Idaho National Laboratory

RELAP5-3D Compressor Model

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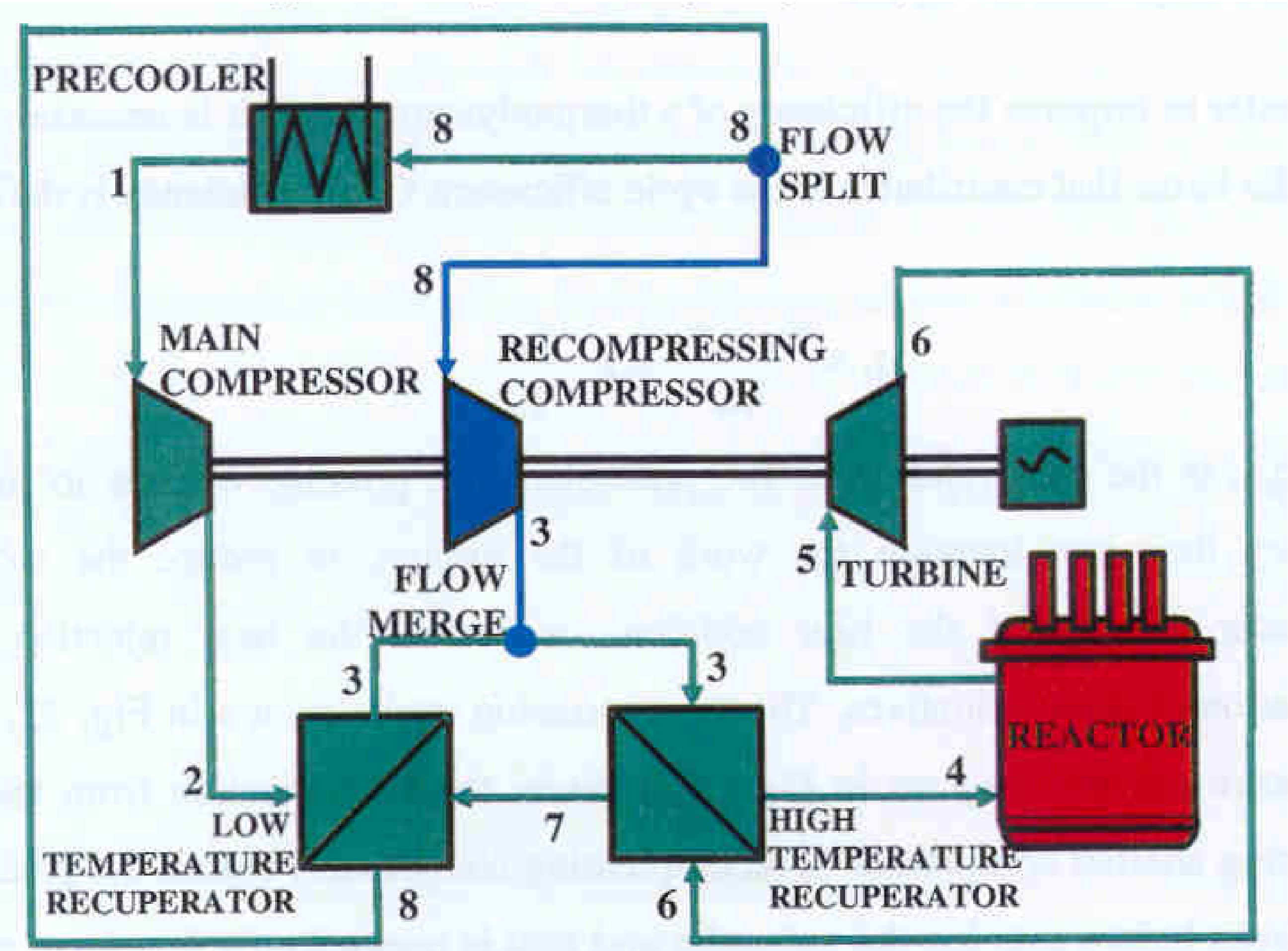
Outline of Presentation

- Compressor characteristics and applications
- Implementation into RELAP5-3D
  - Comparison/contrast to existing pump model
  - Input data considerations
- Verification testing
- Conclusions

