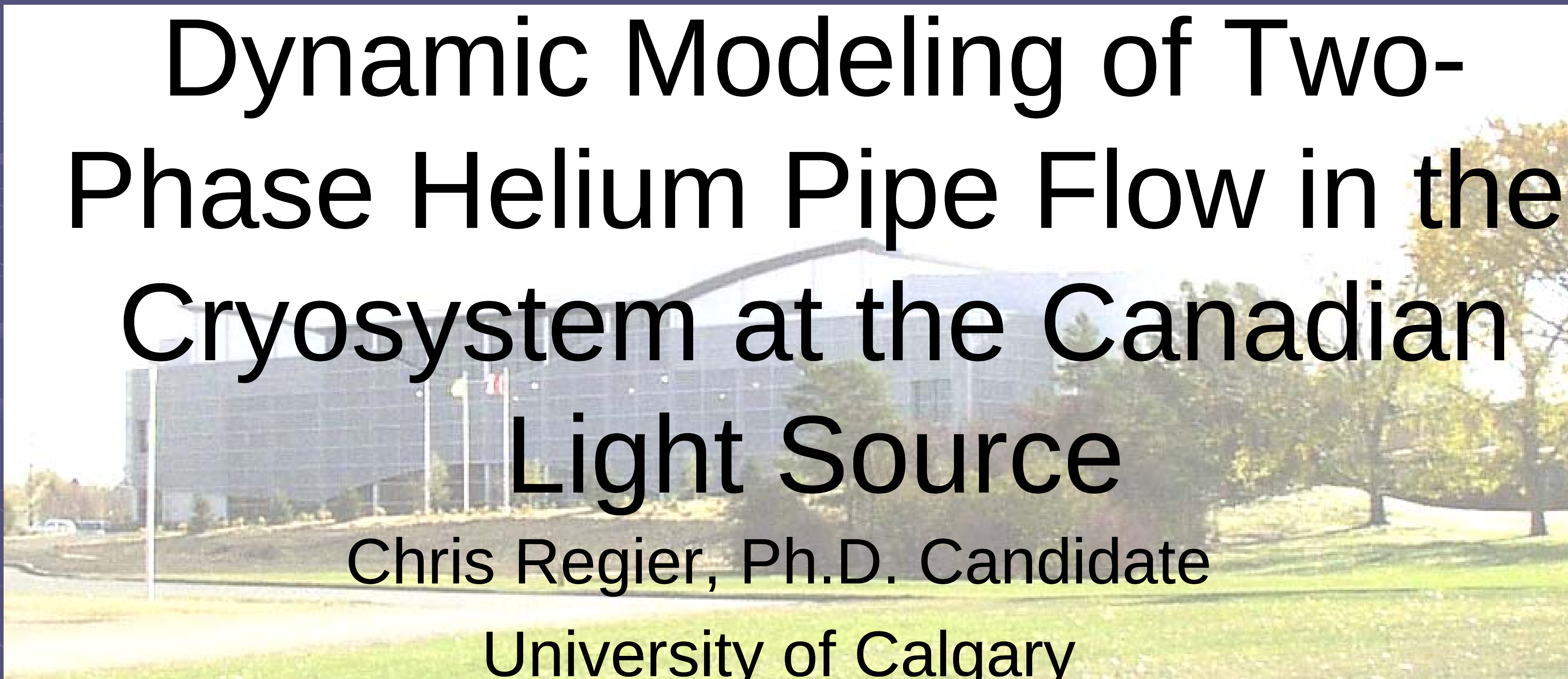

Dynamic Modeling of Two-Phase Helium Pipe Flow in the Cryosystem at the Canadian Light Source

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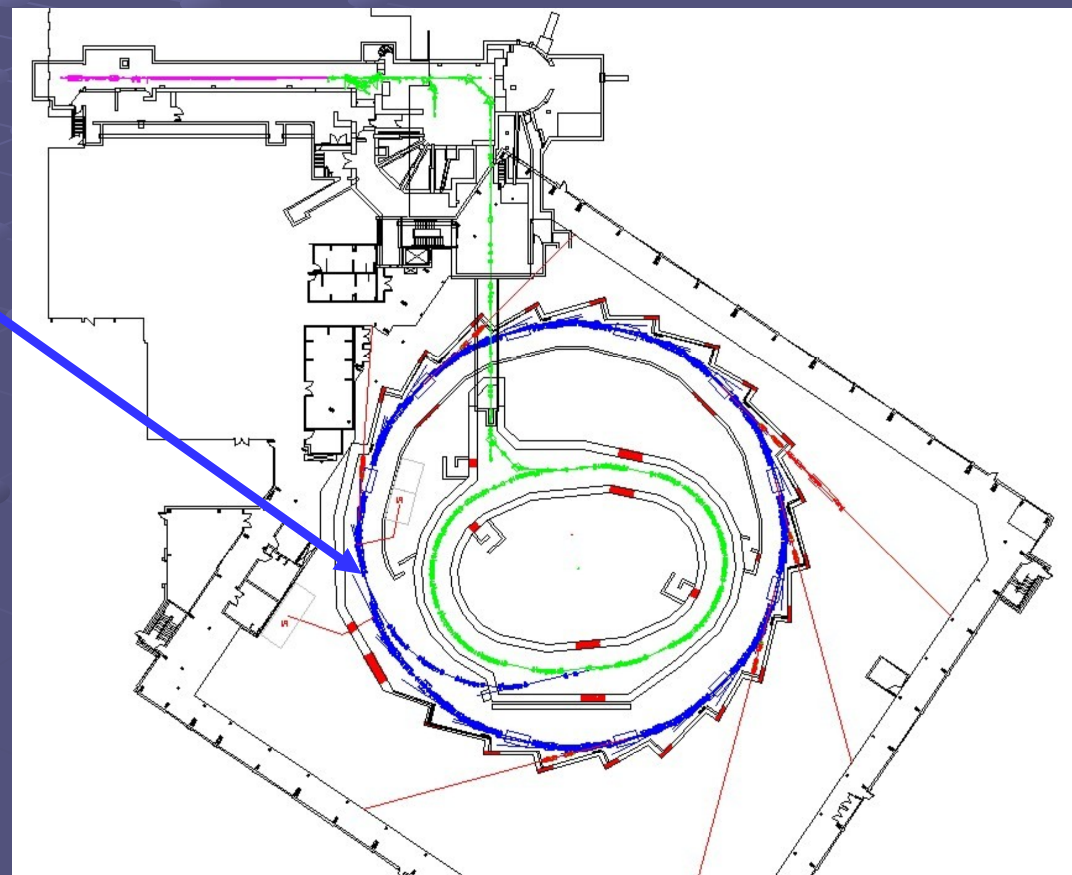
June 11, 2008

