Overview of MSFC's Applied Fluid Dynamics Analysis Group Activities

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Presented at:
MSFC Falls Fluids Workshop
November 19, 2002

Overview

- Introduction
  - Fluid Mechanics at MSFC

- Relevant Fluid Dynamics Activities at MSFC
  - Turbomachinery
  - Nozzles
  - Combustion devices
  - Systems
  - MDA

- Related Topics
  - Hardware investments
  - Process improvements

- Concluding Remarks
Introduction

- High-fidelity fluids design & analysis expertise at MSFC focused in the space transportation directorate
  - CFD (TD64), induced environments (TD63), cold flow testing (TD62, TD63, TD74), and functional design (TD61)
- Fluid dynamics expertise a core competency at MSFC
- Support focused in two broad areas
  - Space Shuttle propulsion
  - Next Generation Launch Technologies
    - Space launch initiative (2nd generation RLV)
    - Advanced Space Transportation Program (3rd generation RLV)

Introduction: Role of Fluid Mechanics Expertise

- Fluid mechanics applications at MSFC focused on improving the safety, reliability, & cost of space transportation systems
- We define geometry, quantify environments, and predict performance
  - Incident investigation support (analysis and test)
  - Environments and performance definition (analysis and test)
  - Develop advanced hardware concepts and designs (analysis and test)
- We support the programs in meeting their goals
  - Assist the programs in being "smart buyers"
  - Provide innovative technical solutions
- We work with external partners who possess key capabilities
  - Other NASA centers, other government agencies, industry, academia
Introduction: CFD Goals

- Provide personnel with the tools to succeed
  - Maintain and enhance civil service personnel capabilities
  - Provide challenging work, hands-on experience, training
  - Continuously improve analysis techniques, computing resources, and test facilities

- Acquire/develop capability to perform broad, CFD-based parametric design concept studies
  - Spend more time engineering, less time "CFDing"
  - More efficient use of available computing resources
  - Requires automation in all phases: grid generation, flow solver, post-processing

- Expand range of CFD applicability
  - Improved models, combustion, transient processes, relative motion, cavitation, multi-component
  - Greater efficiency and robustness in flow solvers

Turbomachinery Activities

- Turbomachinery Dynamic Environments and Performance
  - High power density of rocket engine turbomachinery requires high-fidelity definition of the flow induced environments
  - Supported in TD64 w/ CORSAIR and w/ test definition & support

- Turbopump optimization task
  - 2 stage supersonic turbine, instrumented rotor
  - Tool improvements, design process improvements, rig design, manufacture, and testing

Optimized supersonic turbine
Turbomachinery Activities

SLI Turbine Airflow test rig:
- Subsonic, high flow turbine
- Design, analysis, manufacture, testing
- Instrumented rotor for code validation
- Turbine test rig in manufacture

CFD analysis of tester predicts similar flow patterns as for engine conditions

Test rig mechanical design complete

Rig parts in manufacture

Turbomachinery Activities

- Conducting CFD code validation to support pump-feedline design
  - Manifolds/feedlines interaction w/ rotor is an important effect
  - Have benchmarked Corsair and Chem for pipe flows
  - Applying validated code towards optimization of feedline for candidate configuration
    - Initial optimization w/ feedline alone
    - Final optimization to include coupling of feedline to rotor
Turbomachinery Activities

- **Space Shuttle LPOT nozzle cracking**
  - First application of Corsair to "incompressible" flow field prediction
- **Shuttle feedline flow liner cracks investigation support**
  - Predicting large $p'$ at flow liner due to back flow from inducer
  - Circumstantial evidence supports predictions

Deep Throttle Turbopump task
- Cooperative effort between Ames/MSFC/Rkdn
  - Generate CFD validation data set for pumps
  - Apply validated CFD code to develop deep throttling pump design concepts
  - INS3D from Ames applied to SOA designs
  - Assess code, improve designs
- Task back within project guidelines for FY03
  - Task largely dormant in FY02 due to program budget cuts

Evaluate diffuser concepts to select test configuration
Turbomachinery Activities

- **Concepts NREC Inducer design Phase 2 SBIR**
  - Develop engineering design tools for cavitating inducers
  - Verify through new inducer designs
- **CRAFTech Cavitation Analysis Capability Development Phase 2 SBIR**
  - Extend current model to cryogenic propellants
  - Add time accurate capability in cavitation model
- **Developing Phantom to better support unsteady turbomachinery analysis**
  - Uses much of Corsair infrastructure
  - New formulation will support real fluids model
    - Improved efficiency for solving pump problems
    - 2-phase flows, non ideal fluids, etc.

Turbomachinery Activities

- **Supported Cobra Turbine designs**
  - PW/AJ joint venture staged combustion LOX-H2 engine
  - Performed CFD of main turbines in various environments
    - full 360-degree analysis
  - Supported design of low pressure turbomachinery
  - Airflow test rigs designed

ATD High Pressure Turbines under Cobra Conditions

<table>
<thead>
<tr>
<th>CFD based design parametrics</th>
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Partial admission full annulus calculations variable GAMMA time-averaged flow
Nozzle Activities

- **Technology need**
  - Nozzles are a key component in setting the engines performance, thrust to weight, and operational life limitations
  - Application of CFD tools to advanced nozzle designs immature

- **Recent/Ongoing activities**
  - Have completed initial interaction with European community via NATO RTO Working Group #10
  - Testing of Aerojet designed altitude compensating nozzles complete
    - Full-flowing and separated CFD code validation data sets
    - FDNS comparisons look very good, but painful to obtain
    - Chem validation to follow