Compressor Characteristics

- Positive Displacement
  - Low flow rates, high pressure ratio
- Dynamic
  - Convert velocity to pressure in continuous flow process
  - Centrifugal
    - $1.3 < P_o/P_i < 13$
    - $75\% < \eta < 87\%$
  - Axial flow
    - $1.1 < P_o/P_i < 1.4$
    - $80\% < \eta < 91\%$

Recompression Brayton Cycle Reactor



Similarities Between Compressor and Pump Models in RELAP5

- Rotational velocity
  - Input from table with or without trip
  - Torque-Inertia equation, optionally with motor torque
  - Shaft rotational velocity equation
- Spindown (coastdown) data
- Dissipation

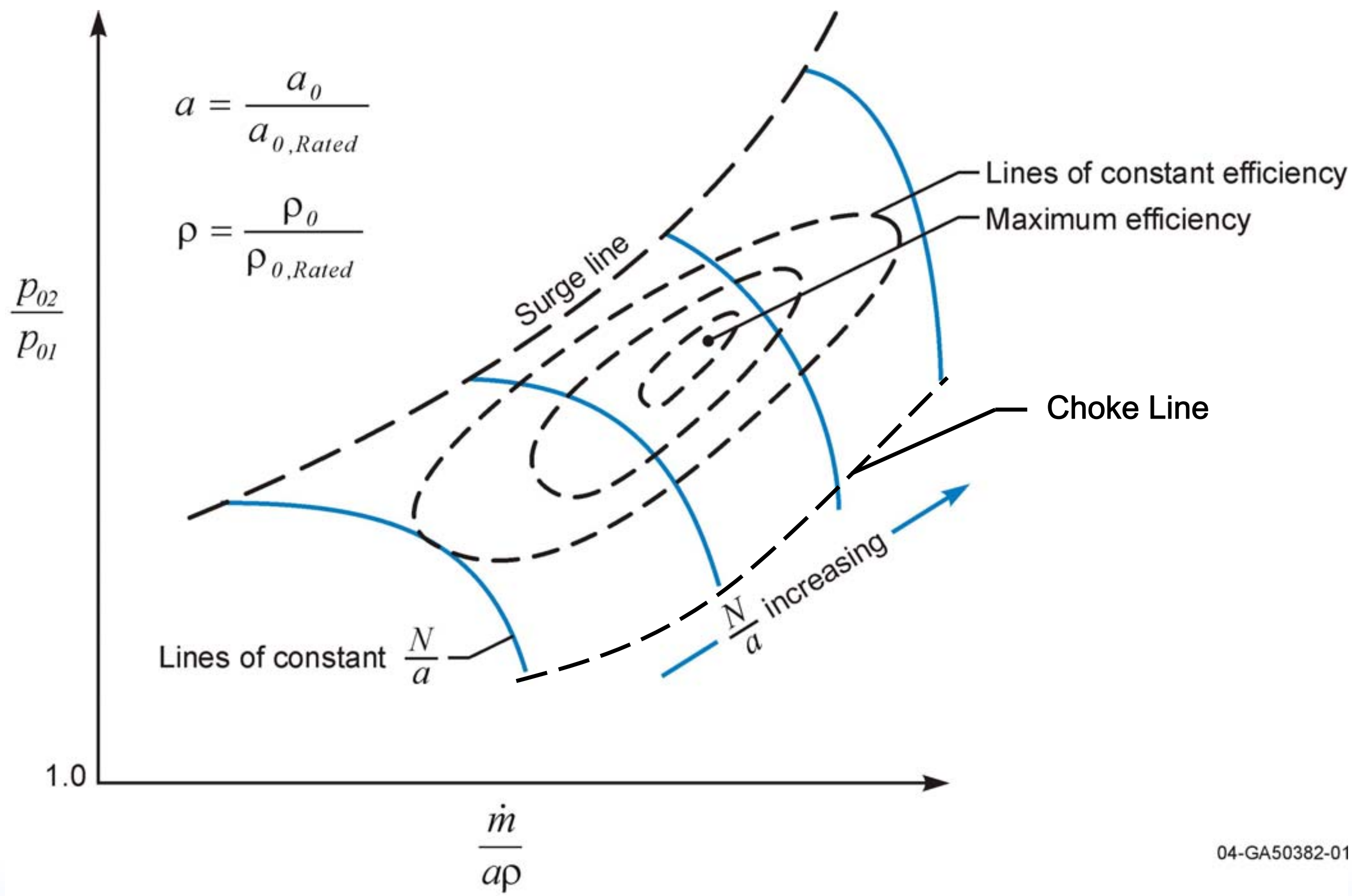
Differences Between RELAP5 Compressor and Pump Models

