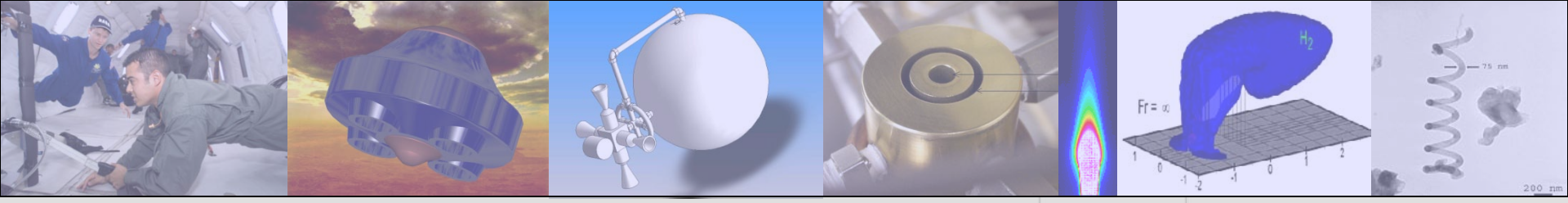

Effects of Combustion-induced Vortex Breakdown of Flashback Limits of Syngas-Fueled Turbine Combustors

DE-FG26-08NT0001719

Ahsan Choudhuri, PhD
Associate Professor, Mechanical Engineering
Director, **C**ombustion and **P**ropulsion **R**esearch **L**aboratory
University of **T**exas **E**l **P**aso

June 9-10
2009 Contractors Review Conference
University Coal Research (UCR); Historically Black Colleges and Universities and Other Minority Institutions (HBCU/OMI)
National Energy Technology Laboratory, Department of Energy
Morgantown, WV

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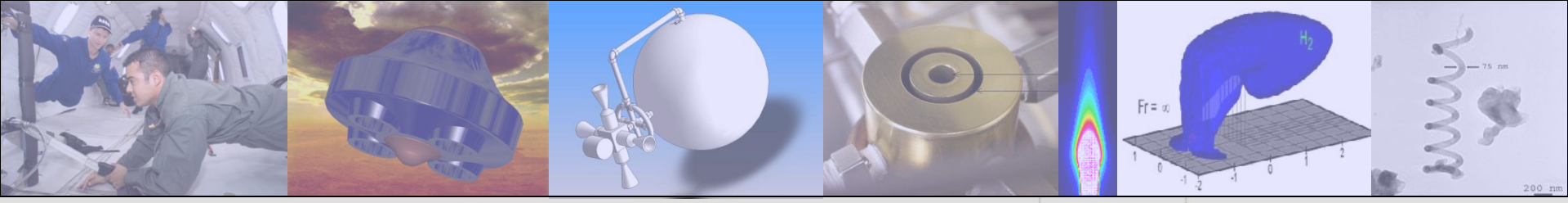
CPRL
POWERING INNOVATION THROUGH DIVERSITY



Project Information

Project Title: Effects of Combustion-induced Vortex Breakdown of Flashback Limits of Syngas-Fueled Gas Turbine Combustors
Grant No: DE-FG26-08NT0001719
Agency: National Energy Technology Laboratory, Department of Energy

DOE Project Manager: Norm Popkie
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National Energy Technology Laboratory
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Duration: 04/01/08-03/31/11

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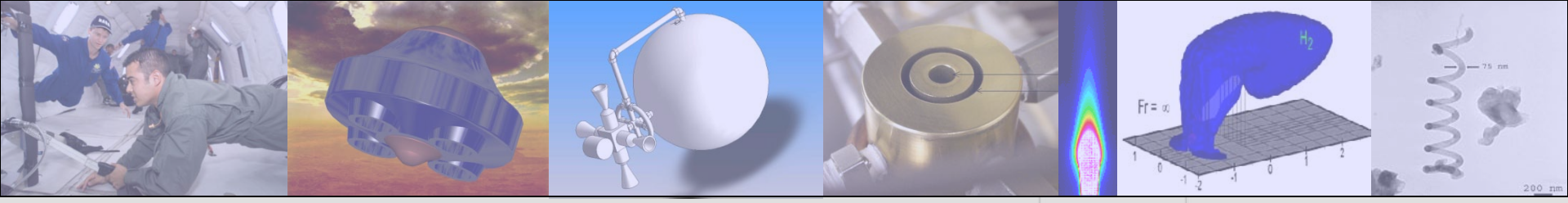

Project Objectives

- **To study the effects of syngas fuel compositions on flashback propensity (BL and CIVB)**
  - Flow-field Parameters [Swirl Number; PVC; Re]
  - Fuel Compositions
  - Flame Characteristics [OH^* /CH^*; S_L and S_T; ρ_u/ρ_b ; T_f]

- **To explore passive modification of combustor aerodynamics**
  - Asymmetric burner exit profiles

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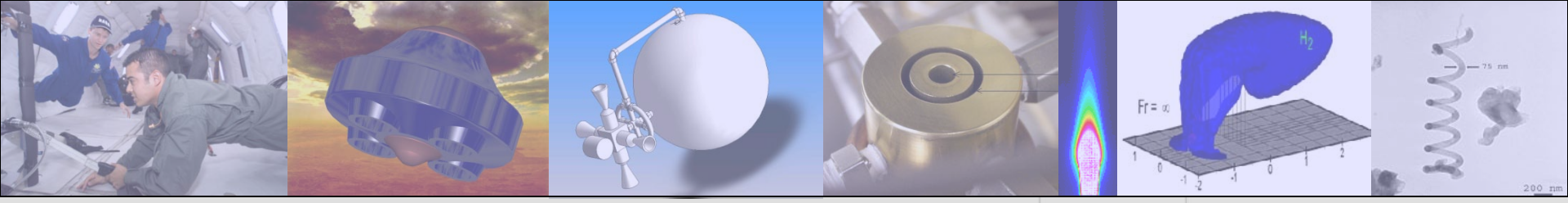

Flame Flashback

- **Boundary Layer Flame Propagation (BL)**
- Turbulent Flame Propagation in Core Flow
- Combustion instabilities
- **Combustion Induced Vortex Breakdown (CIVB)**

