DESIGN AND ANALYSIS OF A TURBOPUMP
FOR A CONCEPTUAL EXPANDER CYCLE
UPPER-STAGE ENGINE

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Symposium on Advances in Numerical Modeling of Aerodynamics and Hydrodynamics in Turbomachinery

Outline

- Motivation
- Numerical method
- Numerical simulations
  - vaneless diffuser
  - vaned diffuser
- Conclusions

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Motivation

- Develop technologies to be applied to CLV/CEV engine programs
  - analytical tools → 1D meanline analysis and 3D CFD
  - mechanical design
  - water flow tests
- Design a conceptual expander-cycle upper stage engine
- Demonstrate the design using water flow testing

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Numerical Methods - I

- Meanline analysis and geometry generation
- Pump Design
  - Concepts NREC design suite
    - Agile Engineering Design System®, PUMPAL®, CCAD®
- Diffuser design
  - Riverbend Design Services pump design code

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Numerical Methods - II

- PHANTOM CFD code
- Three-dimensional, unsteady N-S equations
- Generalized Equation Set formulation
  - Handles liquids and gases
  - Incompressible, compressible and supersonic flow
  - Preconditioning for incompressible flows
- Implicit, time marching, finite difference scheme
- 3rd order spatially, 2nd order temporally accurate
- Modified Baldwin-Lomax turbulence model
- Overlaid O- and H-grids

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Numerical Methods - III

- MPI for parallel simulations
- Fluid property routines
  - Perfect gas
  - Real fluid property routines for xenon, N₂, H₂, H₂O, O₂, RP, CH₄, CO, N₂H₄, MMH and N₂O₄
  - Two types of real fluid property routines
    - **Routines provided by J. Oefelein of Sandia Labs** – liquid and gas
      - Solve equations of state, etc.
    - **Routines derived from the NIST tables** – liquid and gas
      - Surfaces generated from splines of data

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Design Requirements for Water Flow Rig

- Operate in existing water flow facility
- 977 gpm flow rate
- Rotational speed of 3600 RPM
- 70% flow coefficient throttling capability
- Diffuser vane/volute radius and passage constraints due to rig requirements
  - vanes must accommodate 17 bolts
- Actual engine was designed to have two stages, but the water flow model designed to have one stage

Guide Vane and Impeller Design

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Guide Vane and Impeller Design

Mean Streamtube Analysis

Streamlines

Impeller pressure rise

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Guide Vane and Impeller Design

Final Pump Design
1. 15 inlet guide vanes
2. Impeller with 7 main blades and 7 splitter blades

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CFD for IGV, Impeller, Vaneless Diffuser

- Computational grid contains 4.75 million grid points
- $y^+$ values of $\sim 4$ on endwalls
- $y^+$ value of $\sim 1$ on airfoils
- full 360 deg modeled
- Simulations run on 72-106 processors of an SGI Altix

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CFD for IGV, Impeller, Vaneless Diffuser

Relative total pressure (psi)

Time-averaged

Instantaneous

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CFD for IGV, Impeller, Diffuser

Performance predicted by meanline and CFD codes

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CFD for IGV, Impeller, Vaned Diffuser

Time-averaged loading on the impeller and diffuser

![Graphs showing static pressure distribution along arc length for Impeller and Diffuser](image)

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CFD for IGV, Impeller, Vaned Diffuser

Unsteadiness on the impeller trailing edge with downstream diffuser vanes

![Graphs showing pressure trace and pressure decomposition](image)

Vane passing frequency = 1020 Hz

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CFD for IGV, Impeller, Vaned Diffuser

Unsteadiness on the diffuser leading edge with the upstream impeller

Pressure trace

Pressure decomposition

Blade passing frequency = 840 Hz

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Water Flow Tests

Design to be tested in MSFC water flow facility late summer 2006

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Conclusions

- Inlet guide vane, impeller and diffuser designed for a conceptual expander cycle upper stage engine
- Meanline analysis and three-dimensional unsteady CFD show that the design meets the requirements and constraints
- Water flow testing of the design should begin late summer 2006