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October 1998 Working Group Meeting on Heavy Vehicle Aerodynamic Drag: Presentations and Summary of Comments and Conclusions

Rose McCallen, Walt Rutledge
Don McBride, Kambiz Salari
Fred Browand, Anthony Leonard
Jim Ross, Bruce Storms
J.T. Heineck

October 1998

Lawrence Livermore National Laboratory

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October 1998
Working Group Meeting on
Heavy Vehicle Aerodynamic Drag:

Presentations and Summary of Comments and Conclusions

Jointly written by

Lawrence Livermore National Laboratory
Sandia National Laboratories
University of Southern California
California Institute of Technology
NASA Ames Research Center

Introduction

A Working Group Meeting on Heavy Vehicle Aerodynamic Drag was held at NASA Ames Research Center, Moffett Field, California on October 22, 1998. The purpose of the meeting was to present an overview of the computational and experimental approach for modeling the integrated tractor-trailer benchmark geometry called the Sandia Model and to review NASA's test plan for their experiments in the 7 ft x 10 ft wind tunnel. The present and projected funding situation was also discussed.

Presentations were given by representatives from the Department of Energy (DOE) Office of Transportation Technology Office of Heavy Vehicle Technology (OHVT), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), and NASA Ames Research Center.

This report contains the technical presentations (viewgraphs) delivered at the Meeting, briefly summarizes the comments and conclusions, and outlines the future action items.

Overview of the Project, Current Funding, and Future Workshop

An overview of the project was presented by Rose McCallen of LLNL. The viewgraphs are enclosed.

Jules Routbort from Argonne National Laboratory attended the meeting as the DOE OHVT representative and presented the funding situation for this effort. Table 1 summarizes the project funding.

TABLE 1. Funding

	FY 98	FY 99 ($ distributed to date)
LLNL	$100K	$170K ($100K)
SNL	$100K	$80K ($30K)
USC	$50K	$80K ($80K)
Caltech	$50K	$80K ($80K)
NASA	$25K	$25K ($0K)
Totals	$325K	$435K ($290K)

NASA requested that their FY 99 allocation be distributed as soon as possible to cover testing costs.

It was noted that the current budget does not provide funds for the Fall 99 Workshop. LLNL policies do not allow commitment to a location and date without the required funds in hand. It was suggested that the Workshop be scheduled in conjunction with the SAE Truck and Bus Conference, Detroit, Michigan in November 1999. Jules Routbort supplied a contact in the DOE/OHVT that is affiliated with SAE that could possibly provide assistance.

Computational Issues Related to the NASA Experiment

An overview of the Reynolds-averaged Navier Stokes (RANS) modeling being performed by SNL was presented by Kambiz Salari. Current efforts involve the modeling of past experiments on the Sandia Model performed in the Texas A&M wind tunnel. For these RANS simulations the computational field extends to the wind tunnel walls with slip boundary conditions (no penetration) at the walls. The computational meshes for the RANS simulations range from 10 to 30 million zones.

The large-eddy simulation (LES) approach being used by LLNL was presented by Rose McCallen. Issues related to boundary conditions, subgrid-scale modeling, and data analysis were discussed. It is anticipated that the converged LES solution will require finer mesh discretization than the RANS solution. Proposals to reduce the extent of the computational domain by moving boundaries closer to the model, away from tunnel walls, were criticized with warnings that this can introduce approximately 2.5% error in the solution.

Also stressed was the importance of having the time variation of the three velocity components for LES model validation, which will be provided by the NASA experiments in the truck wake.

Further discussions on LES involved wall modeling (i.e., approximations at walls to reduce discretization requirements). Kambiz Salari of SNL has information on a method he called ODT. He will provide the reference to the team.

NASA Wind Tunnel Test Plan

Bruce Storms presented NASA's test plan for the experiments on the Sandia Model in the 7 ft x 10 ft wind tunnel scheduled for January 1999, and J.T. Heineck presented information on the particle image velocimetry (PIV) measurements planned for the test. Their presentations are enclosed. There were informal discussions with NASA's Dave Driver on his oil film interferometry technique (OFI) for measuring skin friction and with NASA's James Bell on his pressure sensitive paint (PSP) measurements. These techniques will also be used in the wind tunnel tests. Afternoon activities included wind tunnel tours.

The viewgraphs from the formal presentations provide details on the wind tunnel dimensions, measurement accuracies, and the test plan. The specific issues raised during the presentations and informal discussions are reviewed below.

The wind tunnel test section is 15 ft long, 10 ft wide, and 7 ft high. There is a 1% divergence on the side walls only. The front end of the vehicle will be placed approximately 6 inches from the wind tunnel contraction section where the two-dimensional time-averaged inlet velocity profile will be provided. It was suggested that by using a potential flow calculation, this inlet profile could be projected farther upstream for use as the inlet condition to the computational models. In this way the blockage effects by the vehicle will be more accurately captured. The boundary layer thickness at the beginning of the 7 ft x 10 ft test section is 2.1 inches and the displacement thickness is 0.6 inch. The streamwise growth of a turbulent boundary layer can be estimated as 1% of the run.

The model is mounted on four 1 inch cylindrical posts so that the base of the truck is 3 inches from the tunnel floor. Fairings will be placed around the posts to seal the floor openings, as was done in the Texas A&M tests. The fairings are also cylindrical with approximately a 1/8 inch gap between the posts and fairings. The fairings contribute are expected to significantly disturb the body underflow and thus, should be included in the calculations.

The proposed test conditions are 200 mph wind velocities for a Reynolds number (Re) of 2 million and a Mach number (Ma) of 0.27. This wind velocity corresponds to a full size truck traveling at approximately 24 mph. Concerns were raised as to the high Mach number flow (i.e., compressibility effects are usually negligible below Ma of 0.1). The necessity for the high flow velocities stems from the need to improve the accuracy of the PSP and increase the loads for the facility balance measurements. Higher velocities result in higher pressures which improves the accuracy of these measurements. The PIV accuracy is not dependent on the velocity magnitude in the range of interest. Since the ultimate goal is to obtain data for validation of our computational incompressible flow models, it was suggested that if a range of Re can be considered, possibly one case at or below Ma of 0.1 be included (i.e., approximately 74 mph winds in tunnel, Re = 740,000, and real truck speed of approximately 10 mph).

It is expected that 2 yaw angles (e.g., 5 and 10 degrees off of center) will be attempted for PSP and OFI measurements and 1 yaw angle for the PIV measurement. The reduction of yaw angles for the PIV measurements is due to the excessive setup time for each yaw angle change compared to the setup time for the other measurement techniques. For validation of the computations, we would prefer to have the more significant change in flow characteristics caused by a 10 degree yaw. However, if more data can be acquired for the reduced angle of 5 degrees, this smaller angle may be a better choice. The NASA team will take a closer look at these issues and provide more information to make the optimum choice. The drag at 0 degrees and each yaw angle will be measured and the wind averaged drag (i.e., drag averaged over yaw angles) will be calculated from this limited sample.

The PIV measurements will be taken in the model wake, providing the three components of velocity in the plane of a laser sheet. Two options were presented for the orientation of the laser sheet. The first choice is to position the laser sheet normal to the stream and choose slices over a 13.5 inch distance behind the model in the streamwise direction. The second choice is to position the laser sheet in the streamwise direction and sweep along the direction normal to the flow, keeping one side of the sheet as close as possible to the backend of the model. With the first choice, it will be difficult to determine streamwise effects because the results in the streamwise direction are measured at different setups and matching the phase of the solution will be difficult. However, streamwise normal vortical roll ups will be observed directly. The second choice will more clearly provide the time evolution of vortices, but the difficulty will be to patch together the picture of the flow in the cross stream direction. The ideal solution may be to provide results from both setup options but settle for less data in each configuration. NASA's J.T. Heinech will further investigate the possibility of acquiring results at both orientations by limiting the yaw angle and piggy backing on experiments directly following our test that require an alternate laser sheet orientation.

The PSP measurements will provide time averaged pressures. There was some discussion on obtaining time-dependent pressures with PSP, since the camera has a 20 Hz sampling rate (at ± 7 psf accuracy). However, setting up for time-dependent measurements by January would be a stretch.

The OFI technique can supply quantitative time-averaged skin friction measurements. The technique requires a shinny surface, which is obtained by applying mylar to the model surface. It was suggested that for this test the OFI measurements be used to determine the separation and reattachment positions on the floor of the tunnel in the wake of the model, since hot-film measurements of skin friction are already going to be measured on the model body. Skin friction measurements on the model body will be provided by Taos hot-film system which can detect flow separation, reattachment, and transition. In the 0 degree (no yaw) case, it is expected that the boundary layer on the top and side walls of the model will transition around the midsection of the model. The approximate locations of separation and reattachment positions for each of the 2 yaw angles are needed to determine the best positions for the hot-film system. This information is not available from the past Texas A&M tests nor from previous SNL RANS computations.

To summarize, many of the questions raised were either resolved at the meeting or some guidance was provided to the NASA experimental team so that decisions can be made on optimum instrument positioning or desired flow conditions. However, the question that still requires a timely answer from the computational team is what are the optimum positions for the hot-film system for skin friction measurements of separation, reattachment, and transition. A one month lead time is needed for any moderate experiment changes from the current test plans.

Future Meetings

The next meeting will take place via conference call and will again focus on the NASA 7 ft x 10 ft wind tunnel tests. This meeting should be held before December 1, 1998 to provide 1 month lead time for modifications in the tests scheduled for January 1999. It is expected that several of the Truck Aero Team members will be interested in visits to NASA to observe the actual testing in January 1999.

