Trends in CFD, Engineering Analysis & Computing

ME-561

An Introduction to Computational Fluid Dynamics for Incompressible Flow

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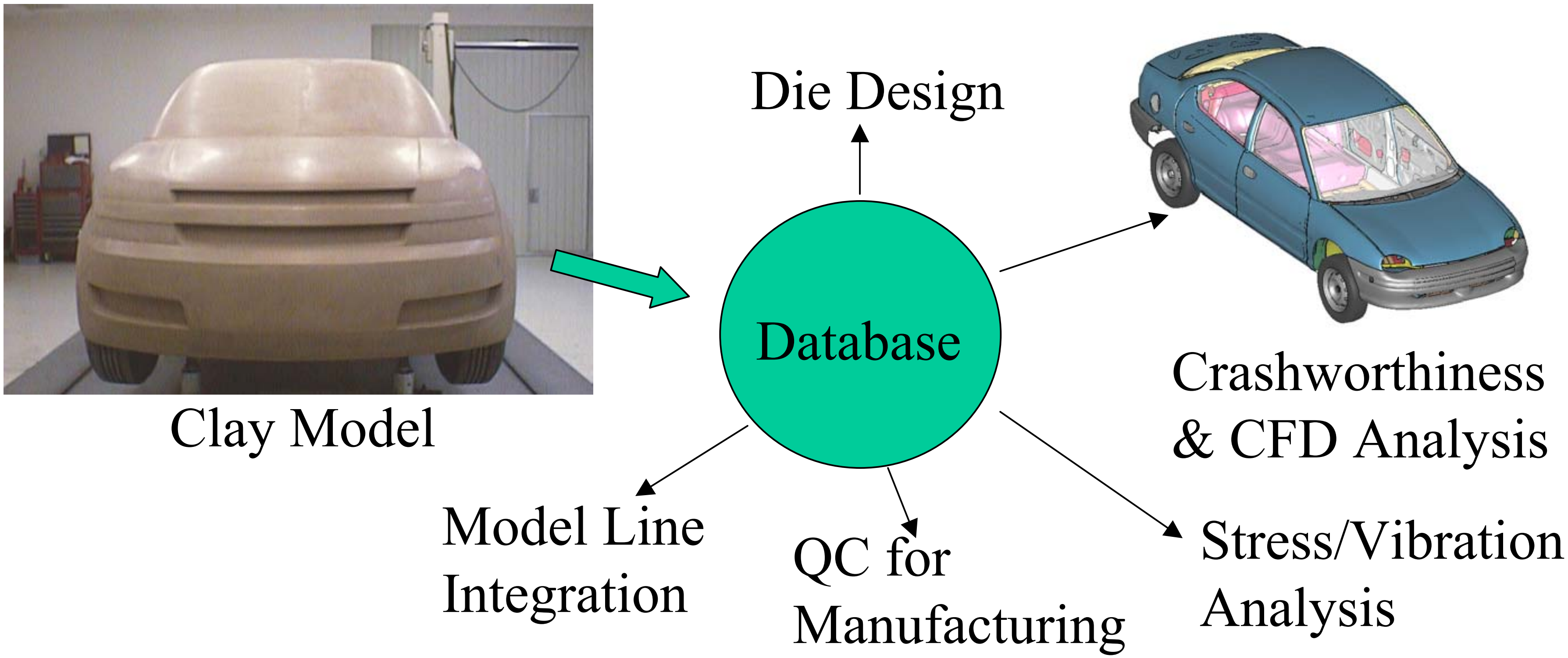
Trends in Computer-Aided Engineering Analysis

- 1965 – 1975: Use of computerized drafting, independent linear FEM
- 1975 – 1985: Integration of drafting with linear FEM analysis
- 1985 – 2000: Integration of nonlinear FEM analysis
  - Use of expert systems for automated design processes
  - Simulation of manufacturing processes, e.g., casting
  - Simulation of prototype testing, e.g., crashworthiness

- Simulation is being used to replace testing due to cost and time requirements, and in situations where testing is not feasible
- Simulation-based design requires simulations to be processed in “minutes” NOT days.

