Intermediate Pressure Combustion Rig

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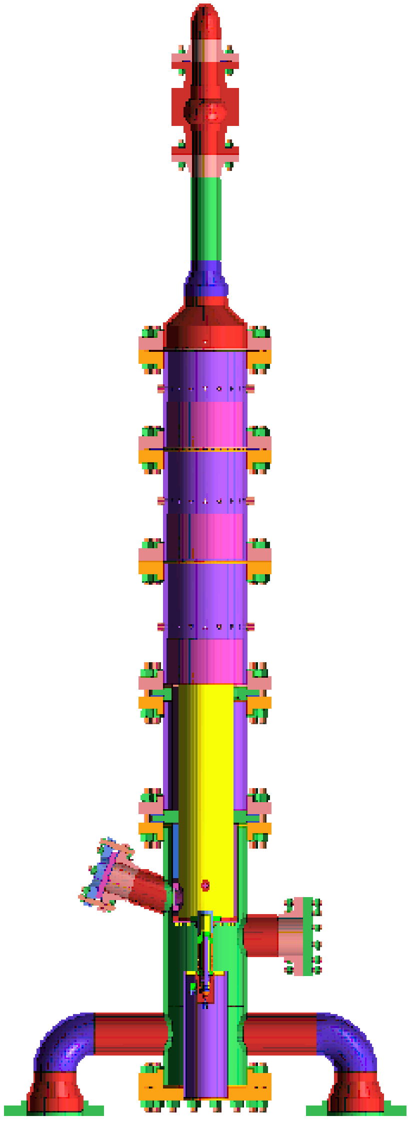
Presentation Outline

- Background
- Cooling Water System (CWS)
- Cross-flow Injection Test
- CWS Nozzle Design
- Miscellaneous

Background

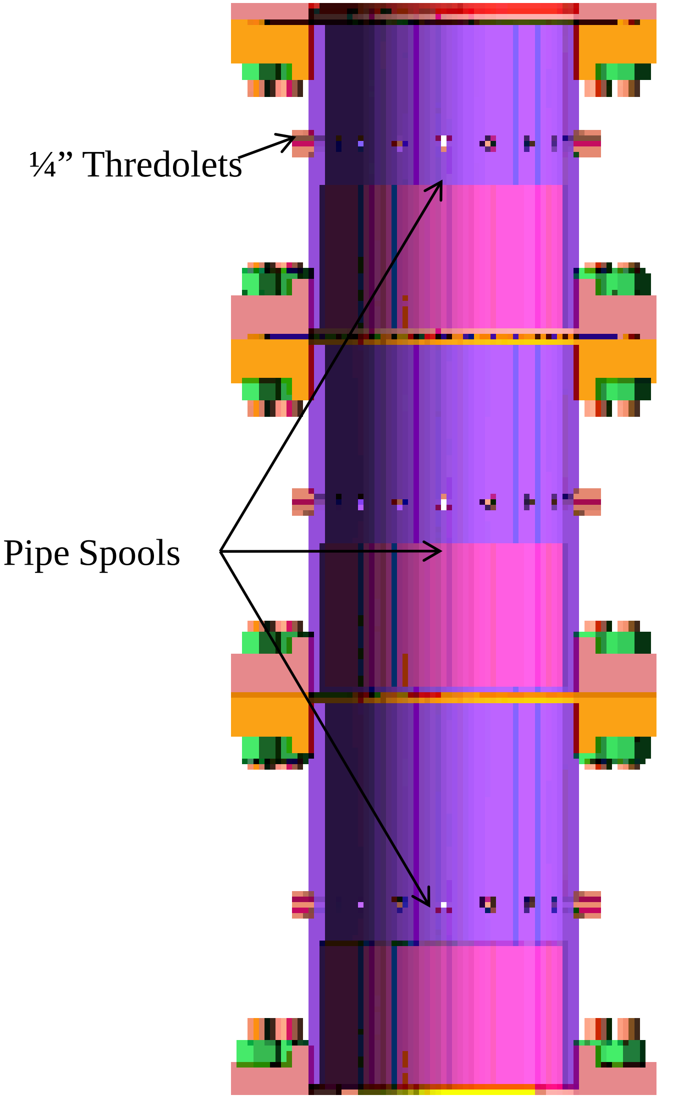
- Woodward began design and construction of an Intermediate Pressure Combustion Rig to support development, testing and analysis of natural gas and kerosene fuel injectors
- The Intermediate Pressure Combustion Rig operating parameters are:
  - 100 PSIG Chamber Pressure
  - 2 PPS Air Supply
  - Heaters to Preheat Air to 600°F @ 2 PPS
- I was assigned to design and build the cooling water system to regulate the exhaust temperature



