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FLUENT Features & Applications For Turbo-machinery Industry

Dec 3. 2004
Technical Support Team

CFD Solution Div.

Advanced Technology Engineering Service

Agenda

- Fluid Flow
  - SRF (Single Reference Frame)
  - MRF (Multiple Reference Frame)
  - MPM (Mixing Plane Model)
  - SMM (Sliding Mesh Model)
- Moving Dynamic Mesh
  - 2.5D Remeshing Technique
- Multiphase
  - Cavitation
- Noise
  - Noise Analysis for Turbo-machinery Applications

Fluent Solutions for Rotating Machinery

SRF/ MRF/ MPM/ SMM

- **S**ingle (Rotating) **R**eference **F**rame (SRF)
  - Entire computational domain is referred to rotating reference frame
- **M**ultiple (Rotating) **R**eference **F**rames (MRF)
  - *Selected regions of the domain are referred to rotating reference frames*
  - Ignore interaction effects steady-state
- **M**ixing **P**lane **M**odel (MPM)
  - Influence of neighboring regions accounted for through use of a mixing plane model at rotating/stationary domain interfaces
  - Ignore circumferential non-uniformities in the flow steady-state
- **S**liding **M**esh **M**odel (SMM)
  - *Motion of specific regions accounted for by mesh motion algorithm*
  - Flow variables interpolated across a sliding interface
  - *Unsteady problem - can capture all interaction effects with complete fidelity*

New Features
Non-conformal & Sliding Interfaces

- "Virtual Polygon" algorithm for non-conformal and sliding interfaces
  - Less sensitive to *small geometric defects at the interface*
  - New cases will use new algorithm by default
  - Old method is retained
    - *Old cases will use old method by default*
  - To apply "virtual polygon" approach to old cases
    - TUI-only command (define/grid-interfaces/use-virtual-polygon-approach)
    - Command is visible if the case is using the older algorithm
  - Applies also to non-conformals at periodic boundaries

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New Features
Non-conformal & Sliding Interfaces

- "Virtual Polygon" algorithm for non-conformal and sliding interfaces (cont'.)
  - Testing to date indicates much improved robustness
    - Sliding interfaces
    - Notable improvement in cases with rotationally periodic boundaries
    - Many cases which failed in 6.1 now work in 6.2
  - No changes to interface
  - Works in serial and parallel
    - Options for both non-encapsulated and encapsulated interfaces
      - Non-encapsulated interfaces more efficient for large parallel problems
      - Encapsulated option still available pending further testing

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Centrifugal Pump Cavitation

- Solver: segregated, steady-state solution
- Single reference frame

- **Non-cavitating cases**
  - Model run over a range of flowrates (100 – 275 m^3/hr)
  - Relation between the pump head rise (pressure rise) and flow rate is studied
- **Cavitating Cases**
  - Flowrate fixed at design flow (210 m^3/hr)
  - Initial exit pressure at 600 kPa was decreased in 50 kPa increments to gradually develop cavitating conditions
  - Predicted head rise vs NPSH compared with data
    - NPSH = $(P_{inlet} - P_{vapor})/(\rho g)$
    (NPSH=Net Positive Suction Head)

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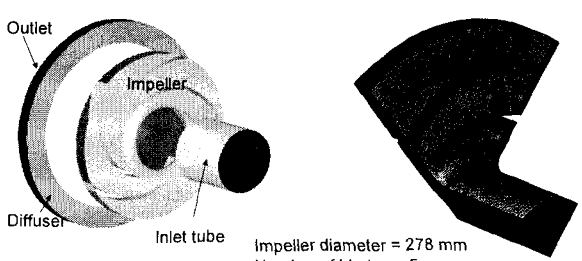
FLUENT

Centrifugal Pump Cavitation

- Single blade passage modeled with rotationally-periodic boundaries



Impeller diameter = 278 mm
Number of blades = 5
Speed = 2160 rpm

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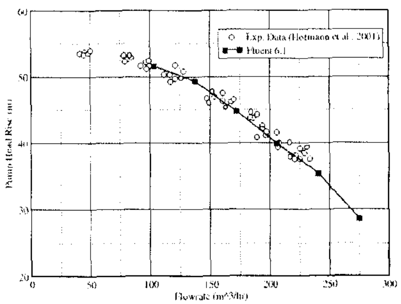
FLUENT

