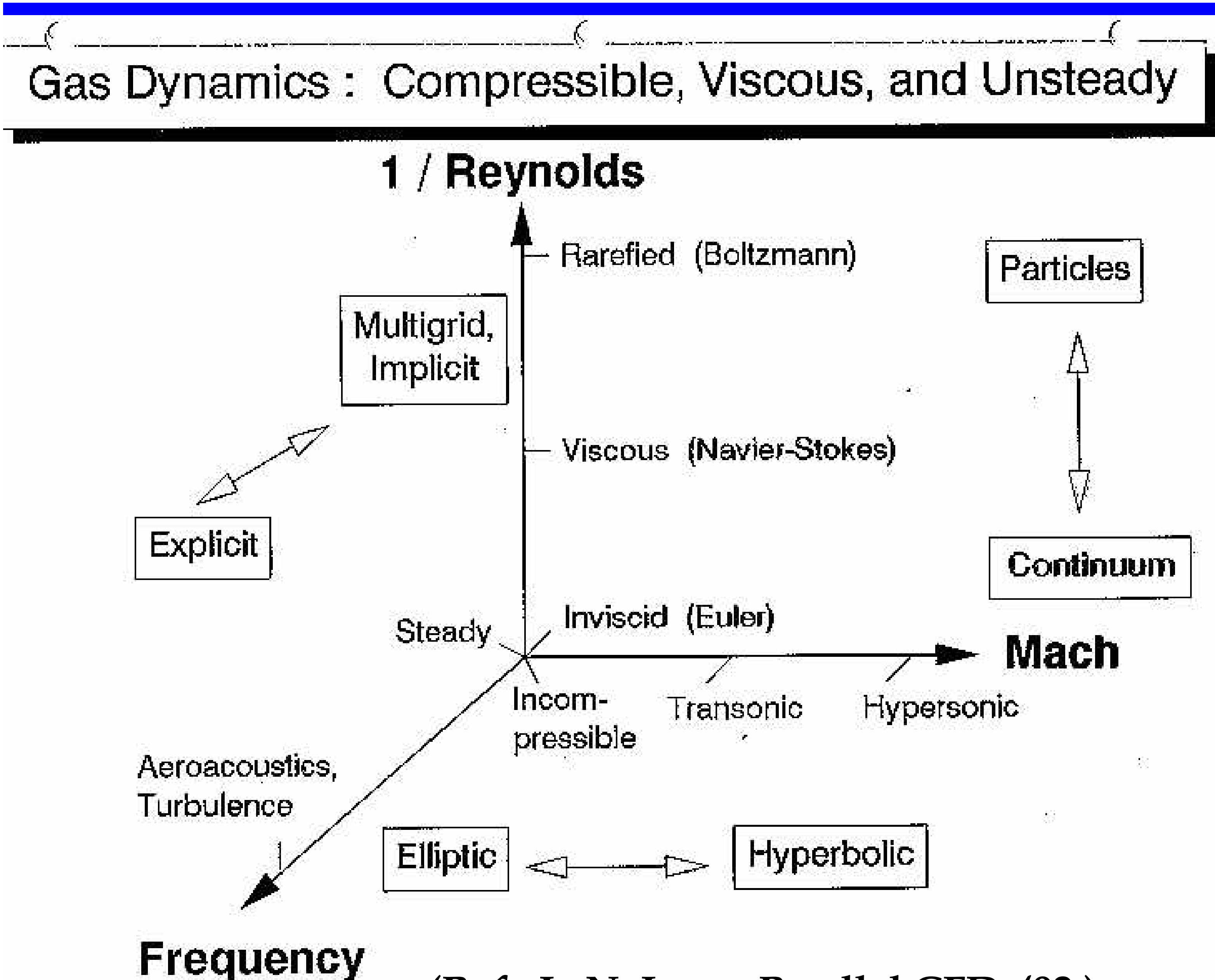
Could send photos of the entire U.S. population in ten hours

Could send photos of the entire earths surface in one hour

24-bit Graphics at 30 frames/sec.

Computational Fluid Dynamics

- **CFD is not a solved problem**
  - » It shows promise, but has been oversold
  - » Quite effective for fixed wing aircraft
  - » Need much more work to make useful for rotorcraft design
- **Better approaches to turbulence are needed**
  - » RANS can only do so much
  - » Dynamic LES promising
  - » Detached Eddy Simulation (DES) promising also
- **Better Unstructured grid generation methods needed:**
  - » GridGen cannot produce viscous grids.
  - » Vgrid produces cells that are much smaller than necessary
  - » Metis works very well for distributing unstructured grid across parallel processors.
- **Coupled Dynamics-Fluid-Structure codes essential for rotorcraft simulations**



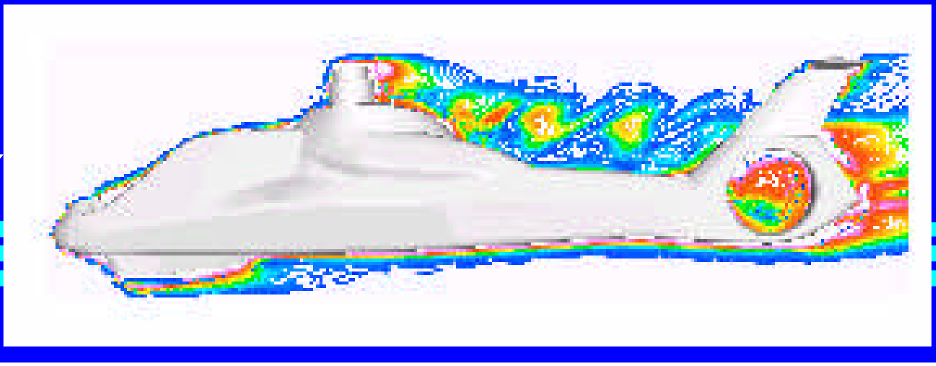
(Ref.: L. N. Long, Parallel CFD, ‘92)

CFD is <u>not</u> a solved problem, but has been over-sold. Only a tiny subset of problems can be predicted well.