Overview

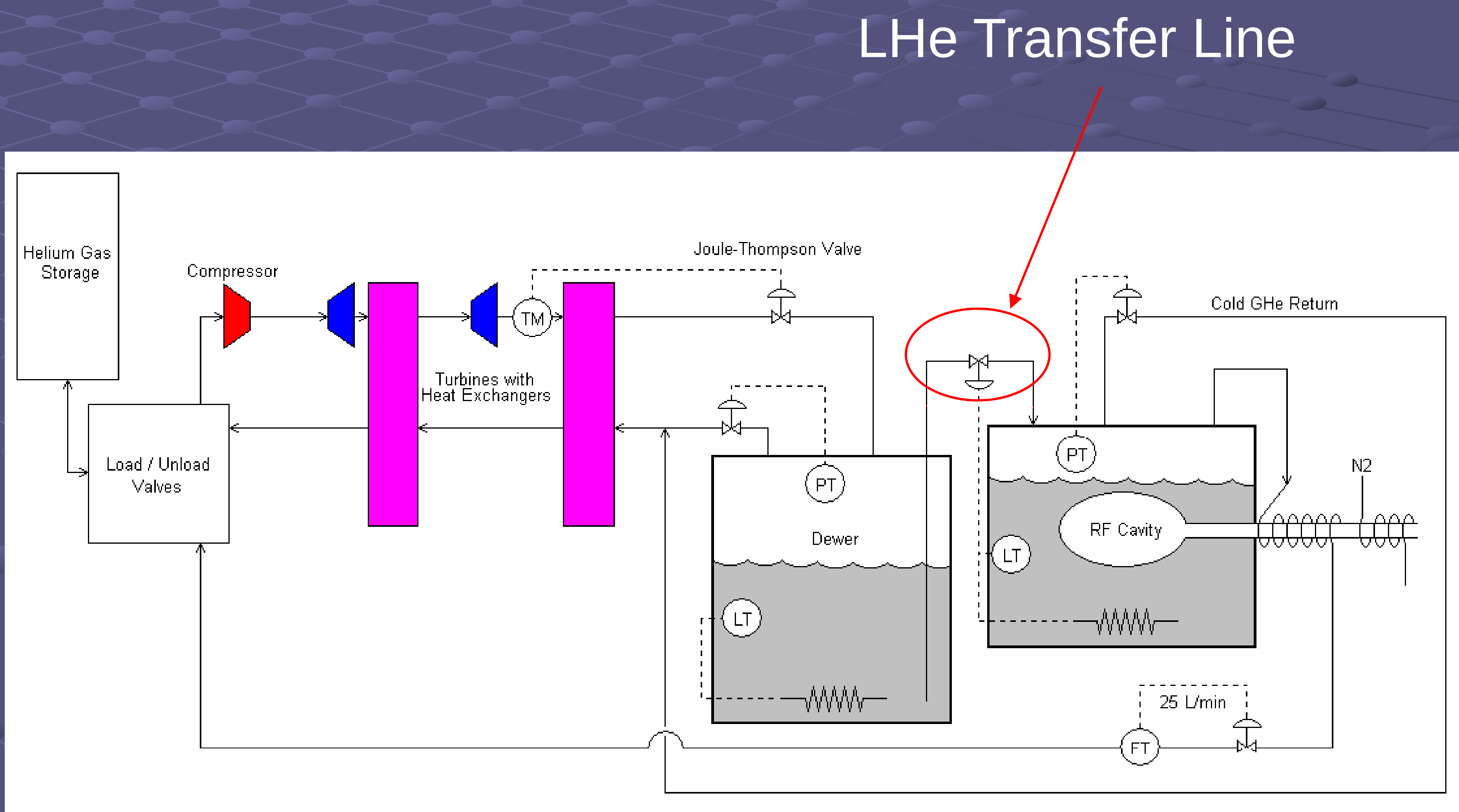
- The CLS and the RF Cavity
- The Cryogenic System
- The Liquid Helium (LHe) Supply Line
- Modeling and Simulation Procedure
- Results