- Only inlet junction has head added to fluid
- Volume is the outlet state
- Outlet junction is optional
- Outlet can be connected to another compressor or a non-compressor

RELAP5-3D Implementation

- Volume-oriented component
- Independent variables are speed and flowrate
- Pressure ratio and linearized density used to calculate real outlet state
- Compressor head appears in mixture momentum equation
  - Added to Inlet Junction
  - Liquid and vapor phase terms present
- Efficiency determines isentropic and dissipative torque components
- Dissipative torque added to energy equation

Compressor Performance Map



Performance Characteristics

- **Normal operation**
  - Region between the surge and choke points
  - Surge
    - Aerodynamic instability in impeller or diffuser
    - Intermittent flow direction (and force direction) reversal
  - Choking
    - Sonic flow at minimum area point
    - Efficiency drops rapidly

Dimensionless Variable Input

- Independent dimensionless parameters
- Corrected mass flow

$$\dot{m}_C = \frac{\dot{m}}{\rho_{0,in} a_{0,in} D^2}$$

- Corrected speed

$$\mathrm{N_C} = \frac{\mathrm{ND}}{\mathrm{a}_{0,\mathrm{in}}}$$

Relative Corrected Variables

- Mass flow rate

$$\mathrm{v} = \frac{\dot{\mathrm{m}}}{\rho_{0,\mathrm{in}}\,\mathrm{a}_{0,\mathrm{in}}} \Bigg/ \left(\frac{\dot{\mathrm{m}}}{\rho_{0,\mathrm{in}}\,\mathrm{a}_{0,\mathrm{in}}}\right)_{\mathrm{Rated}}$$

- Speed

$$\alpha = \frac{\mathrm{N}}{\mathrm{a}_{0,\mathrm{in}}} \Bigg/ \left(\frac{\mathrm{N}}{\mathrm{a}_{0,\mathrm{in}}}\right)_{\mathrm{Rated}}$$

Low Flow Considerations

- Compressor total torque

$$\tau_T = \frac{\dot{m}}{\omega}\,\frac{P_1^T}{\rho_m}\,\frac{R_P - 1}{\eta_{ad}}$$

  Becomes indeterminate if R_P -> 1 and η_{ad} -> 0

- Use l'Hopital's rule

$$\lim_{Rp\to 1,\eta_{ad}\to 0}\frac{R_P - 1}{\eta_{ad}} = \lim_{Rp\to 1,\eta_{ad}\to 0}\frac{d(R_P - 1)}{d(\eta_{ad})}$$

- Apply for $\eta_{ad} < 1\text{x}10^{-10}$

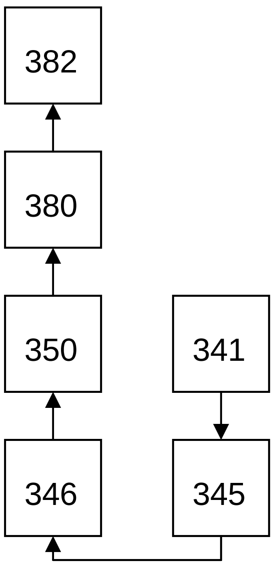
Verification Testing

- Compared to MIT design calculations[1]
  - Gas-Cooled Fast Reactor
  - Supercritical CO_2 Cycle
- Two compressors
  - Main compressor
  - Recompressing compressor
- Results shown for recompressing compressor