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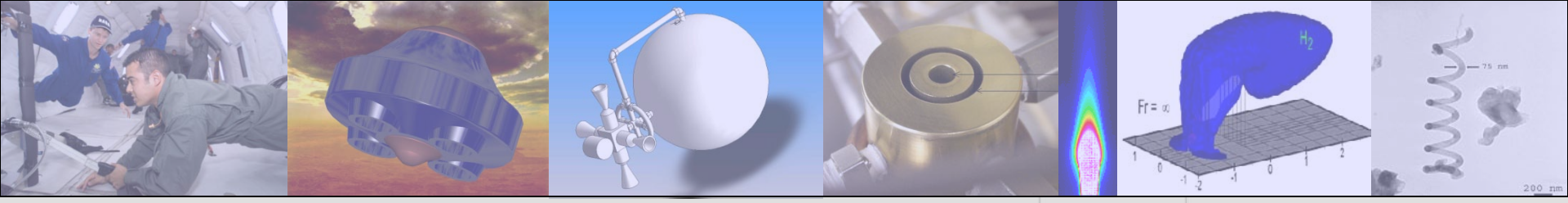
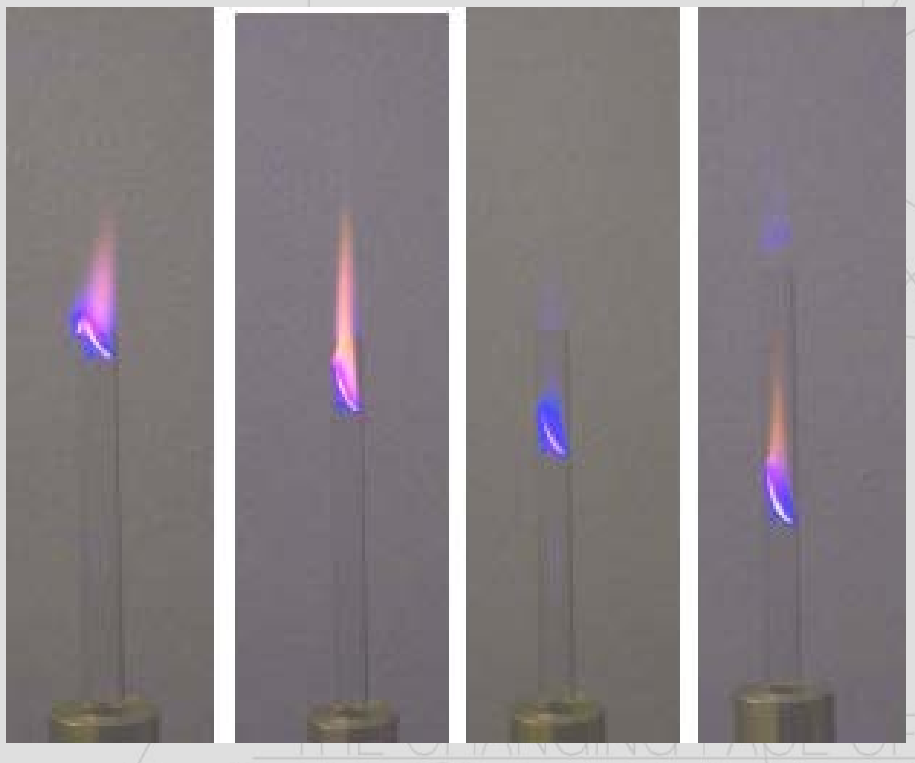
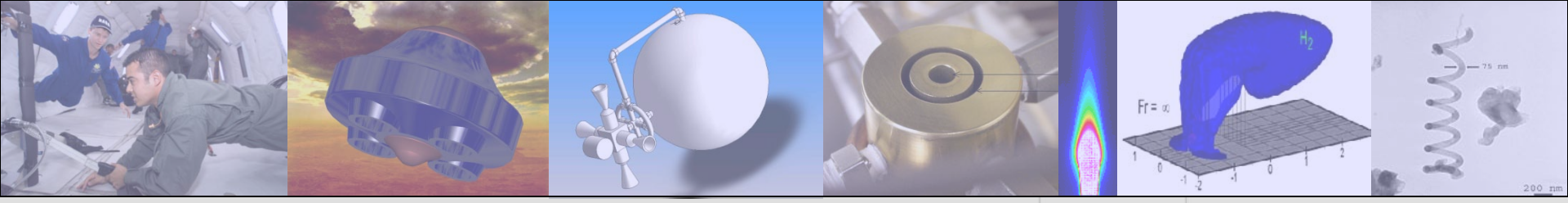


Boundary Layer Flame Propagation



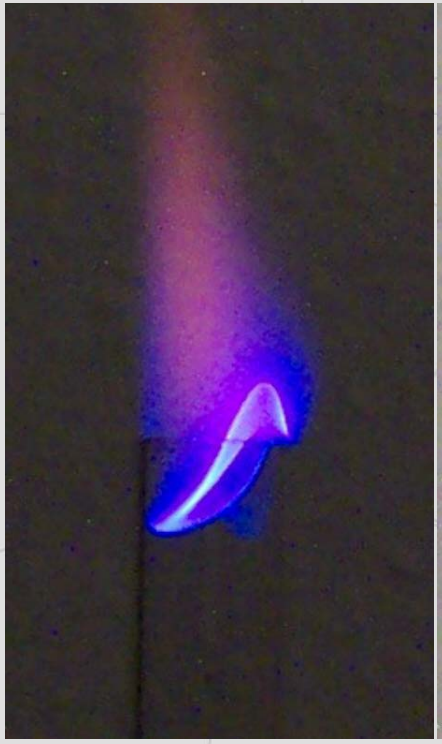


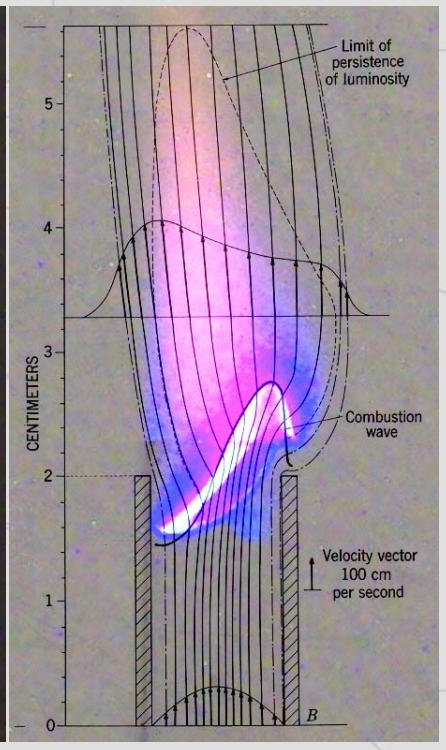
$$g_F = \left.\frac{\partial u_u}{\partial r}\right|_R \approx \frac{u_u}{r} = \frac{S_L}{d_P}$$