Multi-phase flow (e.g. icing, cavitation) and chemical reactions are additional complexities

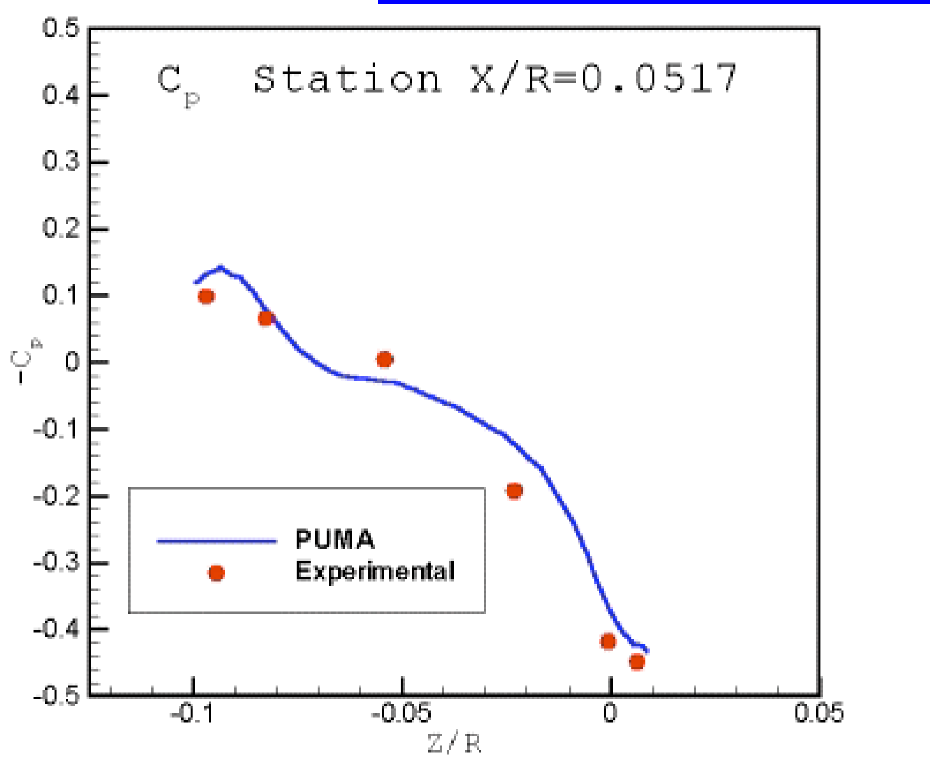
Rotorcraft Fuselage Flows

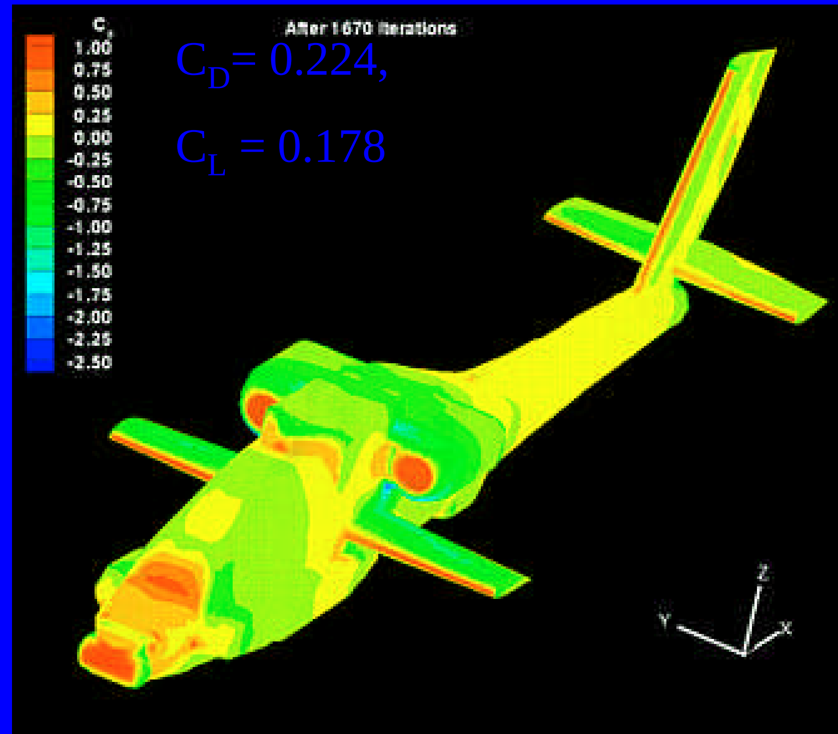
- A common problem on helicopters is unsteady separated flow:
  - Flow separates from hub or fuselage and then impinges on the tail rotor, empennage and control surfaces.
  - This flow is strongly influenced by the main rotor wake
  - These problems are even more pronounced as the forward airspeed is increased, and on low observable aircraft (e.g. Comanche)
  - No helicopter has ever been built where the tail has not had to be modified after flight tests.
- Also, the drag due to the hub and fuselage is a significant fraction (roughly 75%) of total helicopter drag.
- This cannot be simulated using the Reynolds averaged Navier-Stokes equations

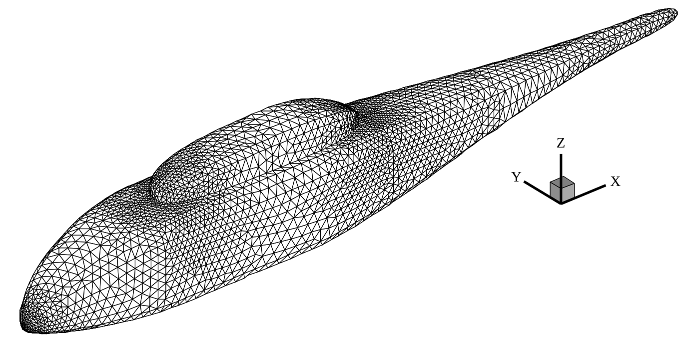


Ref. : Earl Duque

Robin Body & Apache Results







We can predict steady-state, attached-flow solutions over streamlined bodies. We cannot predict flow over aft end of fuselage (e.g. loading and drag).

