Dual Fuel Issues Related To Performance, Emissions and Combustion Instability In Gas Turbine Systems

C. Brossard, J.C. Broda, C. Mordaunt, S-Y. Lee and R. J. Santoro

Propulsion Engineering Research Center

The Pennsylvania State University

University Park, PA 16802

Motivation

- **Gas turbine operation on dual fuels has significant operational payoffs.**
- **The requirement to operate on both gaseous and liquid fuels has potential impacts on:**
  - **Emissions (NO_x, CO and UHC)**
  - **Stability**
  - **Autoignition, flashback and lean blowout.**
- **There is a need for systematic studies directly comparable to natural gas operation.**

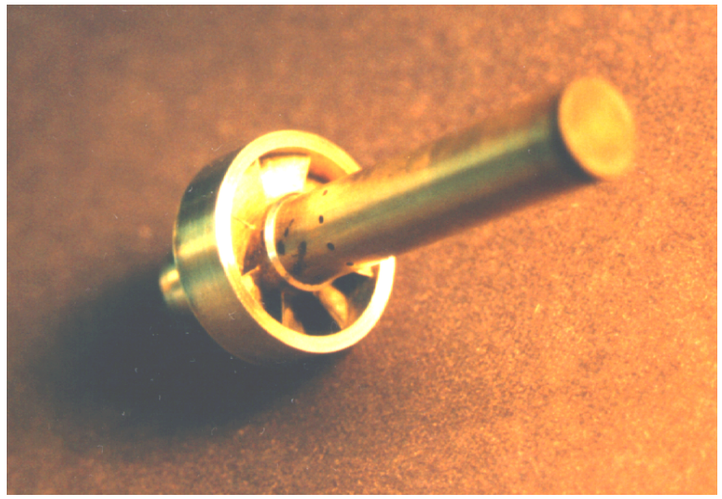
Goals and Objectives

- **Address dual fuel issues related to performance, emissions and combustion stability by:**
  - **Sequentially studying effects of premixing, fuel chemistry, atomization, drop vaporization and multi-point injection**
  - **Investigating liquid fuel effects in a model combustor previously studied for natural gas-air mixtures for comparison**

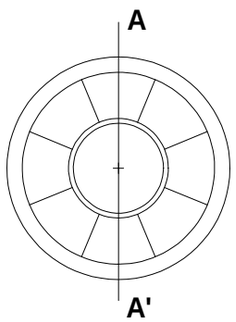
Approach

- **Three phase research program involving:**
  - **Prevaporized liquid fuel studies**
  - **Uni-element liquid fuel spray studies**
  - **Multi-point injection studies**
- **Utilize previously developed optically accessible model gas turbine combustor.**
- **Employ simple swirl injectors**
- **Apply extensive diagnostic tools available to characterize controlling combustion processes.**

PSU SINGLE SWIRL INJECTOR

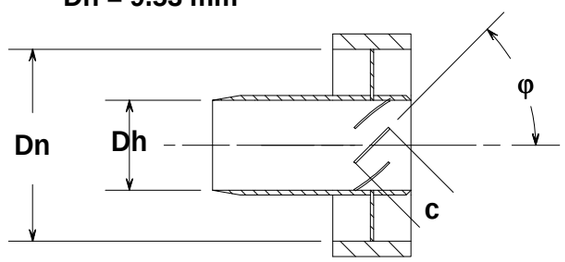


TOP VIEW

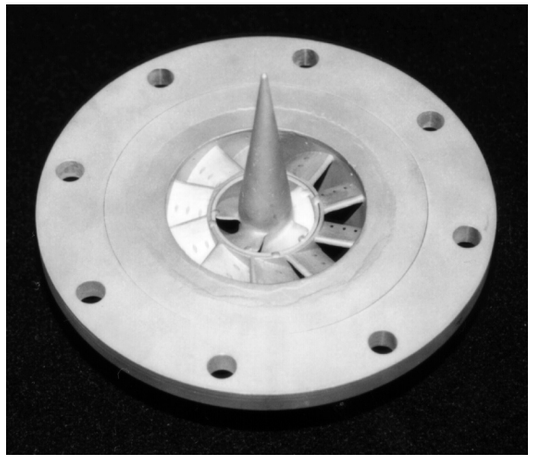


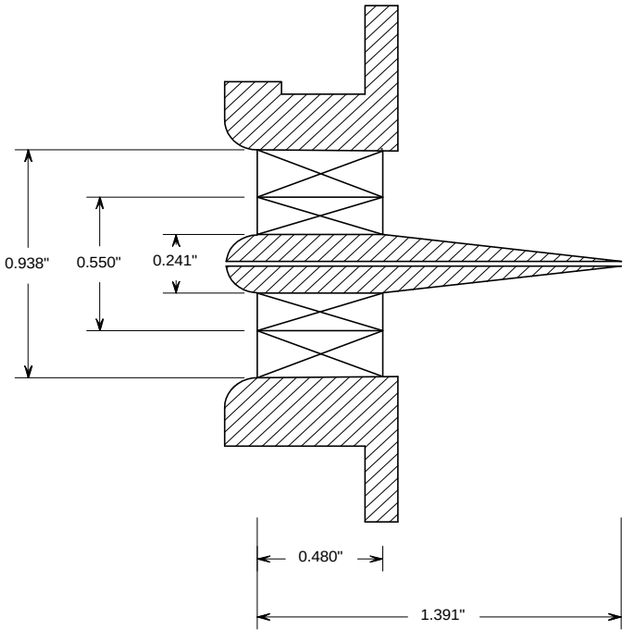
CROSS SECTION VIEW A-A'