$$d_p = a d_q \qquad d_q = 2\sqrt{b}\,\frac{\alpha}{S_L}$$

$$c = \frac{1}{2a\sqrt{b}}$$

$$\boxed{g_F = c\,\frac{S_L^2}{\alpha}}$$





Past Investigation: Natural Gas

$$g_F = 14.125\left[\frac{S_L}{d_q}\right]^{1.168}$$

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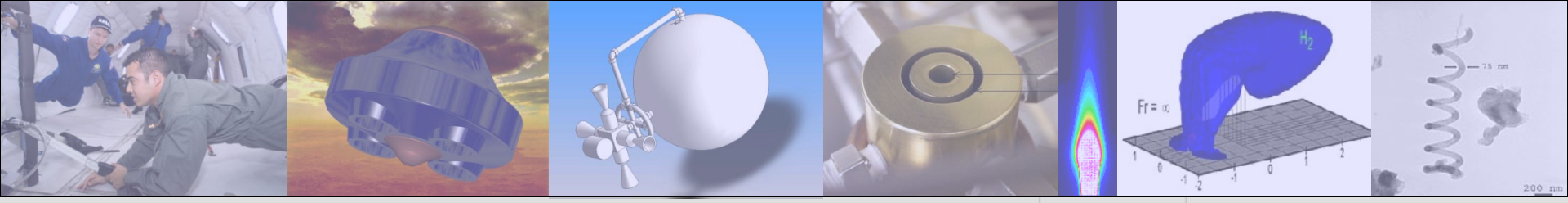
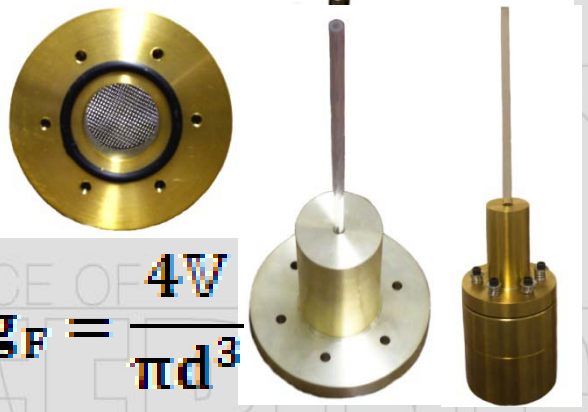


Experimental Setup: Boundary Layer Flame Propagation



$$g_F = \frac{4V}{\pi d^3}$$

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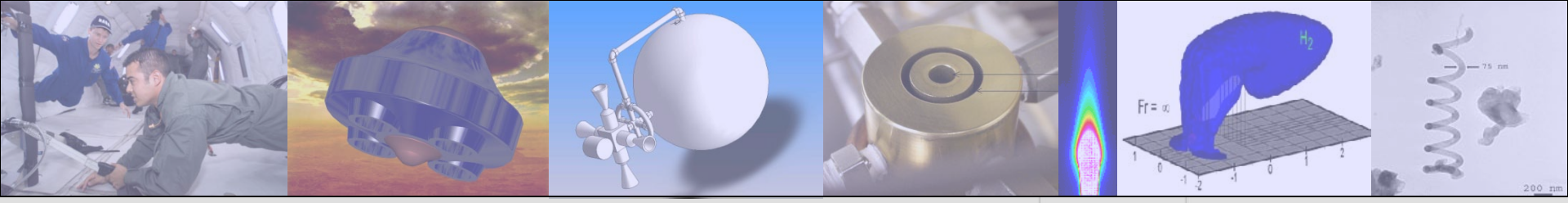
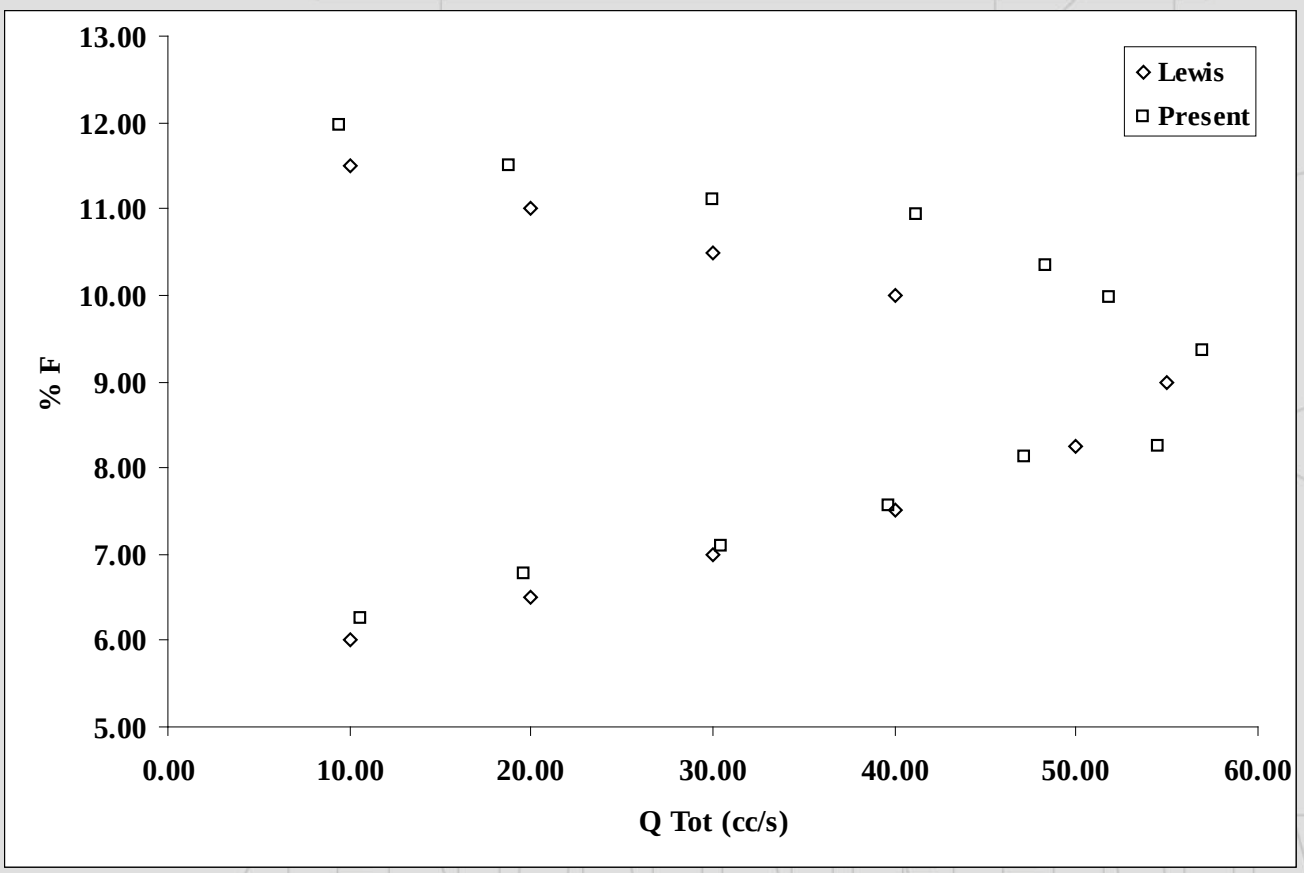
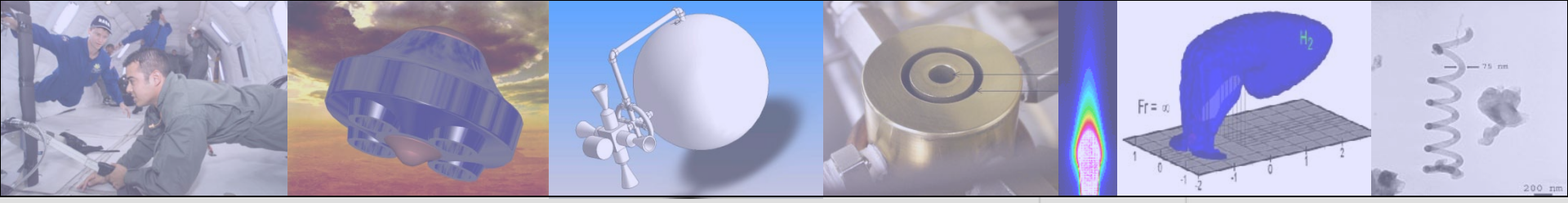


