



Real Gas Effects in HGIs: Progress Report 1

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Outline

- Project Background
- Project Goals
- Error Analysis
 - HGI States
 - Filling States in HGI Bottle
 - Post-Discharge Final Tank State
 - HGI Time-Dependent Process
 - Ignition → Complete Discharge into Tank



Outline - continued

- CFD Codes
 - Real-Gas Capabilities
 - Level of Effort
- Future Work



Background

- TRW uses of Computational Fluid Dynamics (CFD) modeling in design, development and evaluation of inflators
- CFD is a well-accepted and thoroughly validated tool for analyzing many classes of flow problems
 - Incompressible fluids
 - Steady-state
 - Non-reactive
 - Some Combustion Problems
 - Ideal Gas



Background

- Modeling HGI with CFD presents several very unique conditions
 - Very high initial pressure ($\sim 6,000$ psi)
 - Combustion
 - Nearly-closed chamber
 - Rapid
 - High aspect-ratio geometry
 - Sonic venting through radial orifices



Project Description

- Assess cost-benefit ratio of TRW investing in specialized modifications to current CFD modeling



Specific Goals

- Quantify error associated with ideal-gas assumption in HGI modeling
- Assess state-of-the-art in real-gas CFD modeling
- Assess TRW's current CFD modeling efforts
- Provide TRW with recommendations on future modeling activities



Real Gas ?

- $P v = RT Z$
- Z
 - Compressibility Factor
 - Complex function of state variables
- Compressibility factor effects
 - State Properties ($P, v, T, u, s, \text{etc.}$)
 - Discharge Mass-flow Rate
 - Form of Energy Conservation Equation
 - Sound Speed



Examples

- Air and H₂ @ STP
 - $Z \sim 1.0$
- Typical HGI bottle after fill
 - $Z \sim 1.2 - 1.3$

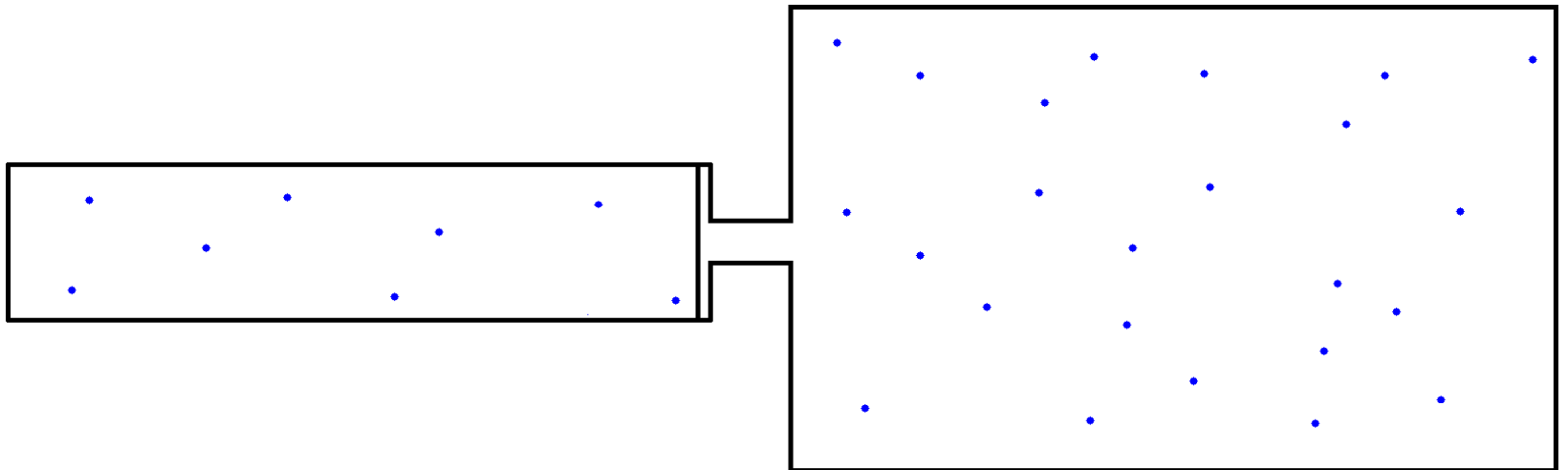


Error Analysis – Filling

- Modified spreadsheet
 - Bloomquist and Fogle
- Sequence of “exact” state calculations
 - Key states during filling process
 - Related to measured/controlled properties
 - Can specify % unreacted fuel
- Independent of rate processes
 - Combustion, discharge, heat loss, etc.
- Program delivered/returned to TRW