Action Items

The follow-on prioritized action items with the individuals responsible for the tasks are as follows:

1. Provide guidance for positioning hot-film system for skin friction measurements. Kambiz Salari of SNL will investigate the possibility of running a 5 or 10 degree yaw case with the RANS model. (R. McCallen and K. Salari)

2. Provide NASA with the size of the fairings to be placed on the supporting cylindrical posts. (K. Salari)

3. Reevaluate times for laser sheet and camera positioning for various yaw positions and laser sheet orientations to assist in developing a prioritized list of measurements for PIV. (J.T. Heineck and B. Storms)

4. Provide references on NASA's PIV techniques to be used in our experiments. (J.T. Heineck)

5. Detailed description of 7 ft x 10 ft wind tunnel. (B. Storms)

6. Provide reference on wall modeling method for LES. (K. Salari)

7. Call SAE contact in DOE/OHVT for assistance with scheduling of Fall 99 Workshop with the SAE Truck and Bus Conference. (R. McCallen)

8. Setup conference call and agenda for next meeting. (R. McCallen)

Truck Aero Team Meeting

NASA Ames, CA

October 22, 1998

Attendee List

Attendee	Organization	e-mail address
James Bell	NASA Ames	jhbell@mail.arc.nasa.gov
Dave Driver	NASA Ames	ddriver@mail.arc.nasa.gov
J.T. Heineck	NASA Ames	jheineck@mail.arc.nasa.gov
Barbara Kornblum	LLNL	kornblum1@llnl.gov
Donald McBride	SNL	ddmcbri@sandia.gov
Rose McCallen	LLNL	mccallen1@llnl.gov
Jim Ross	NASA Ames	jcross@mail.arc.nasa.gov
Jules Routbort	ANL/DOE	routbort@anl.gov
Kambiz Salari	SNL	ksalari@sandia.gov
Bruce Storms	NASA Ames	bstorms@mail.arc.nasa.gov

- Agenda -

Truck Aero Team Meeting

NASA Ames, CA

October 22, 1998

Purpose of Meeting

Present computational and experimental approach

Review experimental test plan

Discussions and sharing of ideas

Introduction

Project Overview (Rose McCallen, LLNL)

Budget (Jules Routbort, DOE/ANL)

Computational Work

RANS Modeling (Kambiz Salari, SNL)

LES Modeling (Rose McCallen, LLNL)

Experimental Work and Test Plan

Test Plan and Instrumentation (Bruce Storms, NASA)

Particle Image Velocimetry Measurements (J.T. Heineck, NASA)

Wind Tunnel Tour

Wrap-up Discussion

Next Progress Meeting

Near Term Action Items

Department of Energy

Aerodynamic Design of Heavy Vehicles

Overview of Project

Rose McCallen, Ph.D.

Lawrence Livermore National Laboratory, Livermore, CA

October 1998

University of California Lawrence Livermore National Laboratory

Sandia National Laboratories

USC UNIVERSITY OF SOUTHERN CALIFORNIA

Caltech California Institute of Technology

National Aeronautics & Space Administration

The MYPP is based on industry needs and consideration of current technology, funding, and DOE interests.

DOE and National Laboratory interest

- Reduce heavy vehicle drag -> reduce fuel consumption and emissions
- R&D for DOE programs

Industry needs

- Advanced computational tools and experimental methods
  - Understand the effects of design changes
  - Simulate fully-integrated tractor-trailers
- Design improvements for drag reduction

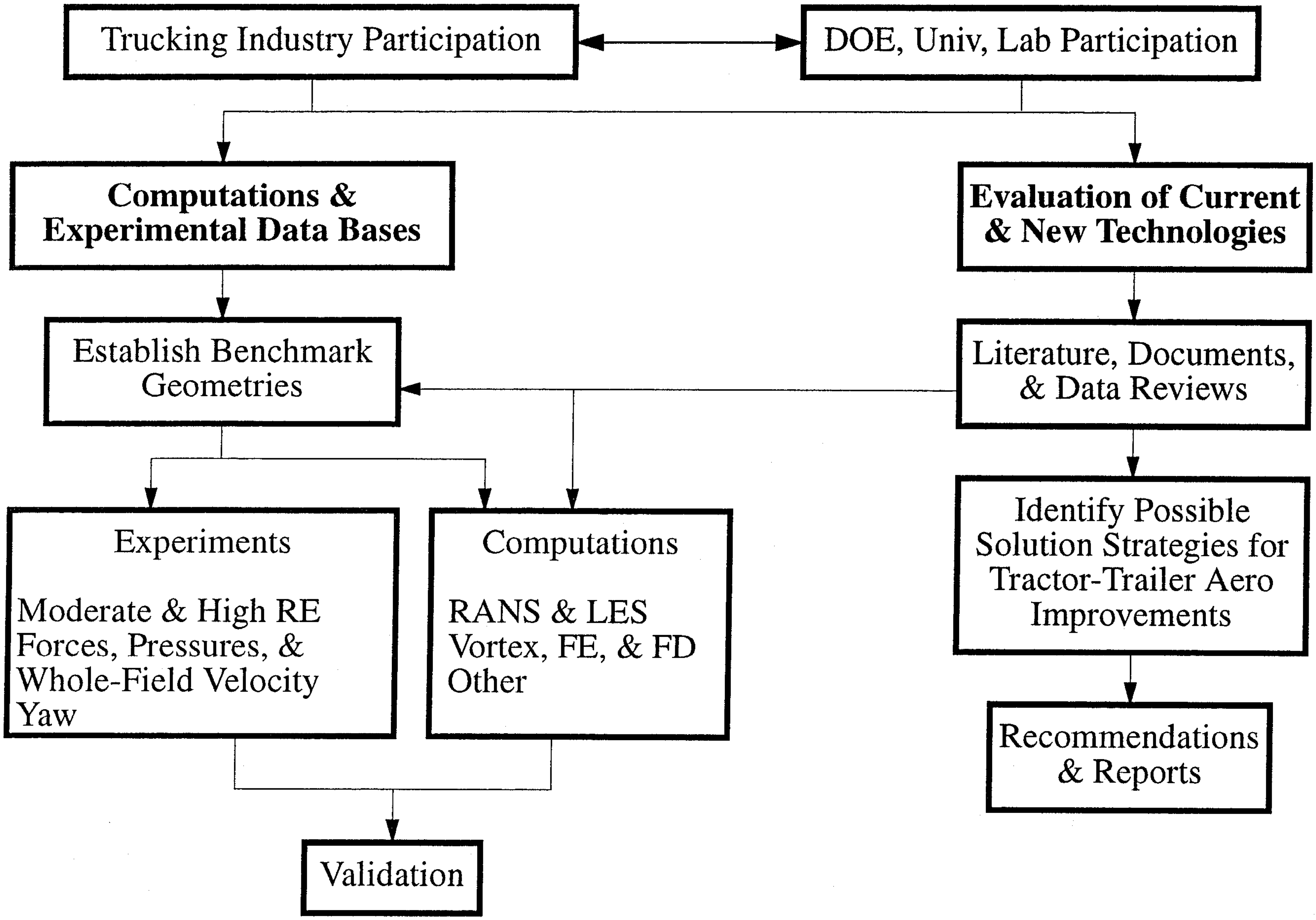
Current technology - CFD is hard!

- Reynolds-averaged Navier Stokes (RANS) is common approach
- Large-eddy simulation (LES) is in development
- DPIV measurements can provide full velocity field measurements

Funding is minimal and we need a plan with a ‘near-term impact’

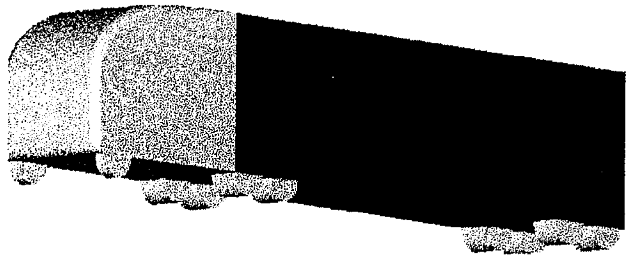
- FY99: $540K (= 85% of requested $635K)

The MYPP focuses on development and demonstration of a simulation capability.



Near-Term Impact: Comparison of RANS and LES and detailed experimental verification for a real truck problem.