Dn = 20.3 mm
Dh = 9.53 mm

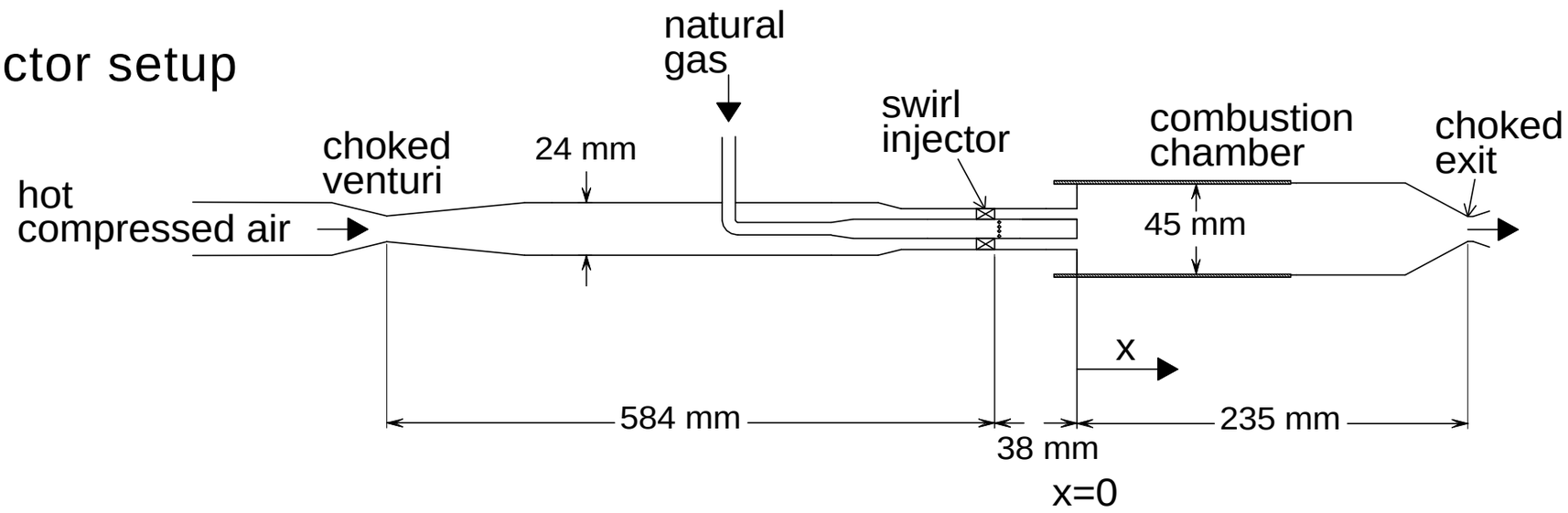


GE CRS INJECTORS

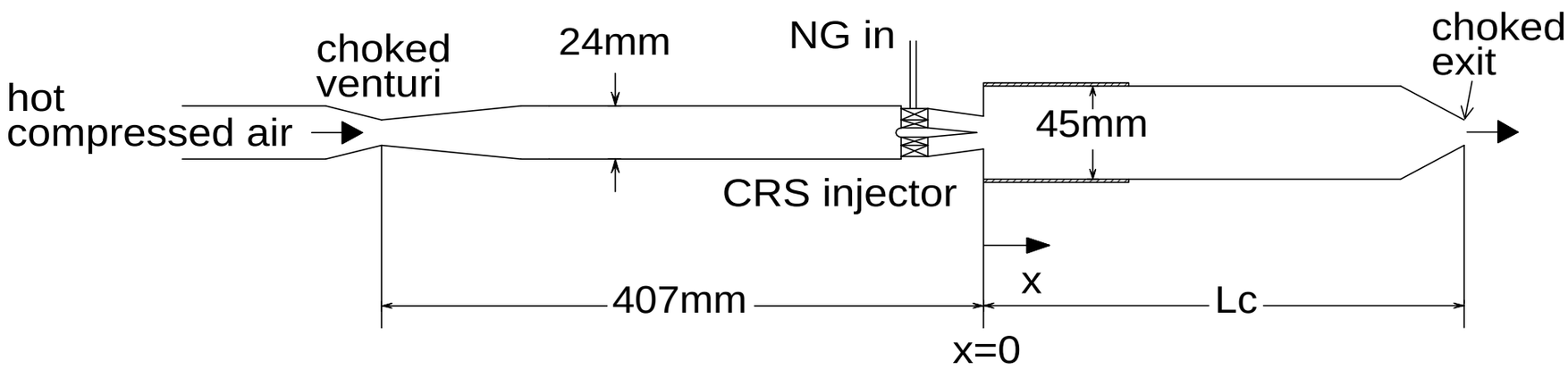




PSU injector setup



CRS injector setup



Lc = 235mm or 350mm

General Results

- Modes of Instability Identified
  - Strong 1L mode of combustor:

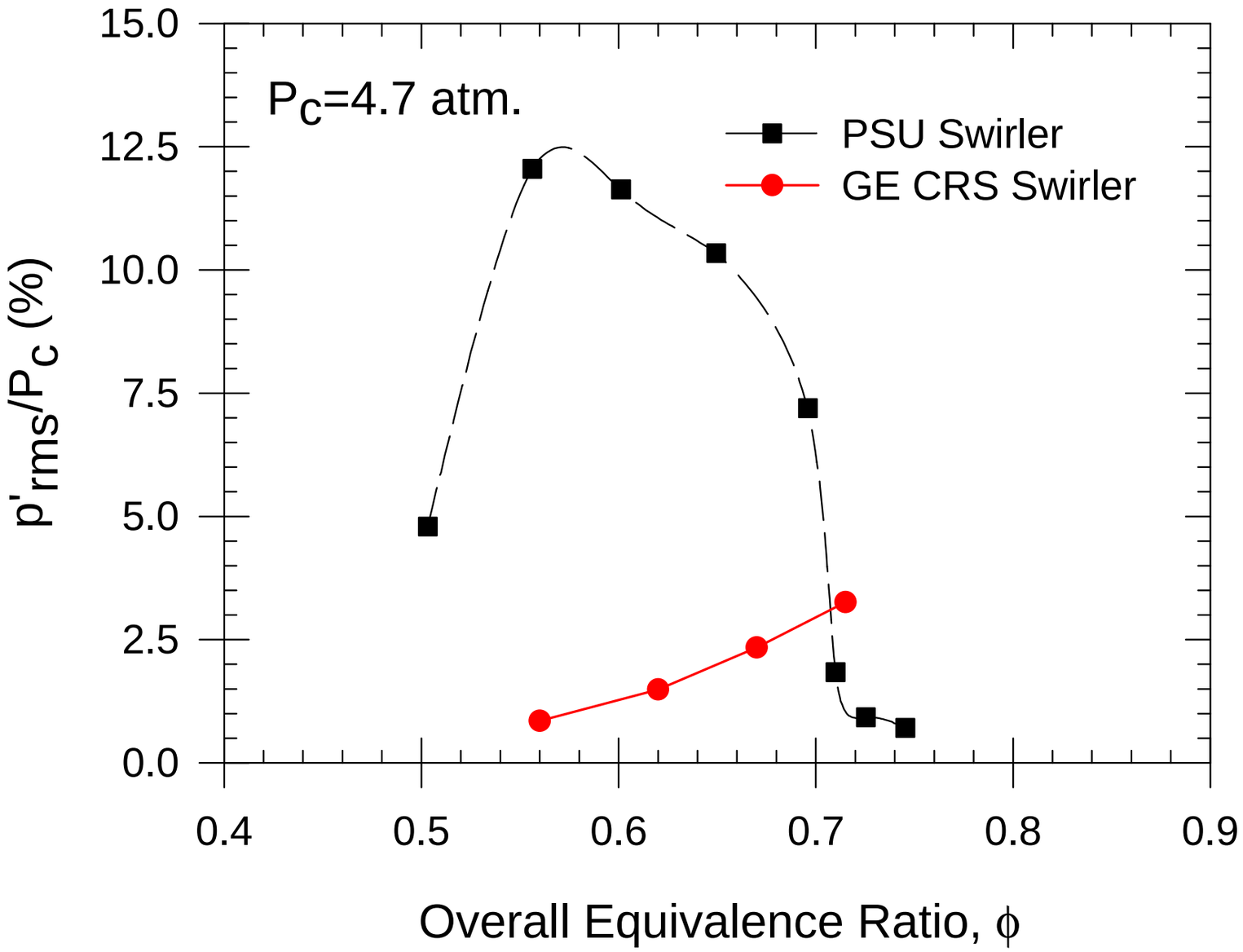
    A_{rms} = 10-15% of chamber pressure