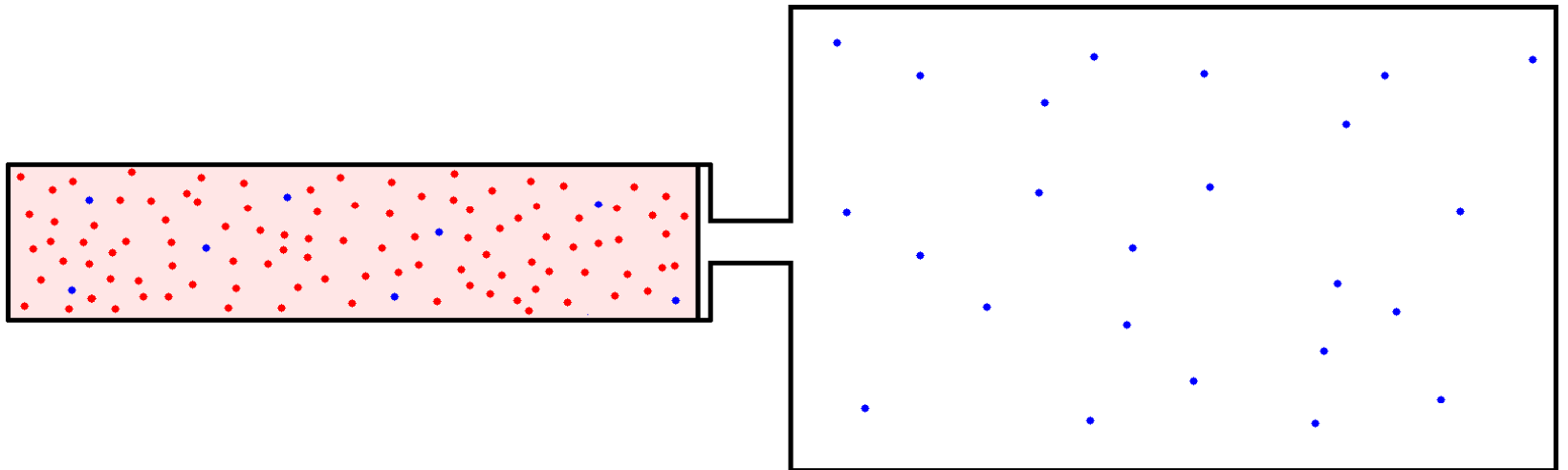


State A – Before Gas Fill



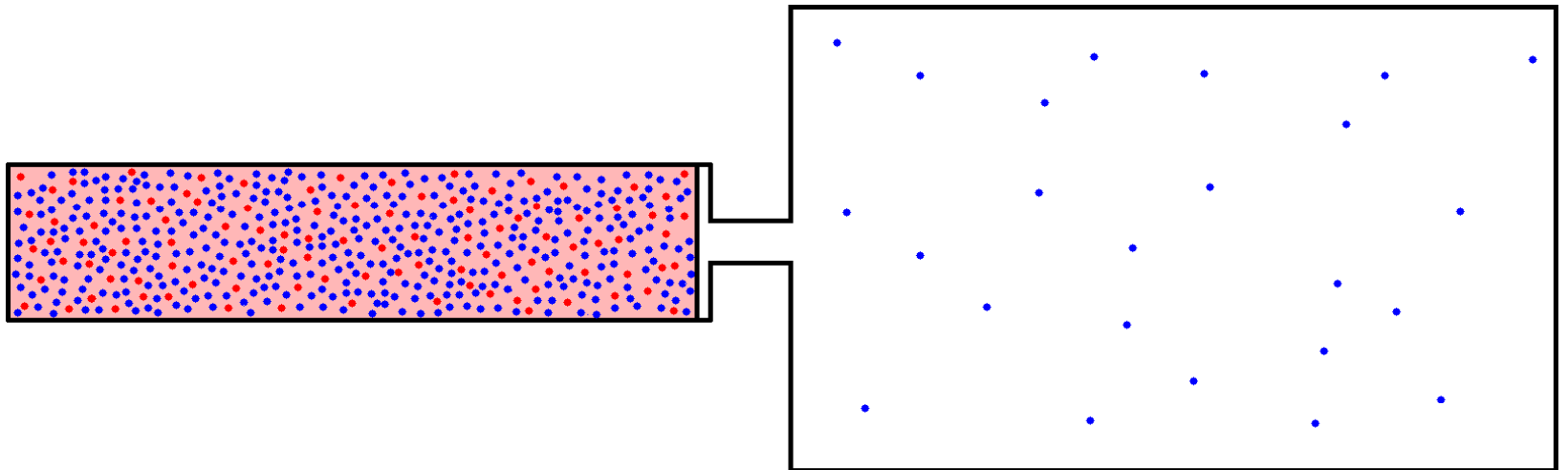


State B – After H₂ Fill