Fuselage Drag Predictions

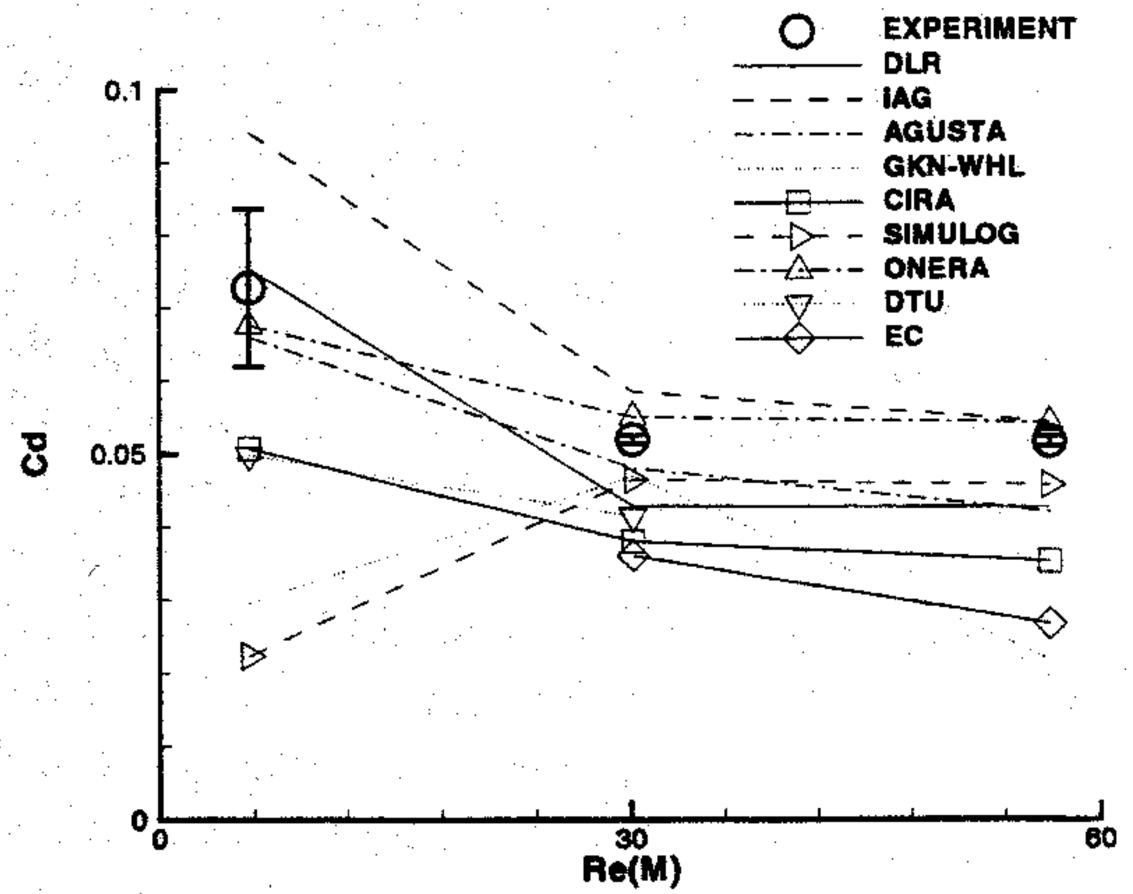
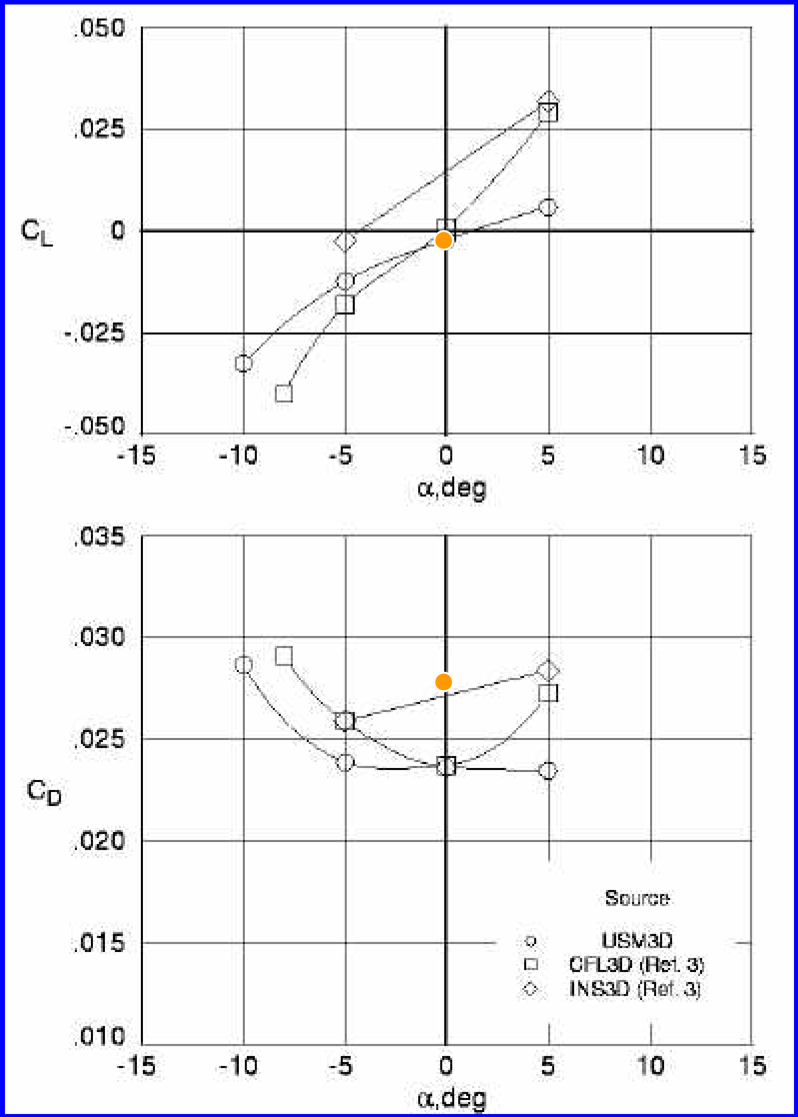