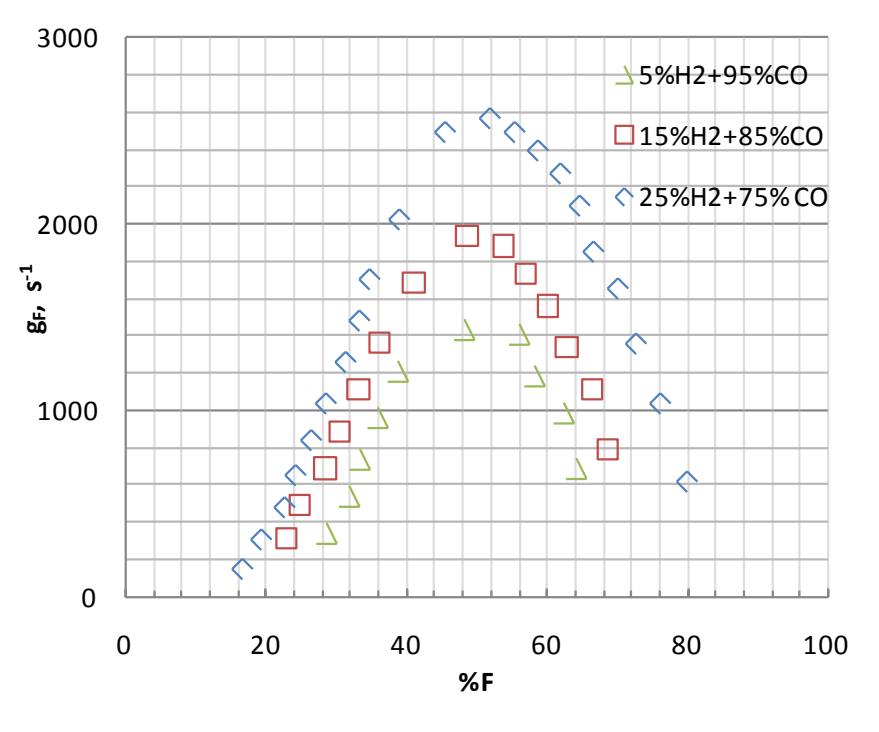
Results

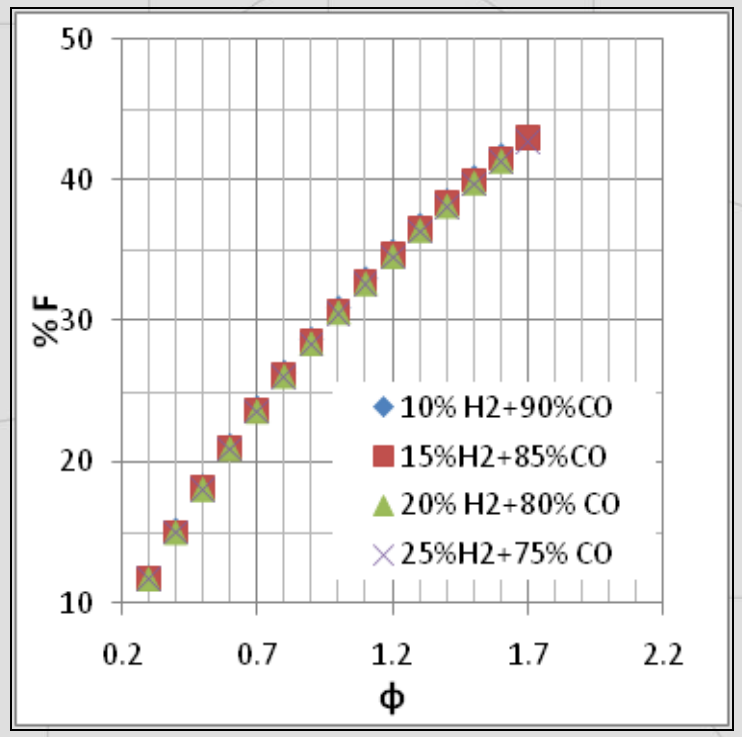


81.8% CH_4, 17.7% C_2H_6 and 0.5% N_2



Results





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