- **Recent/Ongoing activities (continued)**
  - Tested dual-throat linear aerospike (Rkdn design concept)
    - Highly instrumented
  - Setting up to test annular aerospike
    - Validation data for aerospike undergoing differential throttling for TVC

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*Images showing nozzle concepts and test setups.*
Combustion Devices

- **Technology need**
  - Contemporary rocket engine combustion devices similar to 1960s-1970s designs
  - Longer life (robust), higher T/W designs required
    - Experimental demonstration of design robustness/life is cost prohibitive
  - Application of CFD in design of combustion devices hampered by real limitations
    - Inadequate accuracy (lack of physical modeling)
    - Inadequate turn-around time
    - Inadequate validation and verification where required physics are included in the CFD tools
  - Current focus at MSFC is in rocket chamber combustion
    - High pressure, all-speed, reacting flows
  - Presentations Wednesday morning
  - Combustion devices technology roadmap meeting and discussion Thursday morning

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Combustion Devices

- **Focus of groups combustion devices activities is the staged combustion injector technology (SCIT) task**
  - Task objective is to develop, validate, and verify a CFD based injector design process
  - Develop 1D injector design/engineering tool
  - Develop optimization tools to allow efficient use of large number of CFD solutions
  - Develop required CFD capabilities for supporting large design parametrics
    - Robustness, physical models, turnaround time
  - Generate validation data sets
    - Verify by testing injector designed using new process
    - Gas-gas, liquid-gas, liquid-liquid
    - H2-O2, HCl-O2
  - Large task with ambitious goals, progress hampered by:
    - Changes in external priorities, direction
    - Greater than anticipated difficulty in achieving required robust (fire-and-forget) capability in FBNS for injector analysis
    - Difficulty in getting data suitable for code validation
- **SCIT task (continued)**
  - Have performed several gas-gas injectors design parametric studies
    - Each on the order of 50 designs
  - Have tested initial gas-gas elements at PSU (code validation)
  - Liquid-liquid injector test rig in manufacturing
  - Multi-element grid template, porosity models being tested

- **Combustion Devices: Injectors and Chambers**
  - Several key areas are likely to get increased attention
    - Hydrocarbon analysis capability improvement (turn-around time)
      - Enhancement to testing at SSC of RS-84 hardware
      - Test data for code validation
      - Assessment of advanced concepts
    - Transient modeling capability
      - Many combustion devices related failures occur during engine transients
      - CFD turnaround time, sub-critical combustion, lack of validation data
    - Combustion Stability
      - The elephant in the room that everyone tries to avoid/pretend it's not there
      - Potential focused NGLT area of focus
      - AFRL potential new initiative
Engine Systems

- **Technology need**
  - T/W of rocket engines sensitive to design of engine manifolds/ducts
  - Many design shortcomings traceable to interaction between components and engine “plumbing”
  - Combined cycle concepts required integrated design/analysis approach

- **Recent/Ongoing activities**
  - Internal assessment of LOCI/Chem from MSU
    - Unstructured, density based code
    - LOCI architecture designed for MDA
    - Under NASA sponsorship for RBCC flow path application
  - Has been applied to engine powerhead problem
  - Will be used to model RBCC flow path

Propulsion-Vehicle System Integration

- **Technology need**
  - SOA vehicle concepts require a high level of propulsion-to-airframe integration
    - Air-breathers (RBCC or TBCC), parallel-burn multi-stages

- **Recent/Ongoing Activities**
  - Developing stage separation database and tools
    - Use generic but relevant vehicle configuration to develop test database
    - Test effort at MSFC, CFD (w/Overflow) at JSC have been great success
  - Further activities under SLI waiting program assessment relative to vehicle development
    - CART3D (Ames) possible efficient way to support concept development
    - Chem w/automated grid templates being developed in U.F. URET
MDA Development

- Technology need
  - Many space transportation system propulsion system failures are multi-disciplinary in nature
    - Thermally induced, fluid-structure interaction, etc.
    - Many are also related to transient or time varying, 3D events
- Recent/Ongoing activities
  - LOCI framework being developed to support 3D, time accurate, MDA analysis capability
  - Initial demonstrations of fluid-thermal-structural modeling capability demonstrated
  - Under URETI plan to continue development of this capability

Validation for Conjugate heat transfer capability

Demonstration of basic fluids-thermal-structural analysis capability

CFD Process Improvements

- Tendency towards greater CFD based design parametrics
- Enabled by access to traditional and non-traditional "super-computers"
  - Access to NASA-Ames SGI based compute clusters
    - 512 and 1024 processor SGI high-end computers
  - Two local PC-based clusters
  - Local SGI O-2000 systems
  - SGI O-2000 desktop workstations

<table>
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CFD Process Improvements

- Tendency towards greater CFD based design parametrics
- Enabled by labor-reducing utilities
  - Improved process efficiency
  - Automatic or near automatic grid generation system
  - "fire-and-forget" flow solver capability
    - Time-stepping, grid adaptation/refinement, multi-gridding, etc
- Dedicated personnel for internal process improvement
  - Create or improved labor reducing utilities for CFD process
  - Develop visualization technology for pre- and post-processing
  - Created automated test suite for software upgrades testing
    - Testing/validation key to robustness, improvements, reliability
    - Must be made affordable
- Continuous process

Concluding Remarks

- TD64 focused on supporting the space transportation programs
  - Engaged in the Next Generation Launch Technologies program, SSME program, IR&D
- Design and analysis tools being applied and/or under development in the major hardware areas
  - Turbines, pumps, combustion devices, engine systems, propulsion-to-airframe integration
  - MDA capabilities under development
- Increasing the design process efficiency and fidelity is paramount
  - Attempting to address key shortcomings in CFD process
- Code validation, robustness, reliability key to meeting CFD's promise