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The Role of Computational Fluid Dynamics At Marshall Space Flight Center

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Outline of Presentation

- MSFC's Roles and Responsibilities
- Fluid Dynamics Division
- CFD in the Design and Development Process at MSFC
- Cost vs. Value of CFD
- Accuracy
- Future Needs
- Summary

MSFC's Roles and Responsibility (as related to CFD)

- MSFC is the Center of Excellence for Space Propulsion Technology within NASA
- A primary MSFC thrust is to pursue activities that lower the cost of access to space
  - » Operational systems: Space Shuttle Main Engine (SSME); Solid Rocket Motors
  - » Experimental or in Development: X-33, X-34, Reusable Launch Vehicle, Rocket Based Combine Cycle Engines, etc.
- MSFC performs numerous functions related to its Center of Excellence mission
  - » Program development and management
  - » Engineering: design, analysis, coordination/integration
  - » Testing: "cold flow" testing, "hot fire" testing of components, subsystem demonstrations, materials testing, structural testing, etc.

Fluid Dynamics Division

- The Fluid Dynamics Division is part of the Structures and Dynamics Lab
  - » The Lab provides most of the advanced analytical support to MSFC programs
    - CFD, Stress, Structural Dynamics, Thermal, etc.
    - Lab also provides structural design and testing organizations and cold flow testing
- The Fluid Dynamics Division is divided into two branches
  - » Experimental and Analytical
- The two branches are mutually complimentary and are integrated
  - » Most test supported with analyses and most analyses verified with testing
- Experimental facilities include:
  - » Two closed-loop pump test stands (150 Hp and 350 Hp) and one open-loop, all using water as the test fluid
  - » One long-duration blowdown turbine test stand that uses air as the test fluid
  - » Tri-sonic wind tunnel
  - » Rocket engine nozzle test facility that uses
  - » Solid Rocket motor technology test rig