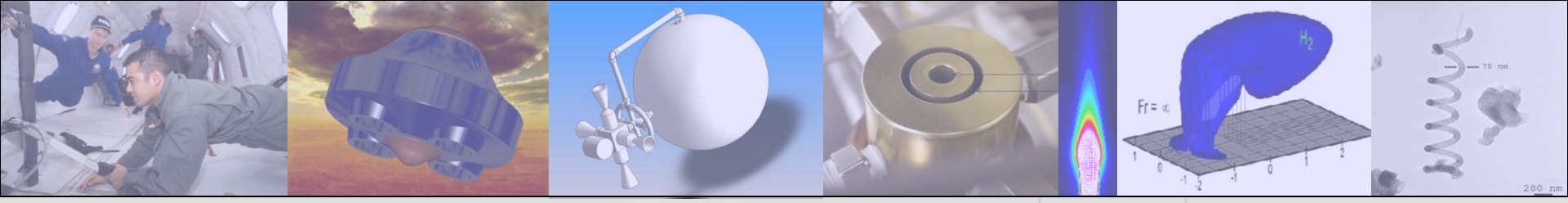
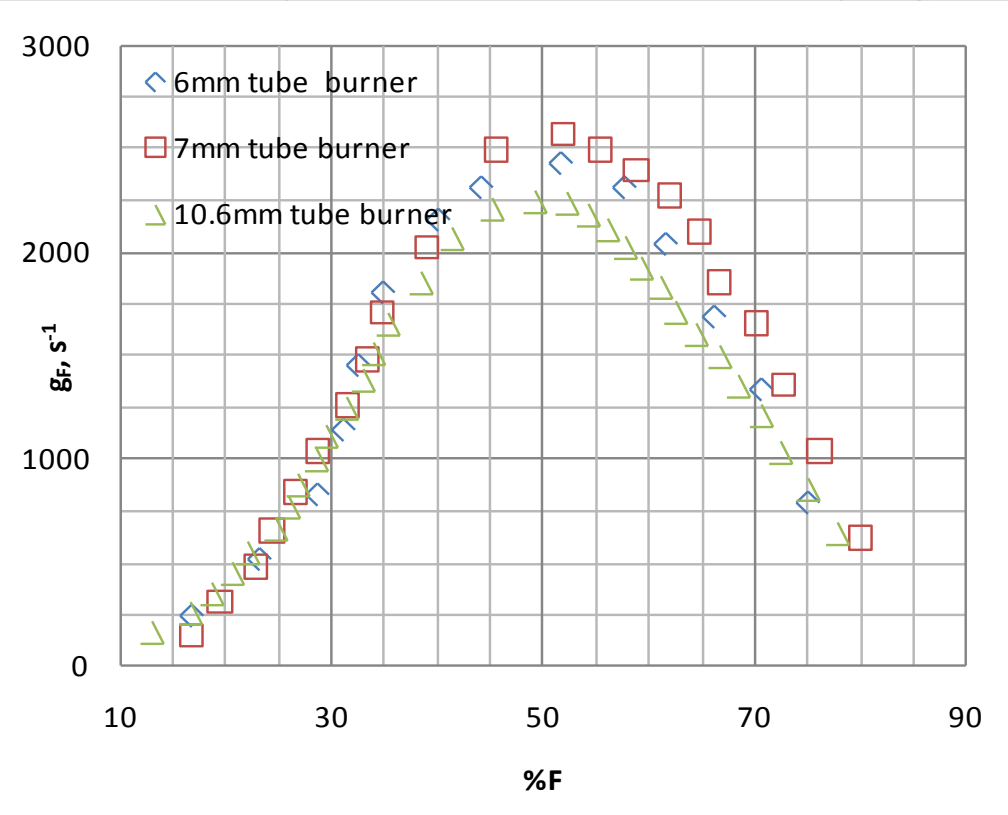
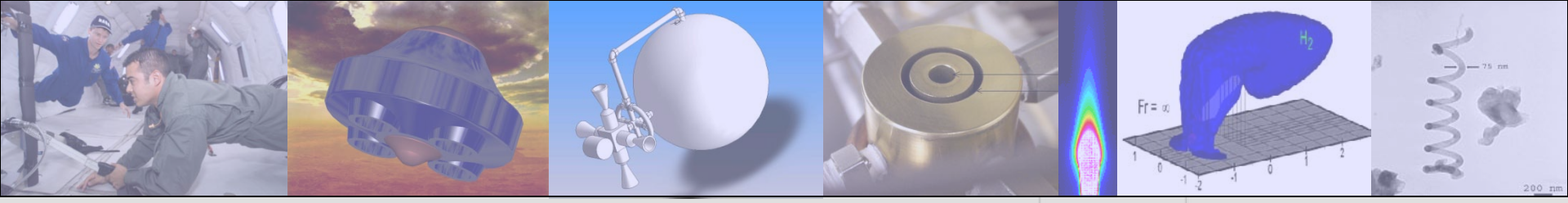
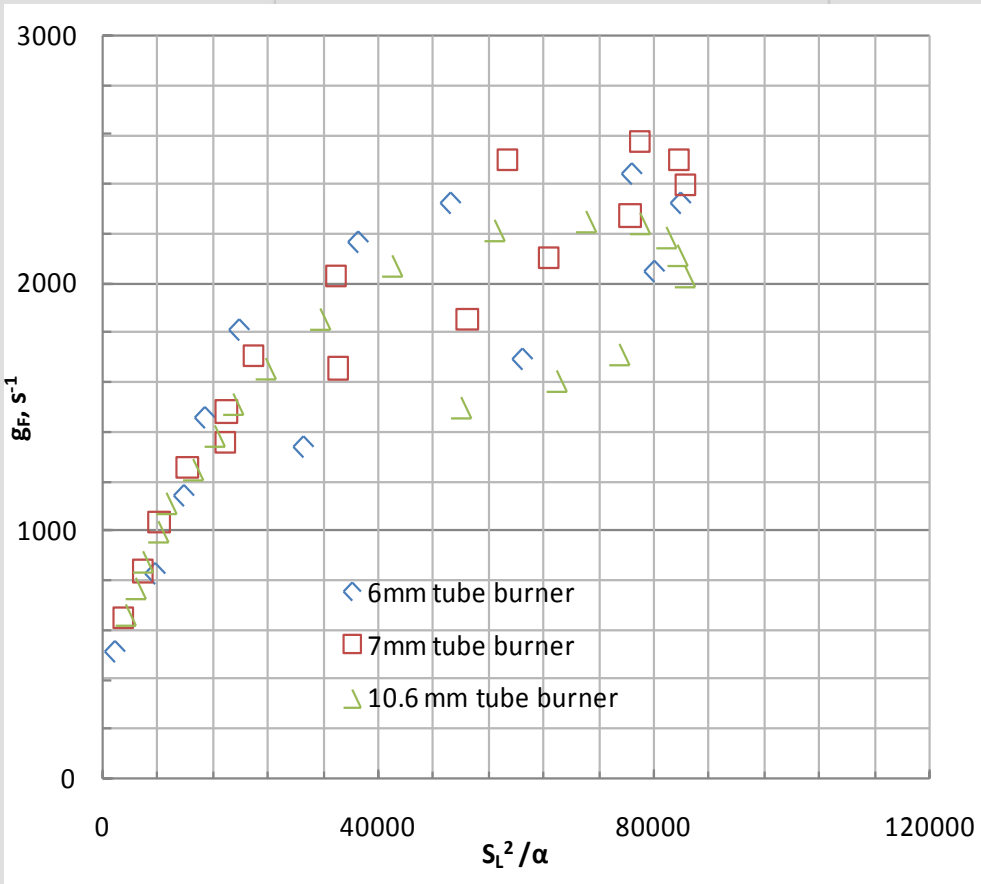
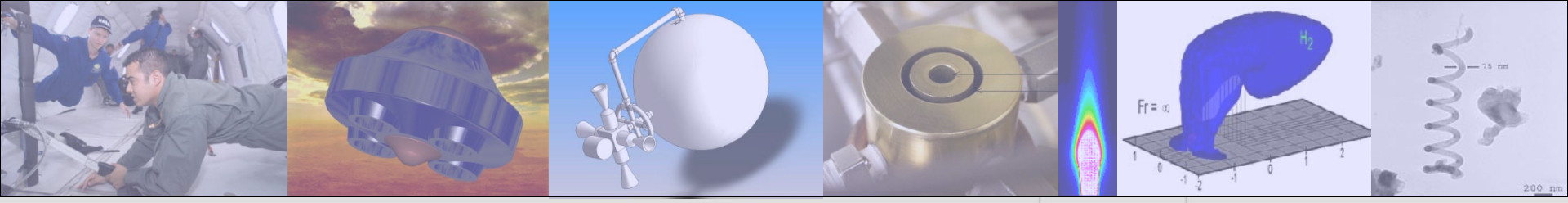