Primary obstacle to using nonlinear analysis in design is the lack of understanding of the physical processes, excessive computer time, and integration into design databases

General Motors as a Design Prototype



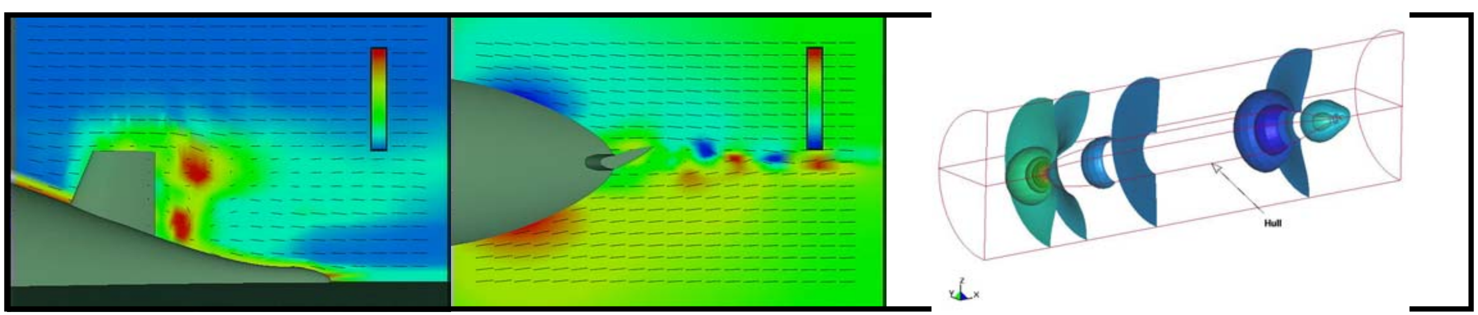
- Analysis is still primarily linear FEM analysis
- Some nonlinear analysis, but primarily in manufacturing processes and crashworthiness

Finite elements have tremendous potential in computational fluid dynamics

- Potential is still not realized today…
- CFD has a strong finite-difference background
- Finite elements are more attractive for CAE integration
  - Leverage existing FEM interfaces for solid/structural codes
  - Leverage existing CAE interfaces for FEM mesh generation
- Finite element and finite volume technologies are growing together in many regards
  - Discontinuous Galerkin, stabilization ideas are unifying/spanning multiple methodologies
  - Growing commonality in treatment of unstructured grids
  - Recognized need for computational efficiency and robustness in the FEM community

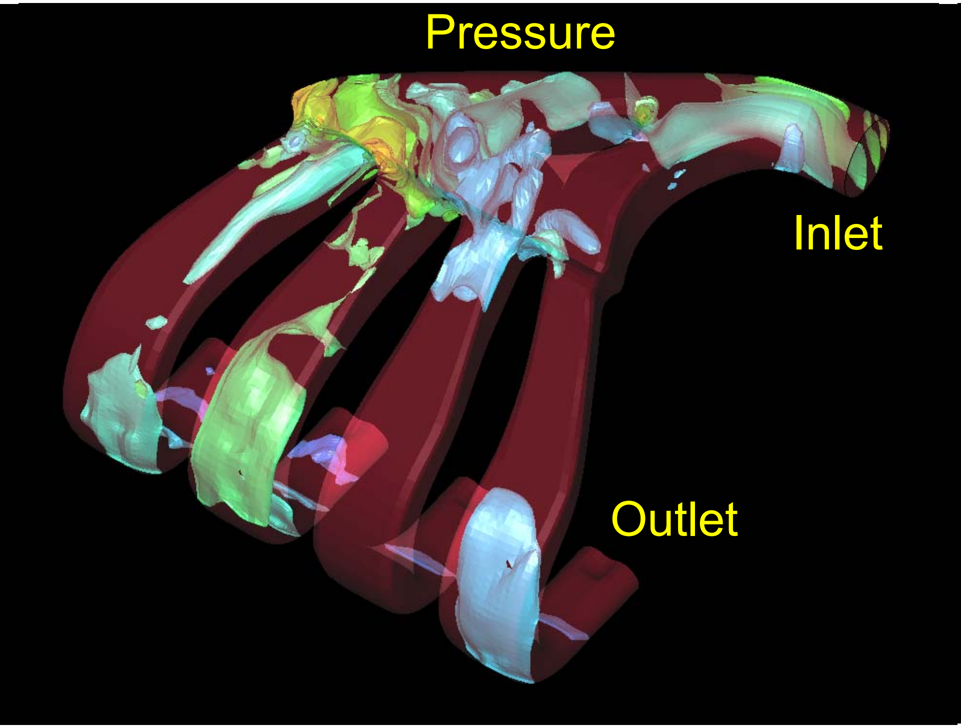
Incompressible and low-Mach flow span a spectrum of applications