Figure 23 : Comparison of drag prediction for C1 configuration

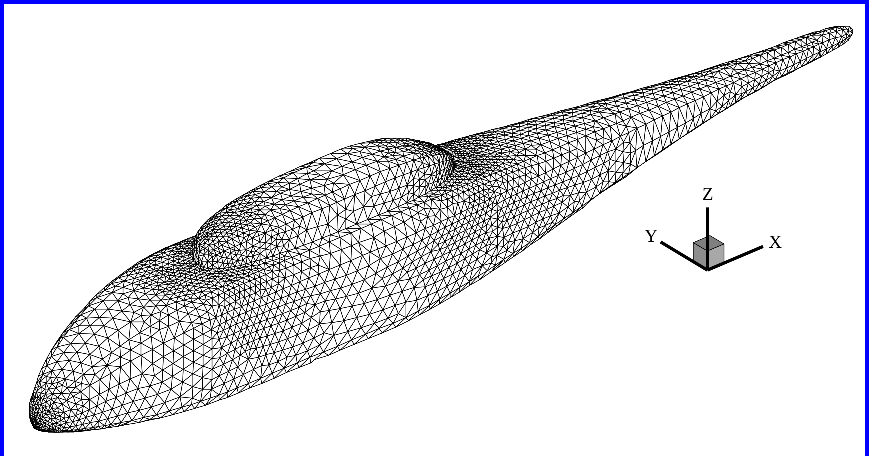
European Helifuse investigation found that turbulence models such as k-? , k-?, Baldwin-Lomax were not able to accurately predict lift and drag on complex helicopter geometries

3D Validation Results



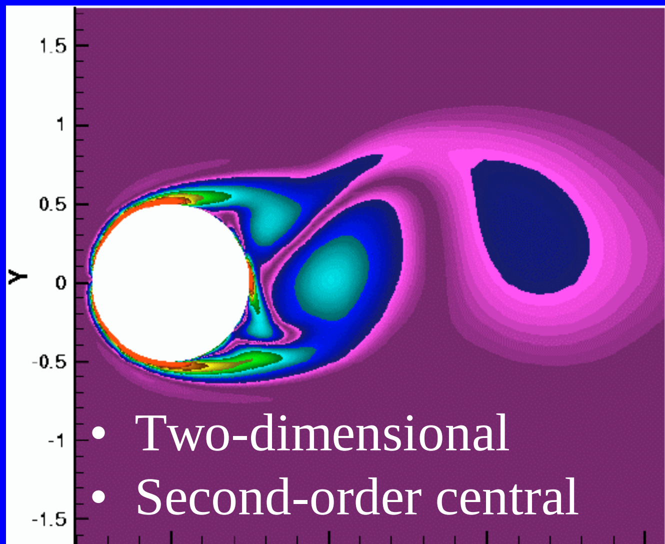
Steady-State: ROBIN

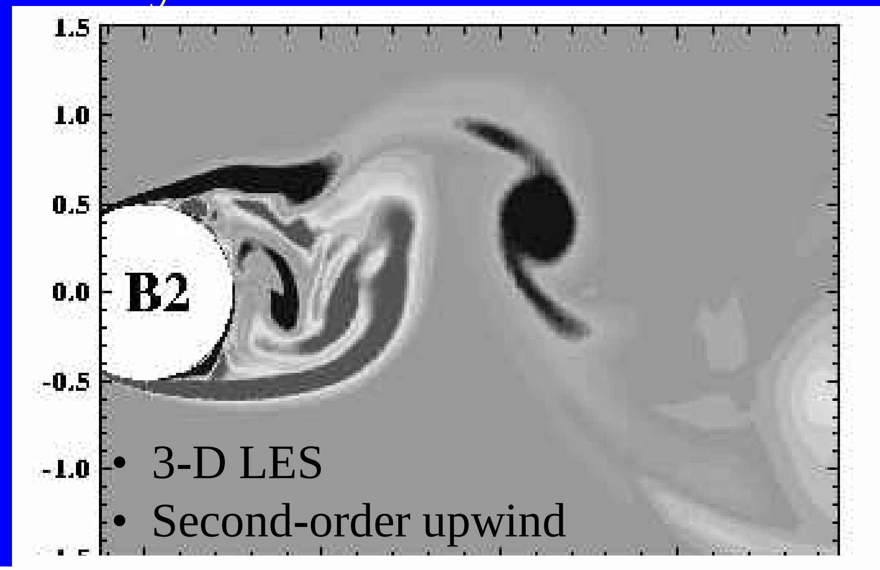
- FLOUS – inviscid grid
- USM3D-unstructured
- CFL3D-structured, thin layer NS
- INS3D-structured, thin-layer NS

