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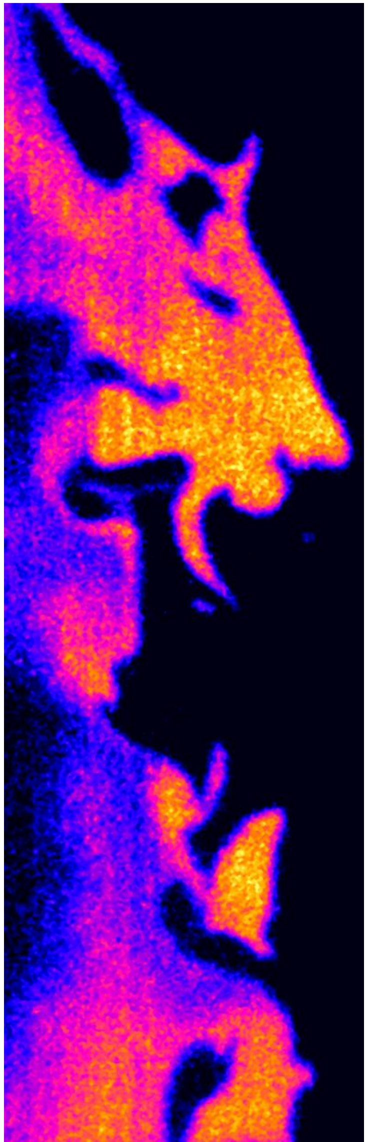
FUEL VARIABILITY EFFECTS ON TURBULENT, LEAN PREMIXED FLAMES AT HIGH PRESSURES



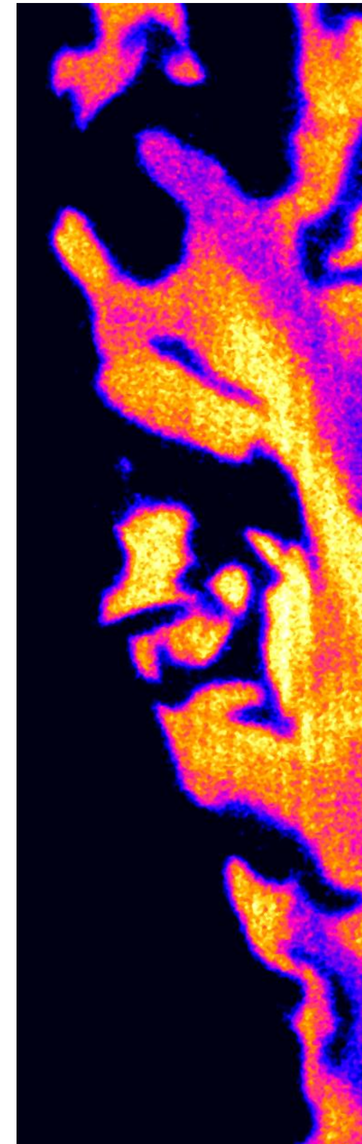
E. Boschek

P. Griebel

P. Jansohn

ASME Turbo Expo 2007: Power for Land, Sea, and Air

May 14-17, 2007, Montreal, Canada



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Introduction

Motivation

- **further improvement of lean premixed combustion technology for gas turbines (GT)**
  - ➢ improved flame stability
  - ➢ lower NO_x emissions
- **generation of experimental database for further development of numerical models**

Objectives

- **flame characterisation for a broad fuel spectrum (CH_4, H_2-enriched, C_2^+, syngas) at GT conditions**
  - ➢ influences of operating conditions and turbulence on flame structure (position, flame brush thickness, flame speed)
  - ➢ Lean blowout limits (LBO), NO_x emissions