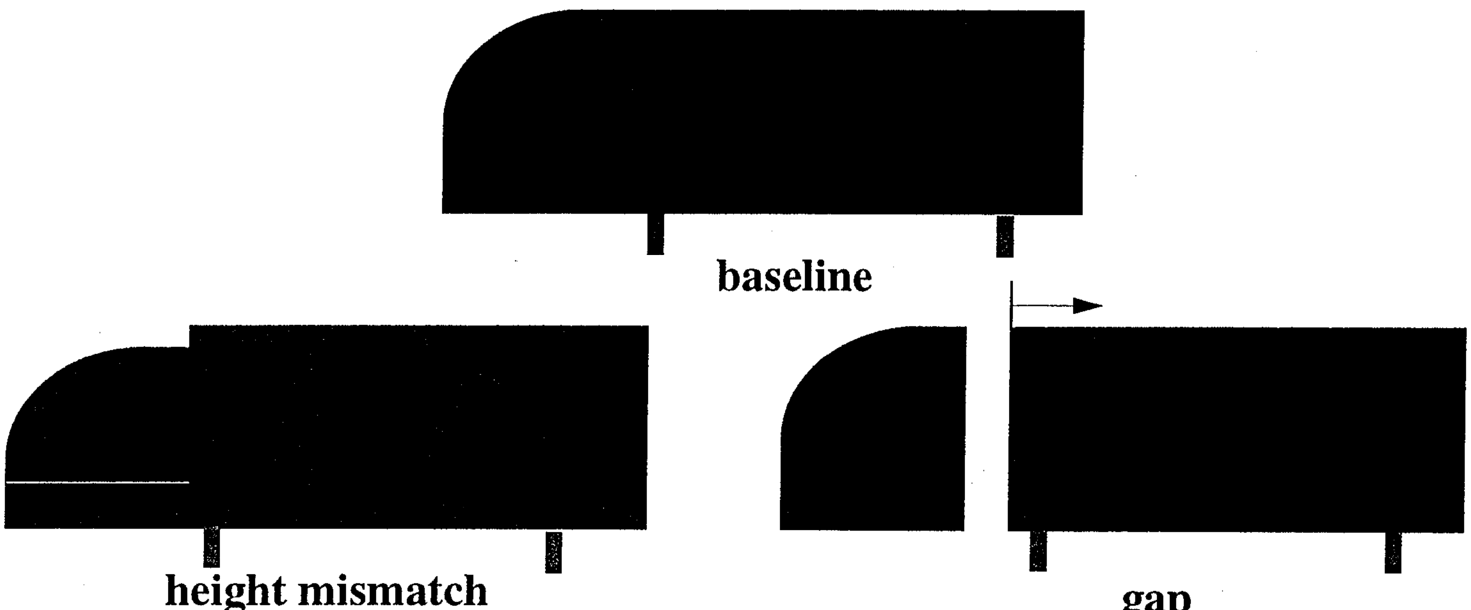
Sandia's Model



Advantages

Simple geometry with some existing data and some modeling already done

The final detail results will be available for comparison to commercial tools



Each organization's contributions are critical to the project's success.

Computational Modeling

Rose McCallen (PI)

University of California
Lawrence Livermore National Laboratory

Large-Eddy Simulation using Finite Element Methods

Anthony Leonard

Caltech
California Institute of Technology

Large-Eddy Simulation using Vortex Methods

Don McBride
Walt Rutledge

Sandia National Laboratories

Reynolds-Averaged Modeling using Finite Difference Methods

Experimental Modeling

Don McBride
Walt Rutledge

Sandia National Laboratories

GTS Experiments at Texas A&M

Fred Browand

USC University of Southern California

Moderate Speed Experiments in Wind Tunnel

Jim Ross

National Aeronautics & Space Administration

High Speed Experiments in 7'x10' and 12' Wind Tunnels

Our near-term tasks have been identified and prioritized.

Benchmarks

1. Sandia Body

   Experiments

   - Texas A&M, Re = 1,600,000
   - NASA 7'x10', Re = 1,600,000 and other moderate to lowest Re

     Oil film interferometry, particle image velocimetry, doppler global velocimetry

     Upstream mean velocity profile provided

     0, 5, and 10 degree yaw conditions
   - USC wind tunnel, two Re conditions within $200{,}000 < Re < 400{,}000$

     With and without trailer/tractor height mismatch and gap

   Computations

   - RANS for high and low Re (SNL)
   - LES for low Re with some attempt at high Re (LLNL and Caltech)
2. New Model Design (USC)
3. Gene's Model for Re sensitivity study (i.e., how high is enough and drag delta's for components)
   - NASA 12', Re_{max} = 5,000,000, model with and without components

Our budget is not consistent with projected funding.

FY99 budget : $540K

	Computations & Experiments	Evaluation of Current & New Technologies	Final Report	Total/Year
FY98	$276K	$34K		$310K
FY99	$630K	$5K		**$635K**
FY00	$1,045K	$188K		$1,233K
FY01	$1,095K	$188K		$1,283K
FY02	$855K	$161K		$1016K
FY03	$818K	$161K		$979K
FY04	$120K	$124K	$34K	$278K
TOTAL				$5,734K

It was necessary to leverage other funding sources.

SNL	- past data obtained at Texas A&M	Free
	- loan of model to NASA	Free
	- LES R&D	LDRD
	- computational resources	ASCI
USC	- instrumentation	Caltrans, NSF
Caltech	- LES model development	ASCI, DOD
	- computational resources	ASCI, NSF, DOD
NASA Ames	- 7'x10' wind tunnel tests	Free
	- 12' wind tunnel tests	1/3 Cost
	- loan of Navistar's model	Free
LLNL	- computational resources	ASCI
	- LES and code development	ASCI/LDRD

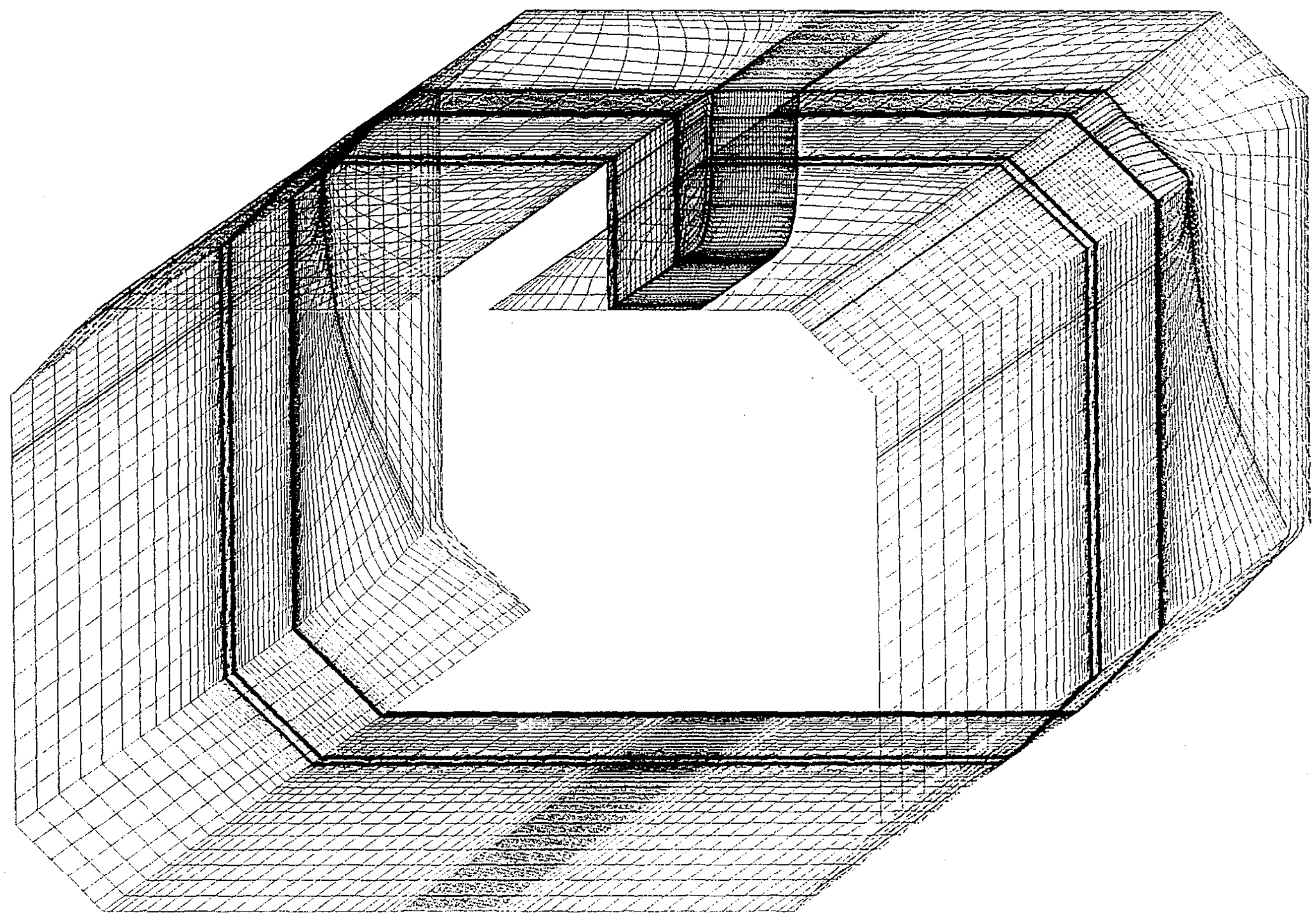
The projected milestones are segregated into benchmark cases with advancing levels of complexity.

Projected milestones for first four years of project (FY98 through FY01)

Task	Milestone
Workshop II	2/98
MYPP with projected budget and milestones	5/98
Continued site visits	12/98, 12/99, 12/00
Level 1 Benchmarks: Establish generic shapes and outline test cases for investigation of trailer-tractor height and gap mismatch (Demo)	9/98
Test data at moderate Re for Level 1 benchmarks (Demo)	9/99
RANS, LES/FEM, LES/Vortex computations of Level 1 benchmarks at moderate Re (DEMO)	12/99
Test data at high Re for Level 1 benchmarks (Demo)	6/00
RANS, LES/FEM, LES/Vortex computations of Level 1 benchmarks at high Re (DEMO)	12/00
Workshop III: Possible computation contest	11/99
Level 2 Benchmarks: Establish generic shapes	9/99
Test data at moderate and high Re for Level 2 benchmarks	9/01