    F= 1700 - 1900 Hz for short chamber

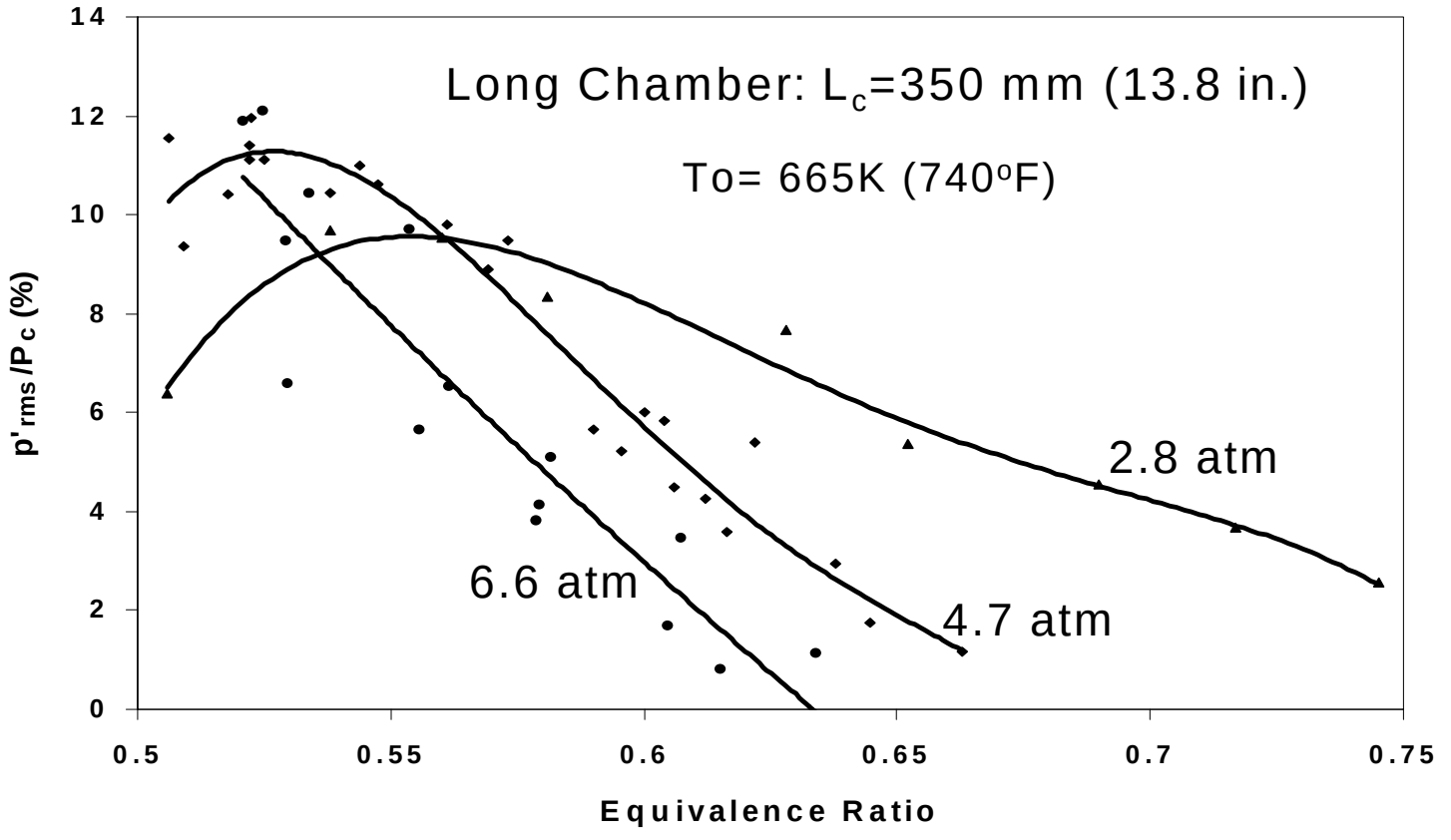
    F= 1100 - 1300 Hz for long chamber
  - Weak 2L mode of combustor

- Operating Parameters with a Strong Influence
  - Injector type (GE CRS versus PSU swirler)
  - Inlet air temperature T_o
  - Equivalence ratio ϕ
  - Level of premixing (fuel injection location X_{inj})
  - Swirl Angle
  - Chamber length L_c
  - Inlet air velocity V