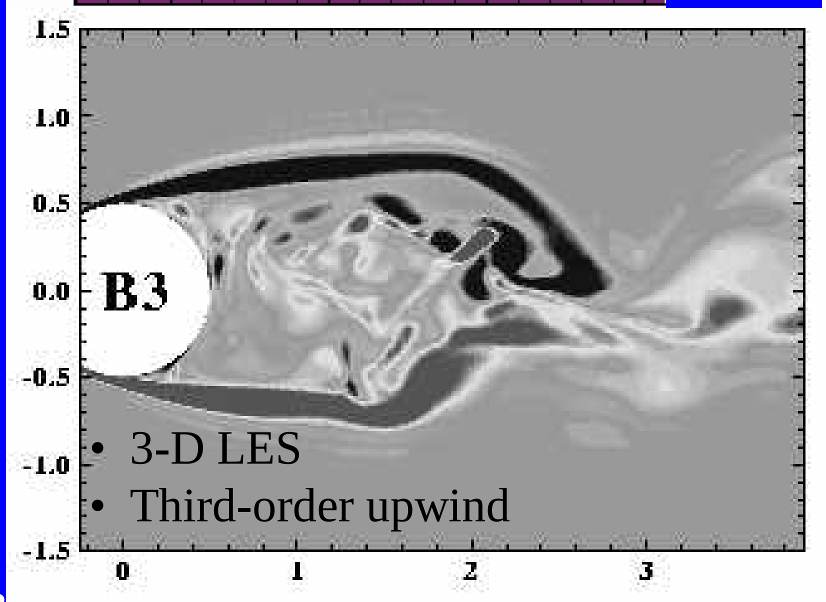


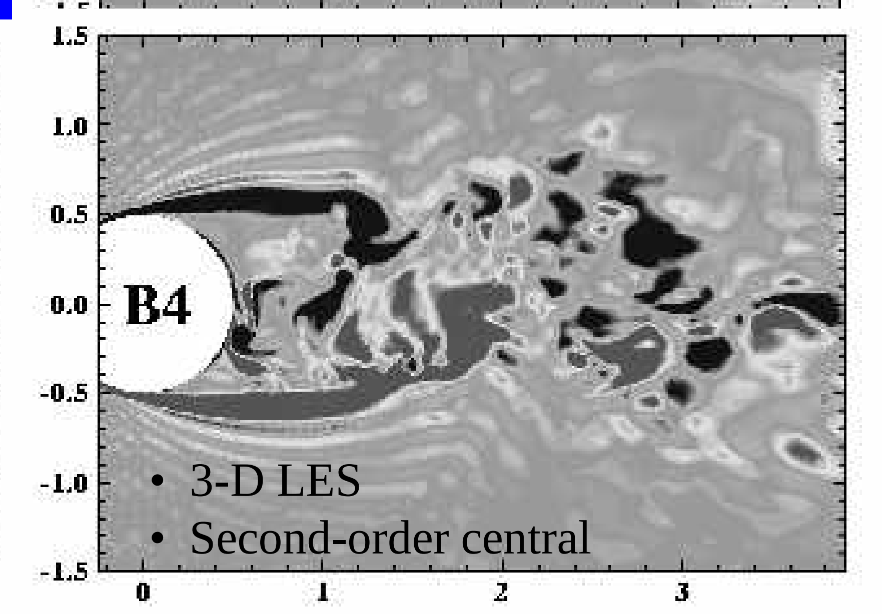
Cylinder Wake: Algorithms

Instantaneous Vorticity



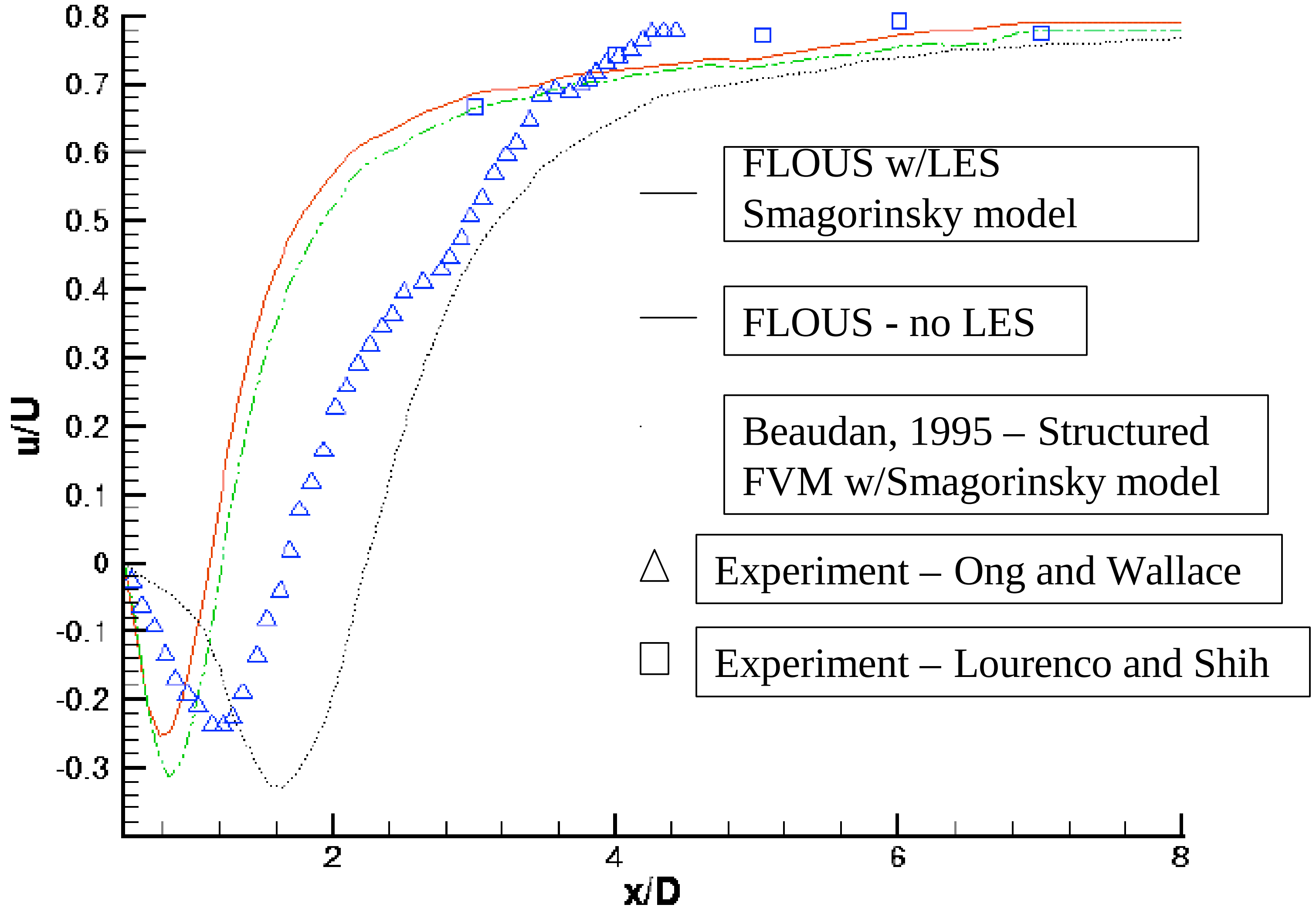






(Ref. M. Breuer, Intl. Jnl. Num. Methods Fluids, '98)

Circular Cylinder – Re = 3900

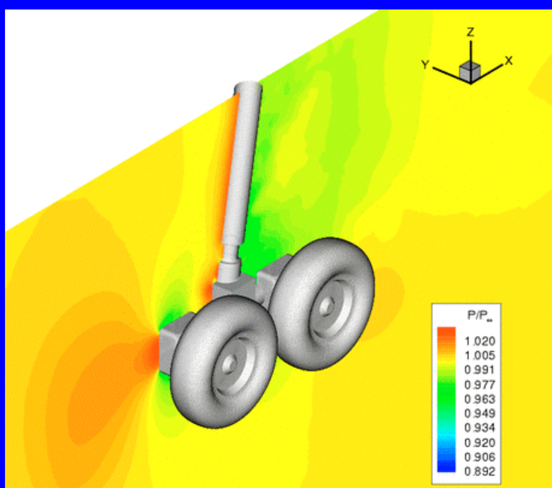


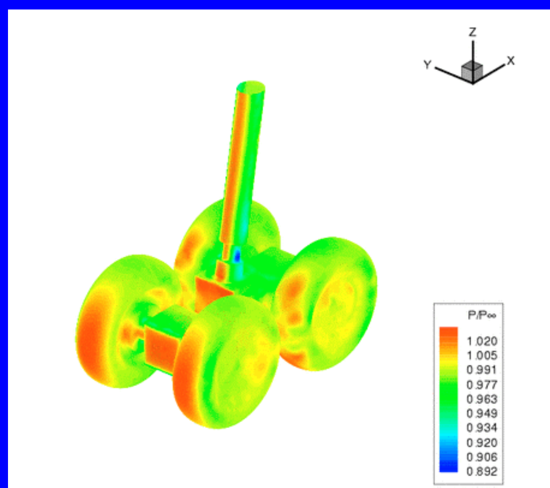
(Ref. R. Hansen, Penn State Ph.D., 2001)