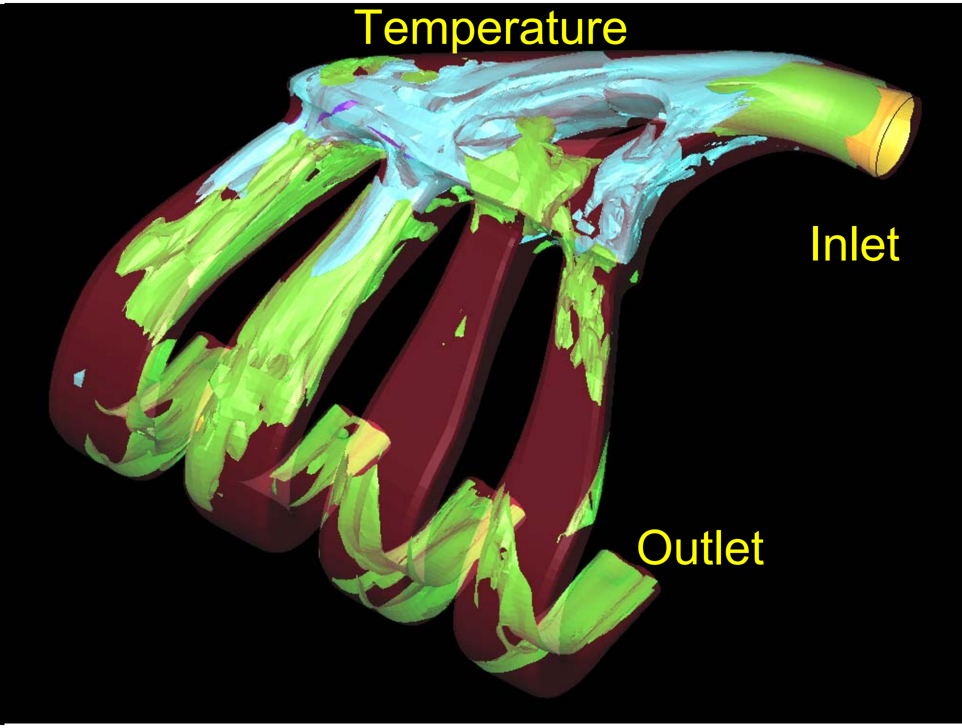
- ❑ Mold filling – casting and resin-transfer molding
- ❑ Encapsulation of electronic components
- ❑ Chemically reacting flows – burners, CVD reactors
- ❑ Dispersal of chemical and biological agents
- ❑ HVAC – environmentally controlled rooms
- ❑ Vehicle aerodynamics
  - ➢ Initial focus for the low-Mach algorithms was submarine flows



Flow-generated noise is a primary concern for auto manufactures (low noise = high quality)