Cooling Water System

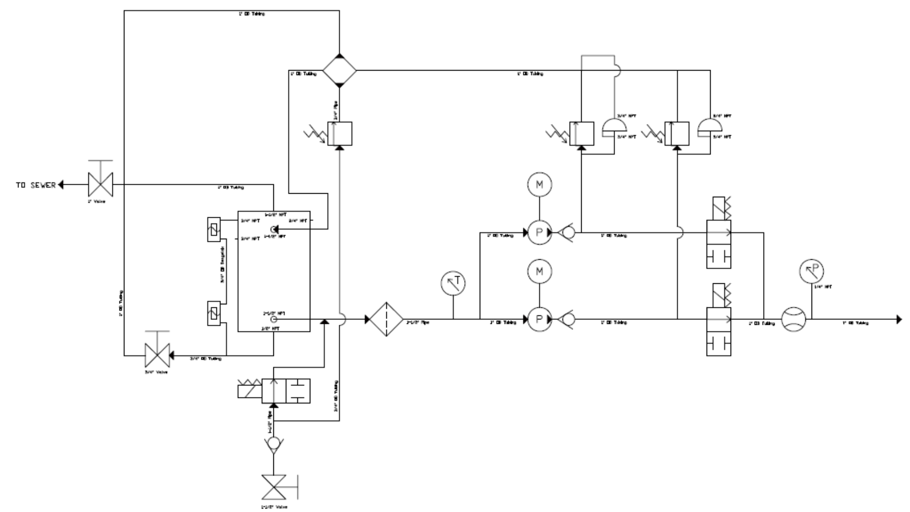
- Cooling Water System (CWS)
  - The cooling water will be injected into the hot gas stream through a series of pipe spools as shown. Each spool has 16 thredolets for mounting of nozzles.
  - CWS Needs
    - Nozzles to mate to existing pipe spools
    - System needs to supply sufficient water to keep uniform gas temperature below 600°F
    - Be safe and reliable
  - CWS Design Steps:
    - Step 1: Energy balance between cooling water and the hot gas stream to determine required water flowrate
      - Rate of Change in Energy of Water = Rate of Change in Energy of Hot Gas

$$\dot{m}_{H_2O}\left(C_{p,liq}\Delta T_{liq} + h_{fg} + \Delta h_{vap}\right)_{H_2O} = \dot{m}_{gas}\Delta h_{gas}$$



Cooling Water System (Cont.)

- Step 2: Develop CWS layout
  - Layout consists of a water supply tank, which feeds two pumps. The water flowrate is regulated through a set of proportional bypass valves.
  - Series of check valves and level transmitters to maintain good and safe operation
- Step 3: Design the CWS nozzle
  - Needs to mate to a ¼” NPT Female thredolet.
  - Nozzle needs to penetrate the cross-flow and quench the hot gas stream uniformly
  - Performed Cross-flow Injection Test to validate design



Cross-flow Injection Test

- Two concerns in the design of a cooling water nozzle are does it penetrate deep enough into the cross flow and does it give complete coverage of the flow for uniform quenching. A crossflow injection test was designed to examine these concerns.
- We were not able to create the same operating conditions as the Intermediate Pressure Combustion Rig, so we decided to match the Momentum Flux Ratio of jet penetration to cross-flow.

$$J = \frac{\rho_{jet} v_{jet}^2}{\rho_{cross} v_{cross}^2}$$

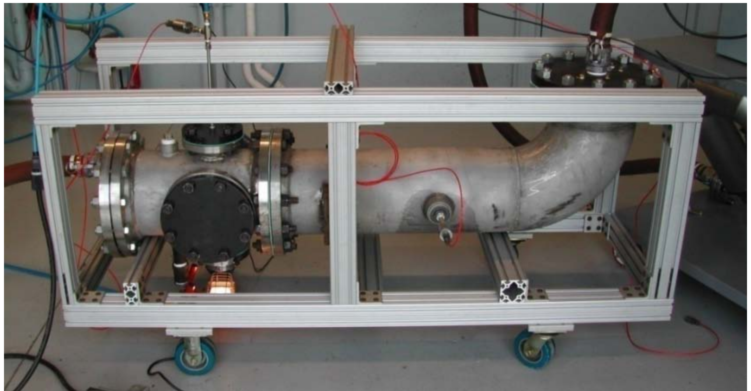
- Lefebvre studied the jet exhaust velocity for a pressure-swirl atomizing nozzle*. Below are noted the formulas used to estimate the jet velocity (U).

$$t^2 = \frac{1560 \cdot \dot{m}_L \cdot \mu_L}{\rho_L \cdot d_o \cdot \Delta P_L} \cdot \frac{1+X}{(1-X)^2} \qquad C_D = 1.17 \cdot \sqrt{\frac{(1-X)^3}{1+X}} \qquad K_V = \frac{C_D}{(1-X) \cdot \cos\theta} \qquad K_V = \frac{U}{\sqrt{2 \cdot \Delta P_L / \rho_L}}$$

*Lefebvre, Arthur H. Atomization and Sprays. Hemisphere Publishing Corporation, 1989.

Cross-flow Injection Test (Cont.)

- The cross-flow injection test rig is shown below.
- Flat spray pressure-atomizing nozzles were chosen as the style to use for the cooling water. Based on that style the momentum flux ratio was calculated and we matched it in our test.
- We did some initial tests with furnace nozzles for preliminary verification. The results were satisfactory, so we purchased some nozzles meeting our specifications. They were tested to validate and verify they meet the design requirements of penetration and uniform coverage.



Miscellaneous Projects

- Along with the work on the Cooling Water System I was involved with the following work:
  - Design and construction of a mobile hose rack
  - Support in testing for studying droplet sizes from air-atomizing nozzles
  - Support other engineers and testing

Thank You

- Working with Woodward through the UTSR Gas Turbine Industrial Fellowship Program was an exciting and rewarding experience.
- Special thanks to Dennis Delp for his mentoring and constant engineering support.
- Gan Starling, Dave McAuliffe, and Tom Verbeek for their excellent support in the Design and Development Group.
- Richard Huddas and Pat Brower for coordinating the fellowship program at Woodward.
- UTSR for providing this wonderful opportunity for learning.