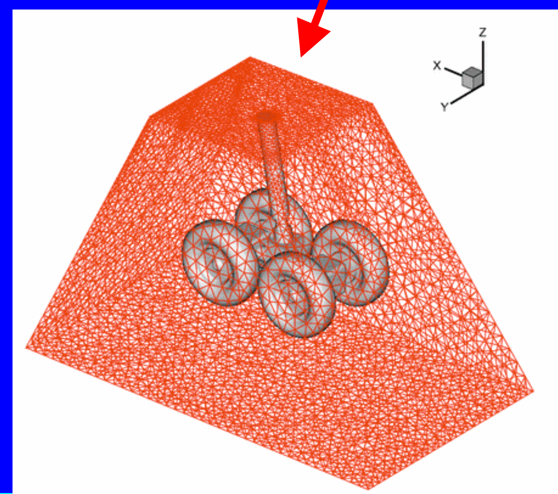
Landing Gear Aerodynamic Noise

- Airframe and landing gear noise is a significant noise source
- Unsteady time-accurate CFD on unstructured grids can be used to predict the separated flow
- Coupled to Ffowcs Williams – Hawkings equations on a surface allows far-field noise predictions
- Need more algorithm and turbulence research

FW-H Surface







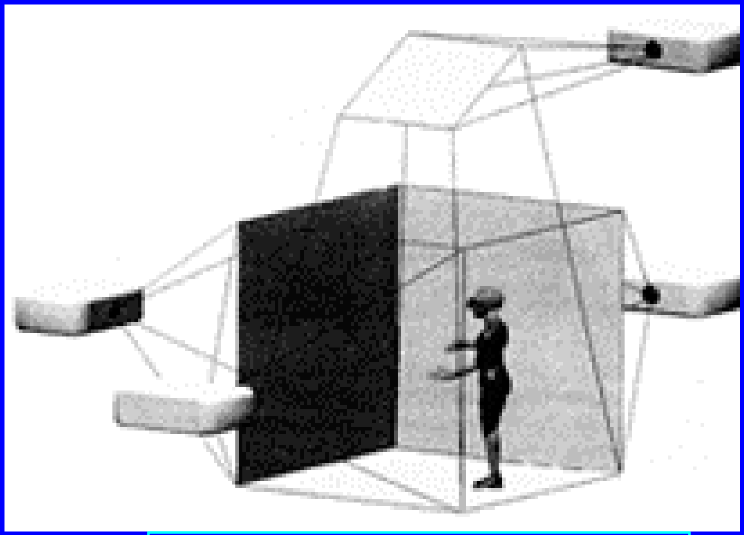
(Souliez, Long, and Morris, AIAA Reno, 2002)

Rotor Wake Simulations

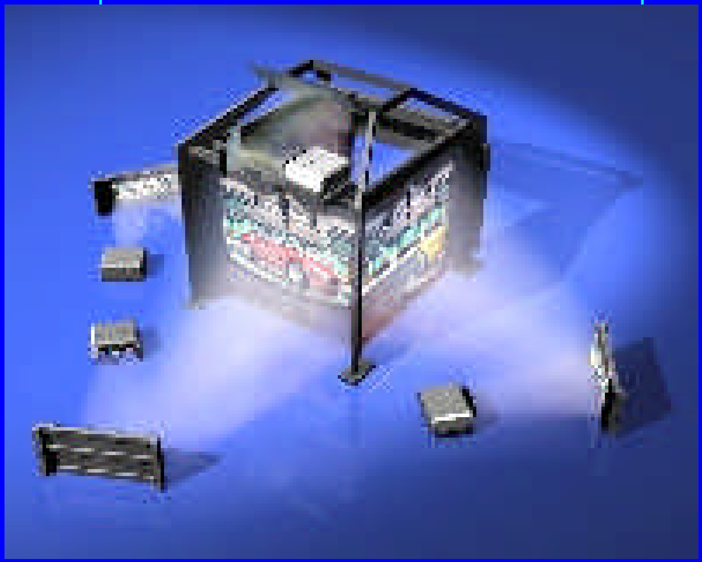
- Rotor wakes have defied all CFD attempts
- We can predict surface properties of rotor blades if:
  - In hover
  - Flowfield is "steady state"
  - Blades are rigid
  - Fully turbulent boundary layers
  - Wake has minimal effect on surface flow
- CFD schemes are too dissipative and dispersive
- "Standard" CFD codes were not developed for time-accurate low dissipation applications
- Higher order accurate schemes have been attempted but the codes are very sensitive & tempermental
- Need new and novel approaches. At current rate of progress, helicopters in forward flight with all the blade motions will not be simulated well for 15 years