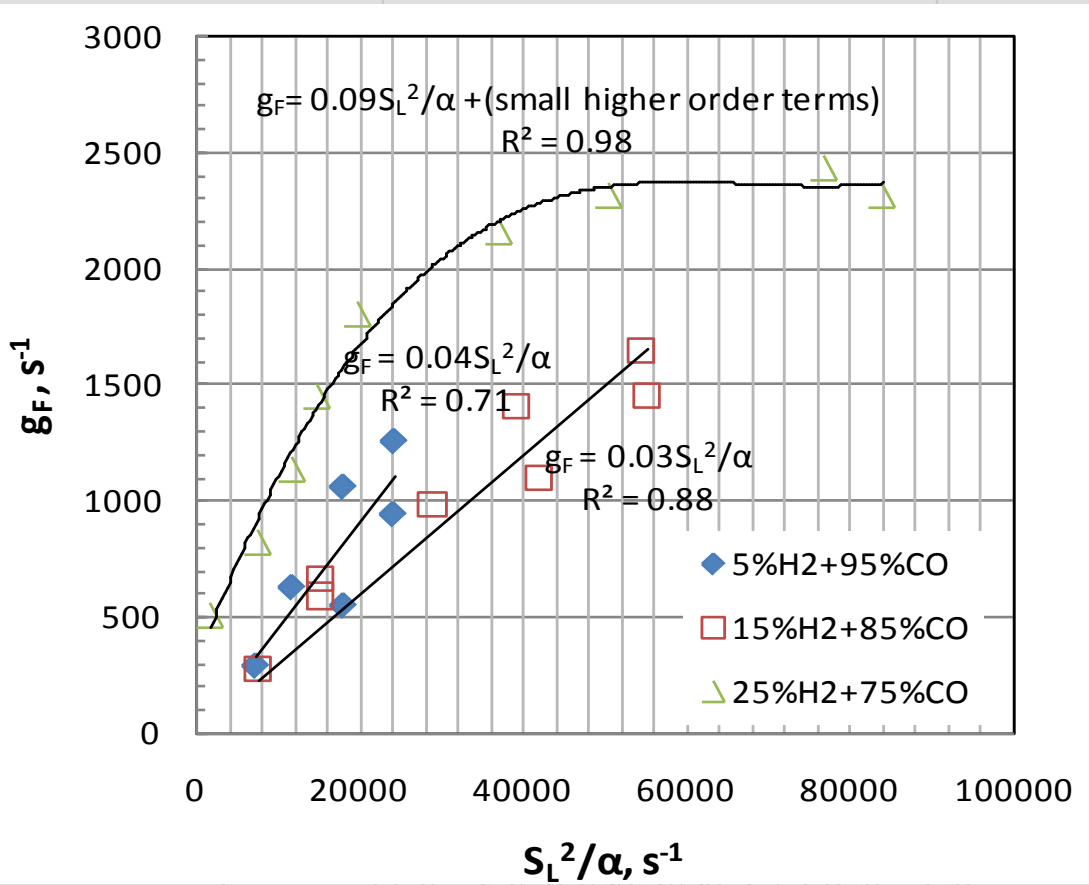
Results

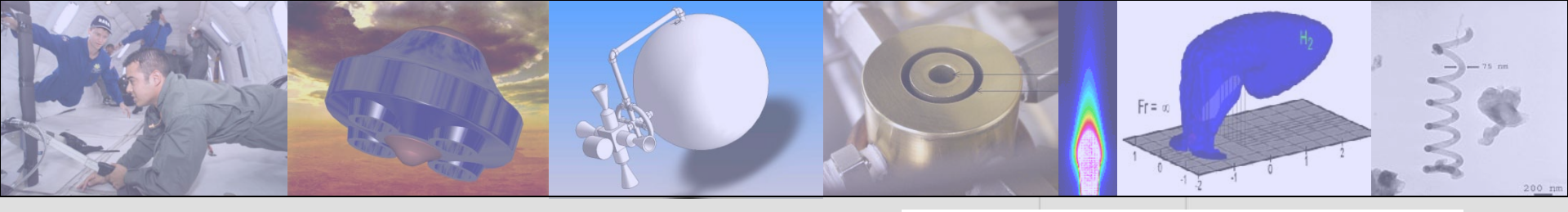

3000
2000
1000
0
10
30
50
70
90
%F
g_F, s^{-1}
6mm tube burner
7mm tube burner
10.6mm tube burner


Fr = ∞
H2
75 nm
200 nm


3000
2000
1000
0
g_F, s^{-1}
0
40000
80000
120000
S_L^2/α
6mm tube burner
7mm tube burner
10.6 mm tube burner




$g_F = 0.09S_L^2/\alpha$ +(small higher order terms)
$R^2 = 0.98$
$g_F = 0.04S_L^2/\alpha$
$R^2 = 0.71$
$g_F = 0.03S_L^2/\alpha$
$R^2 = 0.88$
5%H2+95%CO
15%H2+85%CO
25%H2+75%CO
g_F, s^{-1}
S_L^2/α, s^{-1}
0
500
1000
1500
2000
2500
3000
0
20000
40000
60000
80000
100000