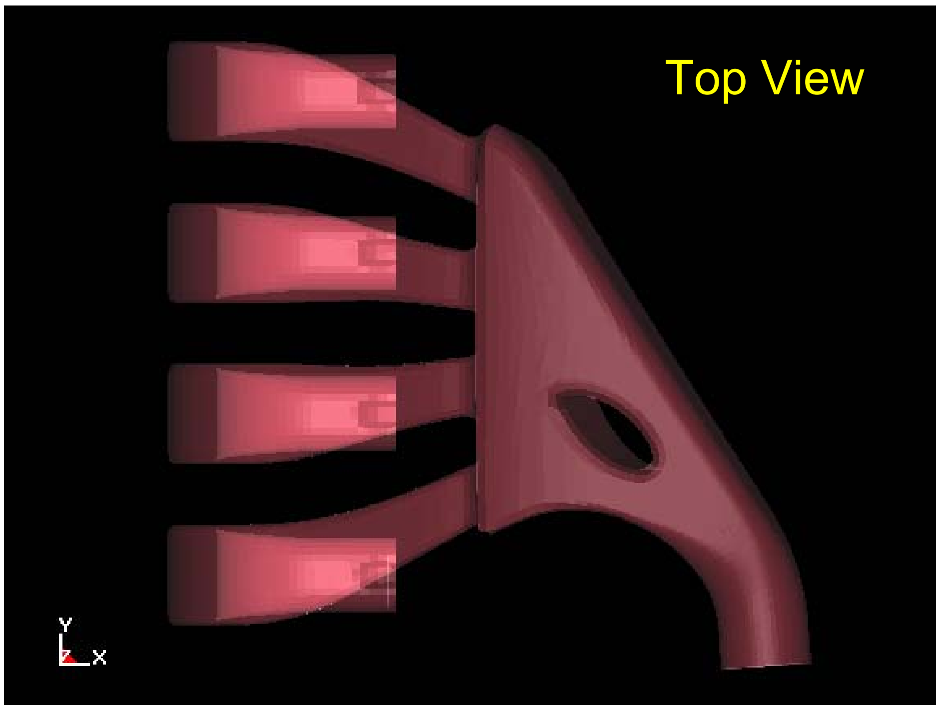
- ❑Working fluid - air
- ❑Re = 150,000
- ❑CFL = 2.0
- ❑Variable time step size
- ❑131,058 Elements, 141,396 Nodes, (696,642 DOF)
- ❑Baseline Smagorinsky Model





Pulsatile flows can be "good" noise generators

- ❑Inlet port draws flow via natural BC's w. prescribed inlet temperature
- ❑Outlet flow rates & temperatures based on engine characteristics, e.g., valve timing