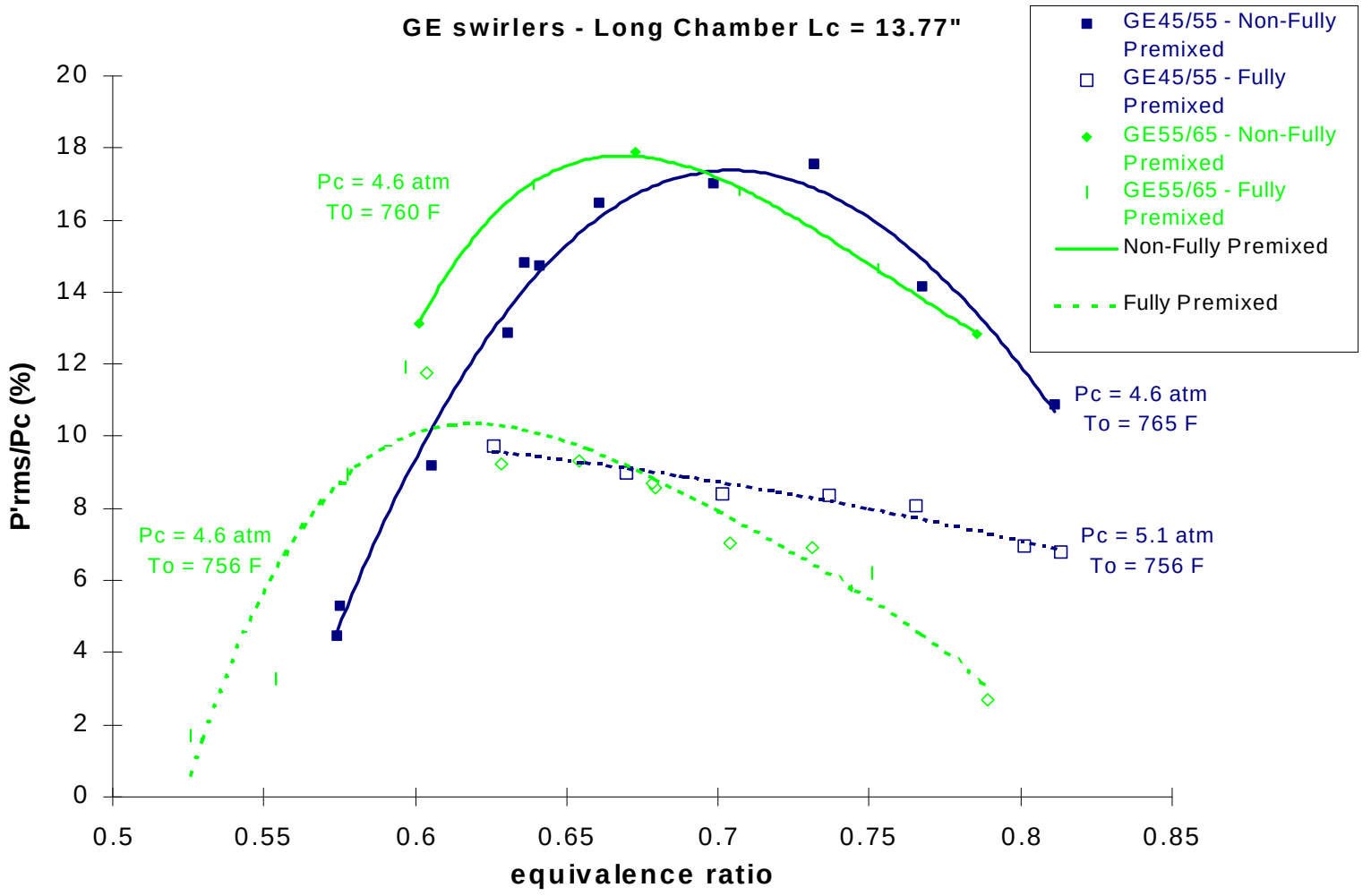
COMPARISON OF STABILITY MAPS FOR TWO TYPES OF SWIRLERS (SHORT CHAMBER CONFIGURATION)



COMPARISON OF STABILITY MAPS FOR TWO TYPES OF SWIRLERS (LONG CHAMBER CONFIGURATION)