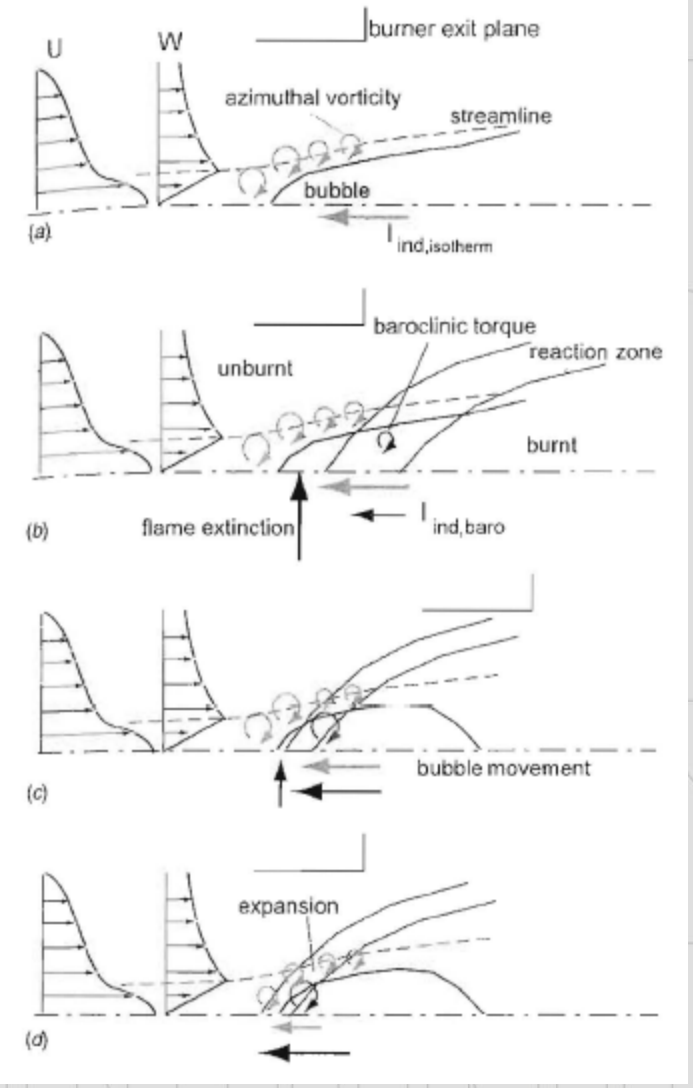


Combustion Induced Vortex Breakdown

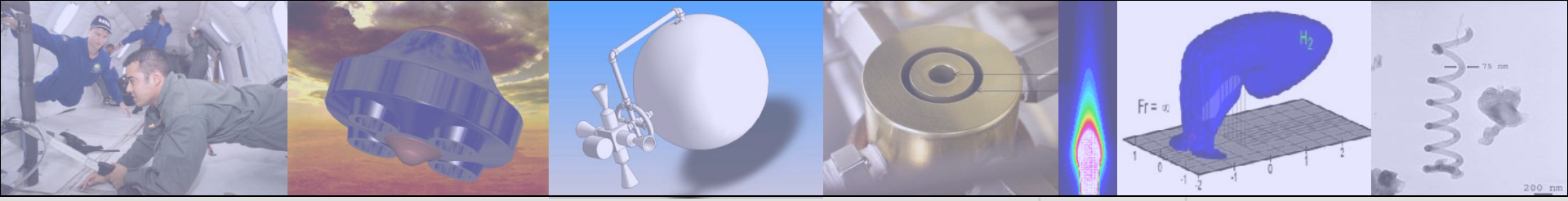
$$S = \int (w_R, \frac{\rho_b}{\rho_u})$$

$$\left.\frac{UD}{\alpha}\right|_{flow} \propto \left.\frac{SD}{\alpha^2}\right|_{flame}$$

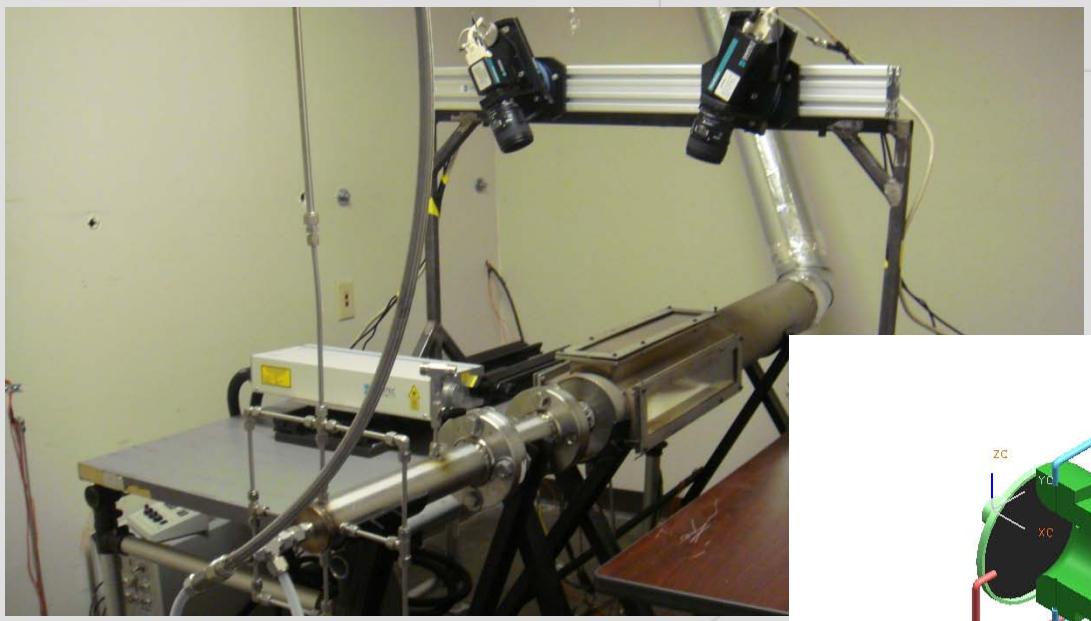
$$\left.\frac{UD}{\alpha}\right|_{flow} = C\left.\frac{SD}{\alpha^2}\right|_{flame}$$