Centrifugal Pump Cavitation
Result: Non-cavitating

Non-cavitating Pump Curve



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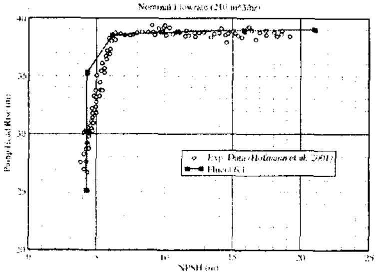
Centrifugal Pump Cavitation

Result: Cavitating



- Excellent agreement with test data
- NPSH *reaches a minimum value as system pressure level is reduced*

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Moving & Deforming Mesh

Spring Analogy/ Layering/ Remeshing/ 2.5D Capablities

- *Dynamic adaption in conjunction with dynamic mesh*
- Improved parallel performance
  - *Particularly when multiple mesh motion methods are used*
- Expanded remeshing and layering capabilities
  - *More general usage of remeshing and layering*
  - Local remeshing in mixed cell zones
  - 2.5D remeshing and smoothing
- Expanded capabilities for mesh motion events
  - Event handler available for all dynamic mesh simulations
  - Additional event definitions

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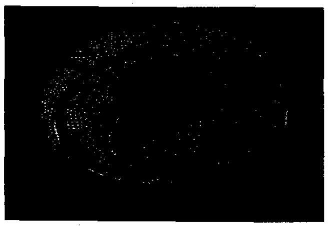
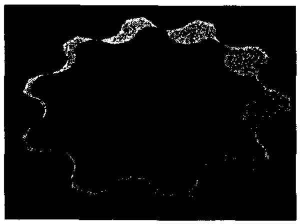
Flow Meter & Gear Pump



Flow Meter



Gear Pump

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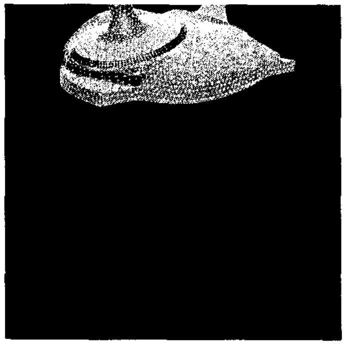
Boundary Region Remeshing



- FLUENT 6.1
  - Single zone
  - Closed loop
- FLUENT 6.2
  - Symmetric boundaries
  - Across multiple zones
  - Feature preservation
  - Non-closed loops

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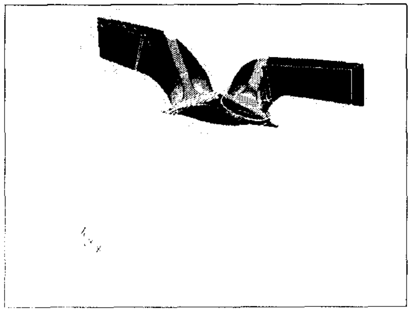
FLUENT 6.2