The CLS and the RF Cavity

- RF Cavity
  - 500 MHz VHF
  - Replenishes lost electron beam energy
  - Superconducting
  - Operates ~ 4.5 K
  - Requires LHe Cryogenic system

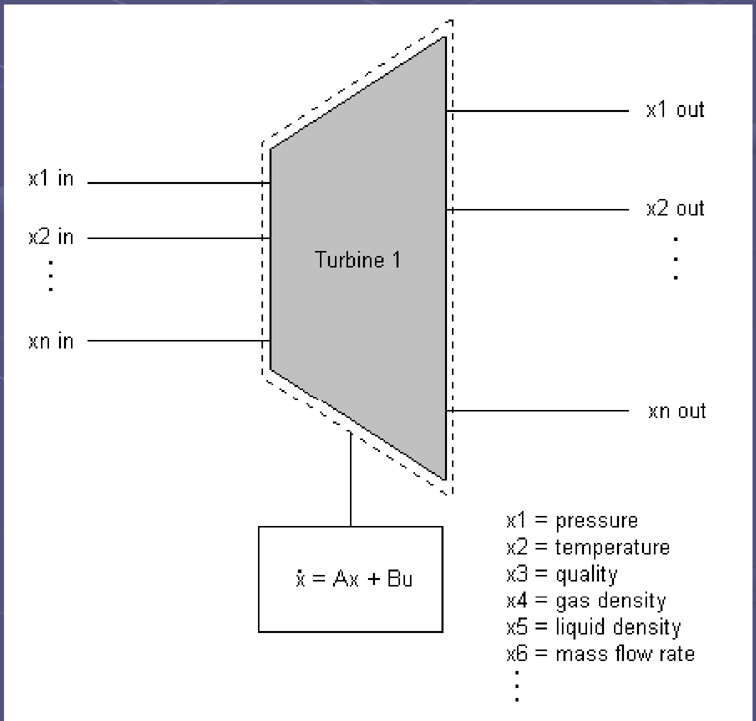


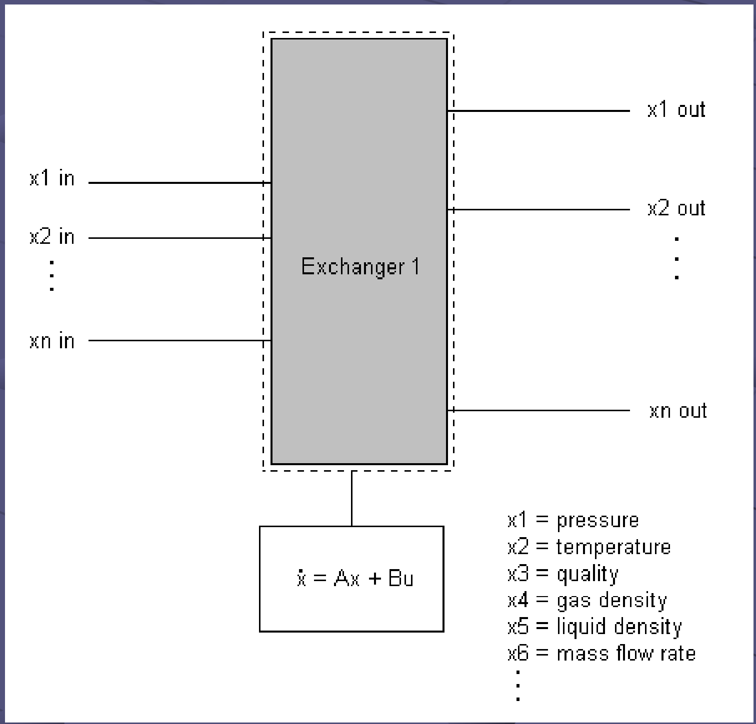
The Cryogenic System



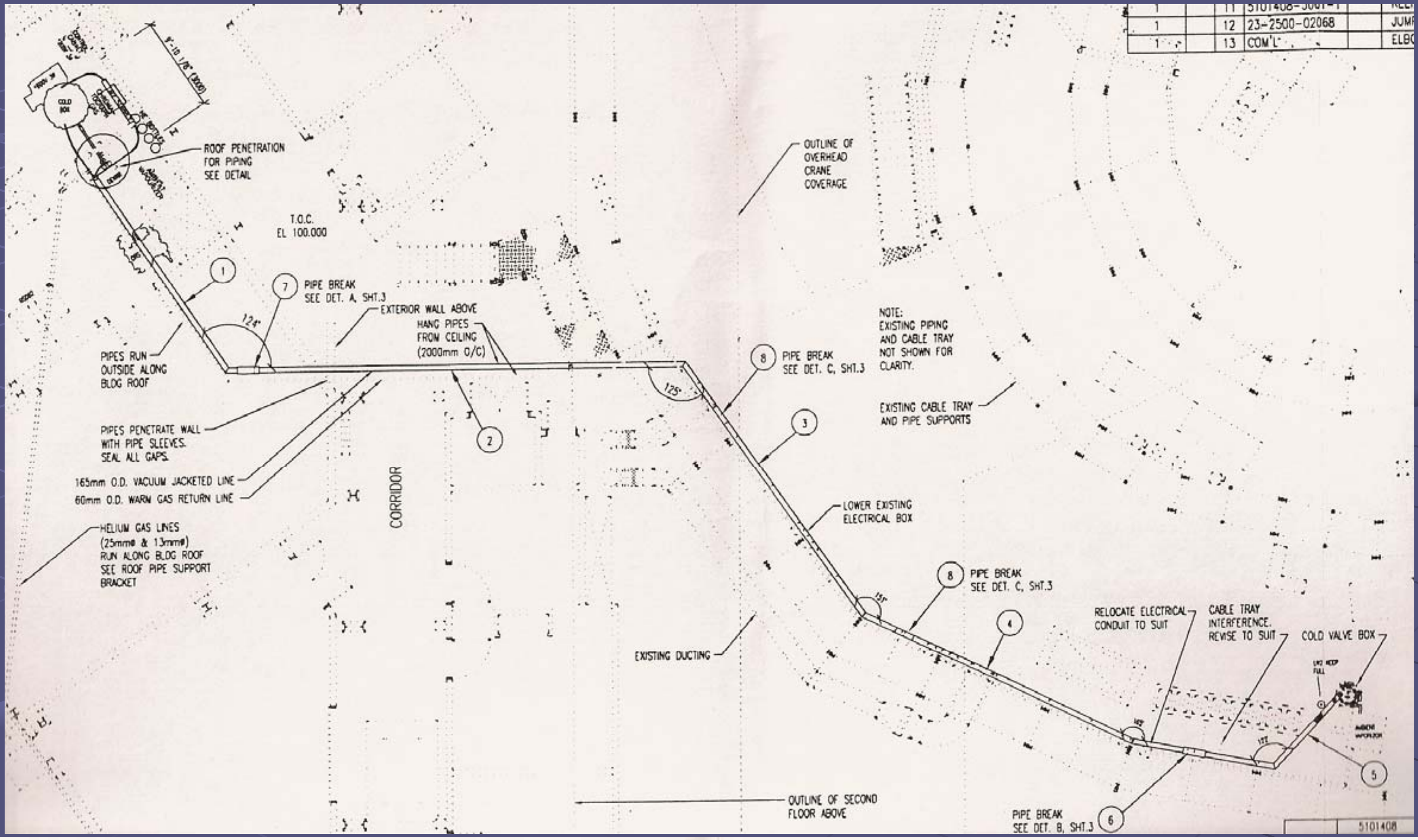
The Cryogenic System

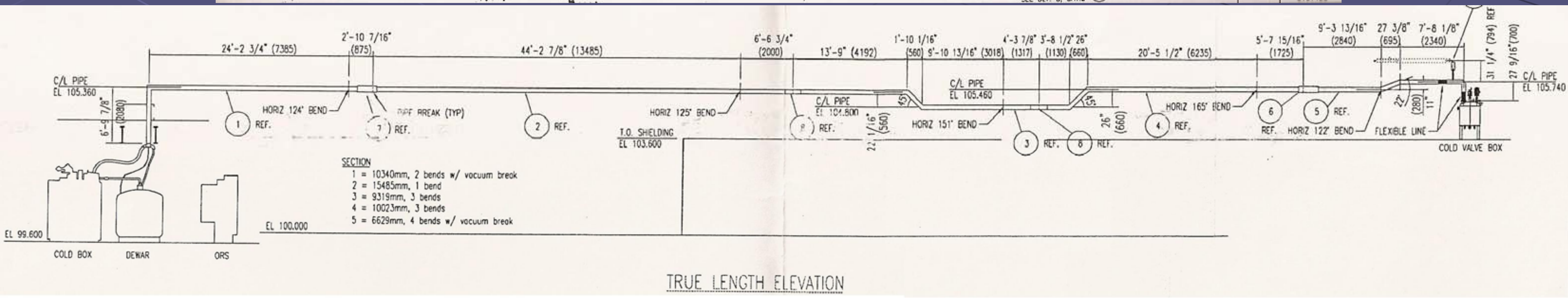
- Computer Model of entire cryo system desired
  - Dynamic system model – Controls perspective
  - Can answer questions about system operation
  - Model individual components and connect





The LHe Supply Line





The LHe Supply Line

- LHe Line is one component of the system
  - Possibly most complex model

- LHe Line Exhibits Two-Phase Flow
  - Much more difficult to simulate
  - May be required to create effective dynamic model
  - Flow boiling due to:
    - Temperature increase
    - Pressure decrease causes majority of boiling

Modeling and Simulation

- Objectives of LHe Supply Line Simulation:

  1. Ability to simulate liquid and gas flowrates exiting the LHe line
  2. Determine whether gas has impact on flow
  3. Determine whether a simpler model can produce accurate results
     - Quasi-Steady-State?
     - Simple dynamic model?

$$TF = \frac{(s + z_1)(s + z_2)\ldots.}{(s + p_1)(s + p_2)\ldots.}$$

Modeling and Simulation

- Two-Phase Flow Modeling
  - 1-D Conservation equations
    - Mass of Gas

$$\frac{\partial\left(\rho_g \alpha_g\right)}{\partial t} + \frac{\partial\left(\rho_g \alpha_g v\right)}{\partial x} = \frac{\dot{Q}_b}{\zeta}$$

    - Mass of Liquid

$$\frac{\partial\left(\rho_l \alpha_l\right)}{\partial t} + \frac{\partial\left(\rho_l \alpha_l v\right)}{\partial x} = -\frac{\dot{Q}_b}{\zeta}$$