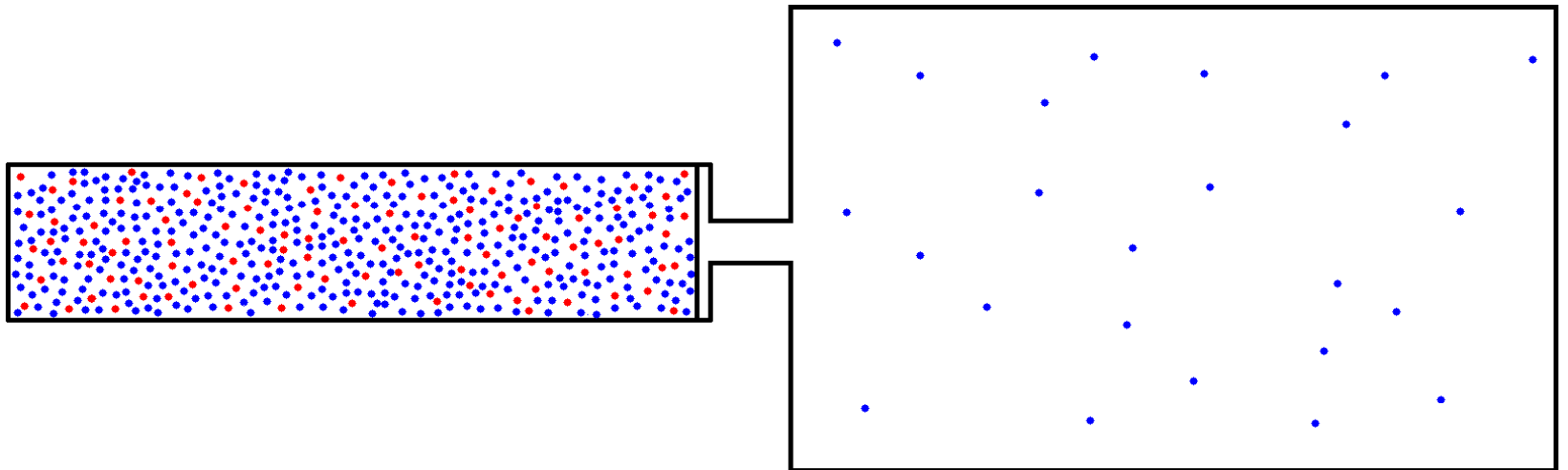


State C – After Air-He Fill

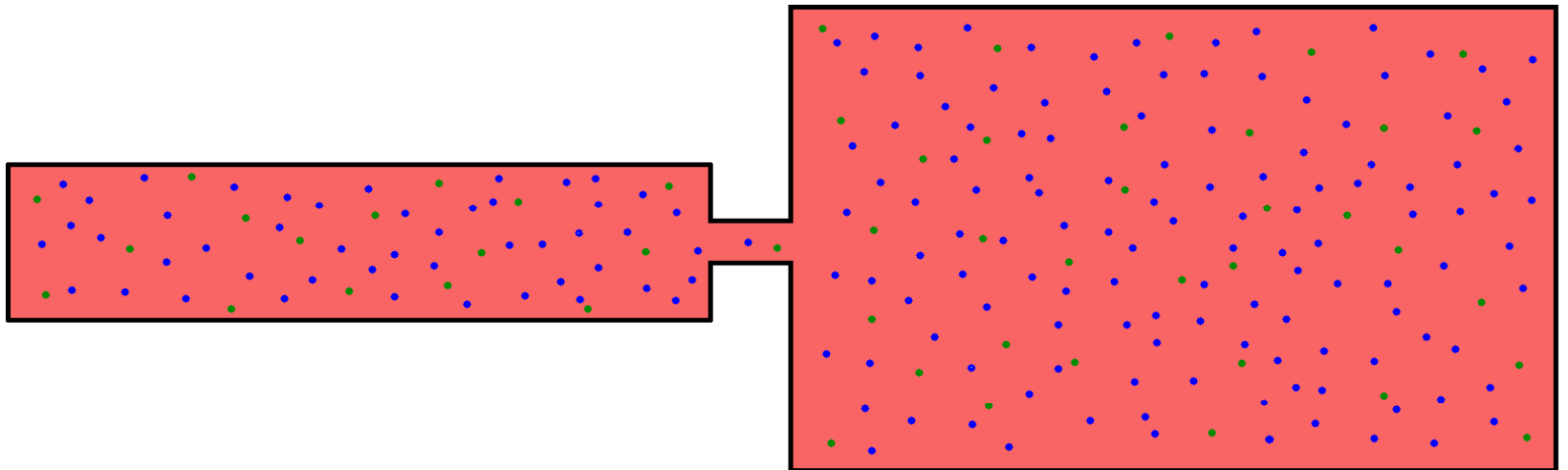
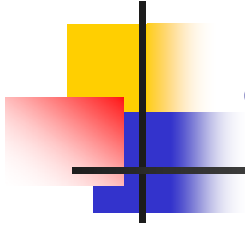