Virtual Reality

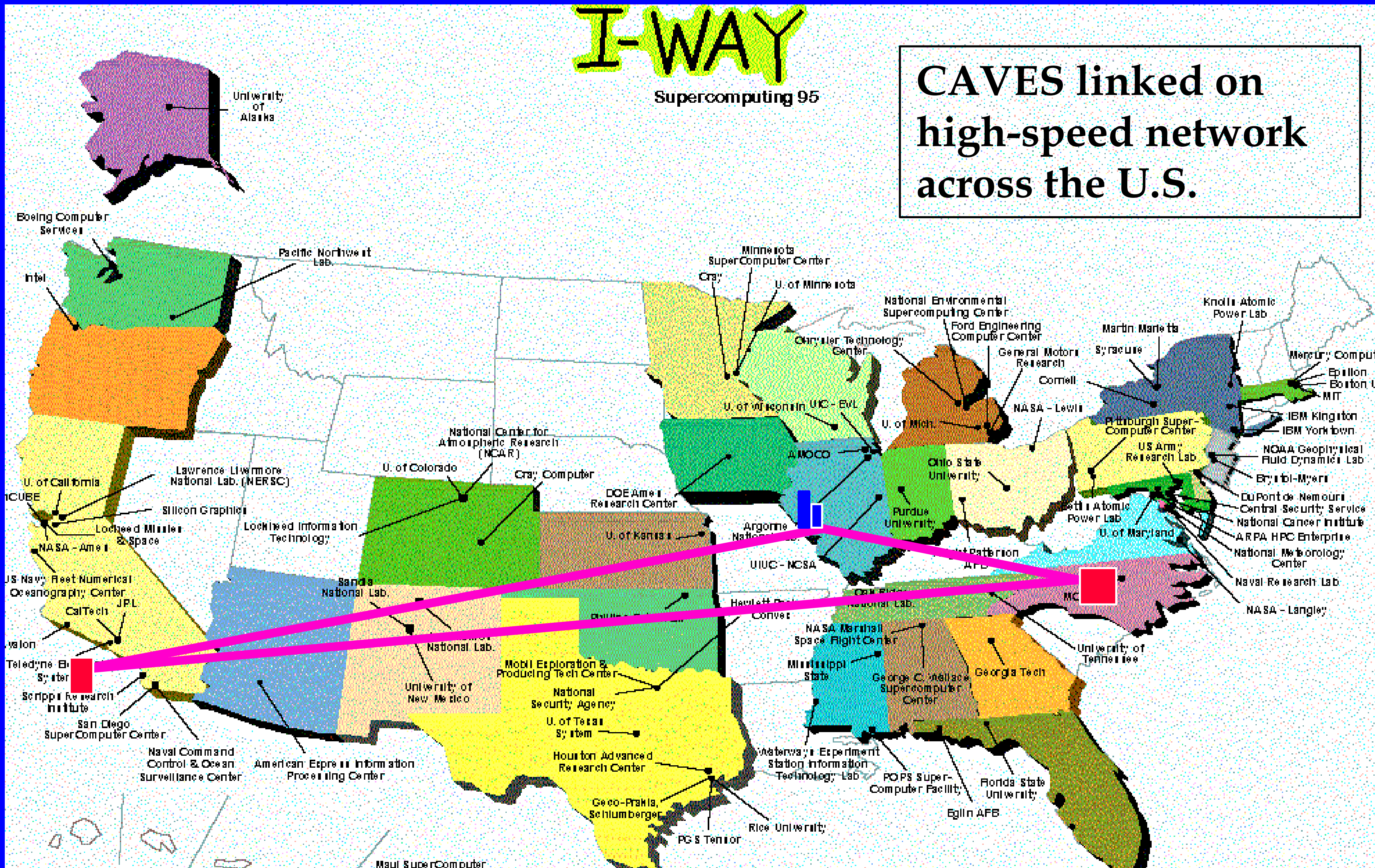
- As cost of this technology falls, this will have a huge impact
- Stereographics PC's now offer performance better than $100K SGI's
- Linked to high-speed networks, will allow entirely new collaborative possibilities
- Training, simulation, mission planning, air traffic control, cockpits, ...
- We have one "Cave" and three "Raves" at Penn State, connected on high-speed network
- Will this permit less travelling ? Not Likely.
- Could this revolutionize ATC ? Very likely.



www.fakespace.com



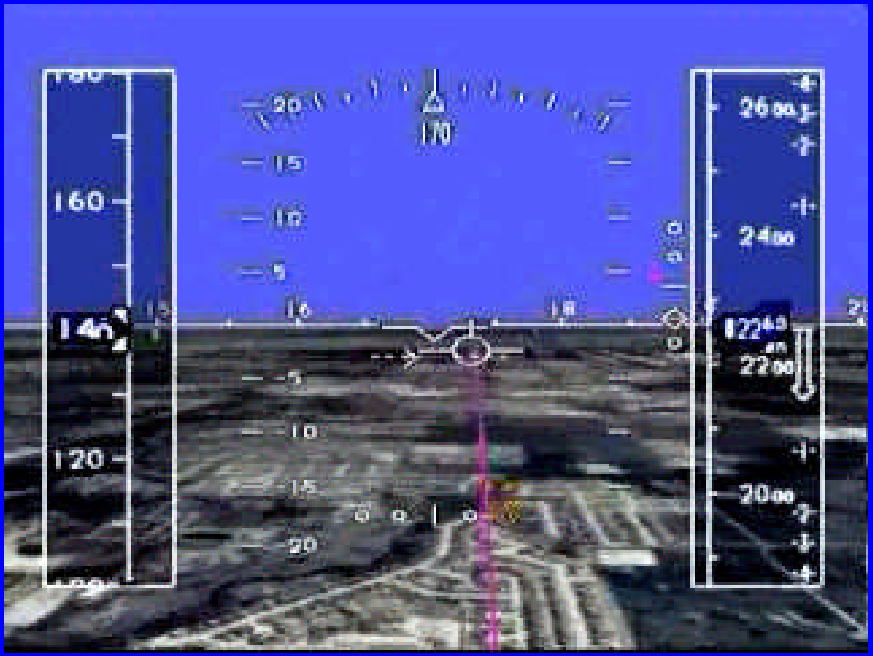
The I-WAY Experiment



CAVES linked on high-speed network across the U.S.

Augmented Reality

- We can take the view out the ATC tower or cockpit window and enhance it with additional information
  - Heads up displays
  - Retinal scanning
  - Stereographic glasses
  - Synthetic vision
  - NASA Highway in Sky



Wake-Vortex Hazards

Vortices can stretch for several miles behind the aircraft and last for several minutes.

Strict rules for aircraft spacing based on aircraft size.

Small aircraft should follow at least 6 nautical miles behind a heavy jet such as a Boeing 747.

These spacings are conservative to compensate for the lack of understanding of the strengths and positions of the vortices (based on "worst-case" scenario).

Penn State's Virtual Reality Wake Tracking System

Pilots say: "show me the vortex". We have begun a program to make vortices visible.

We use simple discrete vortex model, Displayed in stereographics in our RAVE

Vortex motions computed on parallel computer coupled to RAVE

Augmented Reality !