    - Momentum

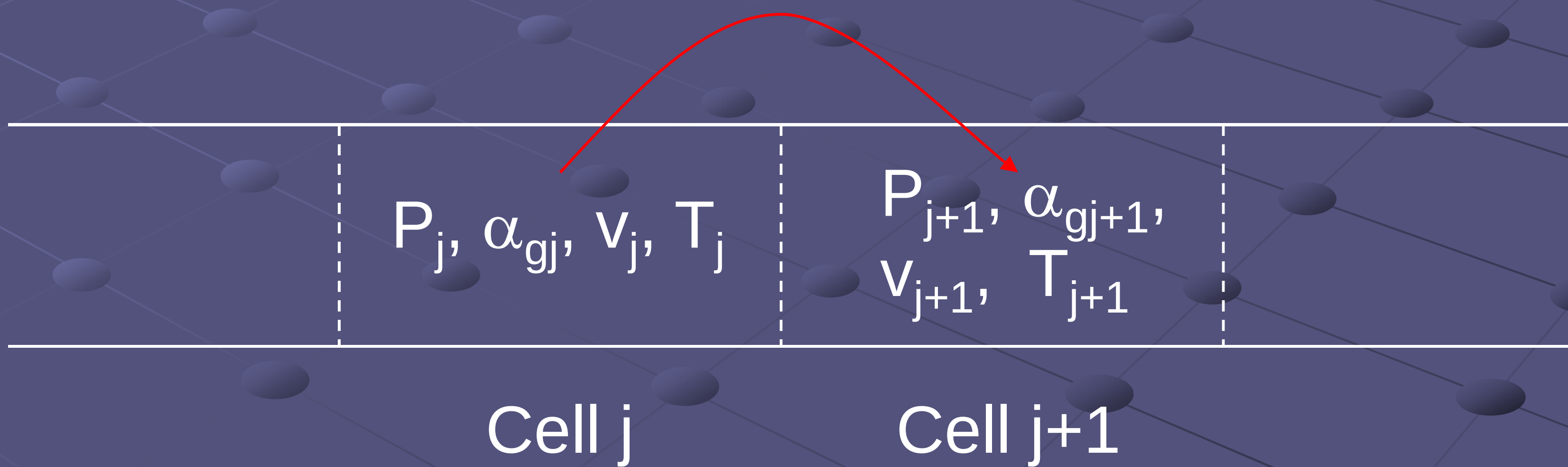
$$\frac{\partial\left(\rho v\right)}{\partial t} + \frac{\partial\left(\rho v^2\right)}{\partial x} = \frac{\partial P}{\partial x} - F_f - F_g$$

    - Energy

$$\frac{\partial\left(\rho e\right)}{\partial t} + \frac{\partial\left(\rho e v\right)}{\partial x} = \dot{Q} - F_f v - \frac{\partial\left(P v\right)}{\partial x}$$

Modeling and Simulation

- Discretize conservation equations
- Use upwind scheme to solve
  - Solution depends only on upstream properties
  - Can start at inlet of line and solve each grid cell in sequence to end of line.