RANS Modeling

Kambiz Salari
Sandia National Laboratories

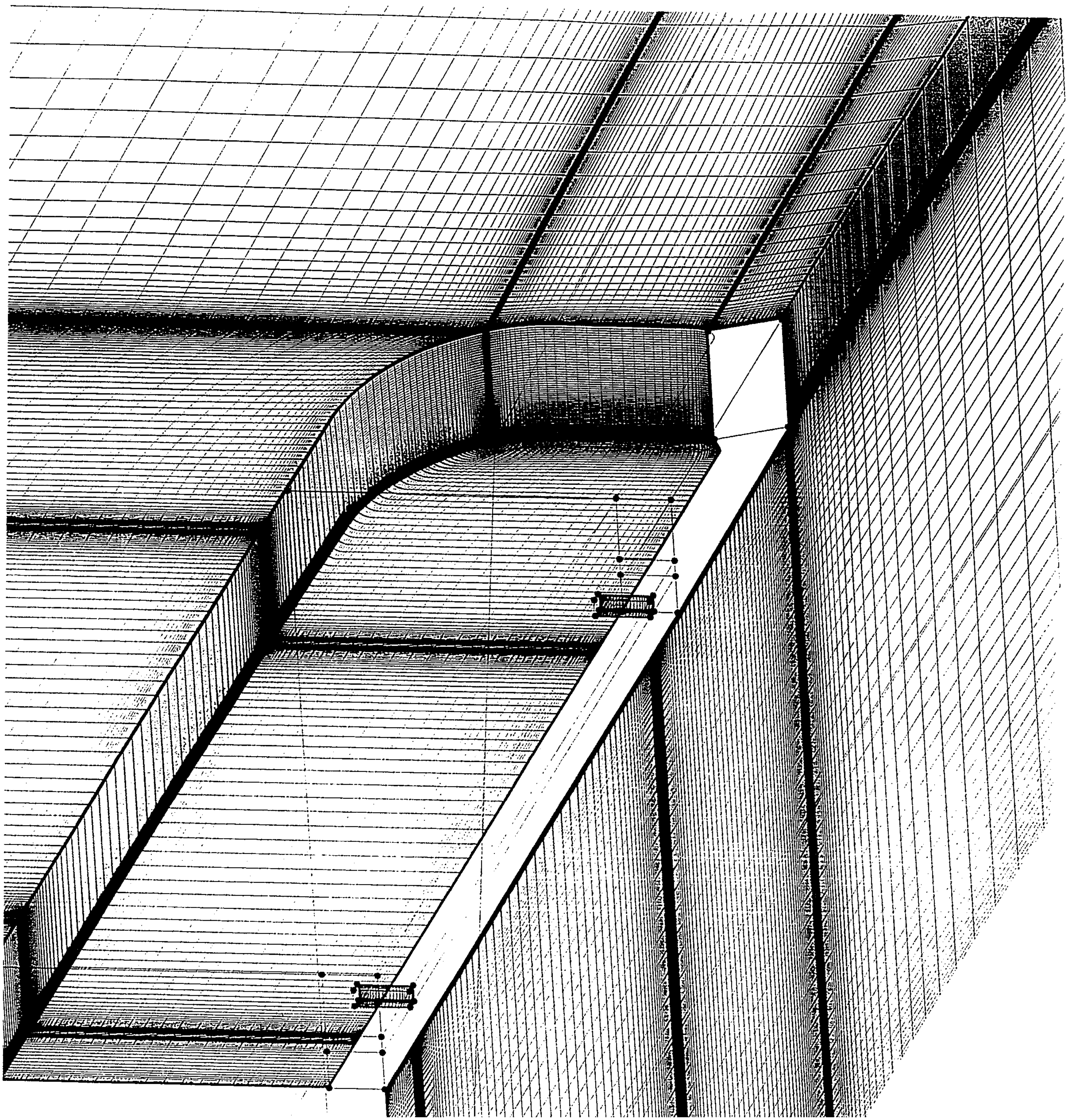


GTS Flow Simulation

Sandia National Laboratories

Engineering Sciences Center

Particle traces, Re = $1.6x10^6$



GTS Flow Simulation

Ground Transportation System (GTS) vehicle

Texas A&M 7'x10' low speed tunnel test

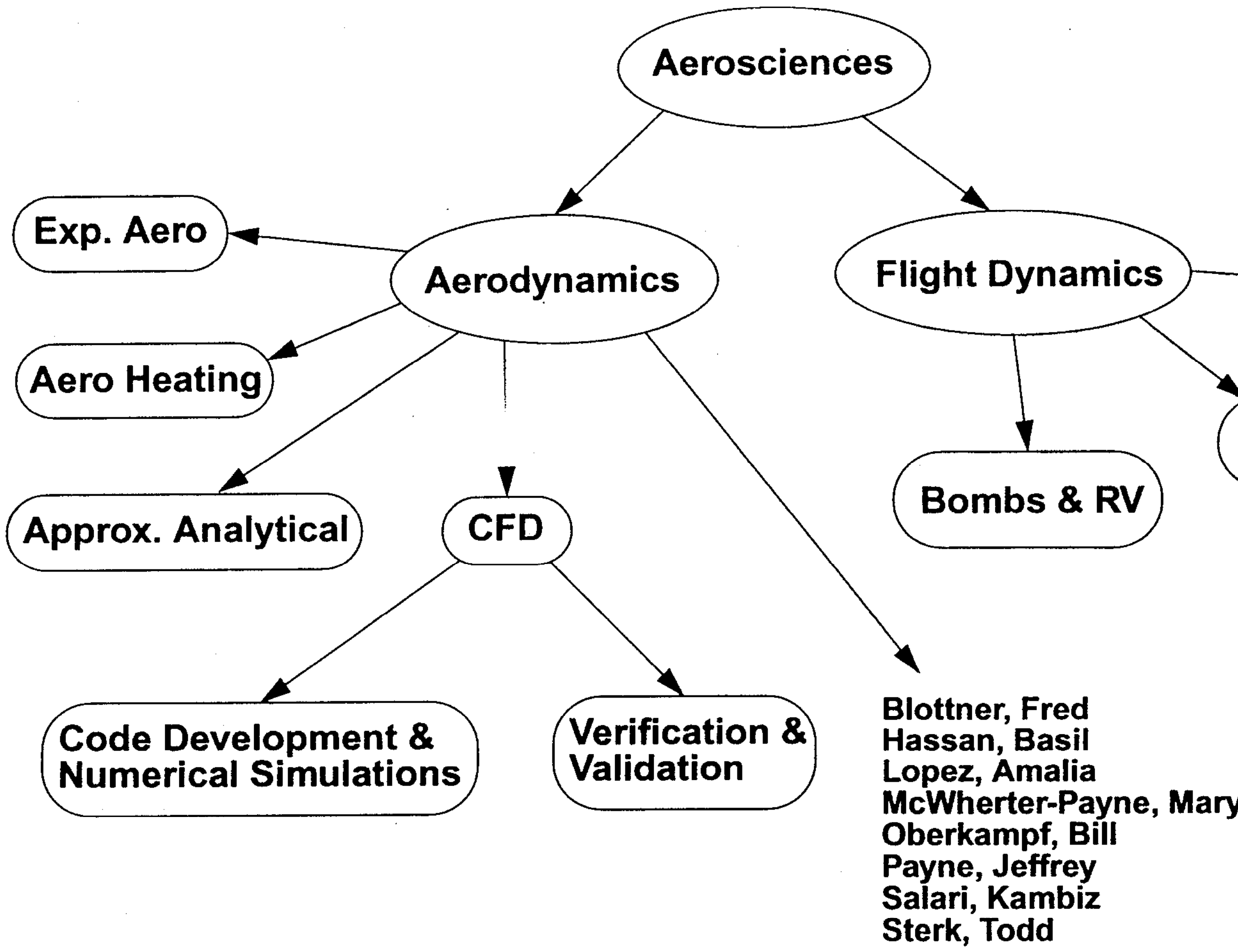
Test condition:

- Run = 31, Re = 1.6×10^6, Wheels removed
- Yaw angle = 0 (deg.)
- Free stream velocity = 78 (m/s)
- Density = 1.17 (kg/m^3)
- Static pressure = 99,470.6 (Pa)
- Kinematic viscosity = 1.555×10^{-5} (m^2/s)

Engineering Sciences, Aerosciences Department

Sandia National Laboratories

Engineering Sciences Center



Aero Applications

- History
  - Primarily high speed flow simulations
  - Recently, there is an effort in low speed flow simulations
- Advanced Computational Capabilities
  - SACCARA (Sandia Advanced Code for Compressible Aerothermodynamics Research and Analysis)
  - CFD-ACE (Navier-Stokes code)
  - CHAD (Navier-Stokes code)
  - NS3D (Navier-Stokes code)
  - SPRINT (PNS code)
  - SANDIAC (Euler code)
  - MGAERO (Euler code)
  - HIBLARG (Boundary layer code)

Code Development & Numerical Simulation

Sandia National Laboratories

- Physics Enhancement through Internal Research Programs
  - ESRF/LDRD
  - ESRF/Tech Base
- Range of Modeling and Simulation
  - Full Navier-Stokes code
    - Large Scale Computing (ASCI)
  - PNS codes
  - Euler Codes
  - Boundary Layer codes

SACCARA
Current Capabilities:

Sandia National Laboratories

Engineering Sciences Center

- Based on parallel version of INCA™ Full Navier-Stokes code
- Implicit, Multi-block, structured grids for 2-D, Axisymmetric, and 3-D flows
- Finite volume discretization (steady and unsteady flows)
- Subsonic --> Hypersonic flow fields
- Ideal, equilibrium, and thermo-chemical nonequilibrium finite-rate gas chemistry
- Zero-,one-, and two-equation turbulence
- MP implementation on a variety of distributed parallel architectures (IBM, Intel, etc.)