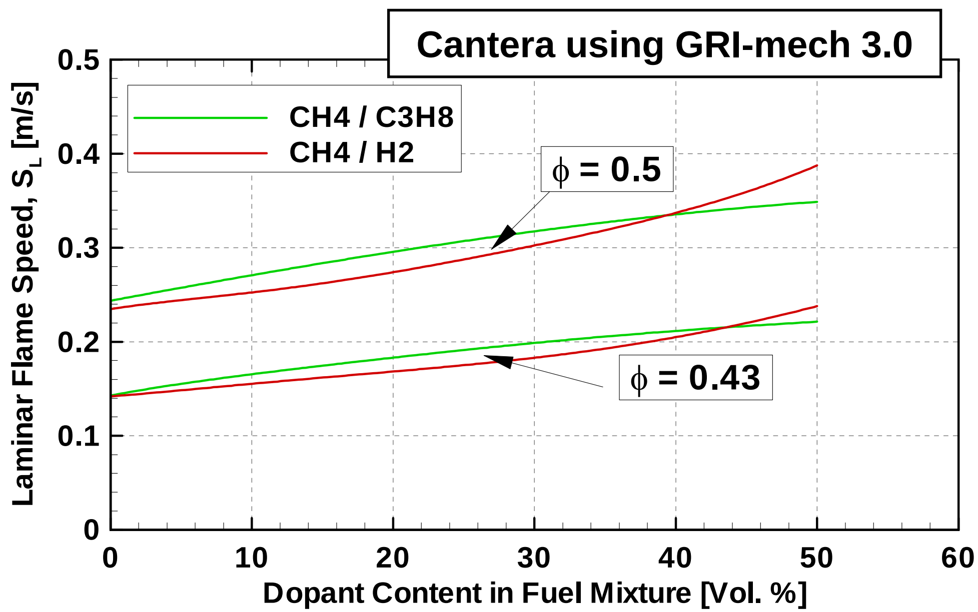
Focus

Fuel Flexibility

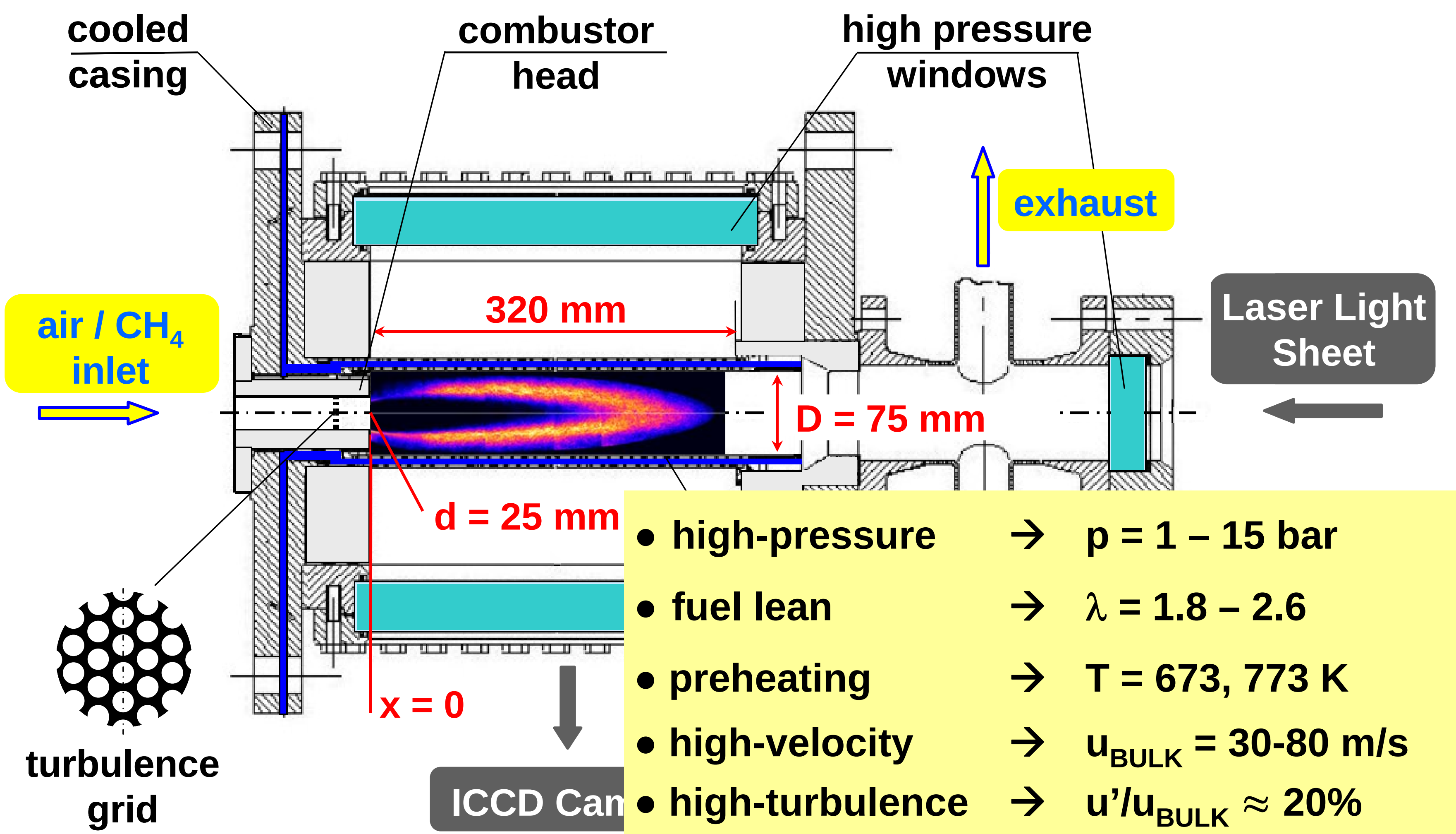
(H_2-CH_4/air flames and C_3H_8-CH_4/air flames)