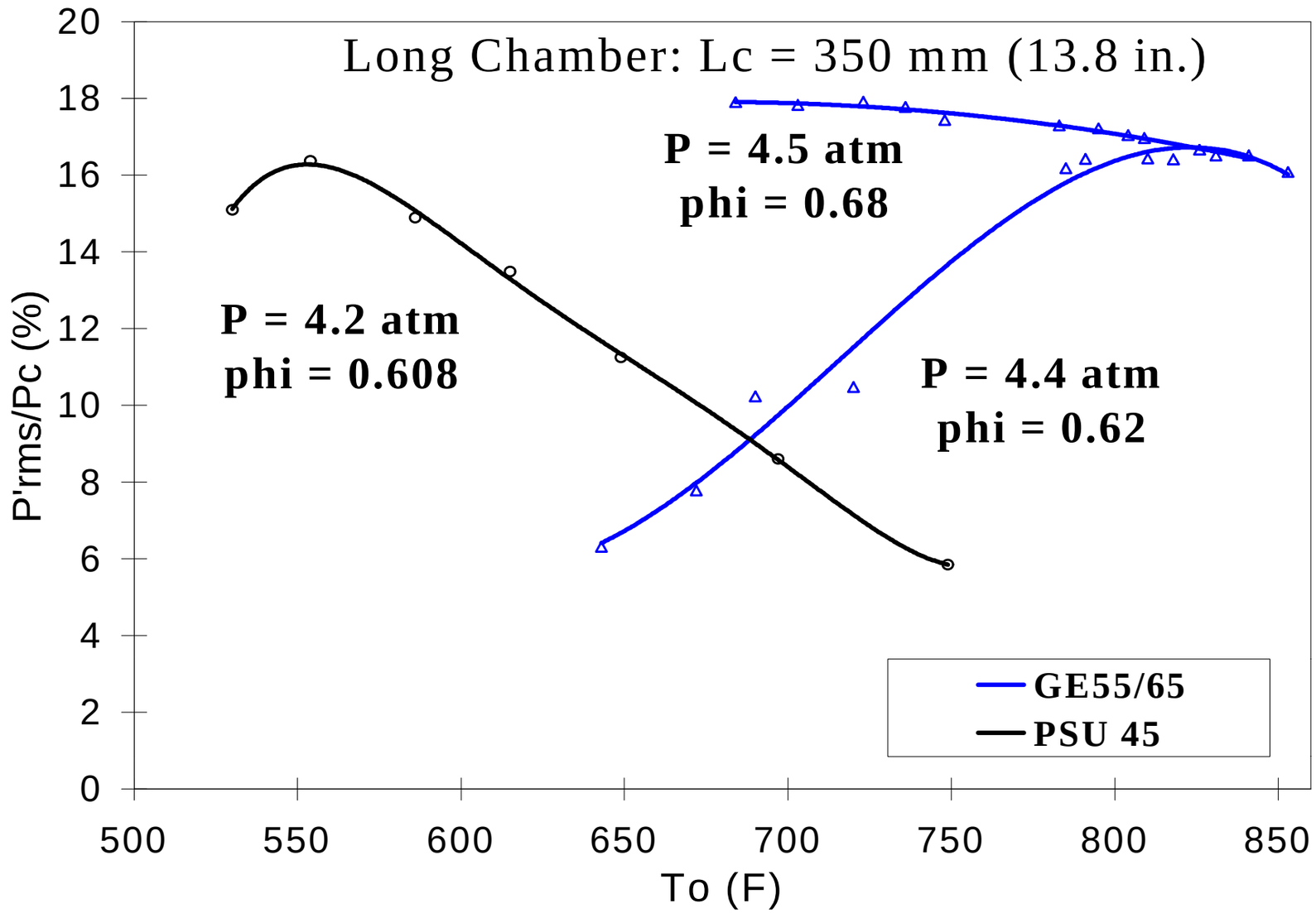
PSU SWIRLER



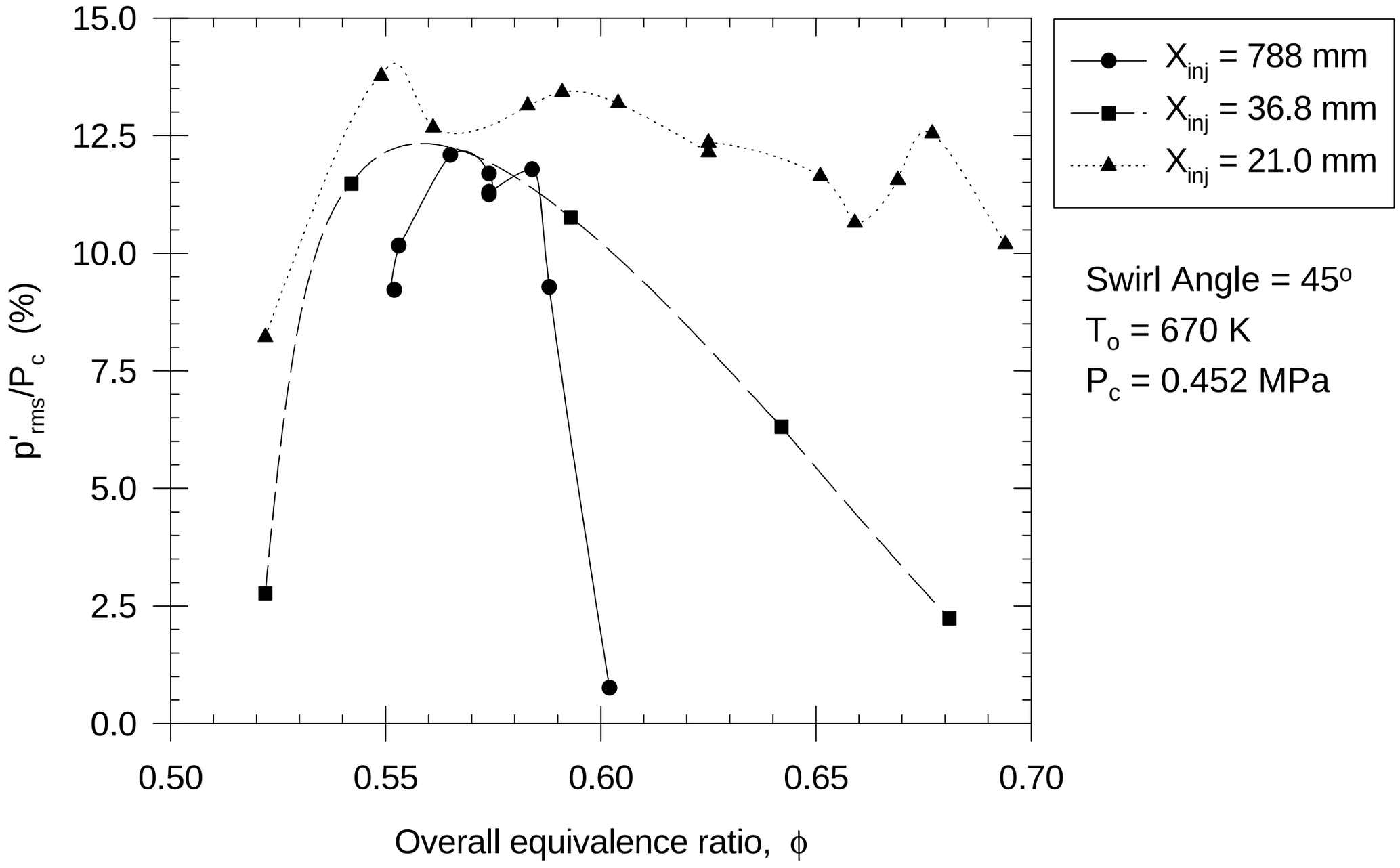
GE CRS SWIRLERS

EFFECT OF INLET AIR TEMPERATURE ON INSTABILITIES

Comparison for Two Types of Swirl Injectors - Natural Gas