Improving Physical Models in SACCARA

- **Methods to model transition**
  - **Engineering models based on boundary layer**
  - **Parabolized Stability Equations (PSE) approach**
- **Turbulence models**
  - **One-equation Spalart Allmaras model**
  - **New two-equation k-ω model**
  - **New two-equation k-ζ model**

DOE Truck Aero Project

- History
  - SNL GTS Work (RAMPANT), LDRD
  - Ahmed-body flow simulation (CHAD), USCAR/SCAAP
- Currently working on
  - Gridding the SNL GTS model
  - Running flow simulations for the GTS model with SACCARA

Truck Aerodynamics:

Large-Eddy Simulation (LES) using the Finite-Element Method (FEM)

Rose McCallen, Ph.D.
Lawrence Livermore National Laboratory

October 1998

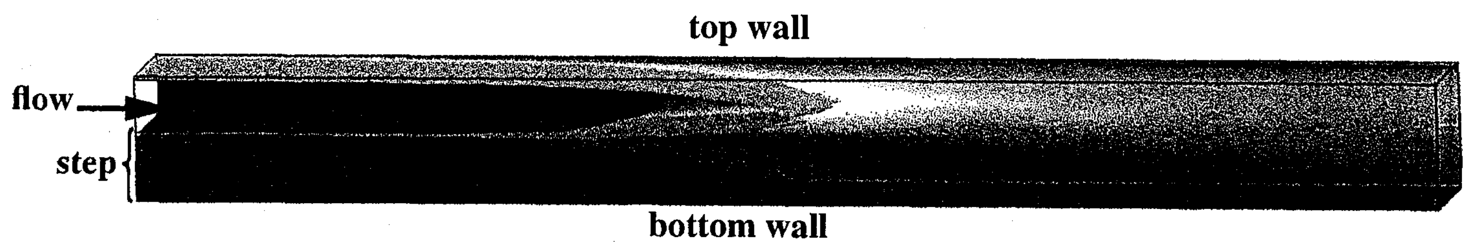
University of California
Lawrence Livermore National Laboratory

Large-eddy simulation provides a wealth of information and less empiricism.

Reynolds-Averaged Navier-Stokes (RANS)

- Many empirical parameters
- 2D, steady, time-averaged solution

Backward-facing step: streamwise velocity



Large-eddy simulation (LES)

- One empirical parameter
- 3D, unsteady solution of vortex shedding

What do advanced tools provide and what are the challenges in developing and using these tools?

Background

LES/FEM

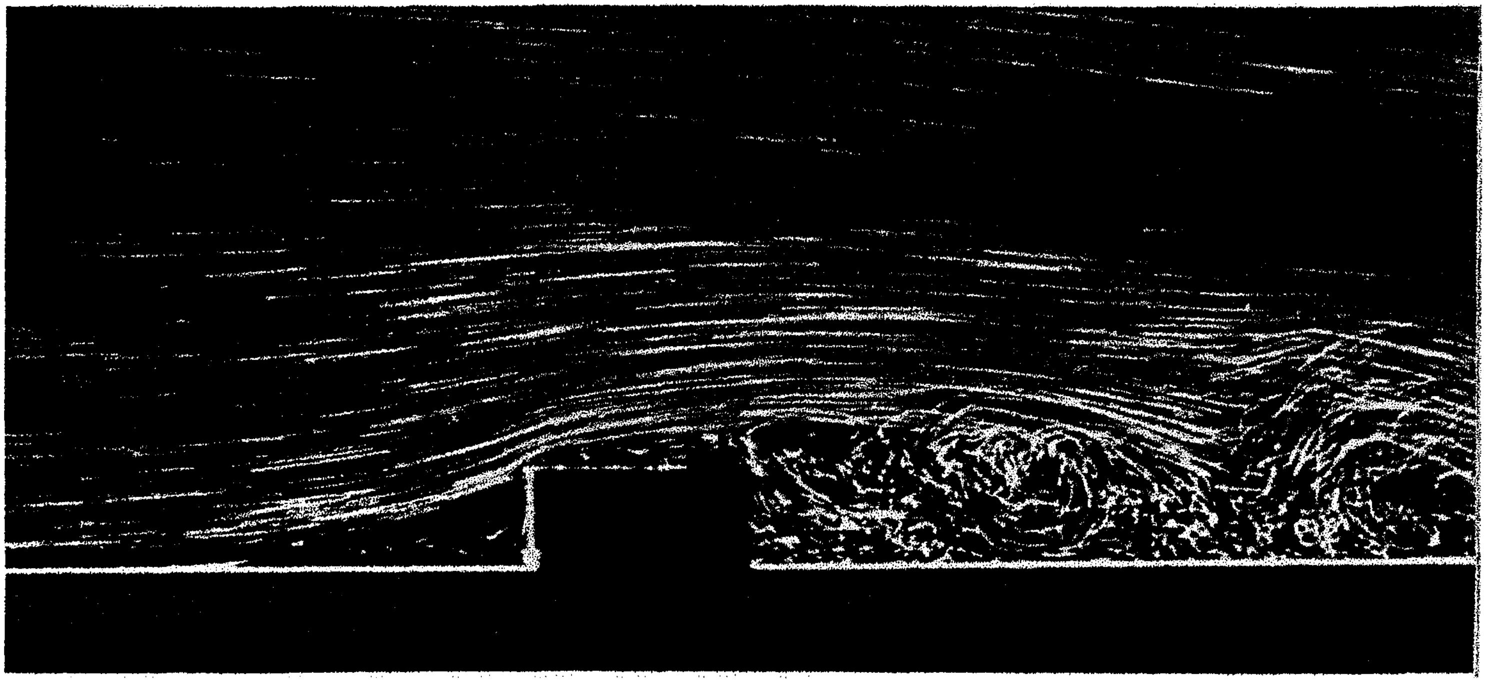
R&D issues

Data analysis

Time-averaging, visualization, time histories, and power spectrum

Approach

Turbulent flow contains eddies ranging from large-scale to small-scale.



Ref. VanDyke, An Album of Fluid Motion

Large-eddy simulation captures the large-scale motion and approximates the small-scale motion.

all turbulent motions = large-scale motions + small-scale motions

= 'resolved' scale + 'subgrid' scale

$$u_\alpha = \bar{u}_\alpha + u'_\alpha$$

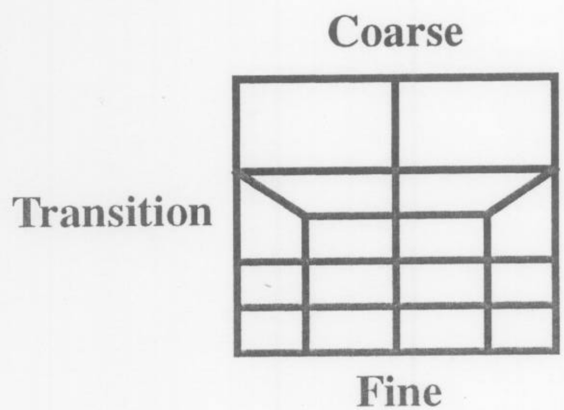
LES/FEM provides a unique approach for solving practical problems.

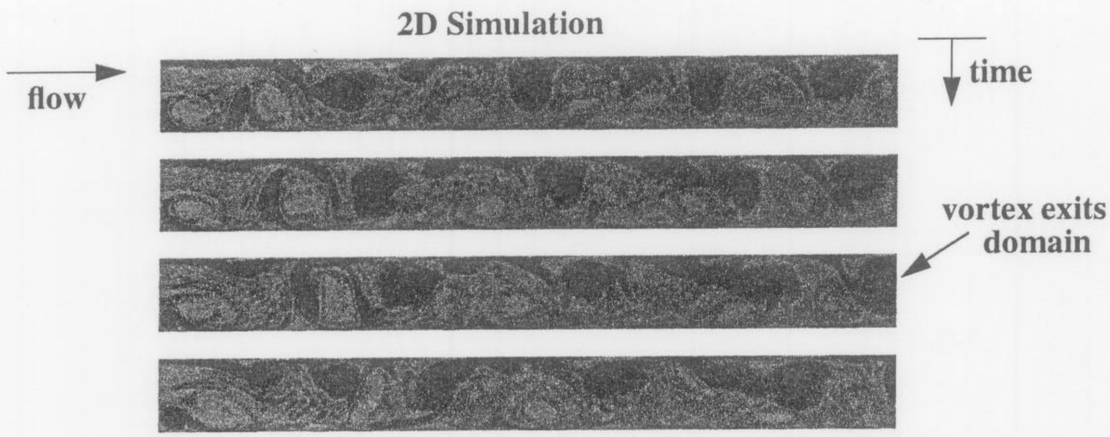
Advantages of LES

- Captures 3D time-dependent motion
- Less empiricism than other methods

Advantages of FEM

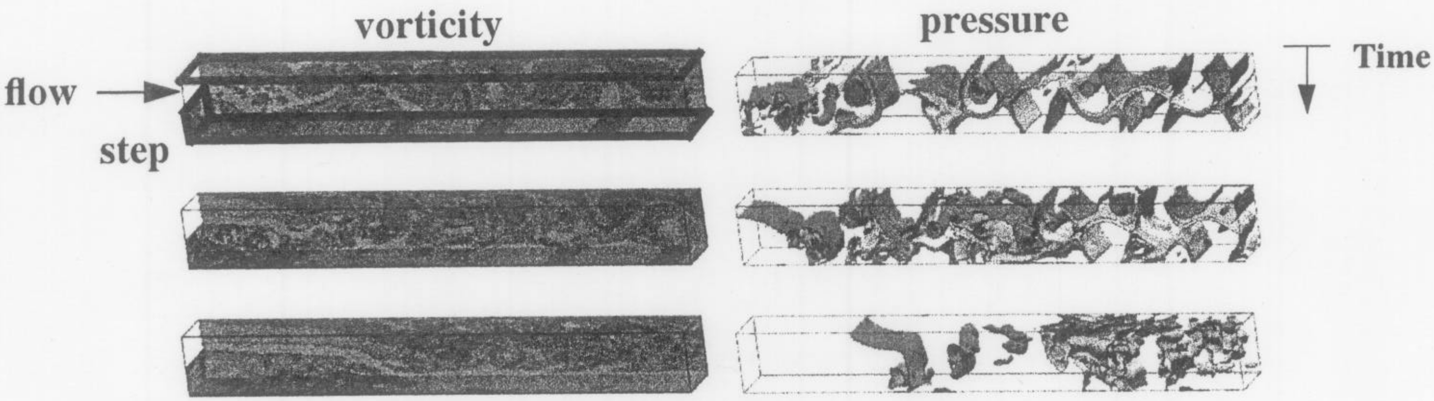
- Unstructured meshes
- Natural boundary conditions
- Coupling to other FEM codes