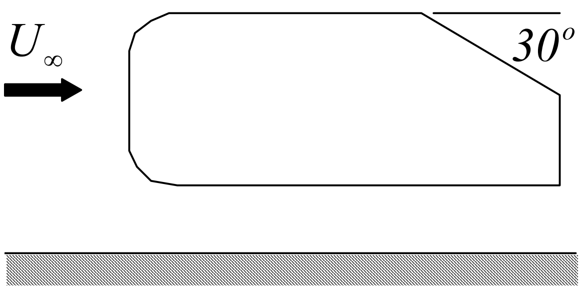


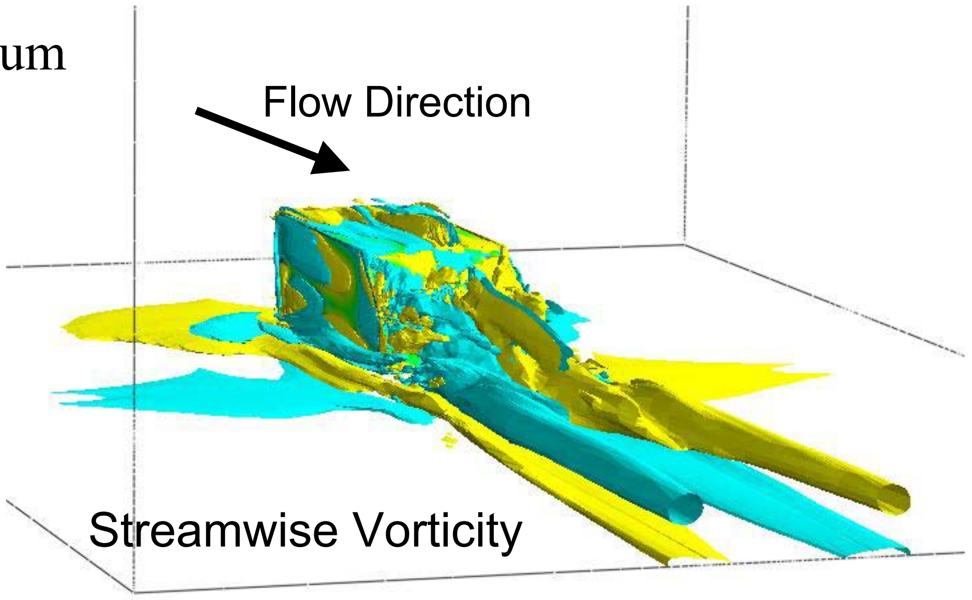
Some of the trends in CFD …

- Steady-state analysis is still predominant, but most flow problems are not steady-state
  - Flow-generated noise
  - Manufacturing processes such as coating, filling
  - Fluid-structure interaction
- Computational demands for time-dependent flows have prevented broad application of transient analysis
  - Moore's law will continue to drive the computing – 10 GFLOPs machines on the desktop by 2011 (2 GLOPs machines today)
- Turbulence remains the pacing technology for CFD
  - Many applications still rely heavily on RANS (k-ε) models for routine applications
  - VLES applications are emerging
  - DNS and "pure" LES remain research tools
- There are still many "simple" problems for which commercial CFD codes fail miserably, e.g., the 8:1 thermal cavity benchmark
  - www.me.unm.edu/~christon/mit_convection/summary/index.html
  - "Is this the end for Fluent" thread at www.cfd-online.com

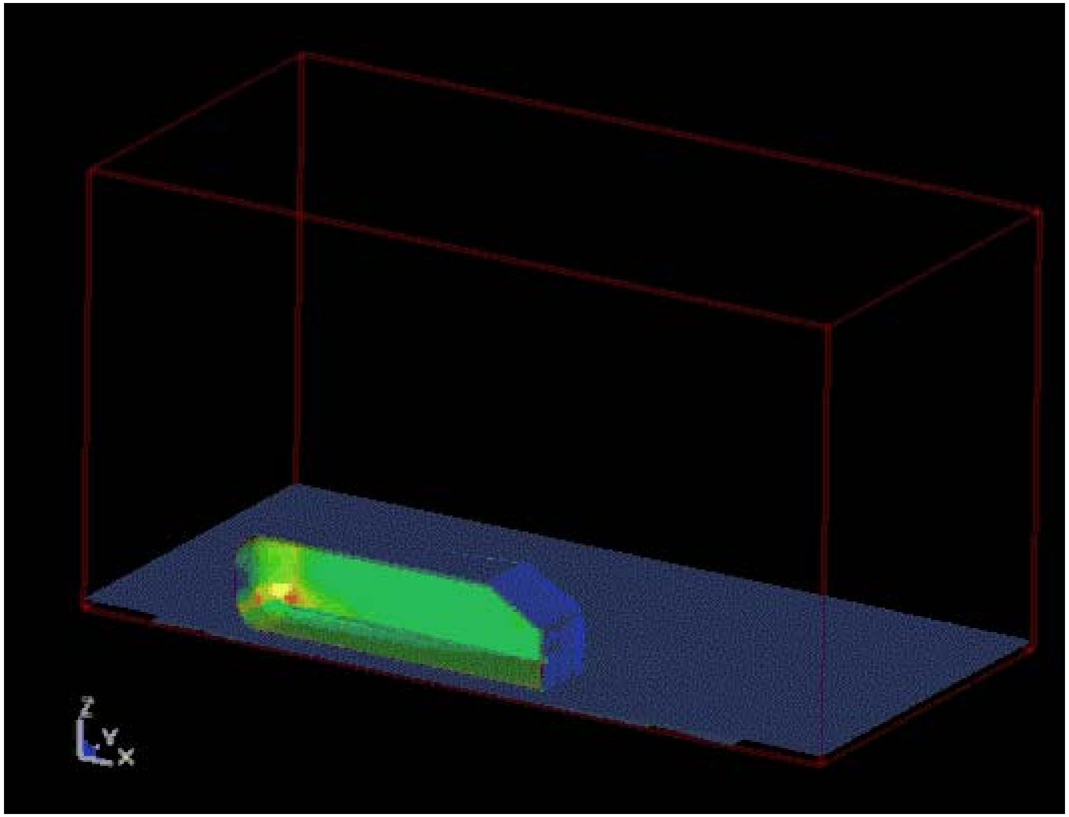
LES computation captures large-scale vortical structures and mean drag coefficient

- Ahmed's body with 30° slant and $Re = 4.29x10^6$
- Experimental drag coefficient: $C_w = 0.378$
- Predicted short-time average drag coefficient: $C_w = 0.386$
- LES crimes:
  - RANS type graded grid (~500,000 elements)
  - No wall functions
  - Under-resolved energy spectrum





Vorticity amplitude - coarse grid (250,000 elements)



Animation courtesy Grant Cook, LSTC