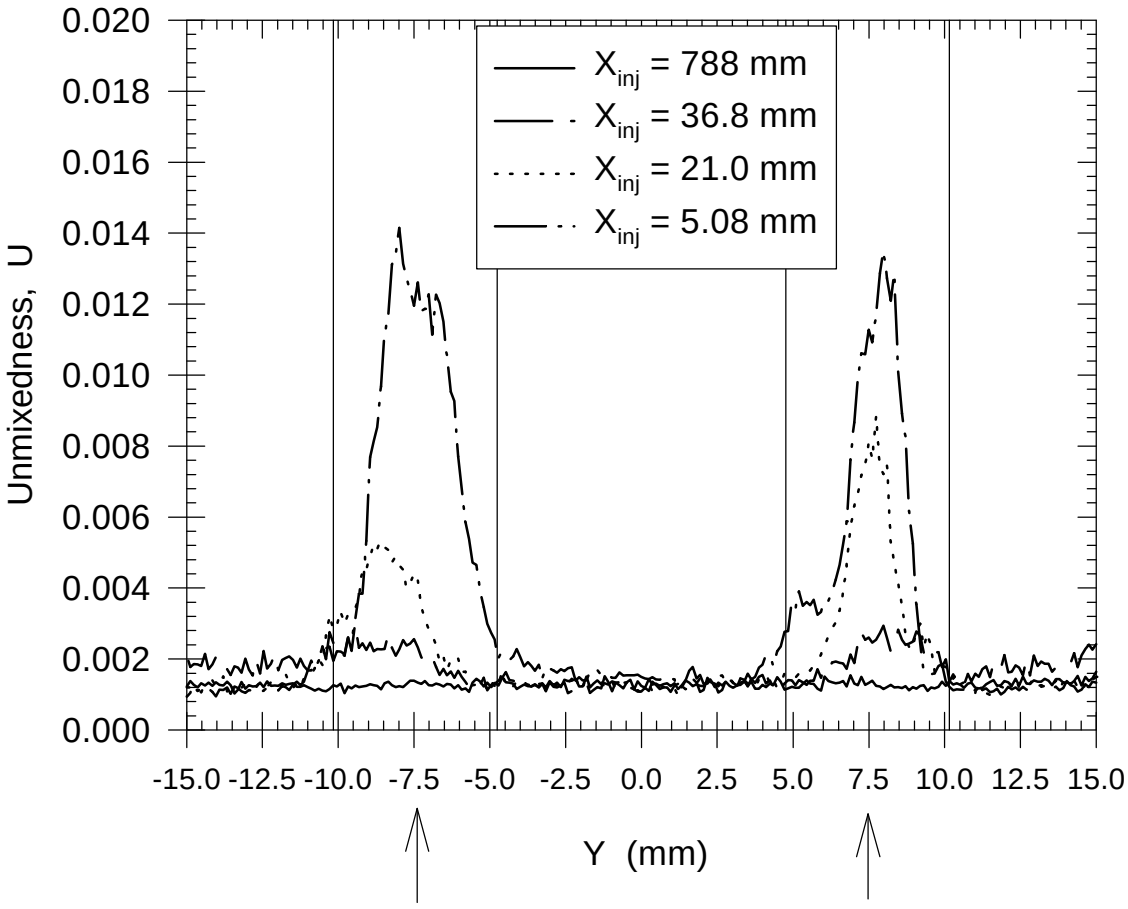


Stability map of PSU swirler as a function of level of premixing

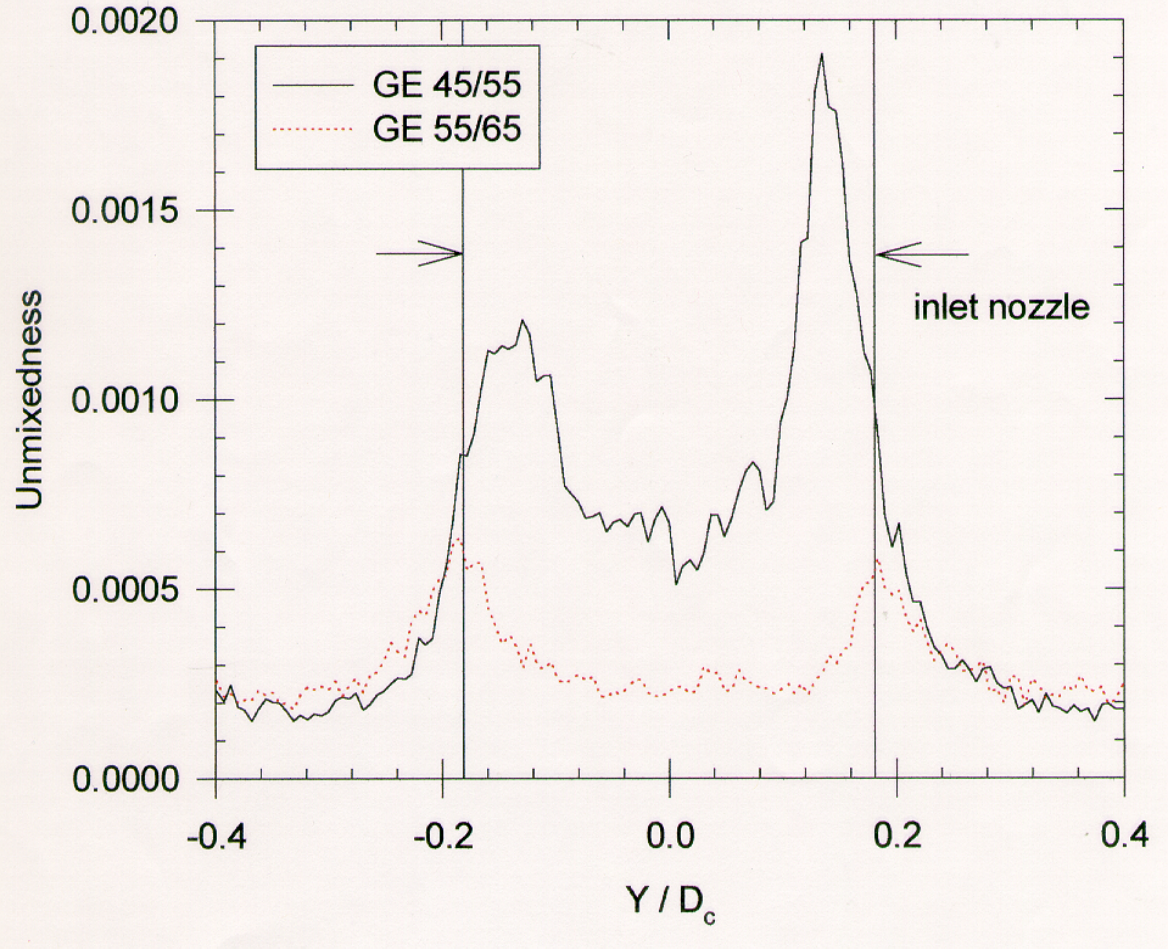


Mixedness Profiles for Both Swirl Injector Types