Zero natural boundary conditions capture the vortical outflow

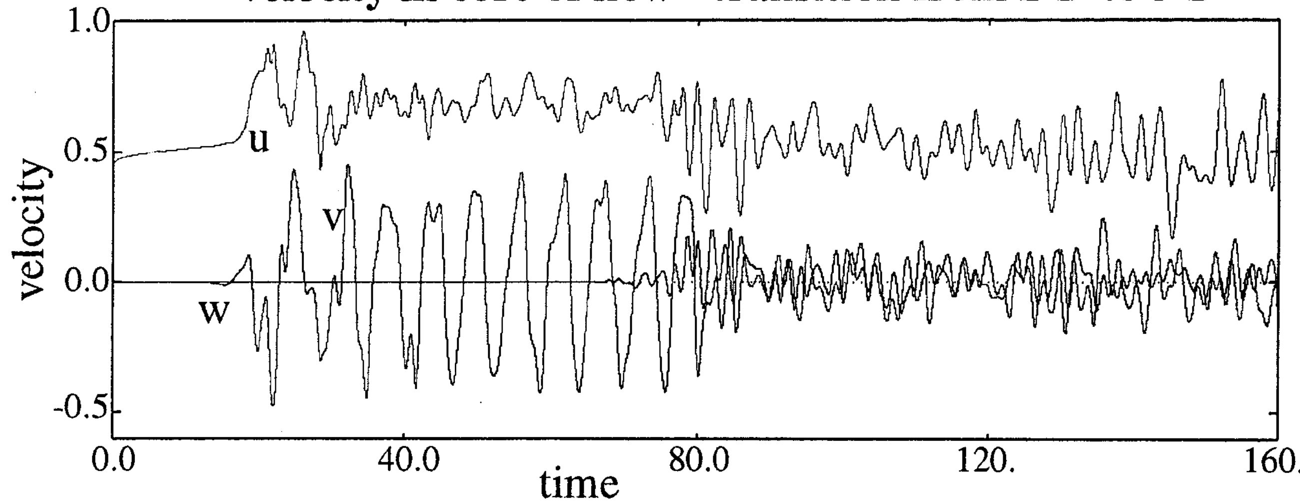
The challenges are related to physical as well as computational modeling.



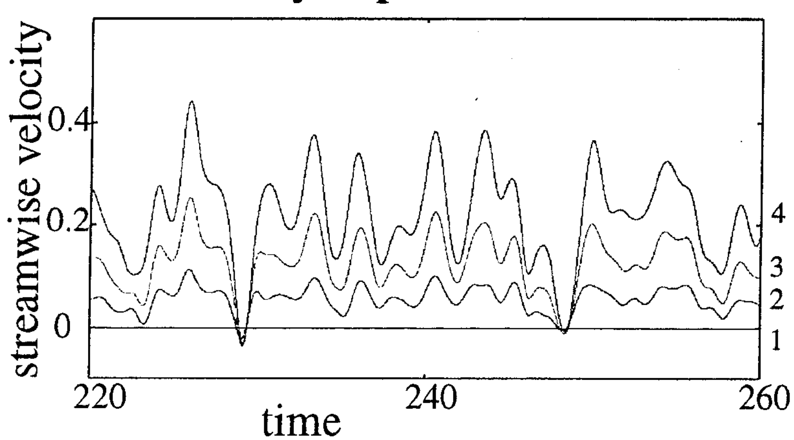
Boundary Conditions	**No slip/slip, outflow/inflow, periodic**
Size and Runtime	**Resolution of small eddy motion, evolution over long time scales**
Mesh Refinement	**Adaptive, unstructured**
Turbulence Models	**Approximations to reduce problem size and runtimes**
Analysis	**Large data sets, visualization, convergence testing**
Numerics	**Appropriate scheme, parallelization, solvers**

Time histories provide local flow information

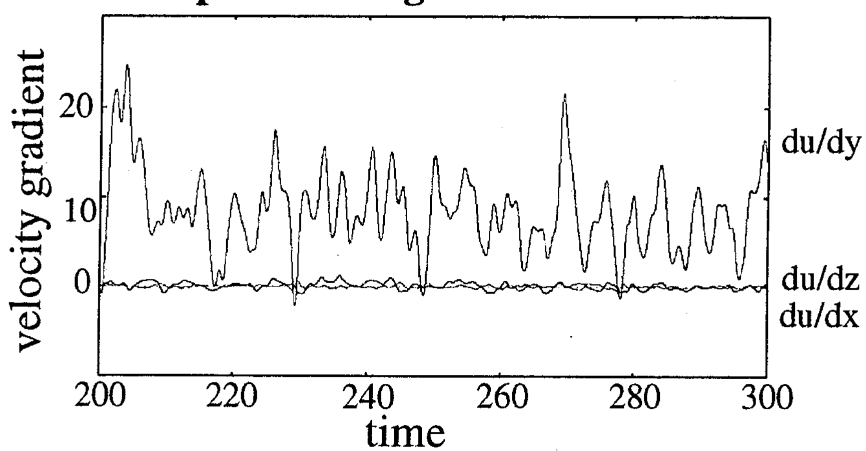
Velocity in core of flow - transition from 2-D to 3-D



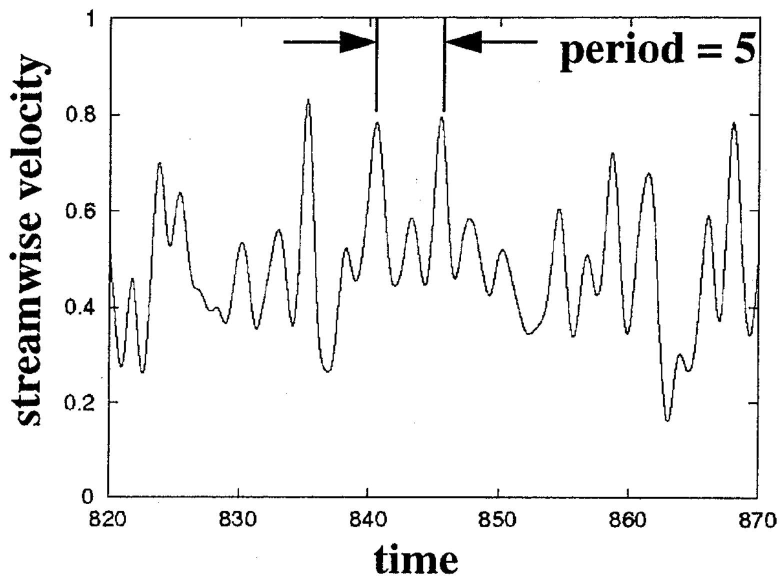
Velocity at points near wall

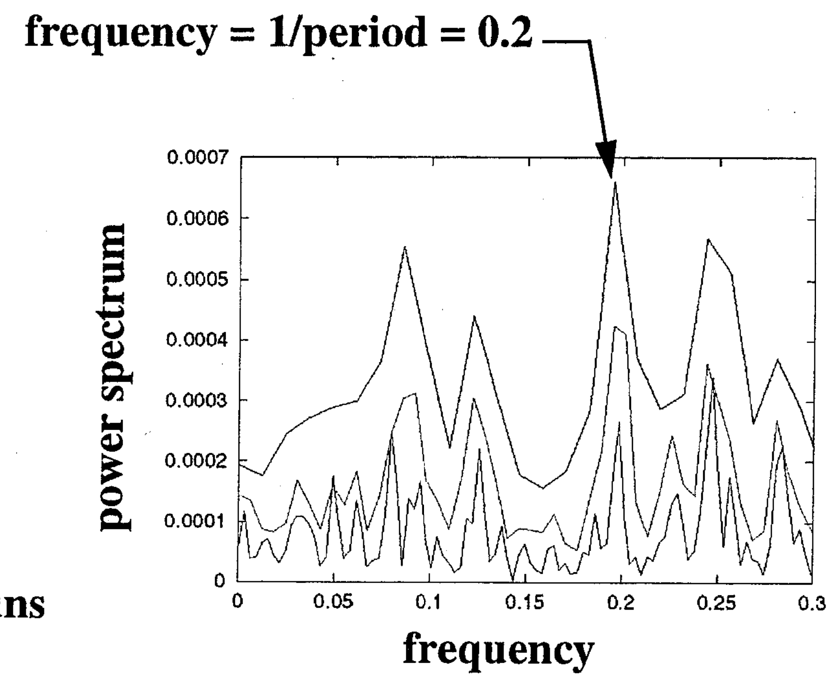


Comparison of gradients near wall



Power spectrum analysis can be used to determine the dominant frequencies.