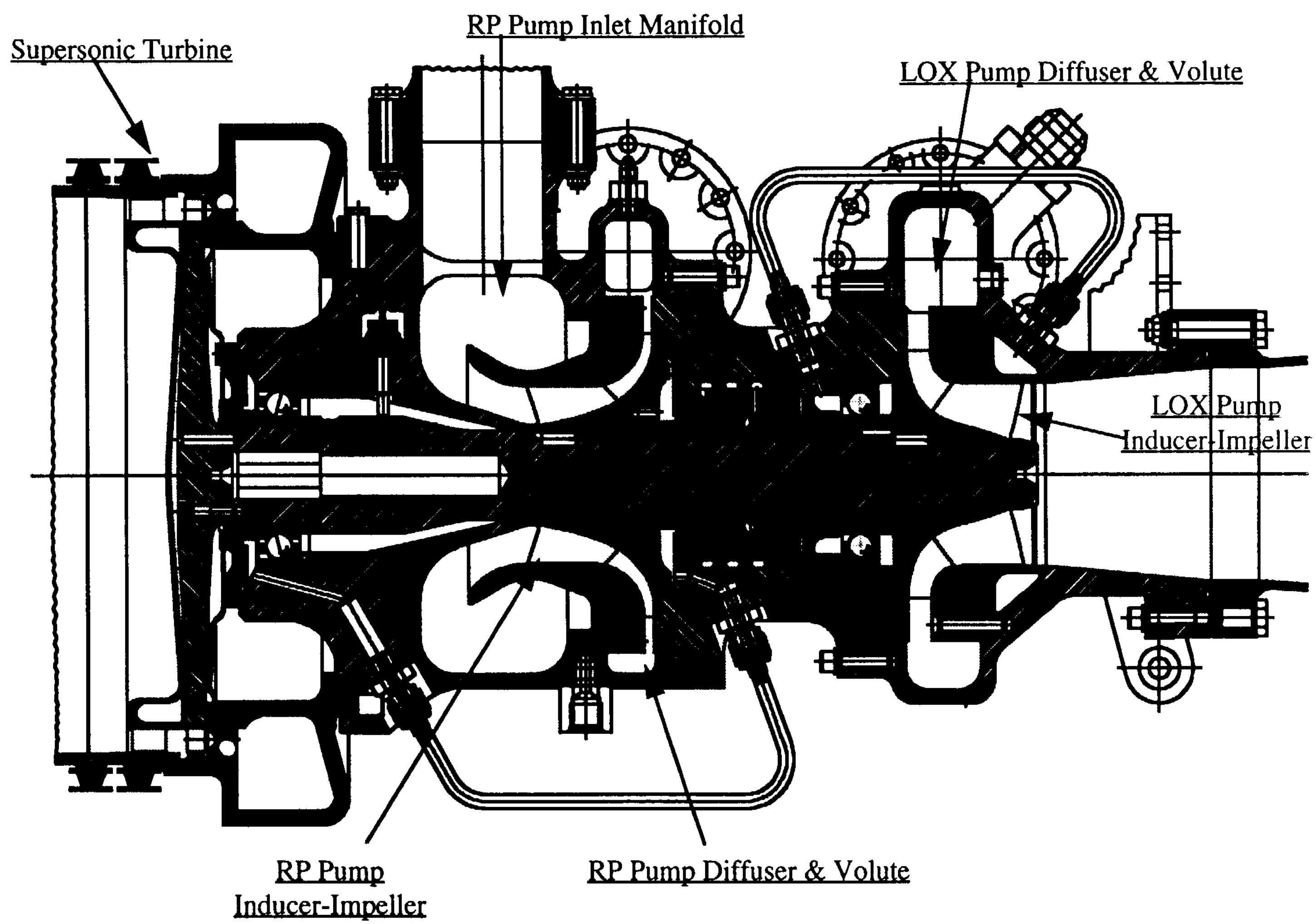
Fluid Dynamics Analysis Branch

- The analysis branch include several related disciplines
  - » CFD, acoustics (including high frequency data reduction, induced environments
- Approximately 16 full time CFD users (out of a group of 27)
- We apply rather than develop CFD
  - » Limited CFD code enhancements and customization
- We apply CFD primarily to reduce the cost of design and development
  - » Maximize analysis fidelity early while the design can be modified inexpensively
    - Do not wait until the design is set in concrete to perform sophisticated analyses
  - » Increase likelihood that the first "final design" will be the last "final design"
    - Continue supporting refinement of design throughout the detail design process
    - Assess the design against requirements, assess for undesirable flow features
    - Provide better environments for structural and thermal design and analyses
  - » Maximize testing value by assessing test plan, instrumentation location, etc.
  - » Support failure investigations

CFD in the Design and Development Process at MSFC

- CFD is applied to a broad range of components and subsystems
  - » Pump and turbine feedlines and feed manifolds
    - – Incompressible or compressible, steady, 3D
  - » All primary and secondary flow paths in pumps
    - – Incompressible, single phase, steady, 2D and 3D
  - » All primary and secondary flow paths in turbines
    - – Compressible, subsonic to supersonic, steady and unsteady, 2D and 3D
  - » Combustion chambers
    - – Compressible, reacting, multi-species, hydrogen and hydrocarbons, 2D and 3D
  - » Rocket engine nozzles and plumes
    - – subsonic to supersonic, reacting, multiple species, internal and external flow, 2D and 3D
  - » Launch vehicles ascent
    - – subsonic to supersonic, integrated engine with engine plume on, reacting, multi-species, various altitudes, 3D

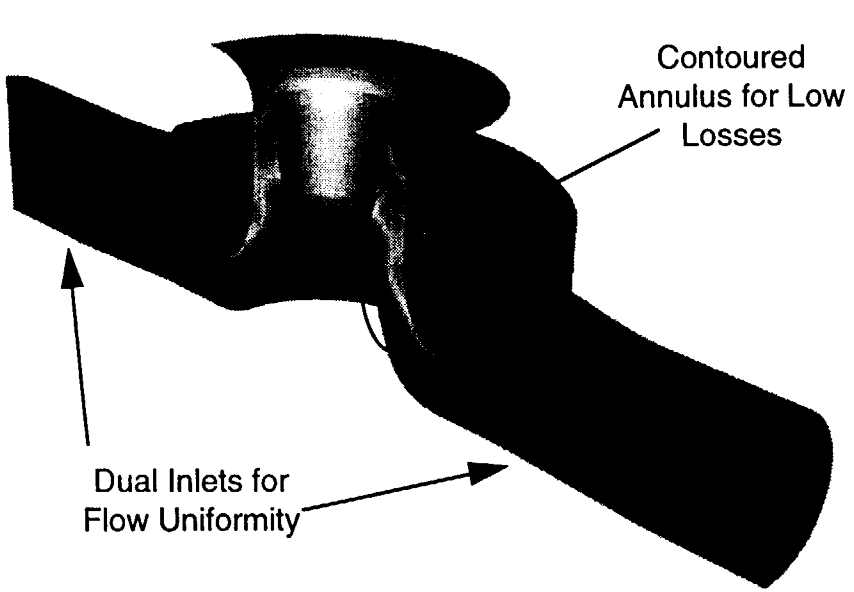
Computational Fluid Dynamics at Marshall Space Flight Center



