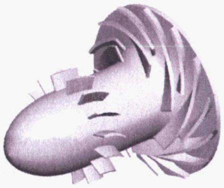
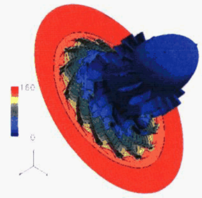
DESIGN AND ANALYSIS OF A TURBOPUMP FOR A CONCEPTUAL EXPANDER CYCLE UPPER-STAGE ENGINE





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Outline

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

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

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

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**

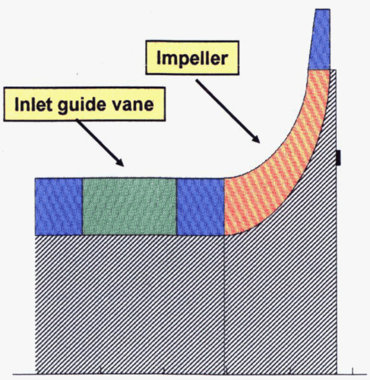
Numerical Methods - III

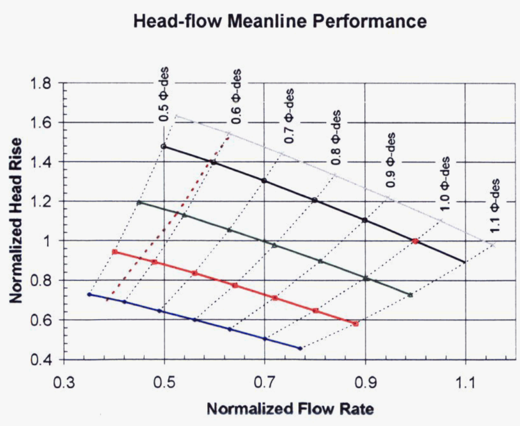
- **MPI for parallel simulations**
- **Fluid property routines**
  - Perfect gas
  - Real fluid property routines for xenon, N_2, H_2, H_2O, O_2, RP, CH_4, CO, N_2H_4, MMH and N_2O_4
  - Two types of real fluid property routines
    - **Routines provided by J. Oefelein of Sandia Labs – liquid and gas**
      - Solve equations of state, etc.
    - **Routines derived from the NIST tables – liquid and gas**
      - Surfaces generated from splines of data