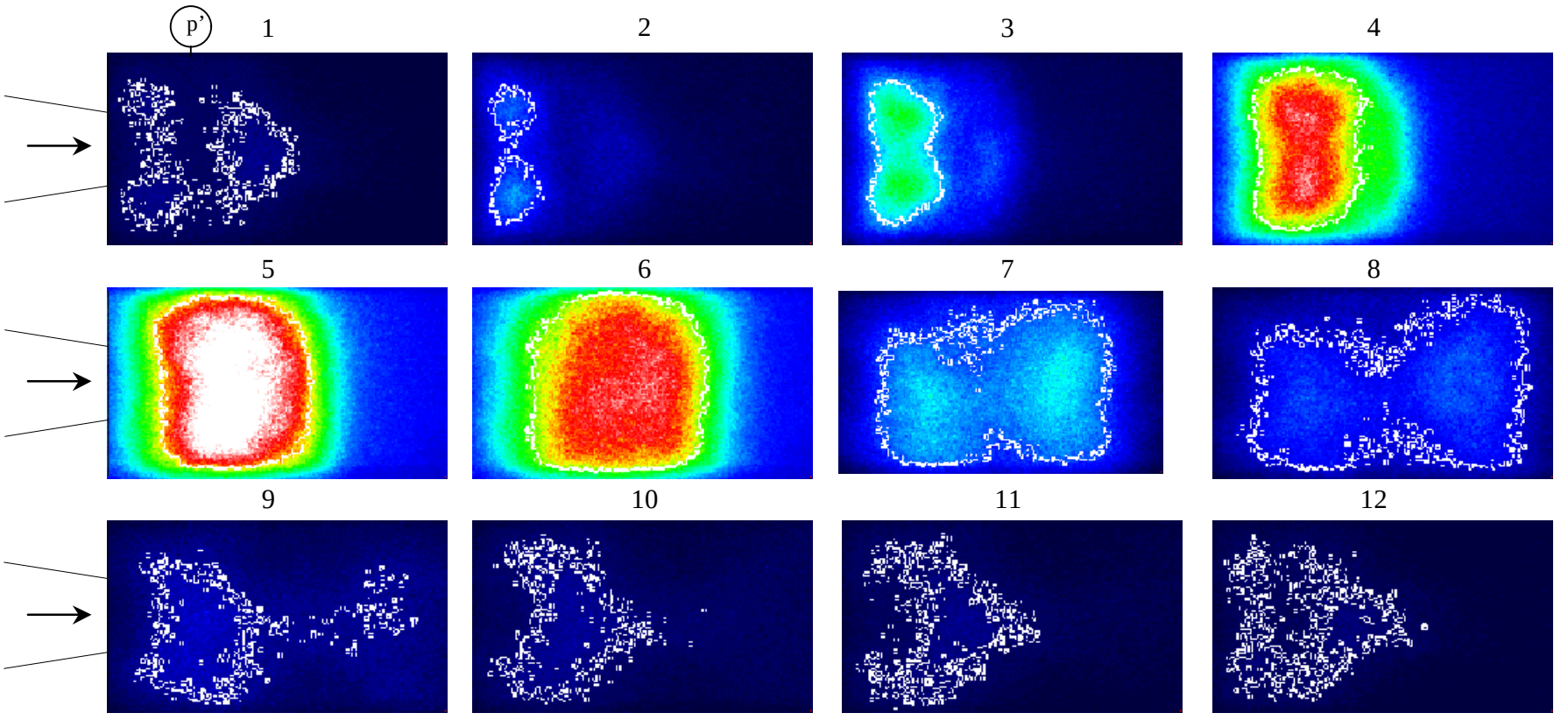
PSU SWIRLER



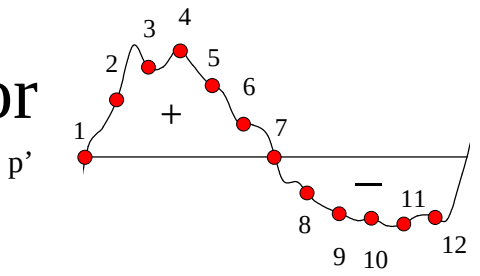
GE CRS INJECTORS



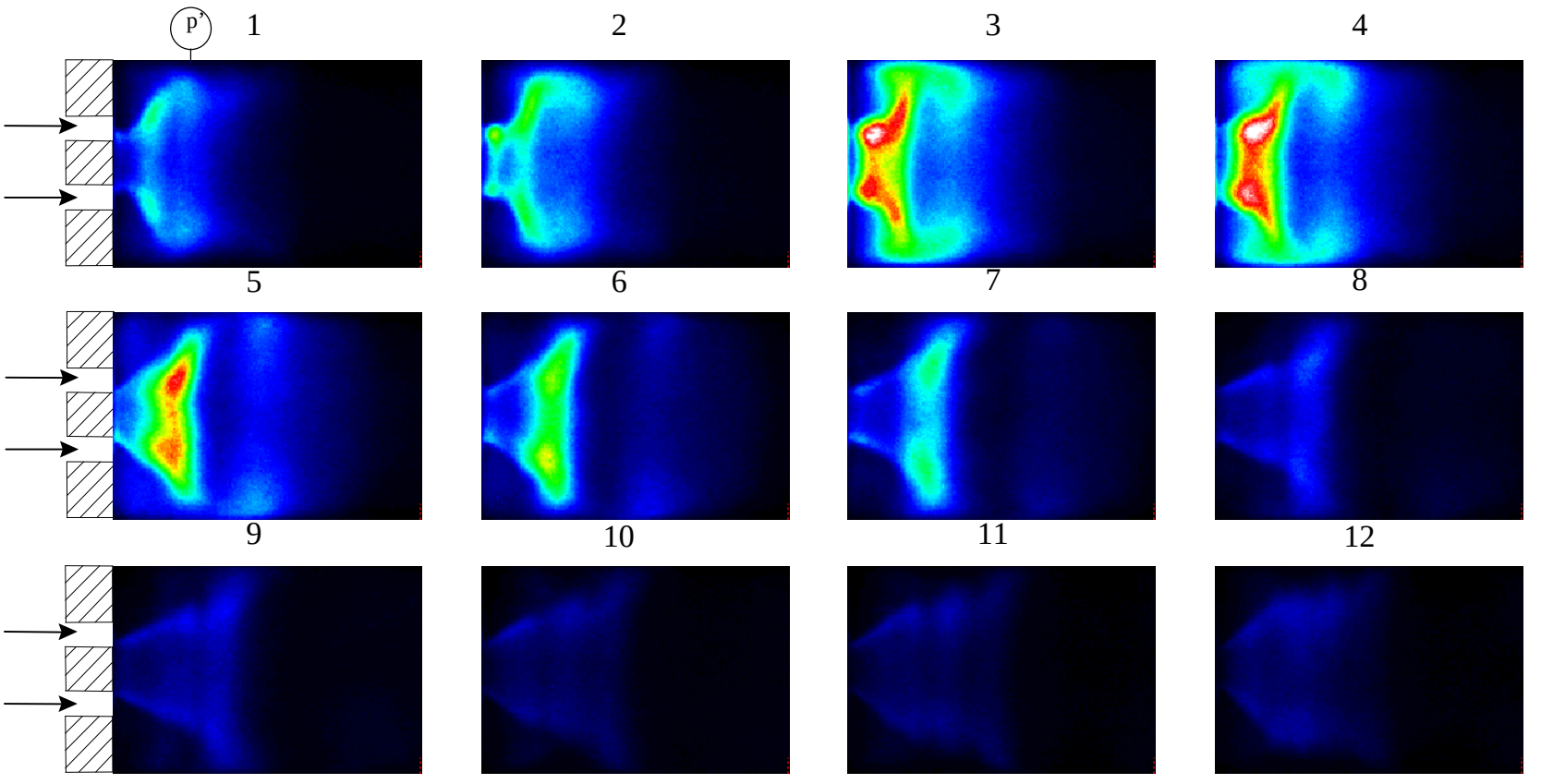
Phase-resolved CH* chemiluminescence images