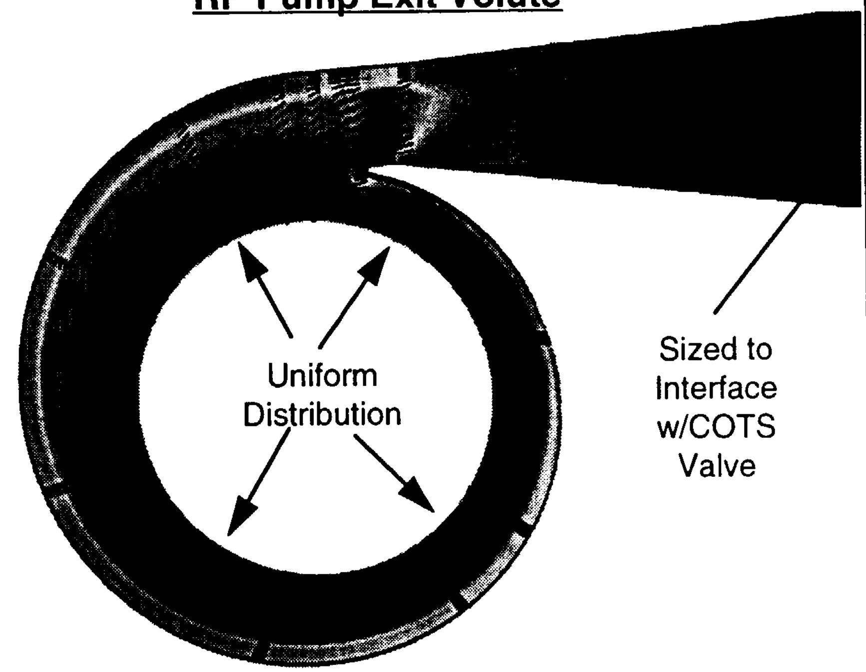
2/27/97 layout

Computational Fluid Dynamics at Marshall Space Flight Center

RP Pump Inlet Manifold



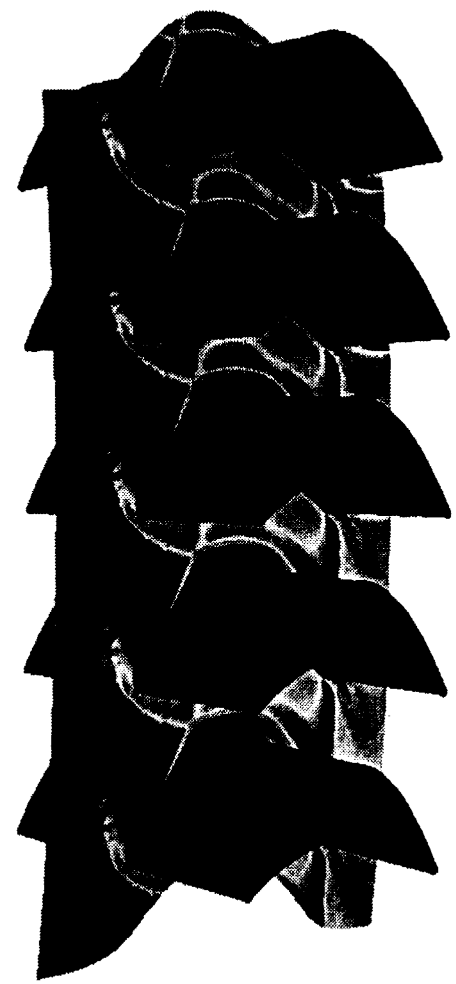
RP Pump Exit Volute



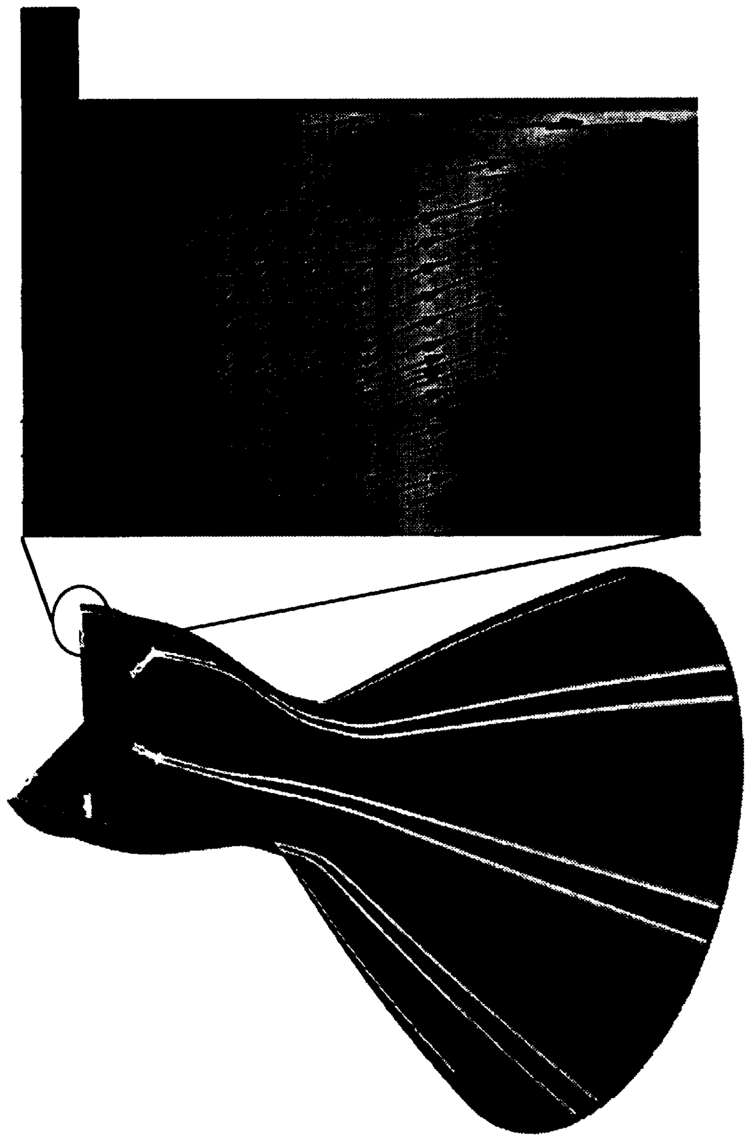