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

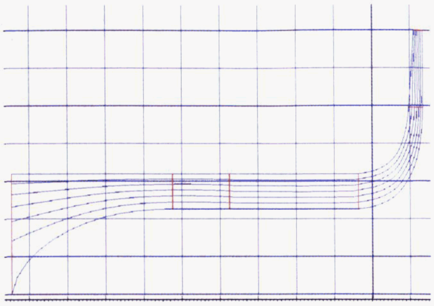
Guide Vane and Impeller Design



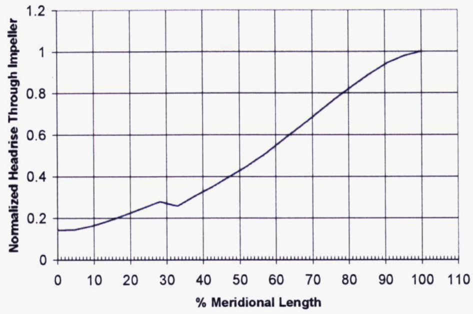


Guide Vane and Impeller Design

Mean Streamtube Analysis

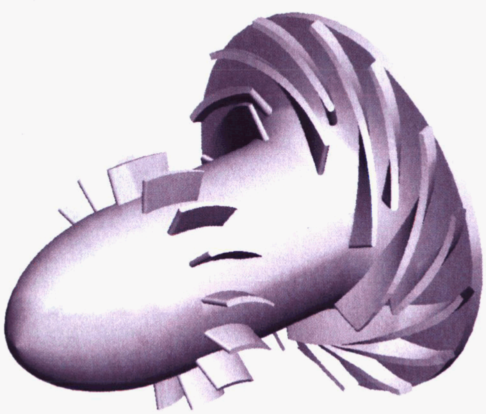


Streamlines



Impeller pressure rise

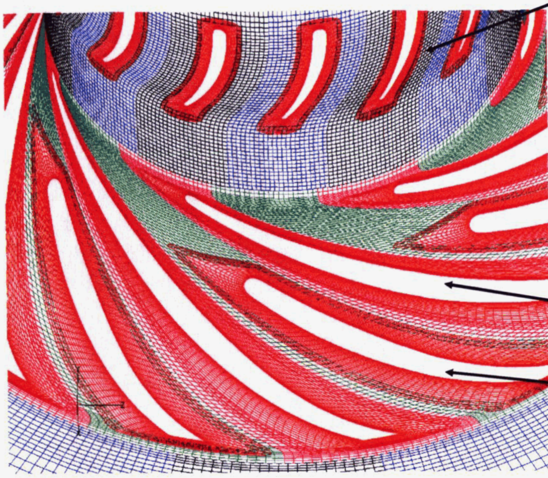
Guide Vane and Impeller Design



__Final Pump Design__

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

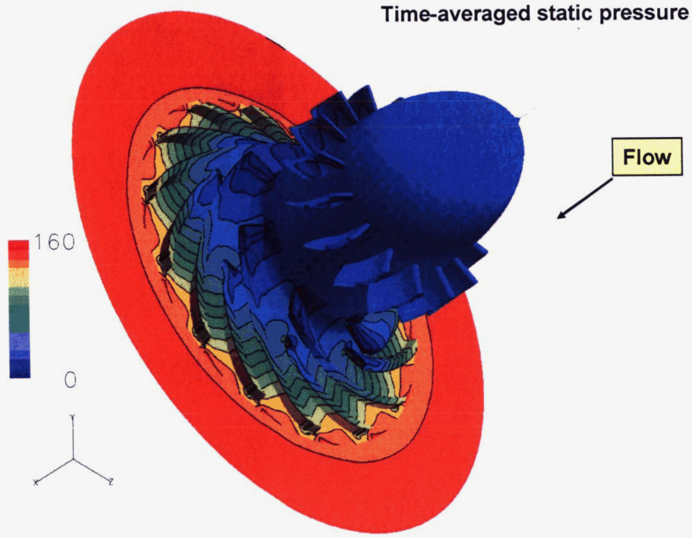
CFD for IGV, Impeller, Vaneless Diffuser



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

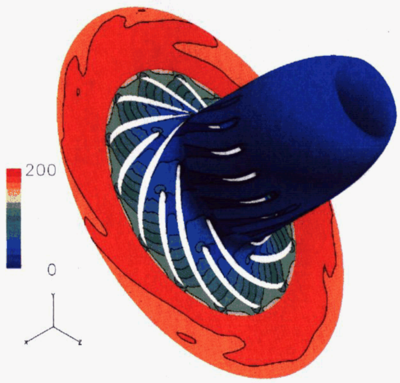
CFD for IGV, Impeller, Vaneless Diffuser

Time-averaged static pressure (psi)

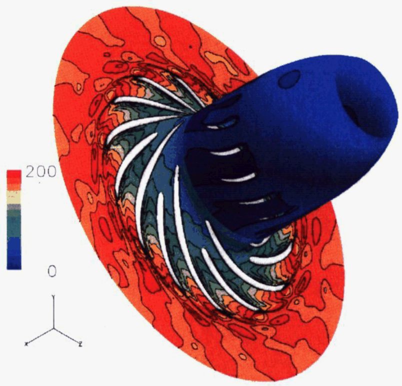


CFD for IGV, Impeller, Vaneless Diffuser

Relative total pressure (psi)