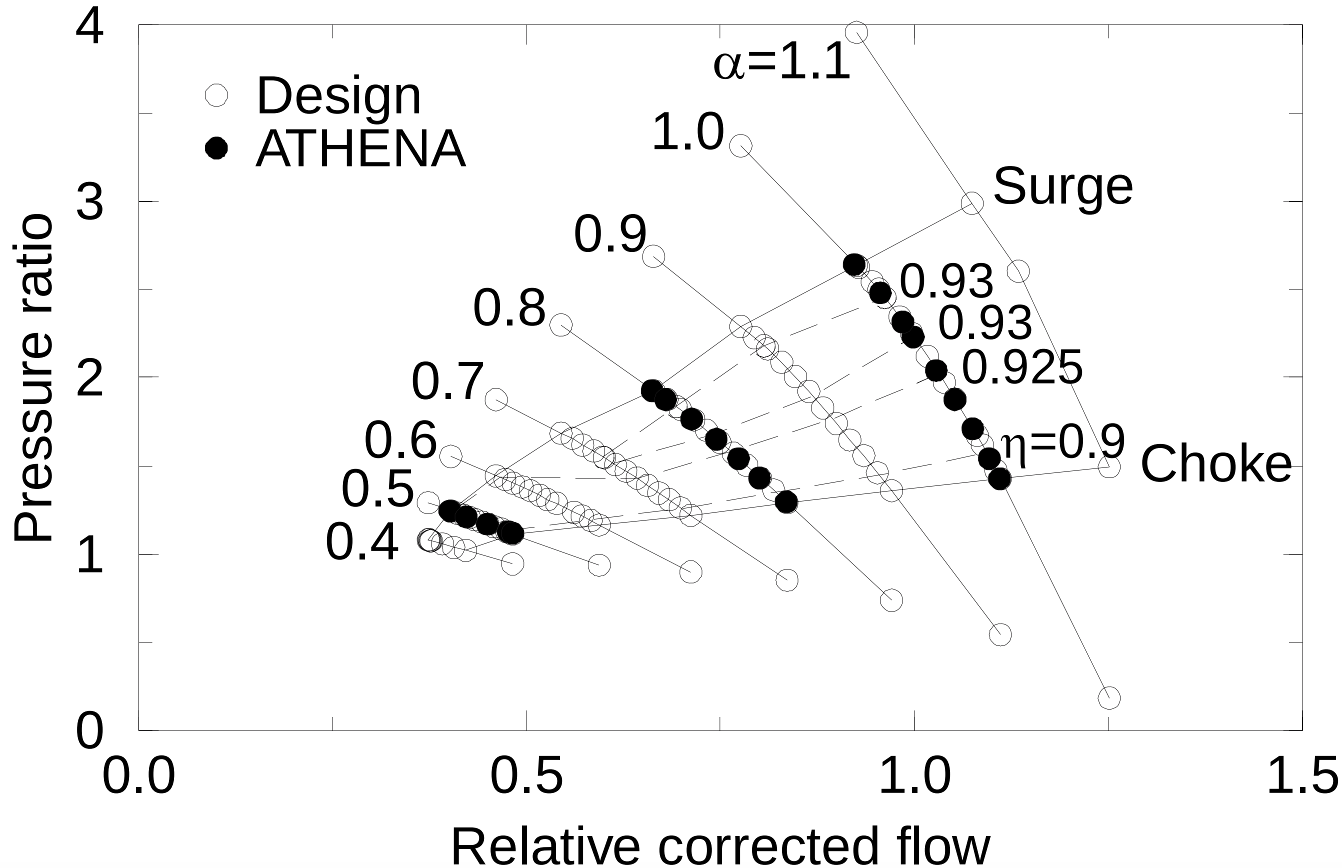
1. Dostal, V. et. al., *CO_2 Brayton Cycle Design and Optimization,* MIT-ANP-TR-090, Massachusetts Institute of Technology, November 2002.