Computational Fluid Dynamics at Marshall Space Flight Center

RP Inducer-Impeller
blade pressures and velocity vectors

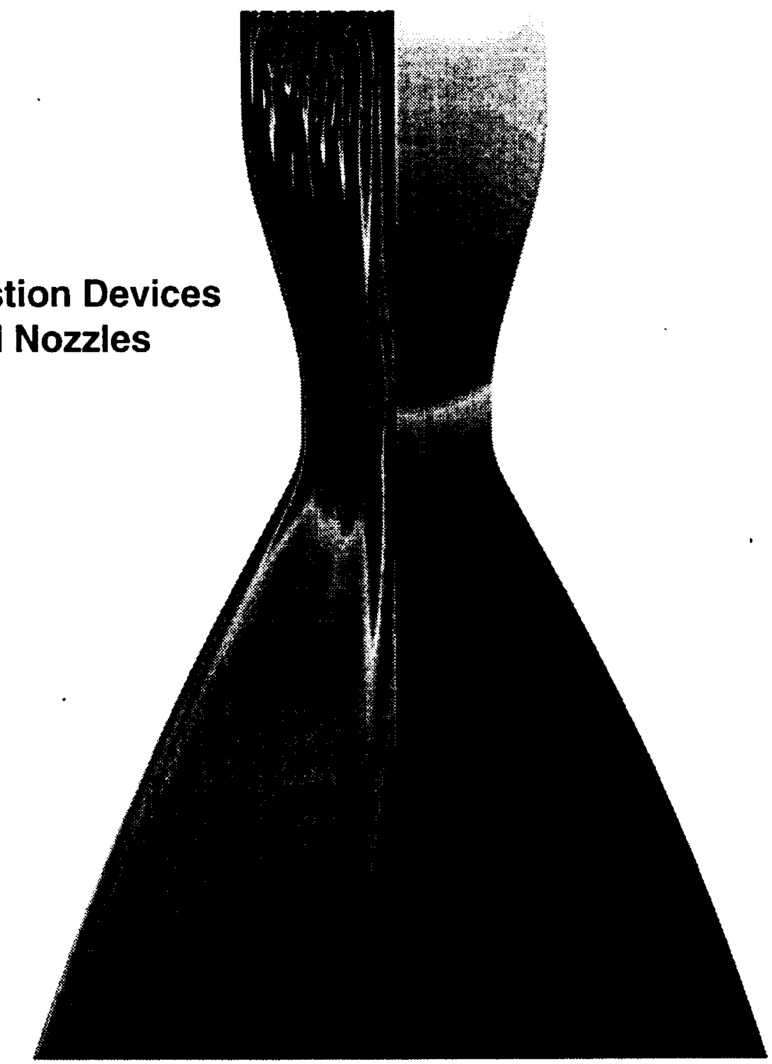
Turbine Rotor Blades
midspan absolute mach number