Time-averaged



Instantaneous

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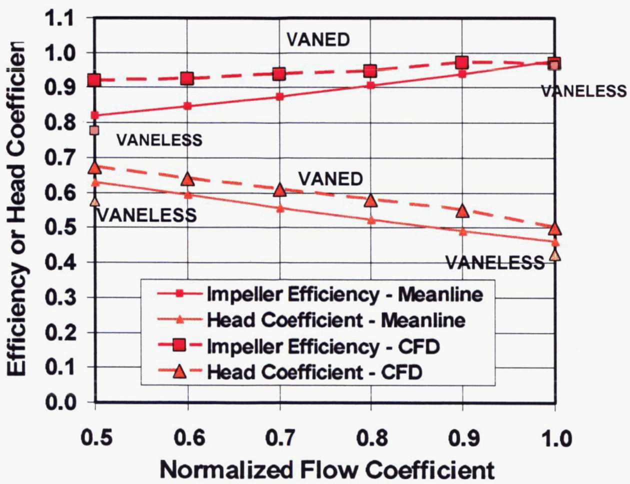
CFD for IGV, Impeller, Diffuser

Performance predicted by meanline and CFD codes



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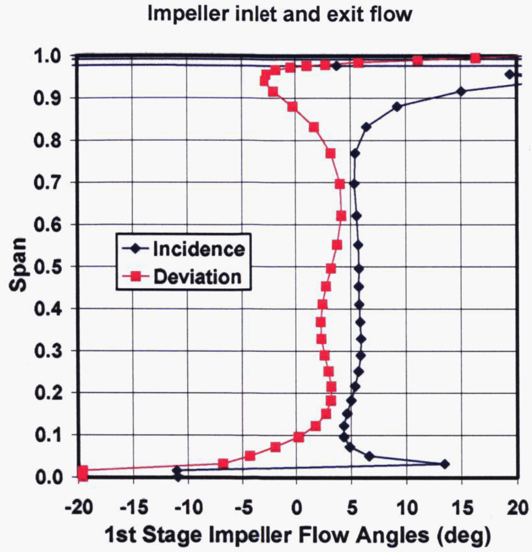
CFD for IGV, Impeller, Vaneless Diffuser



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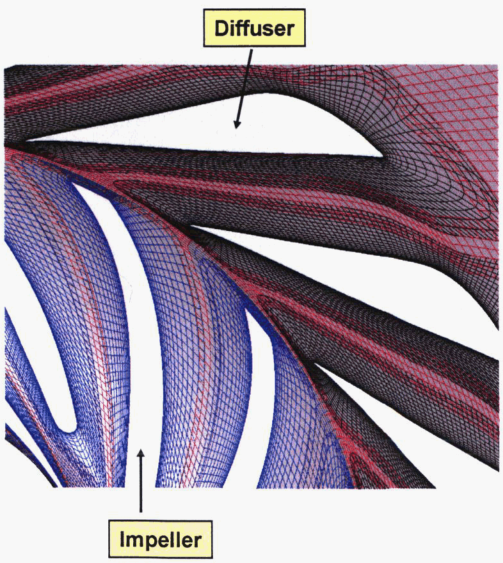
CFD for IGV, Impeller, Vaned Diffuser



Variable	Optimum	Actual
L/W_1	4.00	2.60
W_2/W_1	1.60	1.34
θ (deg)	10.0	7.40

- 17 diffuser vanes
- chord of vane limited by collector

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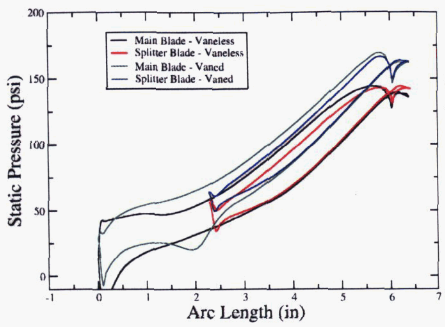
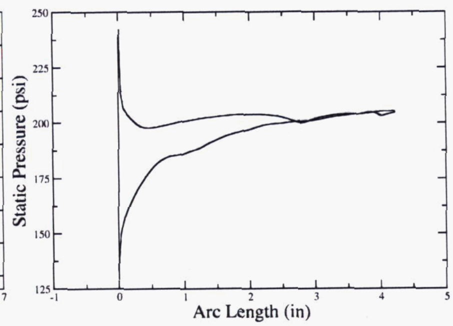
CFD for IGV, Impeller, Vaned Diffuser