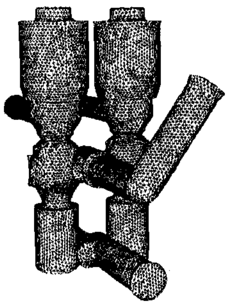
Dynamic Mesh/Symmetry: 4 Stroke Engine



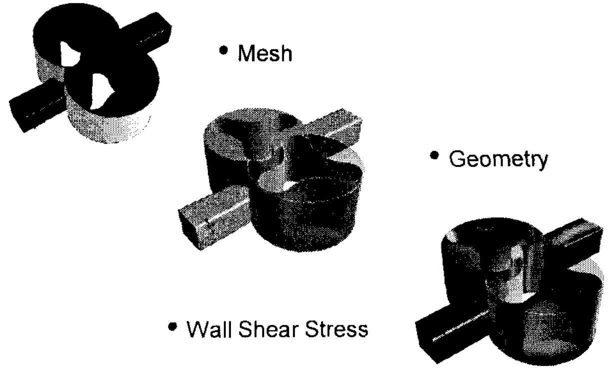
Contours of
Velocity Magnitude

Coolant Control

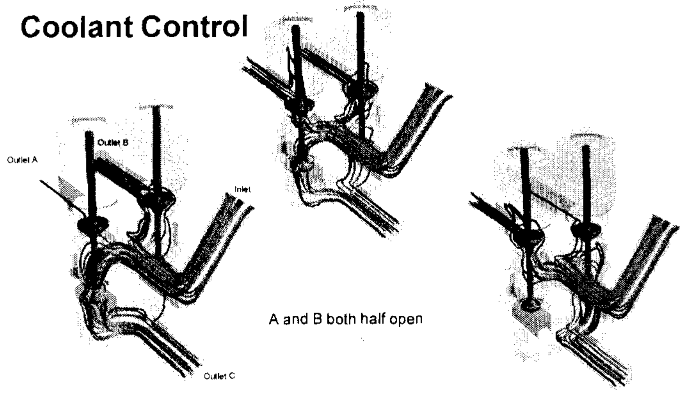
- FLUENT 6 is used
    - Transient analysis
    - Moving and deforming mesh
- Tetrahedral mesh with 170,000 cells
- Incoming flow splits into three outlets
- Valve spools (brown) control flow
- Profile data describe the motion of the valve



Lobed Pump



Coolant Control



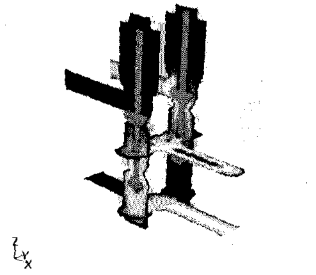
Side B – open, Side A – closed

A and B both half open

Side A - open, Side B - closed

FLUENT

Coolant Control



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New Features
Cavitation

- Cavitation model enhancements
  - Ability to include heat transfer
    - Vaporization pressure, surface tension coefficient can be functions of temperature
  - Improve ease of set-up for cavitation model
  - Ability to add non-condensable gas phases
    - As additional secondary phase(s)
    - As part of a secondary phase "mixture"
  - Enhanced algorithm, more robust and accurate
  - Compressibility of liquid and gas phases
    - Now practical to include a compressible gas phase
    - Compressible liquid modeling (new in 6.2!)
      - Available for both single and multiphase simulations
      - UDF option (user-defined dRho/dp)
      - Water hammer simulations
  - Disable "Outflow" BC when the cavitation model is used

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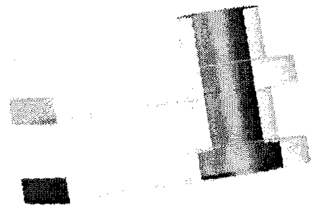
Cavitating Spool Valve

- Spool valves are used to control oil flow and pressure in automotive applications
- Hydraulic forces on the spool, influenced by cavition, are of interest
- A FLUENT simulation of flow with cavitation has been done for a fixed spool position
- The vapor is treated as a compressible gas



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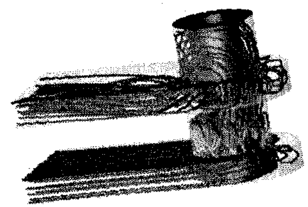
FLUENT

Cavitating Spool Valve

- Oil enters at the bottom left
- When it turns to pass through the annular spool region, there is a drop in pressure
- When the pressure falls below the vapor pressure, cavitation occurs



- Pathlines, colored by vapor volume fraction, illustrate the flow and cavitating regions

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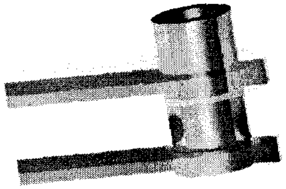
FLUENT

Cavitating Spool Valve

- A mesh of 1.6 million cells is used, with refinement near *the cavitating regions*
- Absolute pressure on the central plane shows the drop in pressure in the spool region (dark blue)



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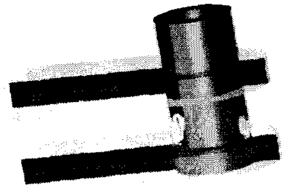
FLUENT