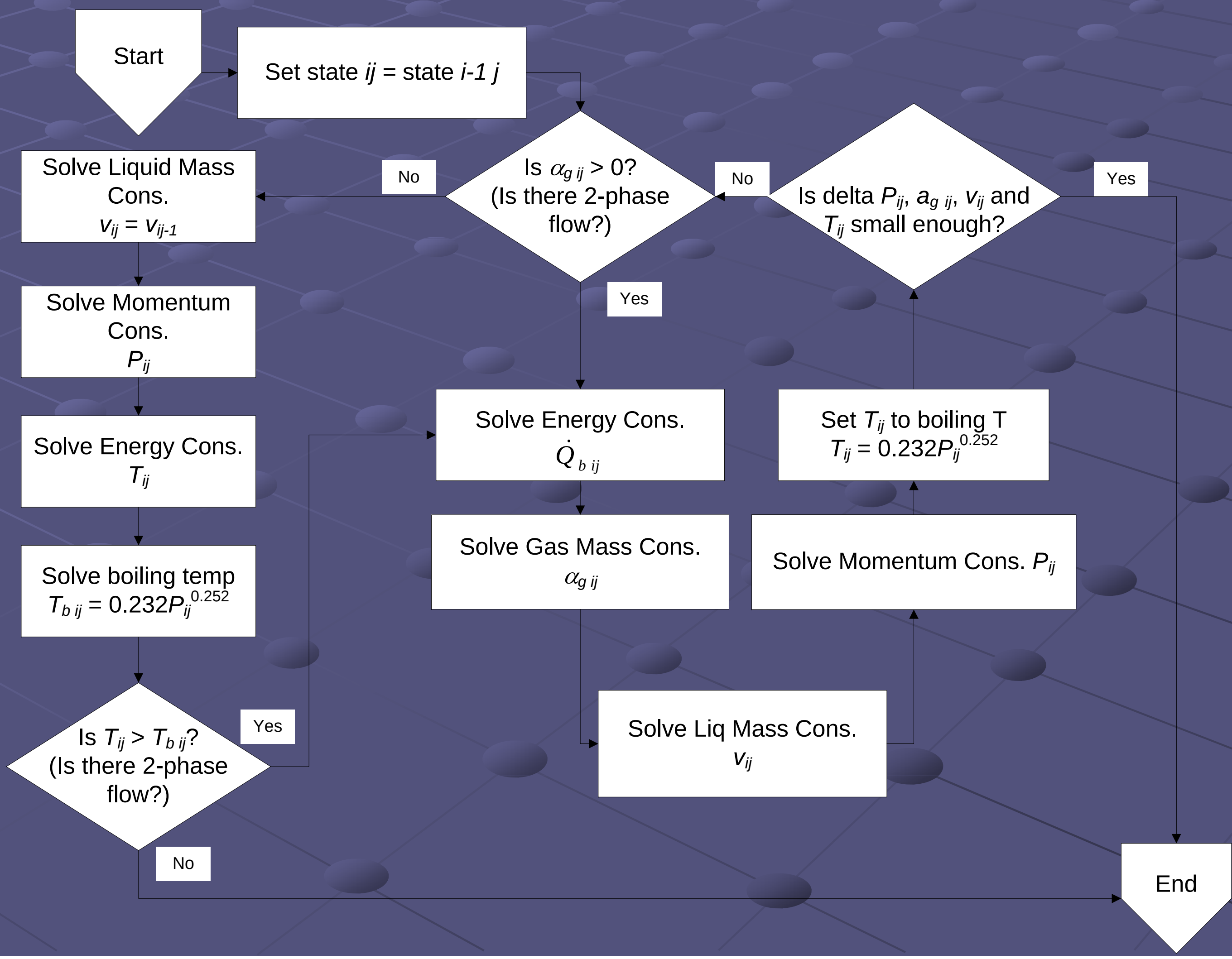
Modeling and Simulation

- BCs complicate solution
  - LHe line inlet velocity not known
  - Outlet pressure known instead

1. Guess inlet velocity
2. Solve P, v, α_g, T for each cell along pipe
3. If outlet P is correct then go to next time step
4. If outlet P is not correct then adjust guess of inlet v and repeat

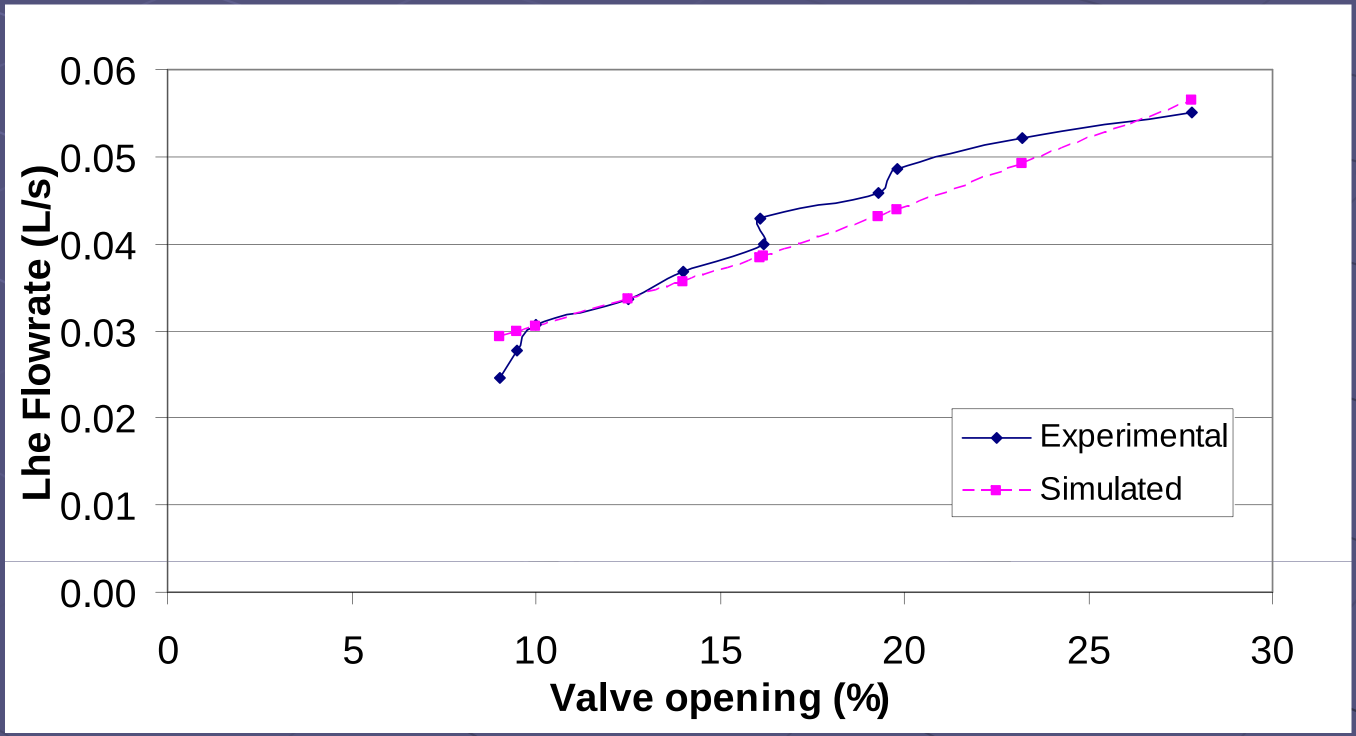
Modeling and Simulation

- To solve P, v, α_g, T for a grid cell
  - Solution of each equation depends on all 4