Representative Fuel Mixtures

- Base Fuel is methane (CH_4) → main constituent of natural gas
- Pure hydrogen (H_2) is added to represent "hydrogen enriched" components
  1. Highly reactive – high laminar flame speed
  2. Extremely light and diffusive
  3. Resistance to strain
- For higher hydrocarbon C_2+ → Propane C_3H_8 was chosen as representative
  1. More reactive than pure methane - higher laminar flame speed
  2. Heavier molecule: less diffusive



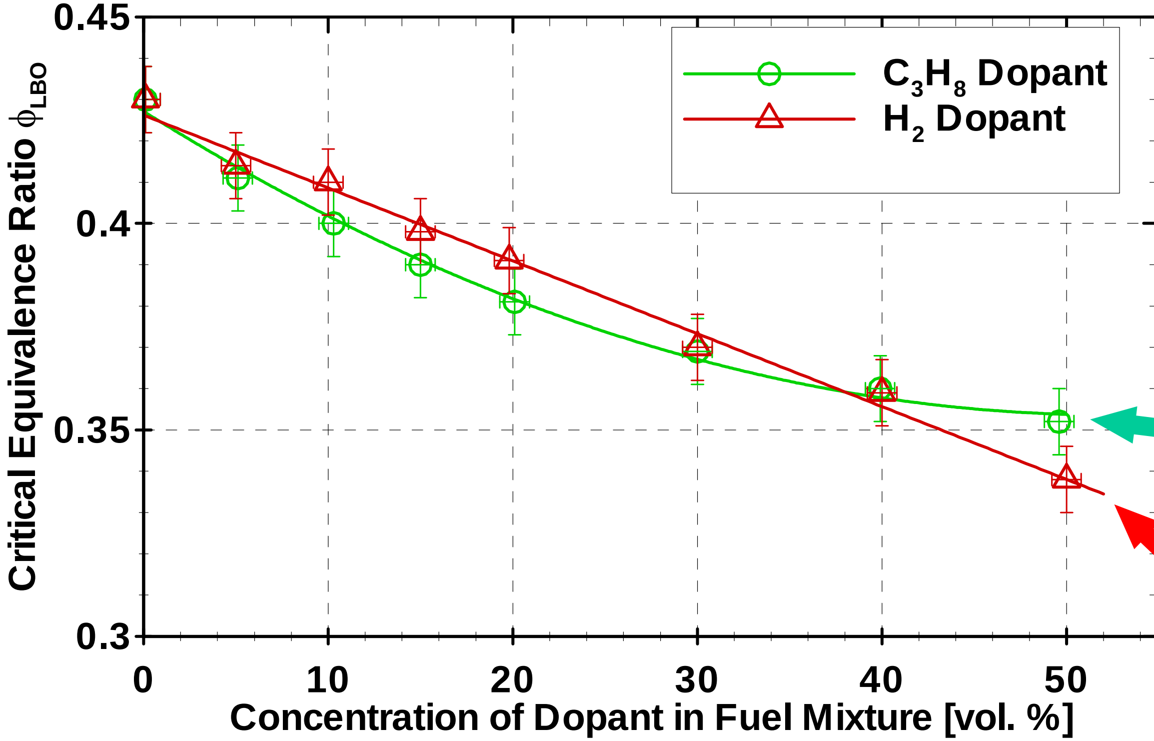
Experimental Set-up



- **high-pressure** → **$p = 1 – 15$ bar**
- **fuel lean** → **$\lambda = 1.8 – 2.6$**
- **preheating** → **$T = 673, 773$ K**
- **high-velocity** → **$u_{BULK} = 30\text{-}80$ m/s**
- **high-turbulence** → **$u'/u_{BULK} \approx 20\%$**
- **fuels** → **CH_4, C_3H_8, H_2**

Lean Blowout Limits (LBO): Influence of Fuel Blend

T=673 K, p=5 bar, U_{bulk} = 40 m/s



C_3H_8 shows slightly higher effect at lower concentrations and levels off at higher ones