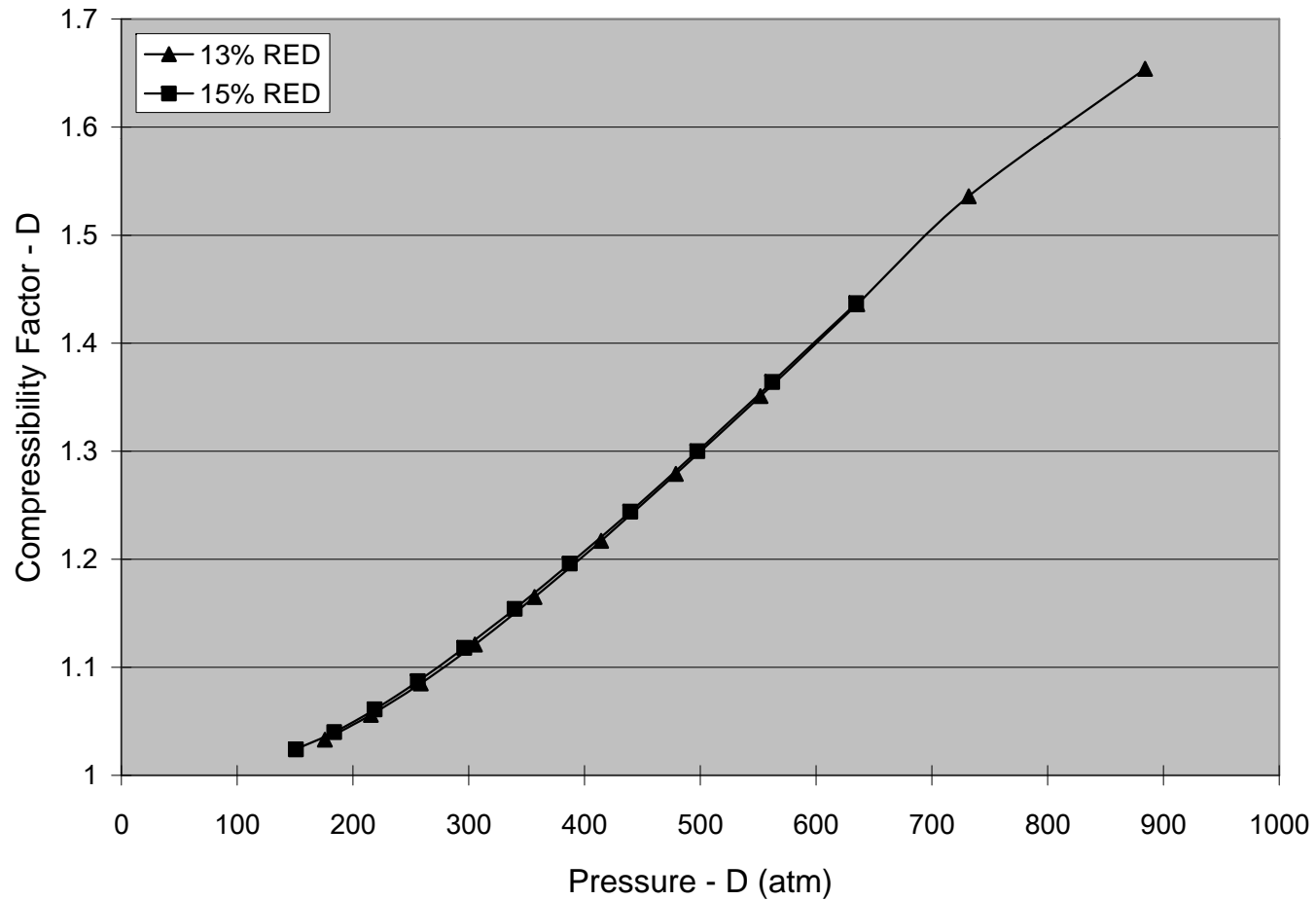
State D – State C at 300 K



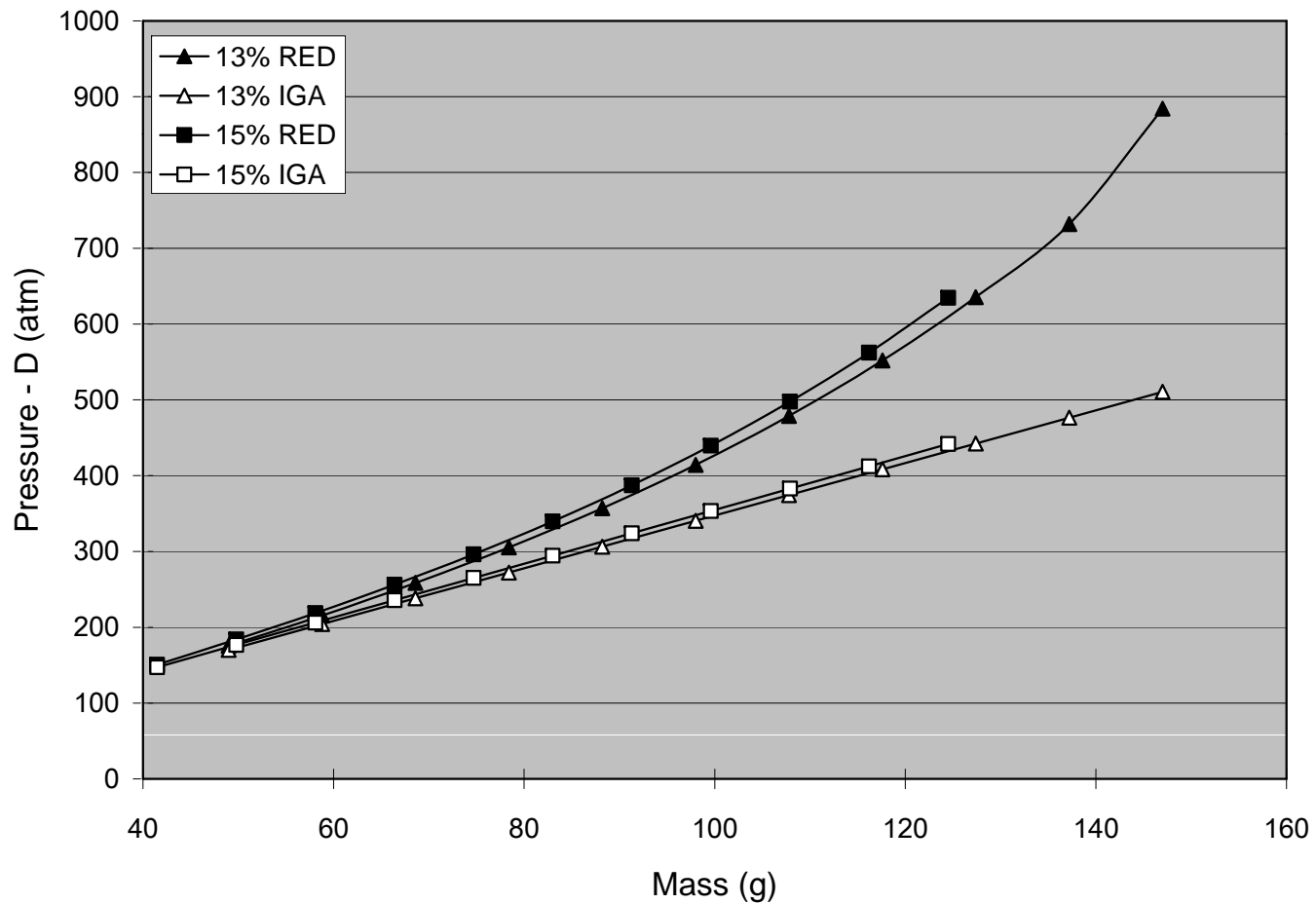
State F – After Combustion and Discharge