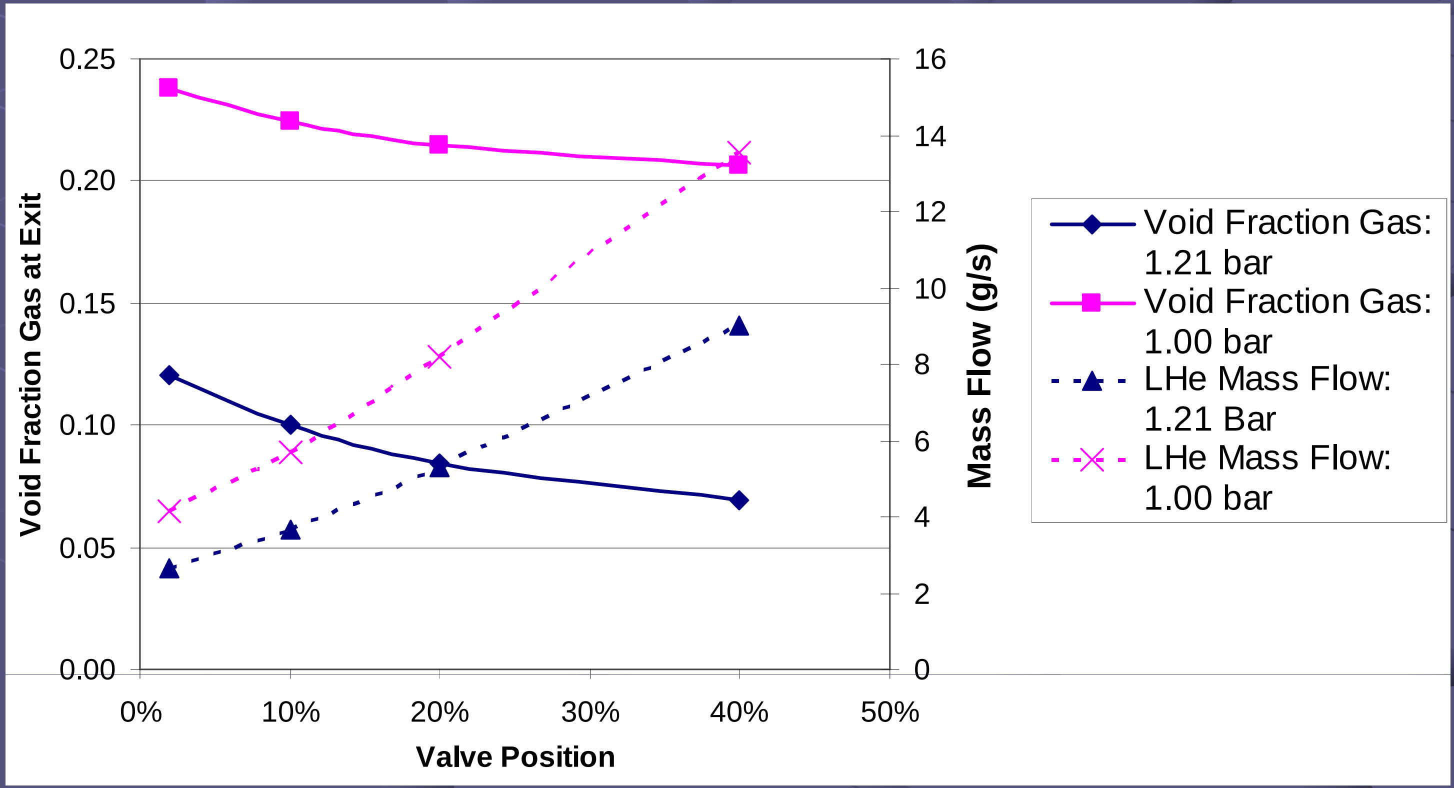
Results

- Objective 1: Ability to simulate various flows
  - R^2 value = 0.91
    - Based on measured rates at CLS
  - Simulated various valve positions & heat loads
    - Average error 6.3%