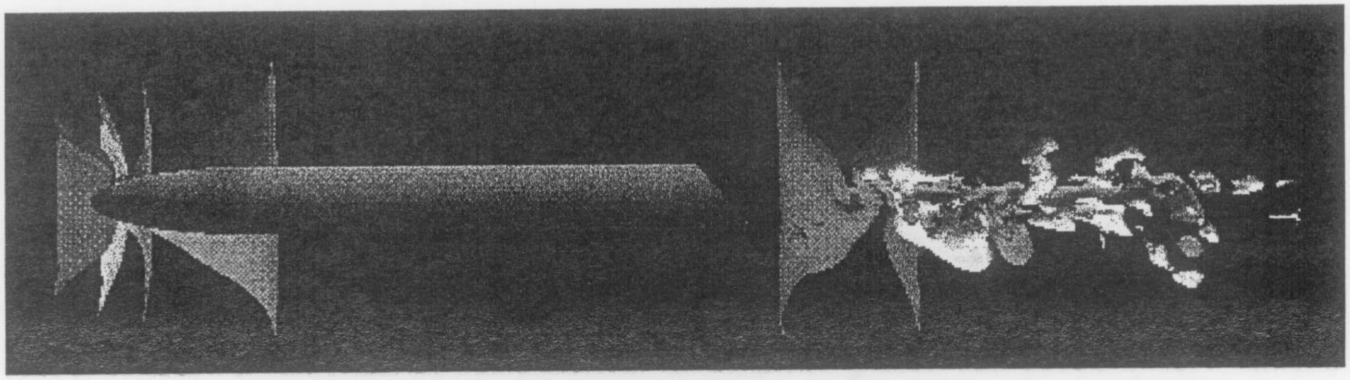
Goal: Use power spectrum to compare runs

- different meshes
- different time steps

Issue: Peak identification

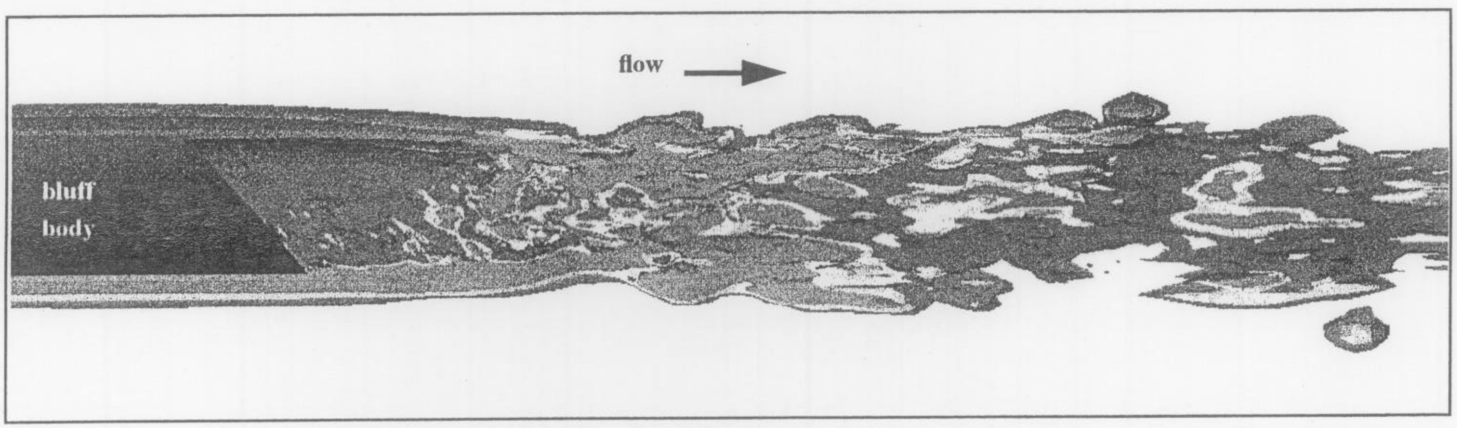
Flow visualization requires choosing the right parameters and movie making.

Pressure



Large-Eddy Simulation of vortex shedding in the wake of a bluff body.

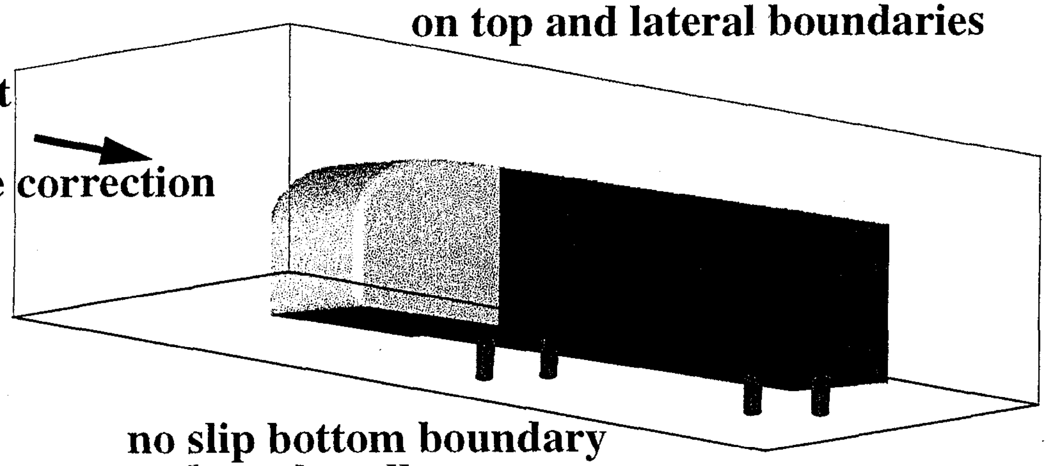
Enstrophy



The first year deliverable is to integrate and develop the flow model and complete the demonstration problem.

Milestone	FY99 incompressible flow demonstration
R&D	Solver integration/parallelization
	Turbulence modeling
	Boundary conditions
	Data analysis

Computational domain is chosen to minimize grid size



LES is a challenge but we have the experience and resources to succeed.

LES/FEM has advantages

Less empiricism

Built-in outflow conditions

Data analysis

Time-averaging, visualization, time histories, and power spectrum

Approach

Take advantage of existing methods and codes

Keep it simple - Smagorinsky SGS model and reduced computational domain

7x10 Test of the GTS Model

CFD Validation for Heavy Vehicle Drag

NASA Ames Research Center

October 22, 1998

Bruce Storms

7 x 10 Capabilities

Tunnel Speed $\leq$ 235 mph (q ~ 140 psf, M=0.30)

Test-section turbulence intensities:

0.14%, 0.30%, 0.34% (u,v,w) at M=0.2

Facility balance capacities:

Normal Force: 1800 lbs rt & lft, 800 lbs rear

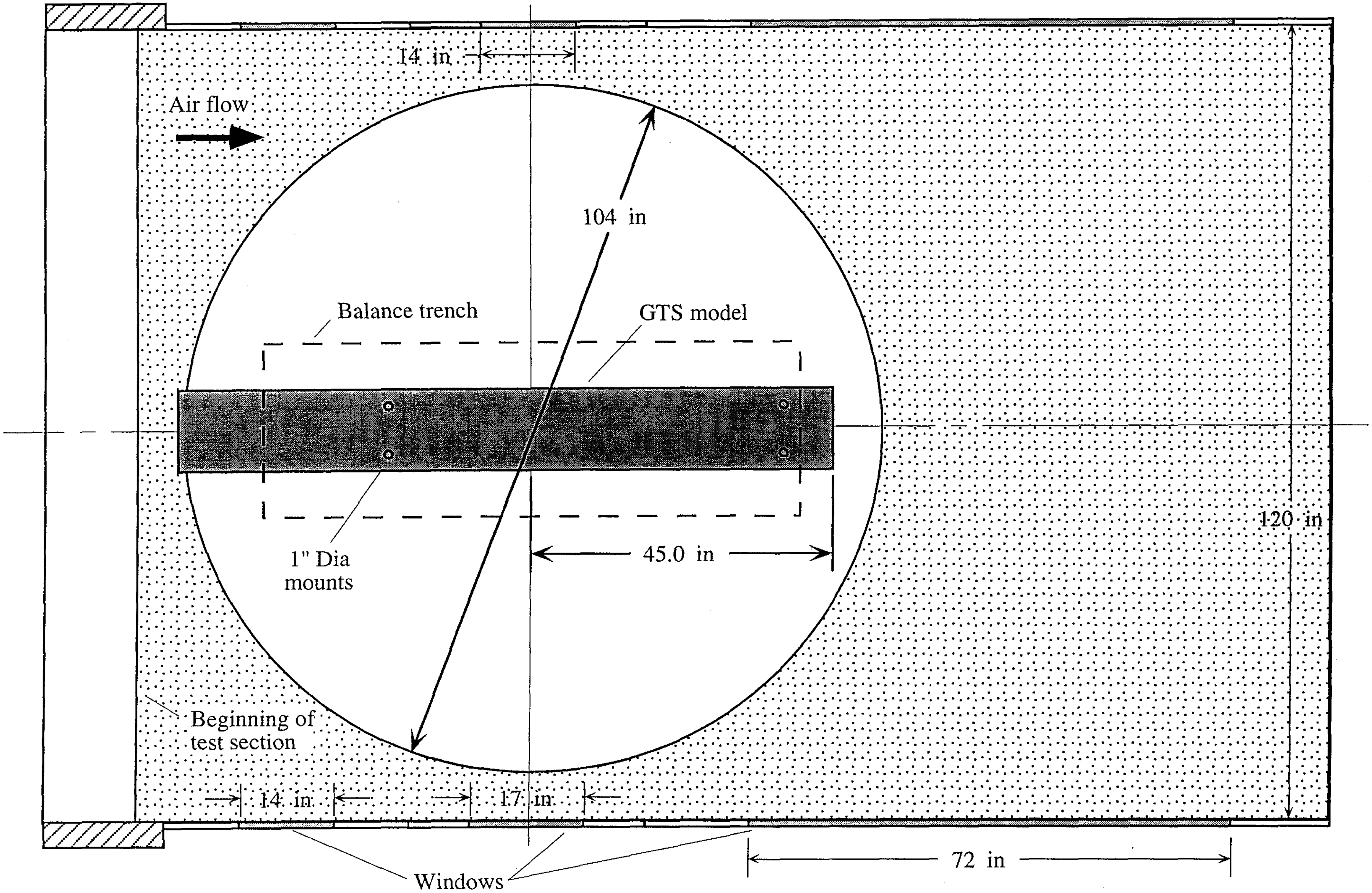
Side Force: ±2000 front, ±500 rear

Axial Force: ±500 lbs (±1 lb accuracy)