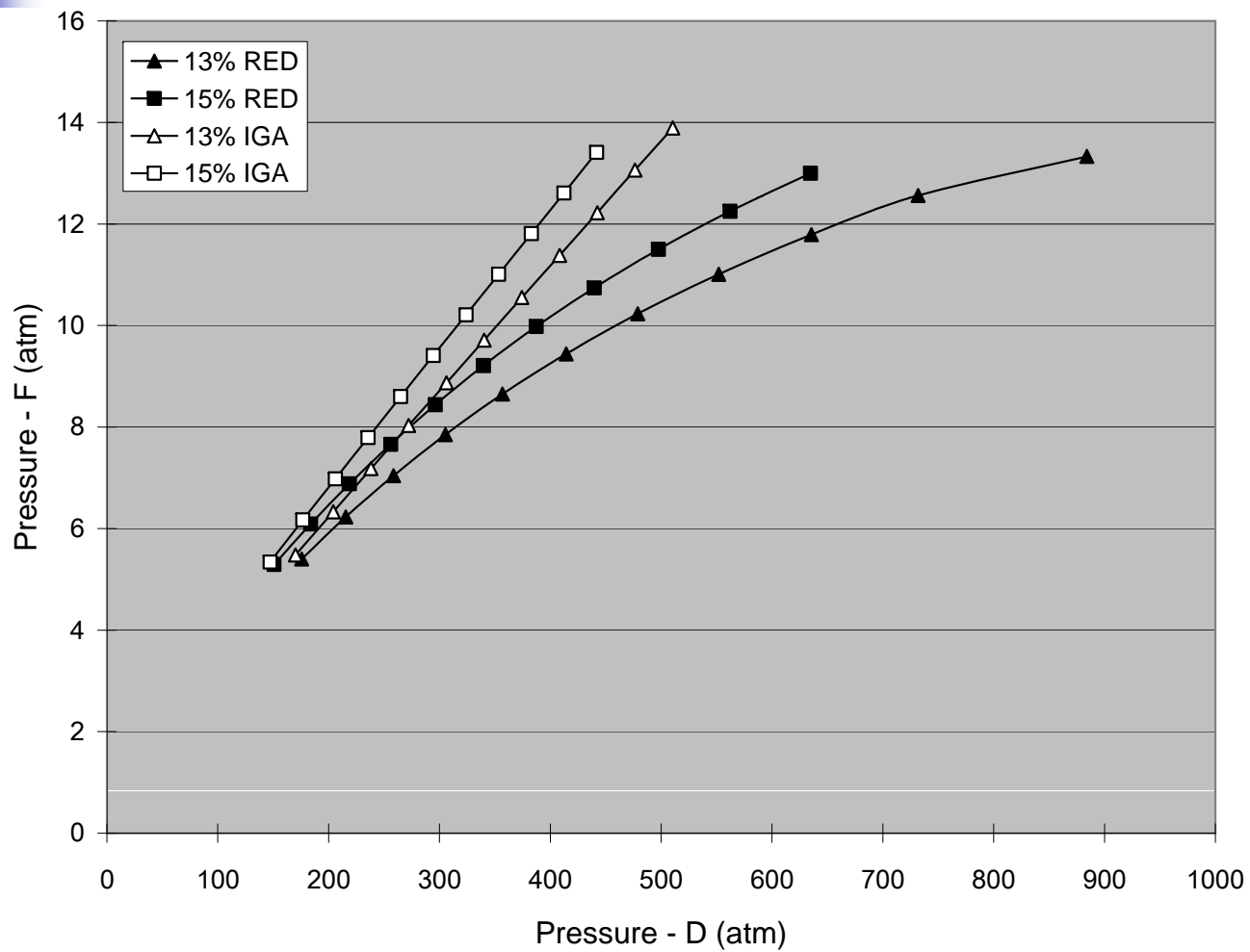
State D – Fill Compressibility



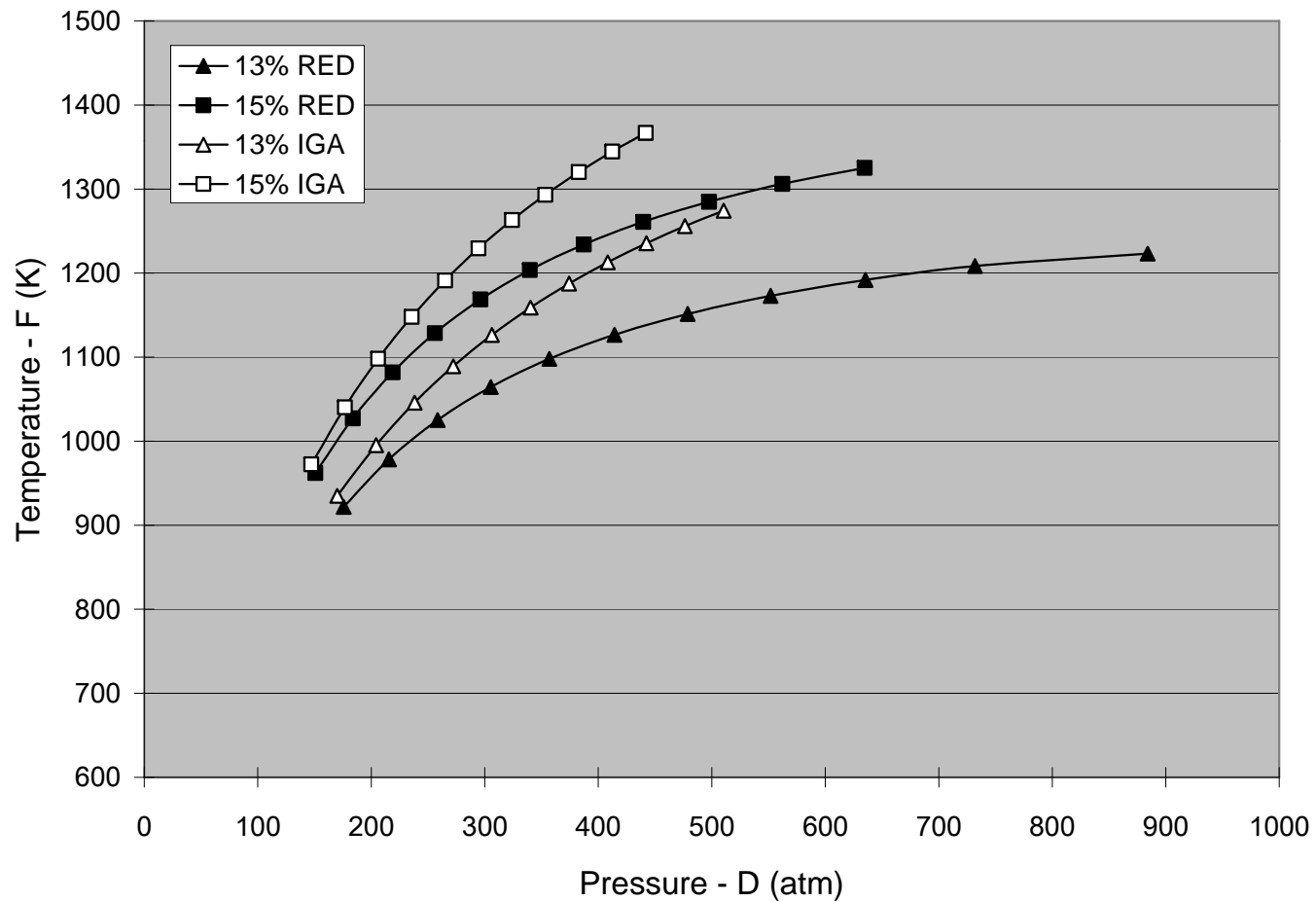
State D – Fill Pressure



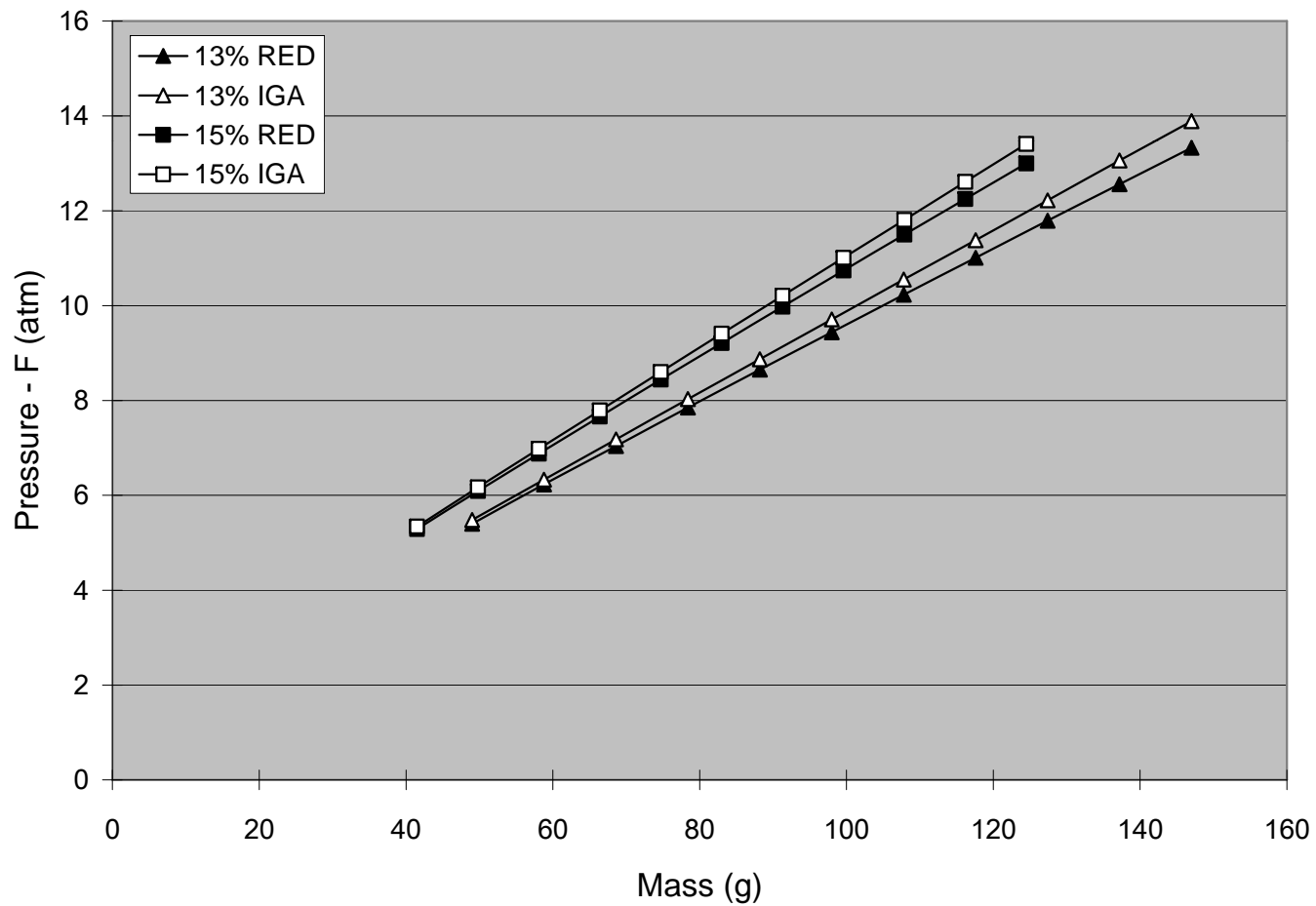
State F – Tank Pressure



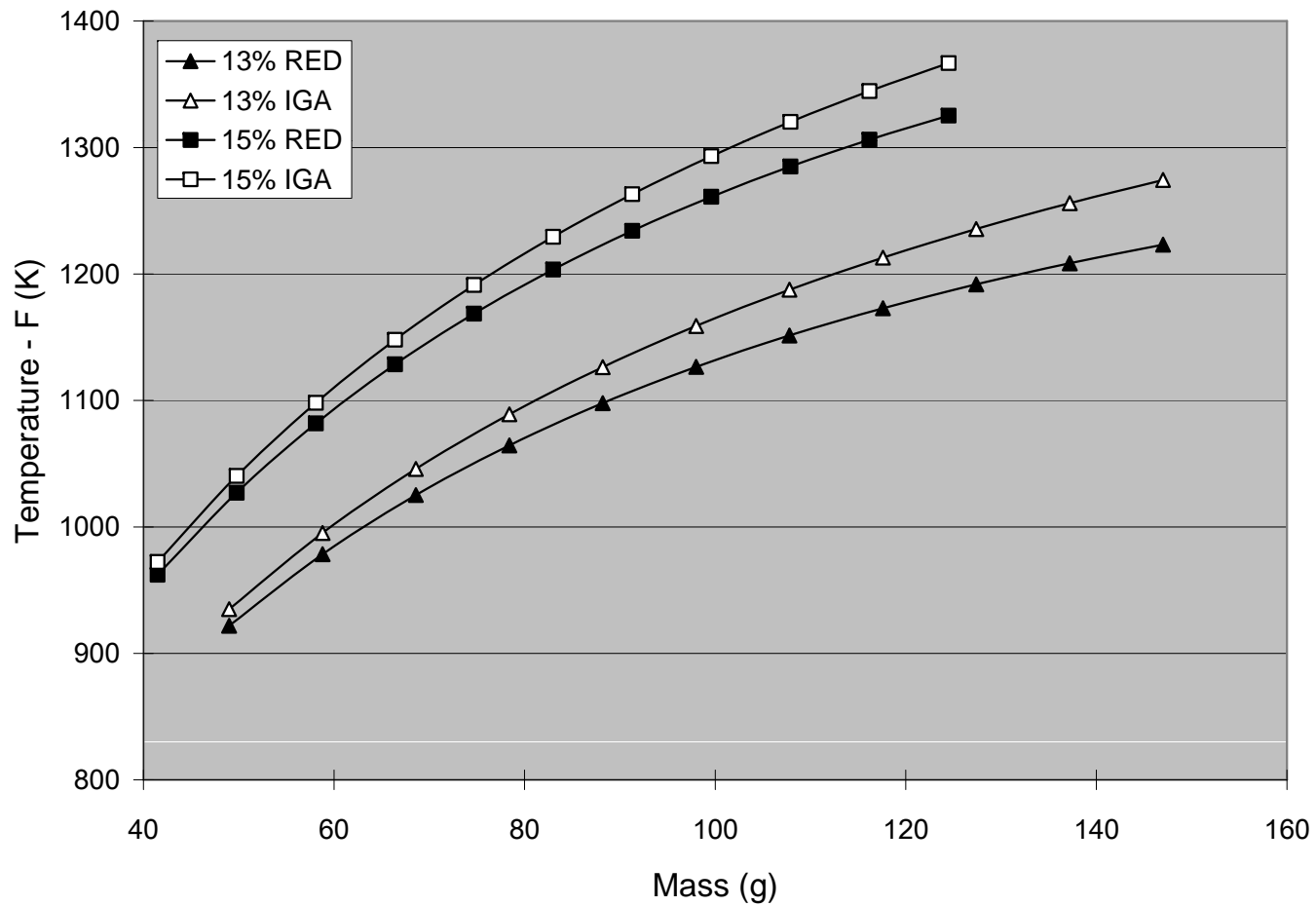
State F – Tank Temperature



State F – Tank Pressure



State F – Tank Temperature