Time-averaged loading on the impeller and diffuser



Impeller



Diffuser

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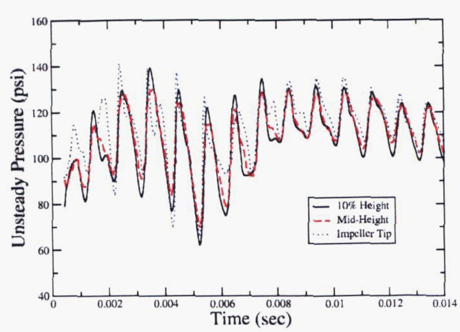
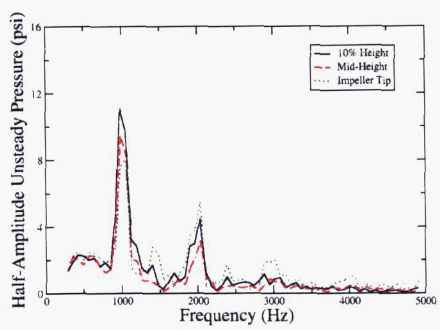
CFD for IGV, Impeller, Vaned Diffuser

Unsteadiness on the impeller trailing edge with downstream diffuser vanes



Pressure trace



Pressure decomposition

Vane passing frequency = 1020 Hz

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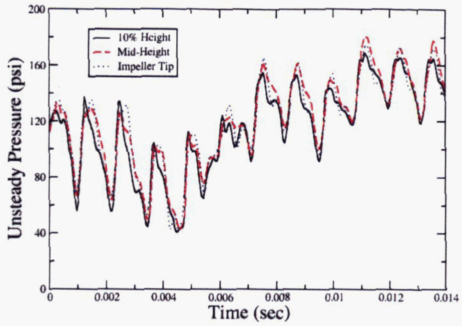
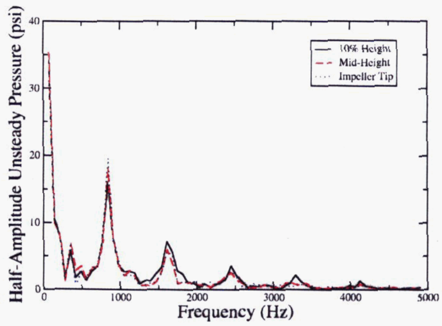
CFD for IGV, Impeller, Vaned Diffuser

Unsteadiness on the diffuser leading edge with the upstream impeller



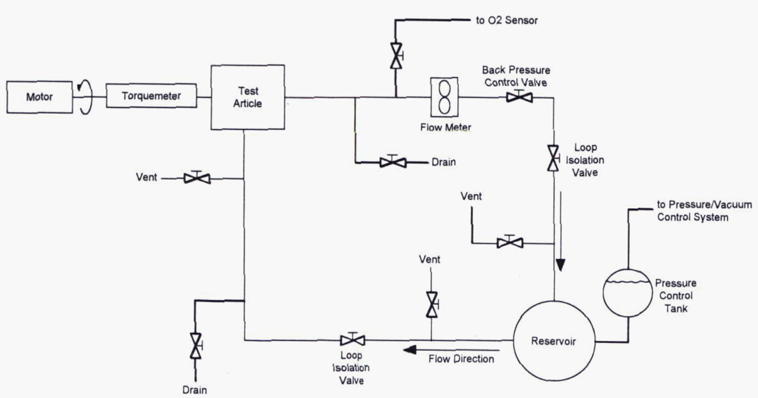
Pressure trace



Pressure decomposition

Blade passing frequency = 840 Hz

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