Computational Fluid Dynamics at Marshall Space Flight Center



Combustion Devices and Nozzles



CFD in the Design and Development Process at MSFC

- This range of applications imposes unique constraints on our software
  - » We cannot afford to have specialized codes for type of application
    - Management, training, support nightmare
    - Rely primarily on three codes (2 of which are public domain codes)
    - More efficient use of personnel
  - » We support development of the codes that we use
    - Insufficient market for much of our unique applications for commercial development
  - » We require generalize grid generation and solution visualization tools
    - Generally separate from the CFD code
  - » A tendency towards specialization among the personnel
    - Grid or visualization specialists
    - Turbomachinery vs. combustion device; internal vs. external flows
    - Familiarity with the specifics of the particular flow being analyzed is key to successful application of CFD
- Minimize leasing of software, opt for public domain or purchase
  - » Due to uncertainty of year-to-year funding (government constraint)

Cost vs. Value of CFD

- Rocket engine hardware is extremely expensive to build and test
  - » Weight and performance at a premium
  - » Designs generally have little margin
  - » Environments are very severe
  - » Nearly every new program outside the experience base
    - – Very little direct scaling is possible
- Relatively high engineering and development cost due to limited production
- The cost of one SSME engine test is greater than the average yearly hardware and software cost for the CFD group
- CFD represents a relatively small investment and overhead relative to the impact it has on the hardware
  - » Most of the designs analyzed are impacted by the CFD results

Cost vs. Value of CFD (continued)

- Computing cost are continuously decreasing
  - » Code robustness and convergence properties have improved
  - » Computing cost have dramatically decreased
    - – Super computer speed on $35,000 workstations
      - Sub-net of inexpensive workstations presents tremendous potential for parallelization and surge capacity
    - – Mini-super computers with multiprocessors (up to 18) for less than $500,000
      - Compared to $4 - $5 million a few years ago
  - » High chip speeds and inexpensive memory cost have led to improvements in interactive grid generation and visualization tools
  - » Personnel cost are the most significant over the long term
    - – Not too many good part-time CFD users; it is a full time job
    - – Reasonable theoretical and/or experimental background is very important
    - – Excellent computer skills including programming skills
    - – Must have some level of proficiency in all steps of the analysis process
    - – Must be able to relate CFD results to hardware design implications
    - – Dedicated hardware and system software specialist required even for small groups

Accuracy

- Predictable error is more useful than inconsistent accuracy
  - » Can adjust or account for the former
  - » Often rely on relative differences in assessing design changes
- Achievable accuracy varies from application to application
  - » Higher accuracy can be expected for pressure or body force dominated flows than for viscous forces (and mixing) dominated flows
    - Radial impeller performance near the design point can be predicted very accurately
    - Diffuser performance prediction accuracy is not nearly as good (test final design)
- Lack of accuracy often caused by improper analyses application
  - » Improperly applied or located boundary conditions
  - » Steady analysis of inherently unsteady flows (i.e., diffusers)
- Benchmark only to the level required to verify code/model fundamentals
  - » Establish code suitability and grid requirements
  - » Elaborate benchmark demonstrations have limited value

Future Needs

- Practical incompressible time-accurate capability
  - » Impeller-vaned diffuser interaction
- Cavitation modeling capability
  - » Every single rocket engine pump cavitates during normal operation
  - » Tremendous numerical and physical modeling challenge
  - » Inherently unsteady
- Hybrid schemes for internal and external flows
  - » Facilitate grid generation of complex geometries
    - lifting body with engine, inducer with tip clearance, etc.
  - » Must address pre- and post-processing issues
- All sorts of automation:
  - » Automated grid generation for specific components
  - » Automated solver initialization based on past results
  - » Automated links between the geometric model (CAD) and CFD, and between CFD and the disciplines requiring the CFD output (stress, thermal, etc.)

Summary

- CFD is used at MSFC to support the design and development of propulsion and vehicle systems
- CFD is part of the process that includes testing
- Broad range of applications at MSFC leads to unique CFD requirements
- CFD is good value relative to the cost of testing and redesign
- Known inaccuracy is important for proper application of CFD results
- Unsteady pumps flows, cavitation, and complex geometries require CFD developer's attention