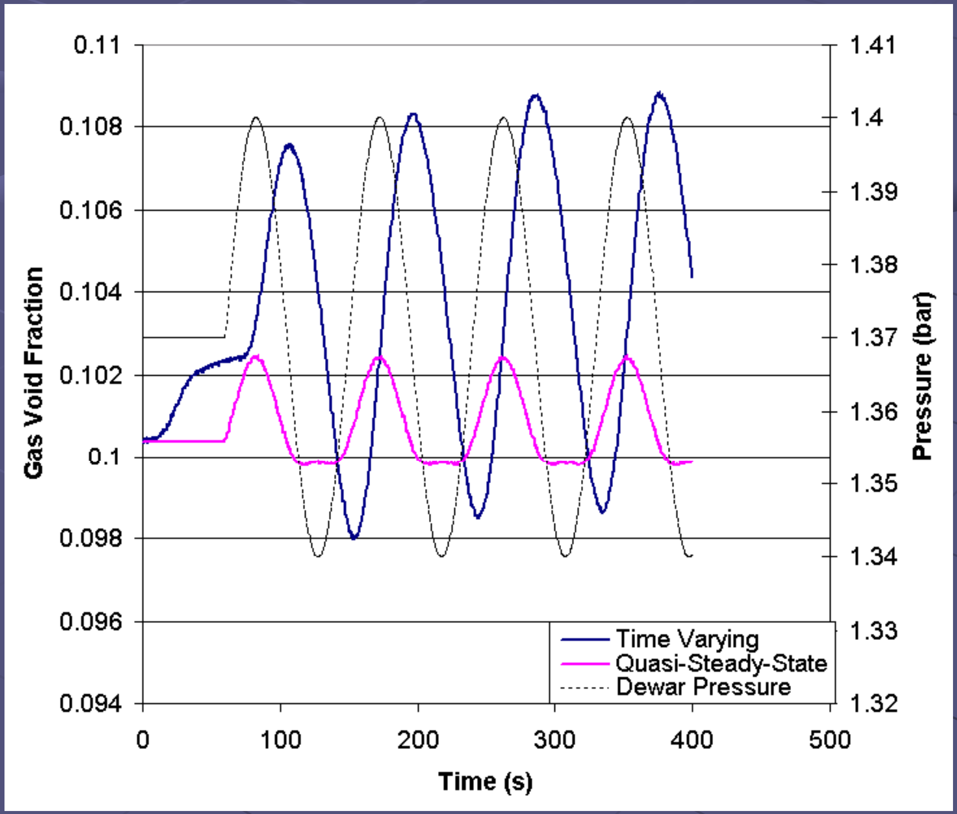
Results

- Objective 2: Determine if gas impacts flow
  - Maximum α_g ~0.12 at pipe exit
  - α_g varies slightly with control valve position
  - Some impact on flow of LHe



Results

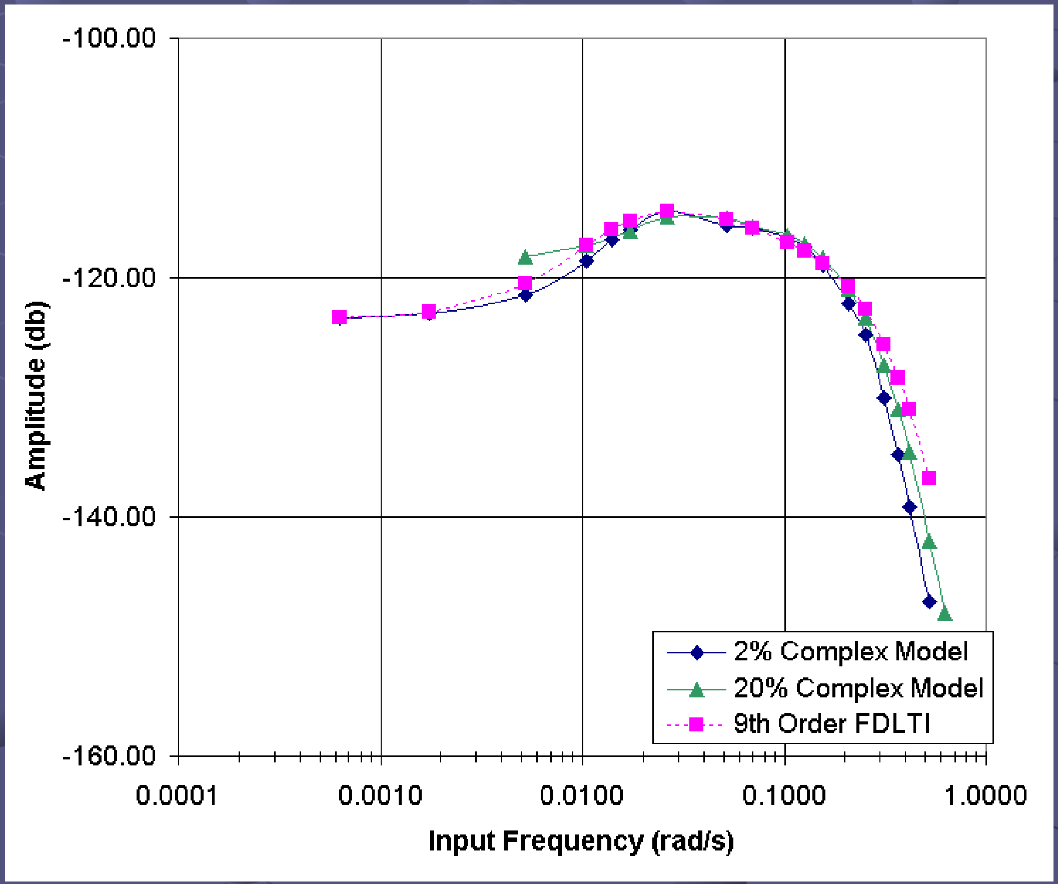
- Objective 3: Can a simpler model be used?
  - Quasi-steady-state has problems
    - α_g dynamics are very slow
    - QSS can incorrectly predict oscillation size and phase



Results

- Objective 3: Determine if a simpler model can be used

$$\frac{2.8\times10^{-8}(s+0.005)(s+0.05)}{(s+0.8)^2(s+0.5)^4(s+0.4)(s+0.025)^2}$$



Acknowledgements

J. Pieper – U of C

Elder Matias - CLS

Mark deJong – CLS

Mark Silzer – CLS

Jon Stampe - CLS

Abdulmajeed Mohammad – U of C

John Swirsky - CLS

J. Bugg – U of S

Carey Simonson – U of S

Tom Regier - CLS

Questions?

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