Cavitating Spool Valve

- Contours of vapor volume fraction show the cavitating region.
- Liquid oil must circulate around the bubbles formed
- CFD *simulations are useful in* analyzing equipment such as this during the design phase, so that problematic designs or operating conditions can be avoided



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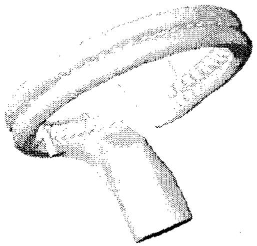
FLUENT

Cavitating Fuel Pump

- Cavitation in an automotive fuel pump is studied using FLUENT
- The pump is immersed in the fuel tank
- Fuel – or a mixture of fuel and vapor – is ingested through the inlet, below
- A rotor transports the fuel around to the outlet, above the *pump*



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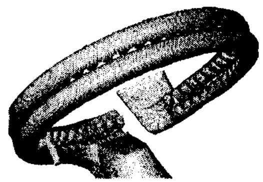
FLUENT

Cavitating Fuel Pump

- A mesh of 680,000 cells is built from the surface grid, right
- The RNG k-ε model is used for turbulence
- The MRF model is used for the rotor motion
- The cavitation model allows for
  - cavitation
  - condensation
  - compressible fluids
  - vapor *ingestion*



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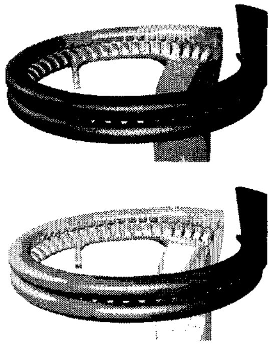
Cavitating Fuel Pump

- Contours of vapor on the pump surfaces for moderate (top) and substantial (bottom) vapor ingestion
- Condensation occurs for both cases
- Local cavitation (red) occurs near the rotor for both cases



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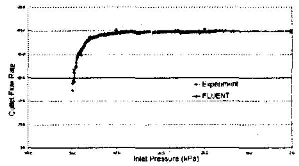
Cavitating Fuel Pump

- Mass flow rate as a function of inlet pressure shows excellent agreement between FLUENT and measurements
- *The simulation helps provide insight into the operation of the pump, and how performance is impacted by design changes*



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New Features
Acoustics

- Ffowcs-Williams & Hawkings acoustics model
  - Support for rotating surfaces (fan noise)
    - *Single reference frame*
      - For steady state calculations, the user will need to input a pseudo time step
    - *Sliding mesh*
    - Not available with *multiple reference frame* model
      - In these cases use sliding mesh
  - Compatible with coupled implicit solver
    - Acoustics in high speed flows

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FLUENT

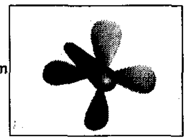
New Features
Acoustics

- Rotating surface noise: Marine propeller

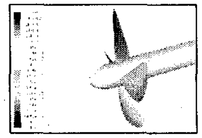
4-Bladed US Navy Marine Propeller

Rotation Speed n=3000 rpm

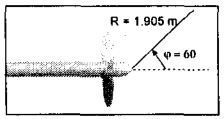
Blade-Passage Frequency BPF = 200 Hz



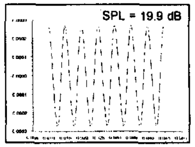
Geometry



Steady-State Static Pressure (Pa)



Receiver's Position



Acoustic Pressure Variation

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FLUENT

New Features
Acoustics

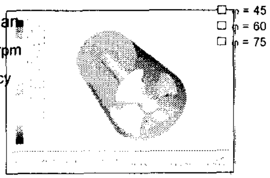
- Rotating surface noise: Ventilation fan

4-Bladed Ventilation Fan

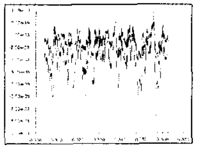
Rotation Speed n=2000 rpm

Blade-Passage Frequency

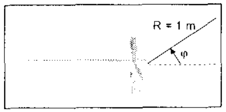
BPF=133.3 Hz



Static Pressure (Pa)



Acoustic Pressure Variation (Pa)



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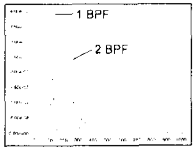

Power Spectral Density (W/m²)

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