RELAP5 Separate Effects Model

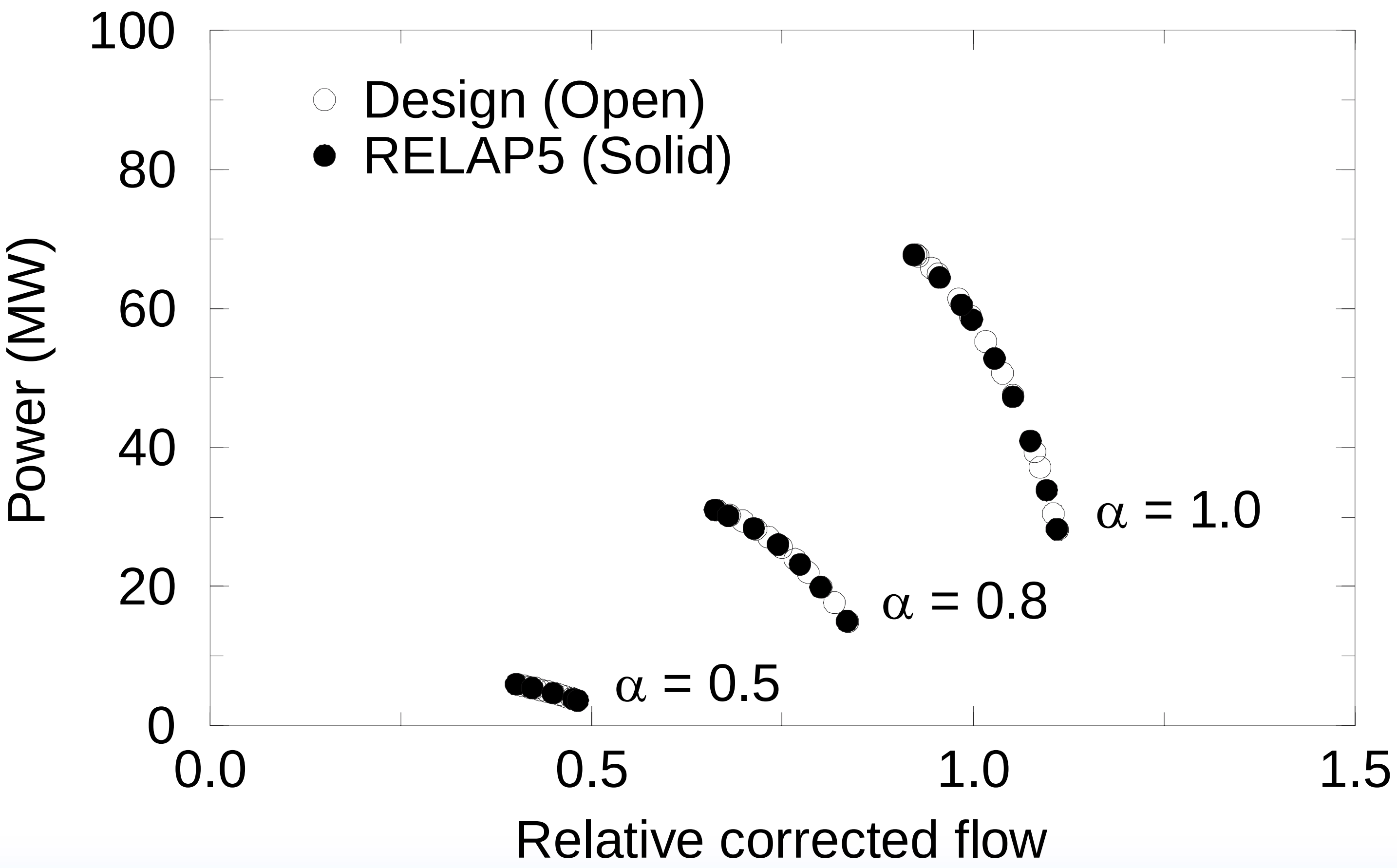
- Compressor is Component 350
- Components 345, 346, and 380 Represent plena
- Area of Component 346 large
- Pressure boundary conditions at 341 and 382
- Steady-state calculations for range of flows and speeds
  - Relative corrected speeds of 0.5, 0.8, 1.0



Pressure Ratio Comparison



Power Consumption Comparison



Conclusions

- Compressor implementation similar to pump
  - All rotational velocity, coastdown, torque-inertia options available
  - Head in mixture momentum equation, dissipation in energy equation
- Linear interpolation over relative corrected speed and flow used to determine pressure ratio and efficiency
- Verification testing demonstrated satisfactory performance