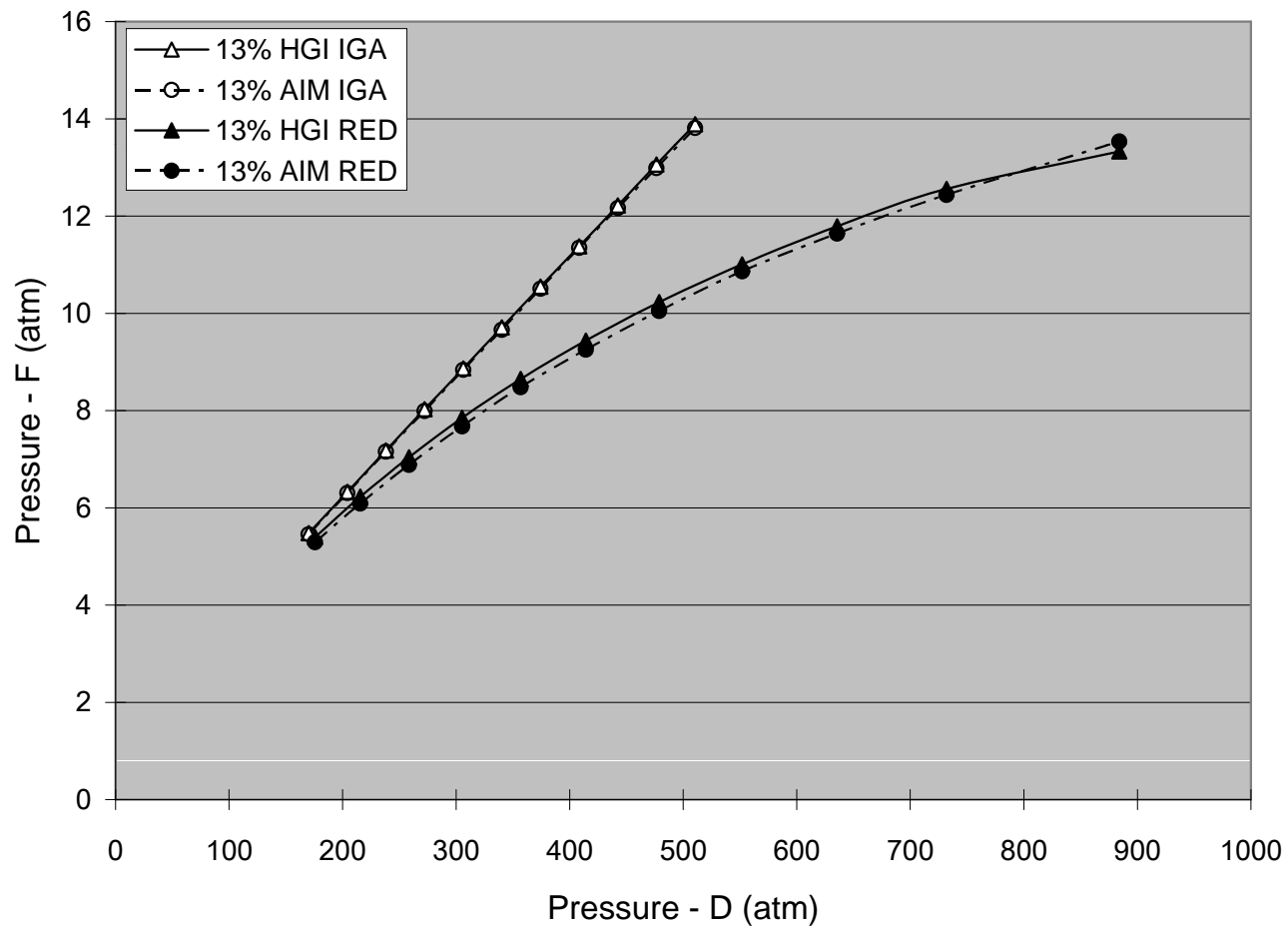




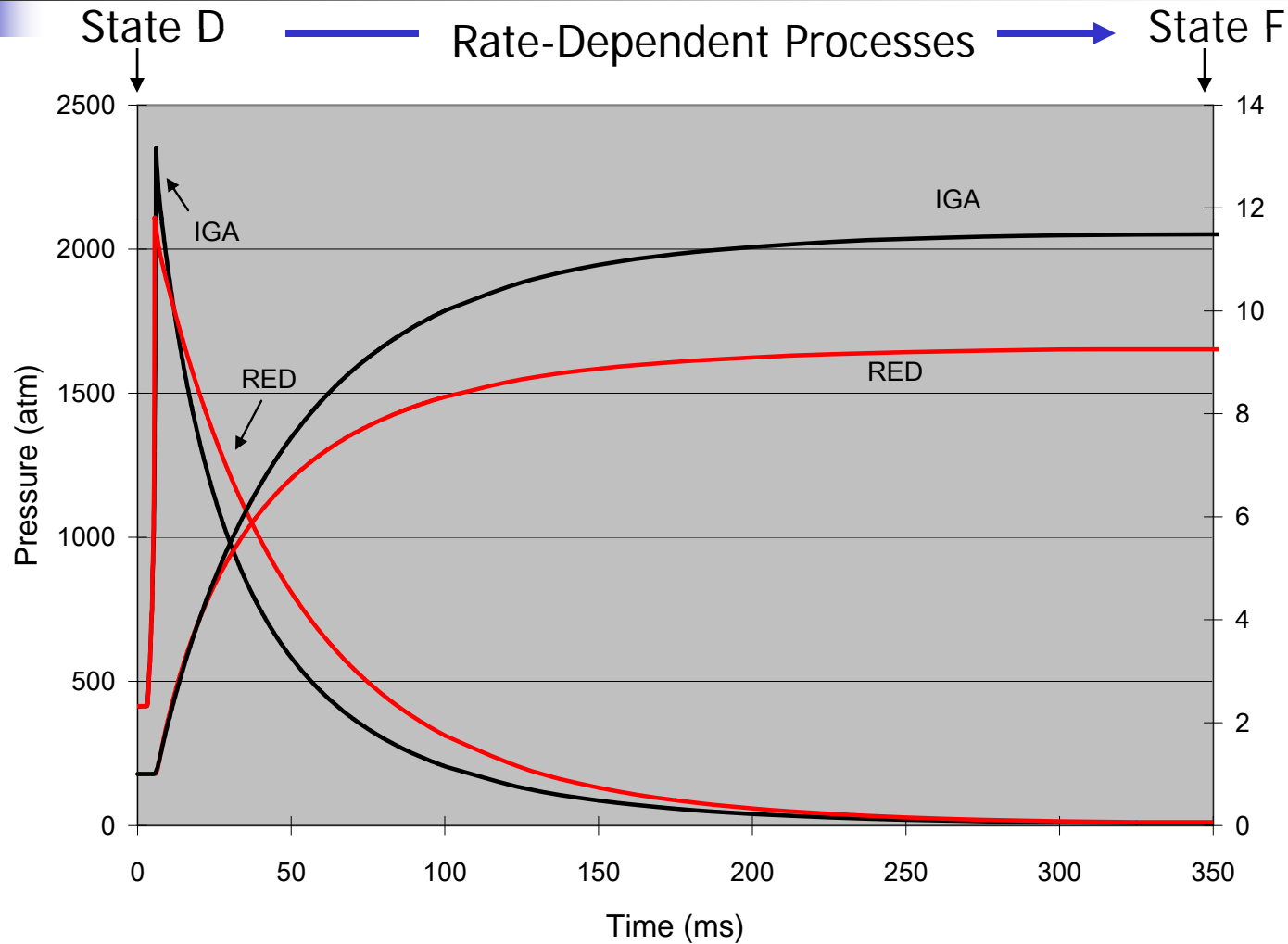
Error Analysis - Discharge

- Airbag Inflator Model (AIM)
 - Exact thermodynamics
 - Multiple species
 - Zero-th Order (volume averaged)
 - Very fast
 - Reconfigure case ~ 2 minutes
 - Run ideal gas ~ 2 seconds
 - Run real gas ~ 5 seconds

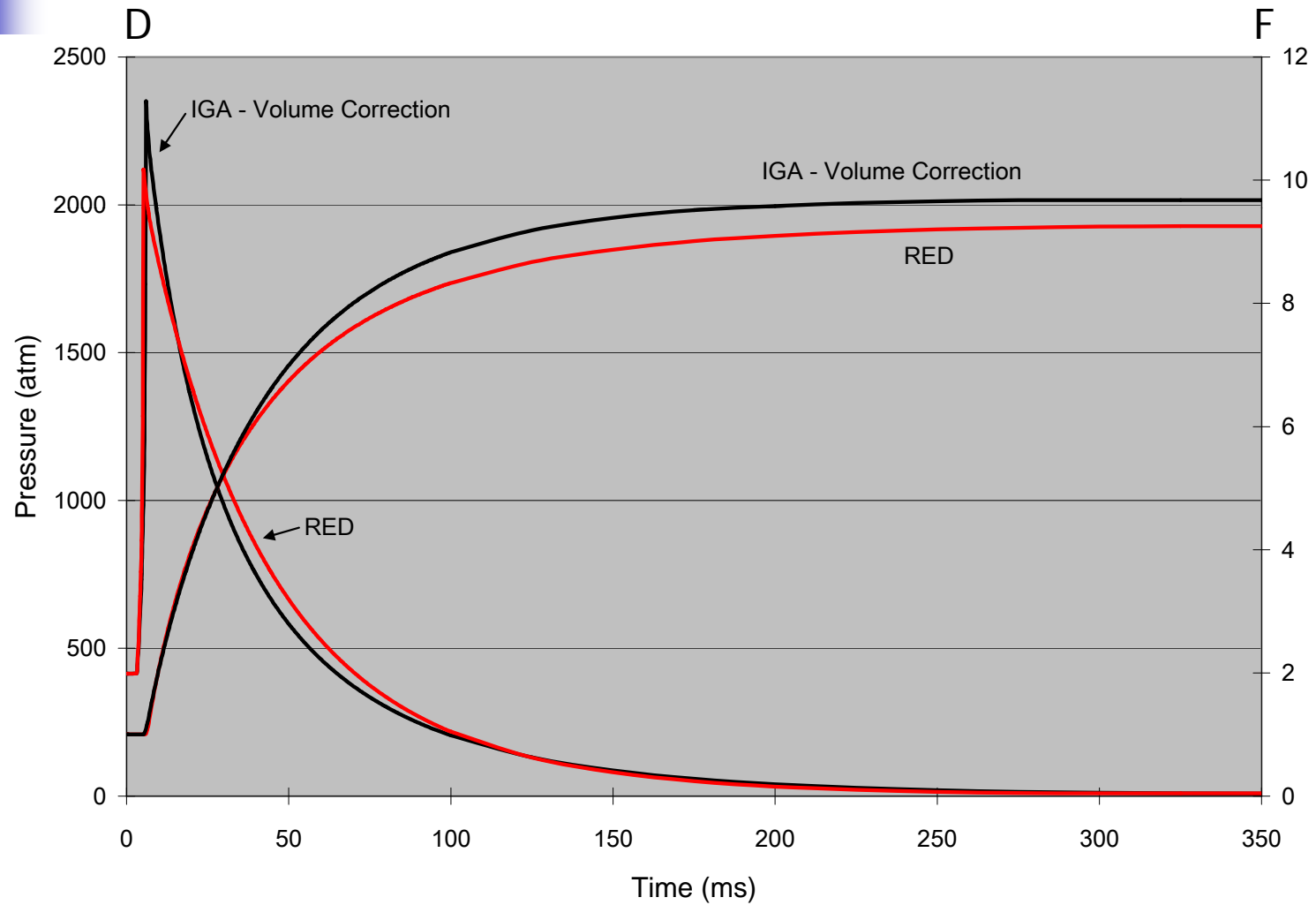
State F – Tank Pressure



Error Analysis – Discharge



AIM – IGA with V Correction





Commercial CFD Codes

- Some claim “Real Gas” capabilities
- Mostly limited to pure species
- Not fully integrated into fabric of code
 - Energy equation
 - Mixture properties
 - Etc.



Results - Preliminary

- Significant real gas effects are present in current HGIs
- Current CFD codes are limited in their capability to model HGI
- Ideal gas modeling with volume-correction works well



Future Work

- Continue to Assess CFD Codes
- Expand AIM to AIM2D
 - Spatially Resolve Field Variables
 - Two-Dimensional
 - Euler (non-viscous)
- Establish Baseline for Comparison
 - AIM
 - AIM2D
 - CFD