PSI system (surface pressures):

±0.1% full scale accuracy

Top View



GTS Model: Ames 7x10 Installation

Scale: 1" = 1.75'

GTS Test Conditions

Tunnel Speed = 200 mph (q ~ 105 psf, M=0.27)

Estimated drag (wind axis): $\psi = 0°$ $\psi = 14°$

q = 105 psf:	D =	41 lbs	120 lbs
q = 80 psf:	D =	31 lbs	92 lbs

Yaw angle: $-14° < \psi < +14°$ for forces & mom, pressures

0°, 5°, & 10° for PSP

0° & 10° (or 5°) for PIV

Model configuration: Baseline, no wheels

Mounted 3 inches from tunnel floor

Flow Measurements

Particle Image Velocimetry

Accuracy: $u = \pm 3.4\%$, v & $w = \pm 1.7\%$

Time to acquire: ~ 10 min / condition (1000 samples)

Pressure-Sensitive Paint

Accuracy: $C_p \pm 0.03$

Acquisition time: ~ 30 min / condition

Skin friction by Taos Hot-Film System

Separation, Reattachment, Transition detection

Oil Film Interferometry - Quantitative skin friction

Wall pressures, surface pressures, force & moments

Test Schedule

Test window : January 4 - 22, 1999 (3 weeks)

Activity	shifts
Installation / Check-out	2
Forces & Pressures	1
Pressure-sensitive paint	4
Particle image velocimetry	7
Removal	1
Total	15

Issues

- Center of rotation closer to turntable centerline
- Tunnel speed significantly higher than previous test
- Second yaw angle: 5 or 10 deg ??
- Wall pressures: yes/no ??
- PIV measurement stations ? >> parallel & perp. to freestream
- PSP on side and back only ? >> OK
- Skin friction measurement location ? >> TBD
- Oil film interferometry for quantitative skin friction ?

    >> on tunnel floor behind model

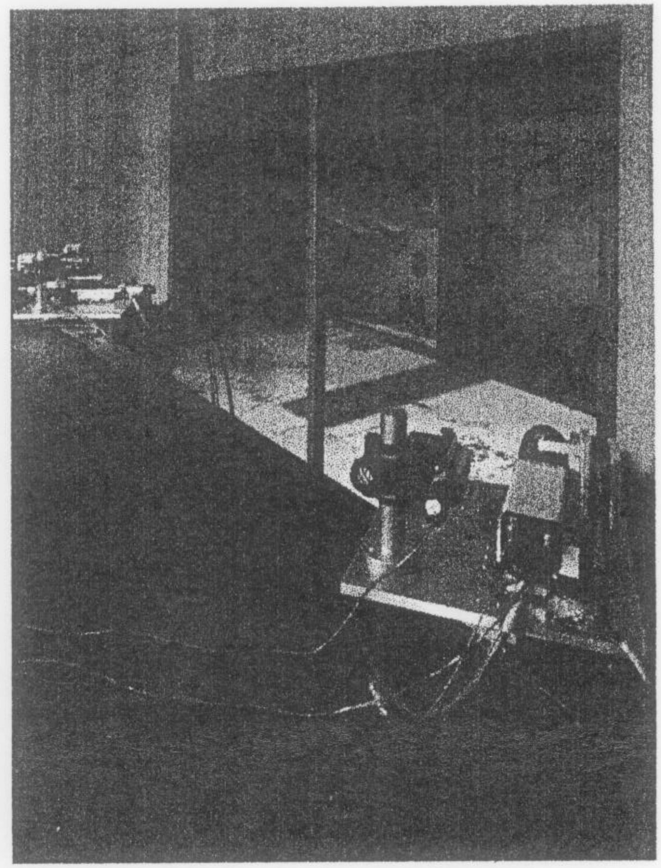
Heavy Vehicle Test in 7x10 at NASA Ames Research Center

PIV Overview

J.T. Heineck, PIV Task Manager
Experimental Physics Branch
NASA Ames Research Center

NASA Ames PIV Team - Capabilities

- Both 2D and 3D vectors for planar measurements
- 2% accuracy for instantaneous in-plane measurements, 4% for cross-plane. Time averaging improves statistical accuracy for steady flows.
- Images acquired and data processed on Windows NT system.
- CFD Grid Matching
- Team Experience in Wind Tunnel Testing
- Uses: Vortex Structure and Position, CFD Validation, Shear Layers, Jets, Flames

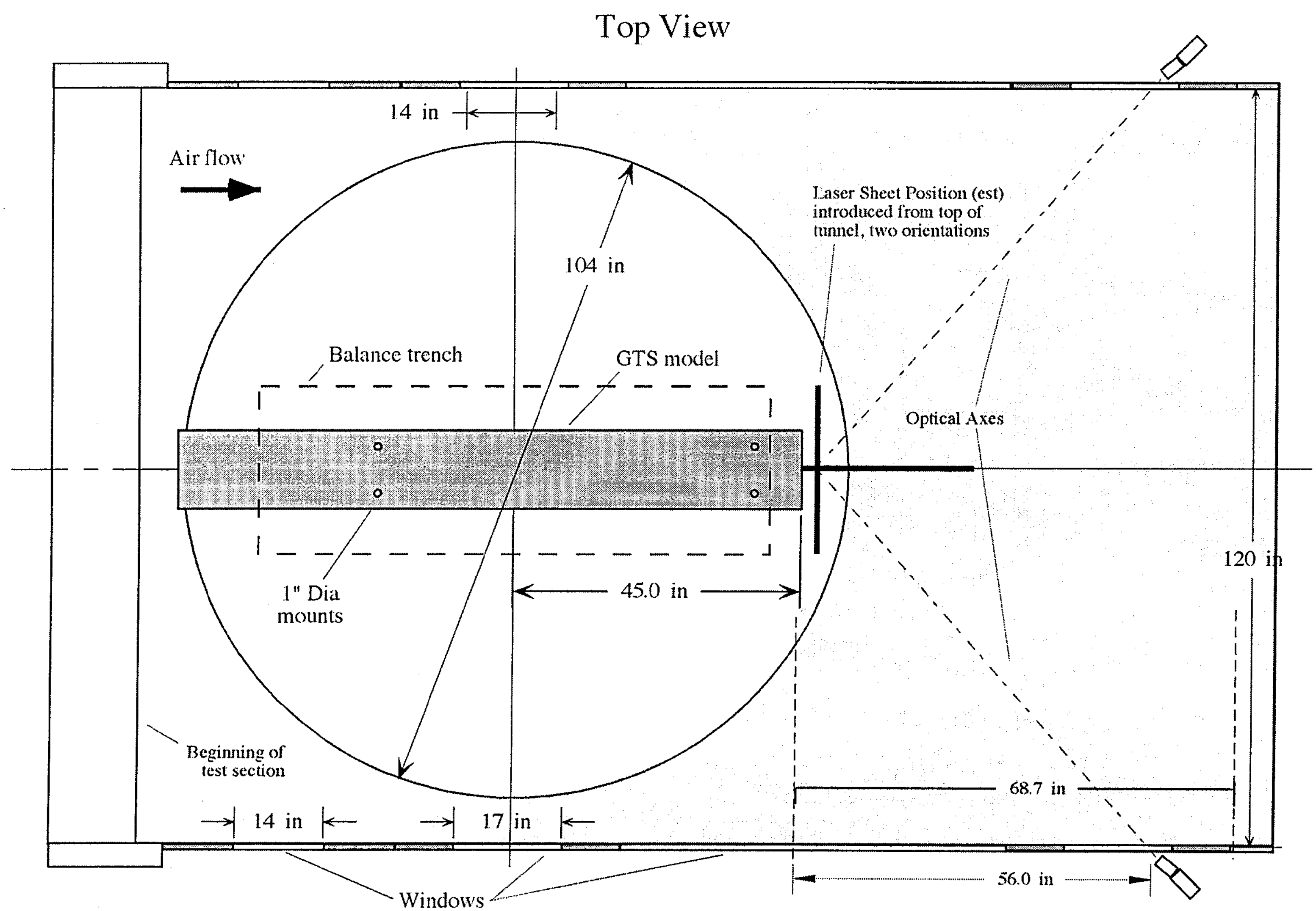


The PIV Method

- The seeded flow is illuminated with dual head pulsed Nd:YAG laser. Laser is optically shaped to form a sheet 1mm thick and spans the region of interest.
- Special high-resolution, dual-exposure digital camera(s) is (are) focused using high resolution lenses on the plane of the laser sheet.
- Timing of pulses are spaced in microseconds, the cameras are synchronized to the laser.
- Images taken are of individual particles in the area of interest.
- The image pair undergoes cross correlation using Fourier methods.
- The distance and direction the particle image shifts at grid points are determined
- Vectors are calculated based on these shifts. The vector field is the resulting data.

PIV Issues for Tunnel Testing

- Identify the region of interest and flow structure
- Determine the data required e.g. 2D vs. 3D, axial and/or orthogonal to free stream, level of statistical accuracy for Reynolds averaged velocities.
- Laser is powerful, may damage the surface or paint of some models
- Consistency of seeding will effect efficiency of data collection and quality of data
- Calibration and focus procedures take approximately 1-2 hours for a laser sheet location change
- 2 days of set up, 2 people needed to operate system.
- Data acquisition takes approximately 10 minutes per condition after tunnel stabilizes.



GTS Model: Ames 7x10 Installation

Scale: 1" = 1.75'

Sample Vector Image