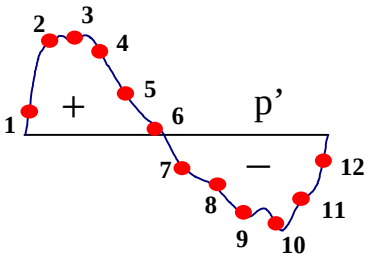
CRS Injector



T_o = 709K, P_c = 0.271MPa, ϕ = 0.61,
φ = 45º/55º and L_c = 350mm



PSU Swirler

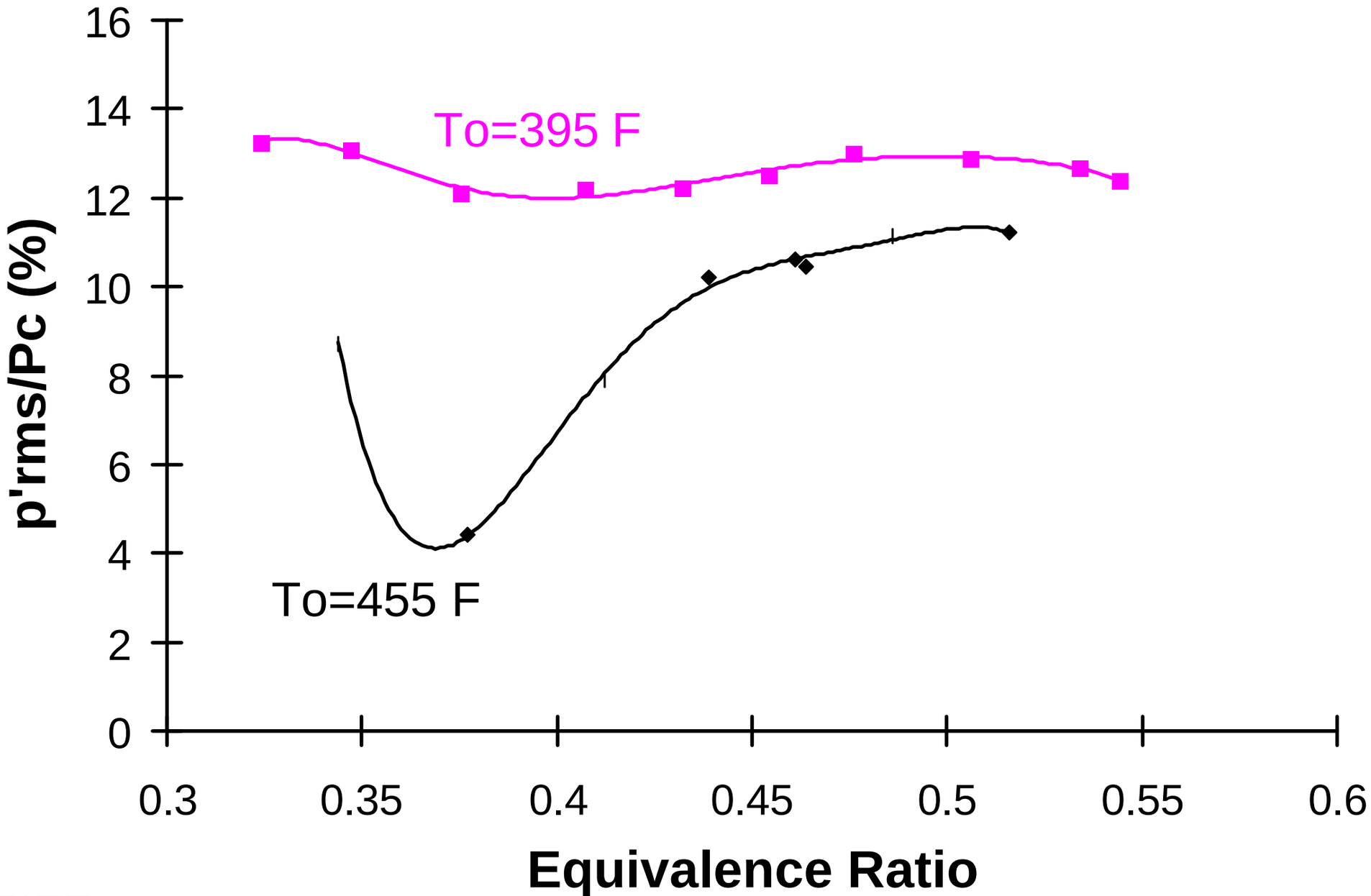


X_{inj}=36.8 mm, P_c=0.448 Mpa, Swirl Angle= 45º
T_o = 662 K and ϕ=0.58 **(1L mode)**

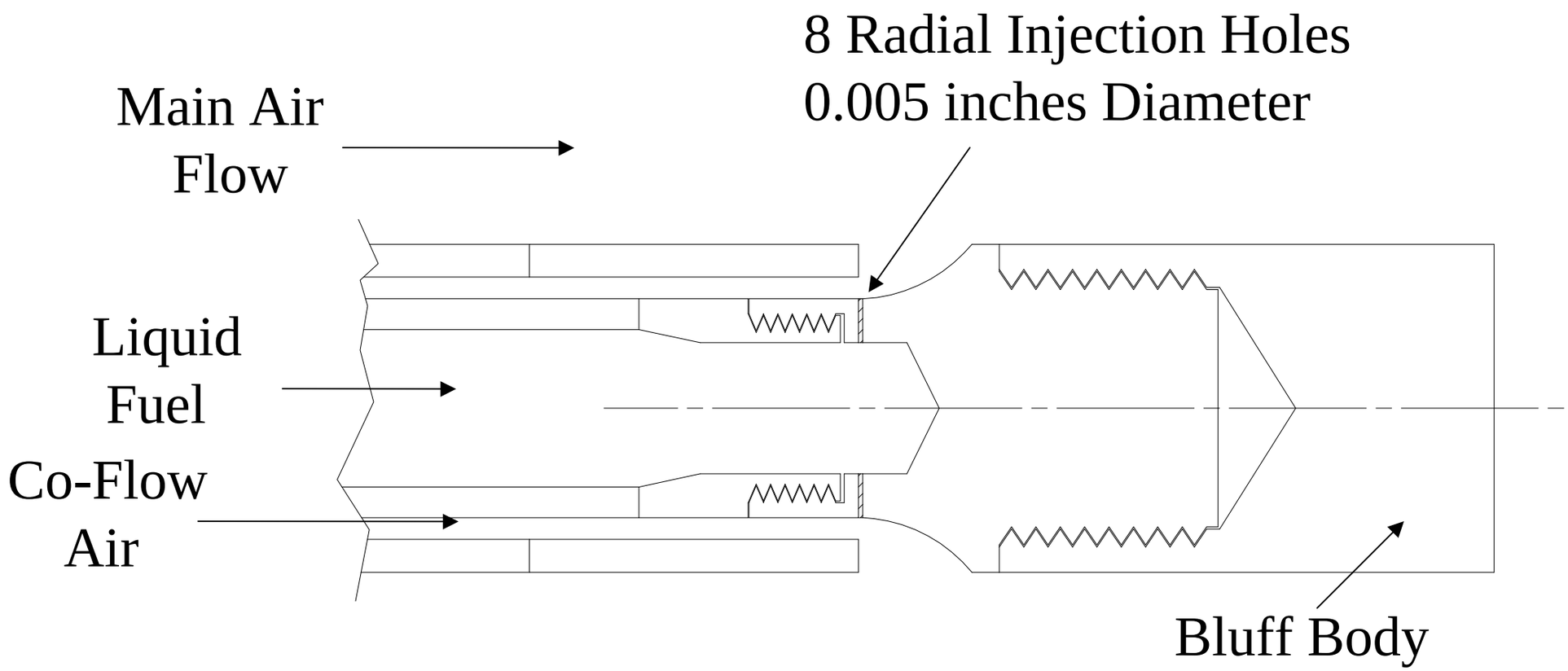
PENNSTATE

Propulsion Engineering Research Center

Stability Map for Ethylene/Air Combustion
Long Chamber (Lc = 13.8 in.), PSU 45 Swirl Injector



Liquid Fuel Injector



CONCLUSIONS AND PERSPECTIVES

- **Both types of swirl injectors produce very different stability behaviors**:
  Short combustion chamber (235 mm long): GE CRS Injectors produce no instabilities, PSU single swirl injector produces significant instabilities;
  Long combustion chamber (350 mm long): both injector types produce instabilities, but inlet temperature has opposite effects;

- **Equivalence ratio modulation is not the only mechanism** responsible for the instability behavior;

- **Controlling mechanism is complex** (equivalence ratio modulation, unmixedness, fluid mechanics effects);

- **Comprehensive results database** for natural gas will allow comparison with future data for liquid fuels

Acknowledgements

This material was prepared with the support of the U.S. Department of Energy, Federal Energy Technology Center, through a cooperative agreement with the South Carolina Energy Research and Development Center at Clemson University, Cooperative Agreement No. DE-FC21-92MC29061.