Pentagon Shield:
Experiments with a nonosillatory forward-in-time CFD code (EuLag) to simulate flow around the Pentagon

8th GMU Conf. on Transport and Dispersion Modeling
15 July 2004

Piotr Smolarkiewicz NCAR/MMM
Bob Sharman NCAR/RAP
Pentagon CFD modeling goals

- Evaluate ability of CFD models to accurately represent flow around the Pentagon
- To better understand the nature of flow around the Pentagon under a larger variety of conditions than can be investigated with limited field campaigns
- Provide baseline against which faster CFD models can be evaluated for operational use
EuLag Description

- Nonhydrostatic, anelastic ($\nabla \cdot \rho_o \mathbf{v} = 0$), Navier-Stokes eqns.
- Eularian/semi-Lagrangian options
- “Multidimensional Positive Definite Advection Transport Algorithm” (MPDATA)
- Extended “terrain-following” mesh (upper, lower, lateral)
- Structured, time-dependent grids
- Preconditioned Generalized Conjugate Residual (GCR) nonsymmetric solution of elliptic p eqn. (Eisenstat, 1983)
- LES type turbulence closure (1 ½ order, prognostic tke)
- Successfully used for a wide variety of engineering and geophysical applications
  - Mountain-valley flows, convective clouds
  - DNS of turbulence in a box
  - Aircraft wake vortices
  - Solar convection, oceanic flows, etc.
- Relative of HIGRAD
Some EuLag References


EuLag Validations

- Analytic solutions
  - Basic pde solution (simple advection, diffusion, etc.)
  - Linear and nonlinear mountain waves (2d and 3d)
  - Hydraulic jumps
- Tank experiments
  - Wake vortex breakdown
  - Boundary current separation
  - Stratified flow over surface mounted obstacles
- CFD intercomparisons
  - Convective BL
  - Boulder downslope windstorm intercomparisons
- Comparisons to observations
  - Flow over Alps
  - Flow over island of Hawaii

Comparison to nonlinear analytic solution ( - - )
EuLag (MPDATA) validations

Initial condition                  upwind                  leapfrog

MPDATA                     MPDATA-FCT

MPDATA                      MPDATA-FCT
EuLag Validations (contd.)

- LES of unstable BL
  - Comparisons to laboratory experiments ($\Delta$)
  - Comparisons to aircraft measurements ($o$)
  - Comparisons to other LES (Schmidt and Schumann, JFM, 2000)
Pentagon Model

- Derived from 1m resolution lidar dataset (April 2001)
- Stated accuracy:
  - 0.5 m H, 0.3 m V
- Data noisy – had to be simplified
Pentagon setup

- Boundary-fitted representation
  \[ z' = H(z-h(x,y))/(H-h(x,y)) \]
- 600x600x31 @ \( \Delta x=\Delta y=\Delta z=2m \)
- 7200 time steps @ \( \Delta t=0.05 \) s
- Rigid upper boundary
- Eulerian option 2\textsuperscript{nd} order in space and time
- sgs 1 \( \frac{1}{2} \) order closure
- Specified CD on building and sfc.
- Neutral with prescribed velocity profile from previous LES simulation (Moeng and Sullivan)
- NCAR supercomputer ("older" IBM MPI using 200 processors): 10 \( \frac{1}{2} \) hrs wallclock time for 7400 time steps (with 3 tracers)
Some results: \( w \) after 7200 time steps (6 min)

\( z' = 0 \)

\( z = 10 \text{ m} \)

\( y = 600 \text{ m} \)

\( z = 25 \text{ m} \)
Some results (cont): $w \ (z=10\text{m})$
after 7200 time steps (6 min)
Some results (cont.):
sgs tke after 7200 time steps (6 min)
Future work

• Validate against wind tunnel results (neutral)
• Perform more sensitivity studies (e.g., to resolution, SGS parameterization, etc.)
• Investigate other stability regimes (stable, unstable)
• Incorporate actual terrain around Pentagon
• Simulate one or more field campaign cases
• Couple Lagrangian particle model (Jeff Weil) to wind output from CFD calculations
• Assess mesh refinement techniques (with Joe Prusa)
Pentagon model simplifications

- Remove terrain
- Neglect
  - peripheral obstructions
  - roof structures, antennas, etc.
  - Corridor bridges
Some results (cont.):
p' after 7200 time steps (6 min)

- $z=10\, \text{m}$
- $z=25\, \text{m}$