- H_2 exhibits consistent decrease on LBO over measured range

18 % extension C3H8

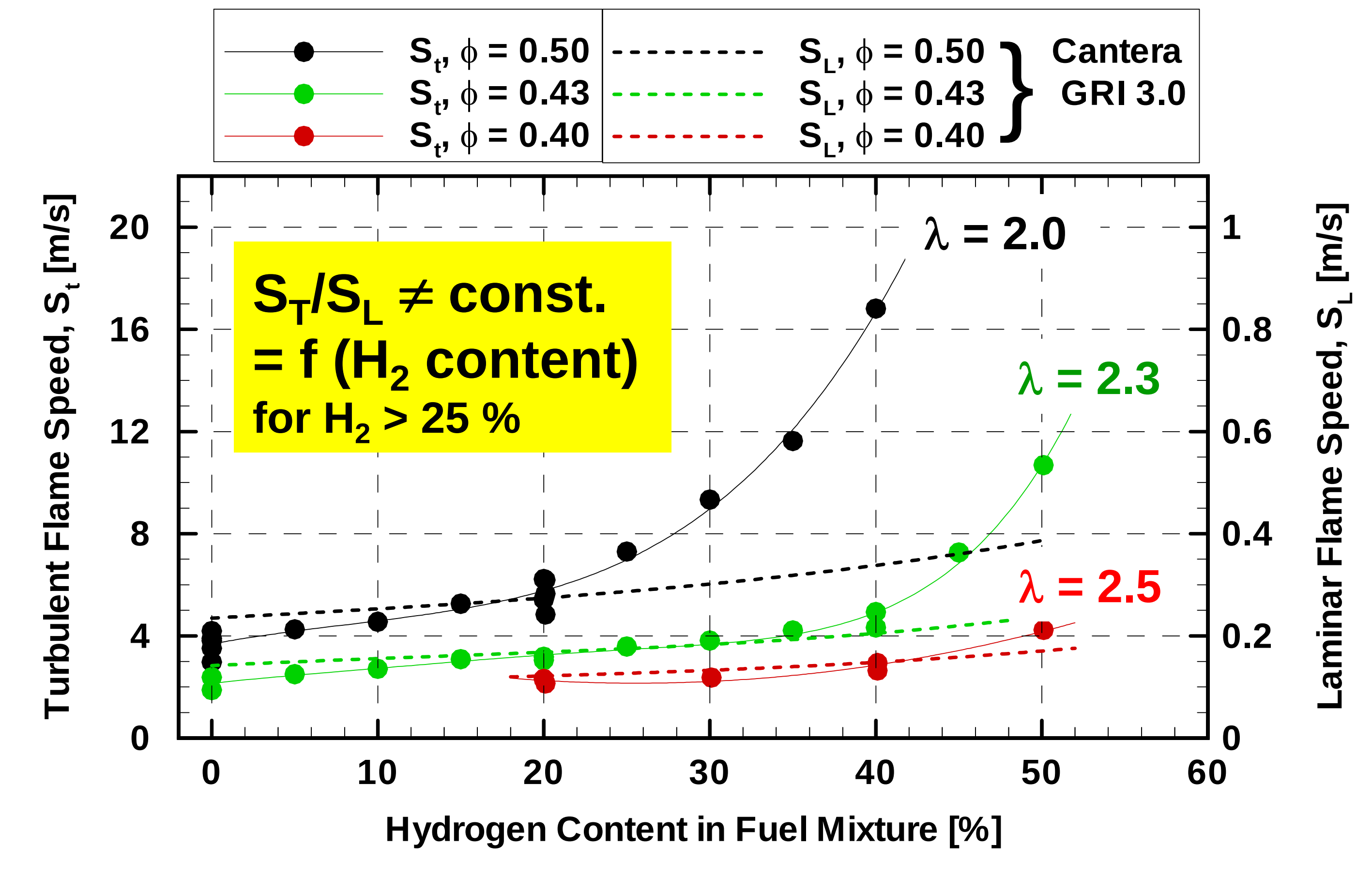
22 % extension H2

- Hydrogen results agree well with a study in a swirl stabilized combustor [1] which showed ~23 % extension at 50 % H_2 (Pressures 1, 4, 8 atm).

[1] Strakey, P., Sidwell, T., Ontko, J. *Investigation of the effects of hydrogen addition on lean extinction in a swirl stabilized combustor*, *Proceedings of the Combustion Institute*, 31(2), 3173-3180, (2007).

Turbulent Flame Speeds as a Function of Hydrogen Content

673 K, 5 bar, 40 m/s, grid g365,xg10



Up to approx. 25 % Vol. H_2: chemical kinetics dominate (S_T/S_L const.)
H_2 > 25 % Vol.: additional effects (preferrential diffusion, fluiddynamics)

Outlook

1. **Flame characterisation for a broad fuel spectrum at GT conditions (high-pressure test rig):**

- **H_2- CH_4/air flames (continuation of present work)**

  determine fundamental reasons for specific characteristics (turbulent flame speed at high H_2 content)

  <u>approach:</u> apply fractal analysis

- **Methane/propane mixtures (finalize present work)**

  determine fundamental reasons for specific characteristics (non-linear/diminishing stabilization effect for high C_3H_8 content)

  <u>approach:</u> chemical kinetic studies

- **Syngas (H_2/CO/inerts) combustion**

  study characteristics (LBO, NOx emission, flame speed)

  <u>motivation:</u> demonstrate&understand safe, low-emission combustion of fuel gases derived from gasification of solid fuels (biomass, coal, …)

Outlook 2/2

2. Fundamental studies (atmospheric & elevated pressure):

- **instationary effects (local extinction, pulsations)**

  exploit benefits of new fast laser system (combined PIV/LIF @ kHz range)

- **partial premix operation (H_2 piloting)**

  optimisation of H_2 injection with respect to LBO extension & NO_x emissions

Funding secured (at least for 2008):

- **Emphasis of activities have currently shifted towards syngas ($CO+H_2$)**
- **Pure & diluted H_2 mixtures targeted in new project proposal (related to pre-combustion decarbonization processes)**