Wake-Vortex Hazard Simulation

- Dallas/Fort Worth (DFW) airport handles nearly 2,300 take-offs and landings everyday
- For the wake-vortex code to track the vortices shed by an aircraft for 5 miles after take-off (assuming 5 meter segments), 3200 vortex filaments have to be tracked.
- For 2,300 take-offs and landings per day: 300,000 vortex filaments have to be tracked every hour.
- If the vortex does not decay for 15 minutes, vortices due to typically half the take-offs and landings every hour need to be tracked at any given time. This is roughly 150,000 vortex filaments.
- If the induced velocity effect due to vortices from other aircraft are ignored: 3200^2=10 M computations/airplane/timestep.
- For 2300 planes/day => 500 M calc / timestep!!

Conclusions

- With computer speed, networking, and visualization improving exponentially, we cannot think incrementally
- We need to think outside the box, and develop entirely new approaches to solving the capacity problem, simulating wakes, and solving turbulent CFD problems
- We need to build systems for tomorrows computers, networks, and visualization systems
- NASA needs to dramatically increase funding for Aeronautics, particularly rotorcraft

Questions ?

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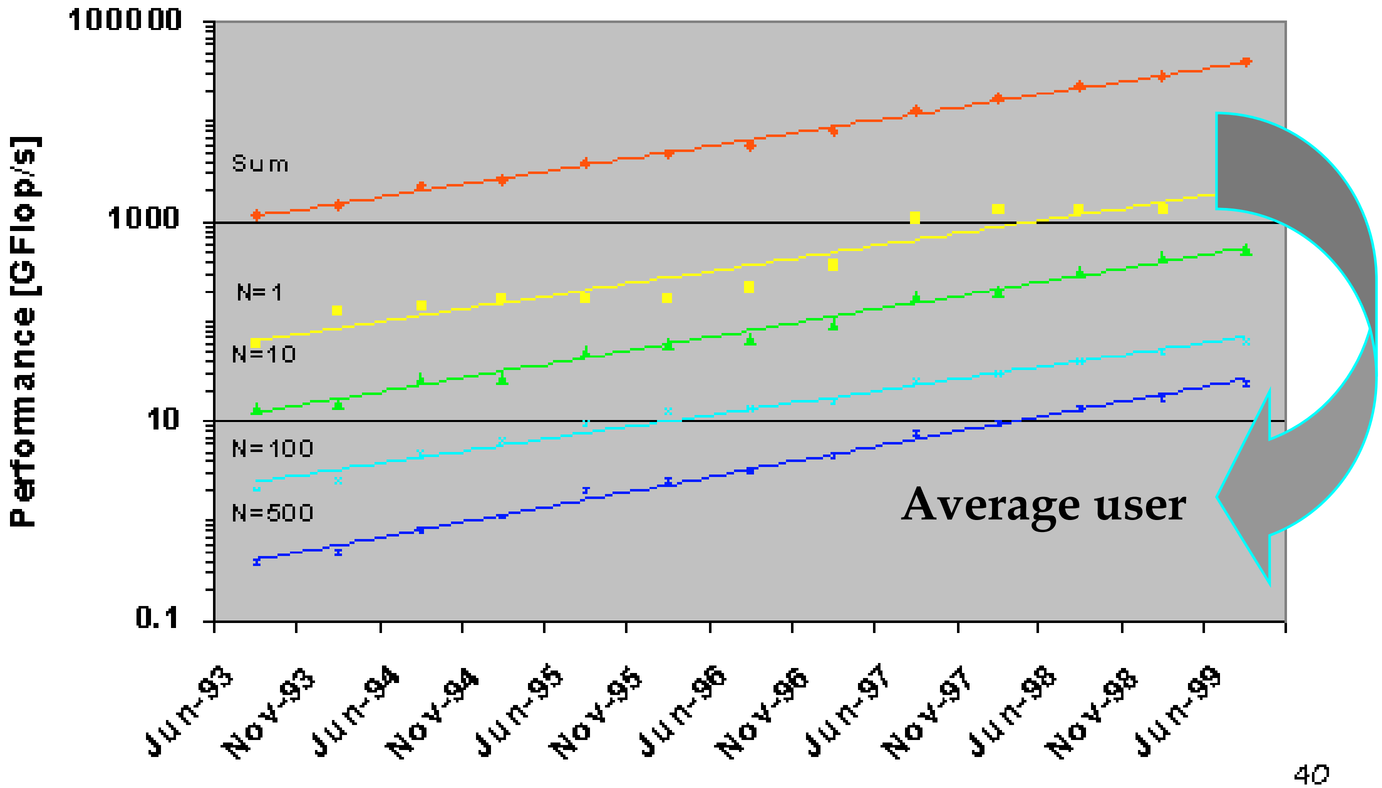
  - www.psu.edu/dept/rcoe/
- Institute for High Performance Computing Applications (IHPCA)
  - www.psu.edu/dept/ihpca

Extra Slides (not shown at conference)

Parallel Computer Performance

Performance Development



($ 50M: 100 sites with 200 processors or one supercomputer center)

Current and future computer speeds are often exaggerated.

Over emphasis of flops of trivial codes (Linpack)

Most users get <20% of peak speed and only have access to about 32 processors

NASA Efforts

- "Highway In The Sky" (HITS) system
  - Uses Augmented Reality to guide the pilots on a preprogrammed destination on a "virtual highway".
- FutureFlight Central, a national ATC test facility dedicated to solving the present and emerging capacity problems of airports.
  - It offers a 360-degree full-scale real-time simulation of an airport, where controllers, pilots and airport personnel interact to optimize operating procedures and to test new technologies.
- Aircraft VOrtex Spacing System (AVOSS).
  - AVOSS determines how winds and other atmospheric conditions affect the wake-vortex patterns of different types of aircraft.
  - It integrates the output from a number of subsystems: weather, wake prediction, wake sensors.
  - AVOSS being tested at DFW airport since 1997.

NASA FutureFlight Central's tower cab

Air-Traffic Control (ATC)

- ATC related delays cost the airline industry an estimated US $5.5 billion annually!

Year	Passengers (Millions)	Passenger Miles (Billions)	Jet Aircraft in Fleet	Domestic Departures (Millions)
2000	639.8	661.8	5610	7.4
2005	767.4	830.3	6903	8.6
2010	931.1	1041.6	8360	9.9
2015	1139.7	1306.2	10034	11.5

- According to FAA, if ATC systems do not improve significantly, there could be a major accident every 7-10 days by 2015.
- FAA has been trying hard to replace and modernize ATC systems for the past two decades.