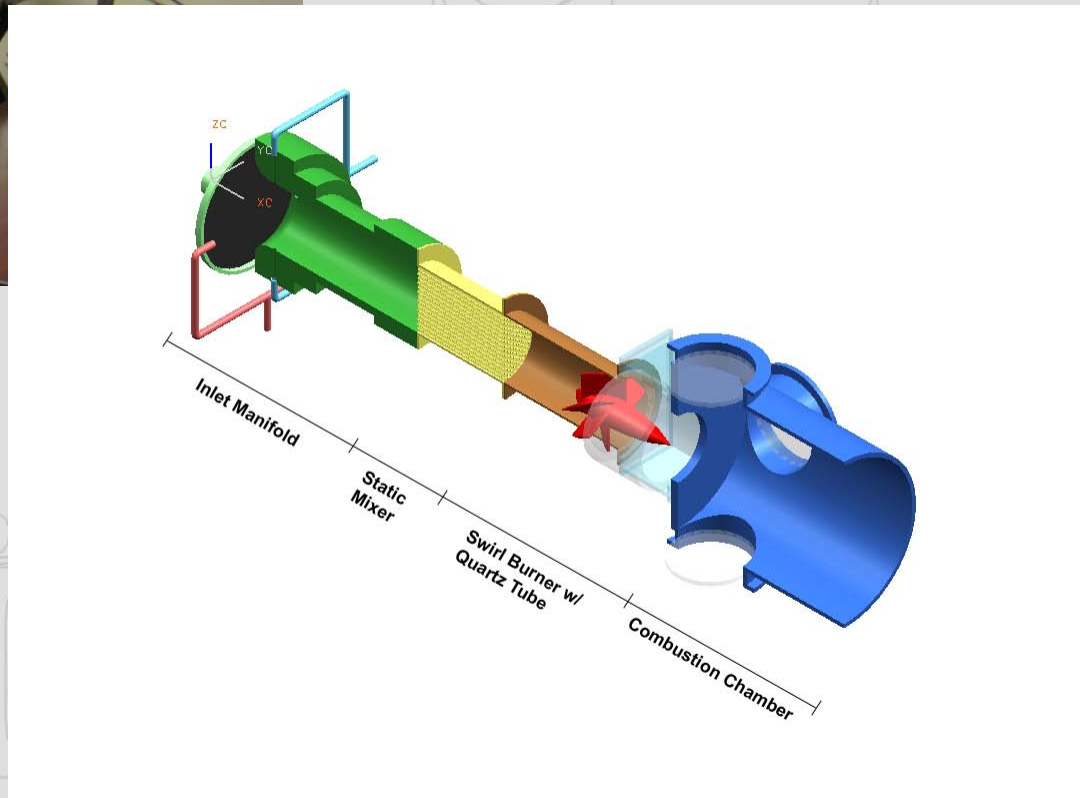


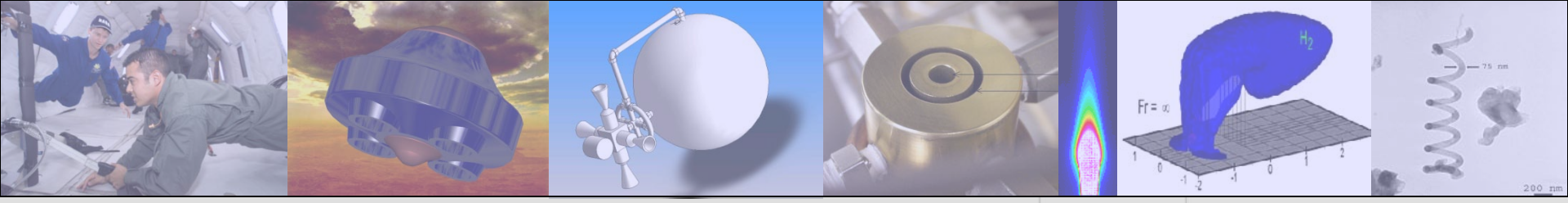
Kiesewetter, F., Konle, M., and Sattelmayer, T. (2007)

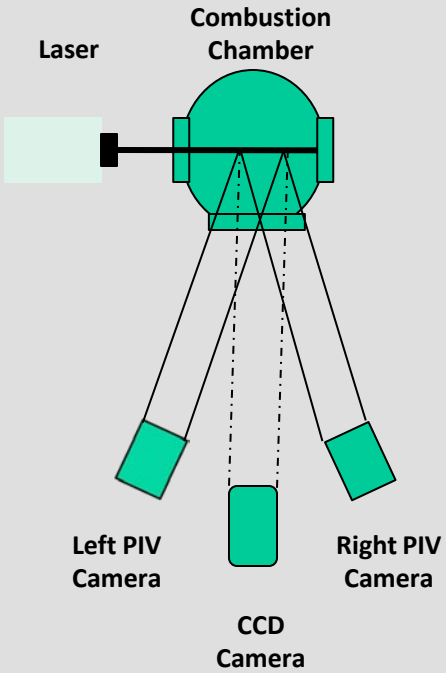


Experimental Setup: Combustion Test Rig



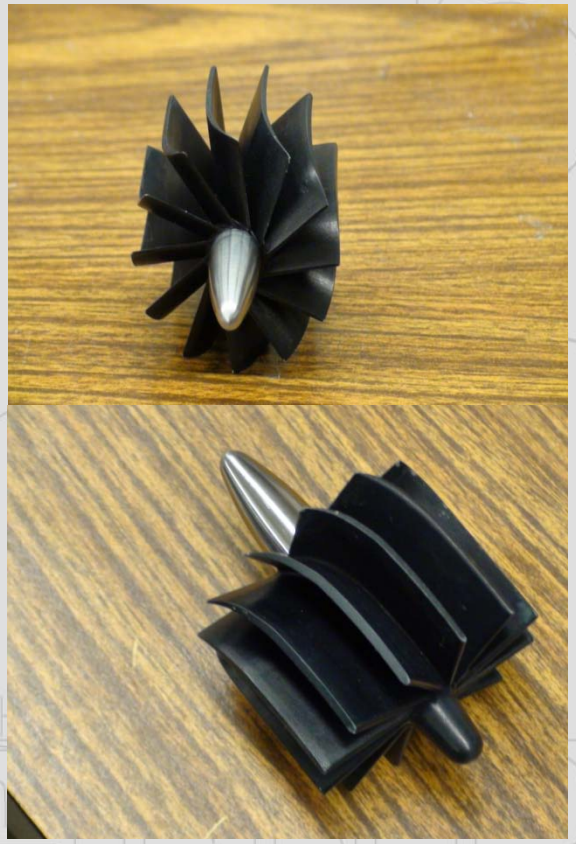


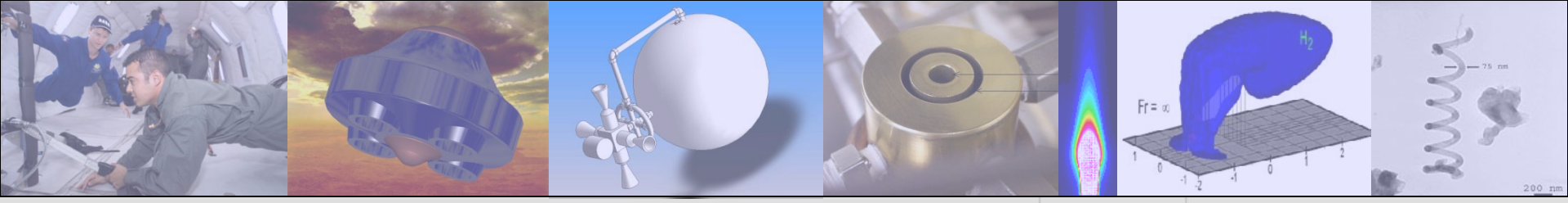


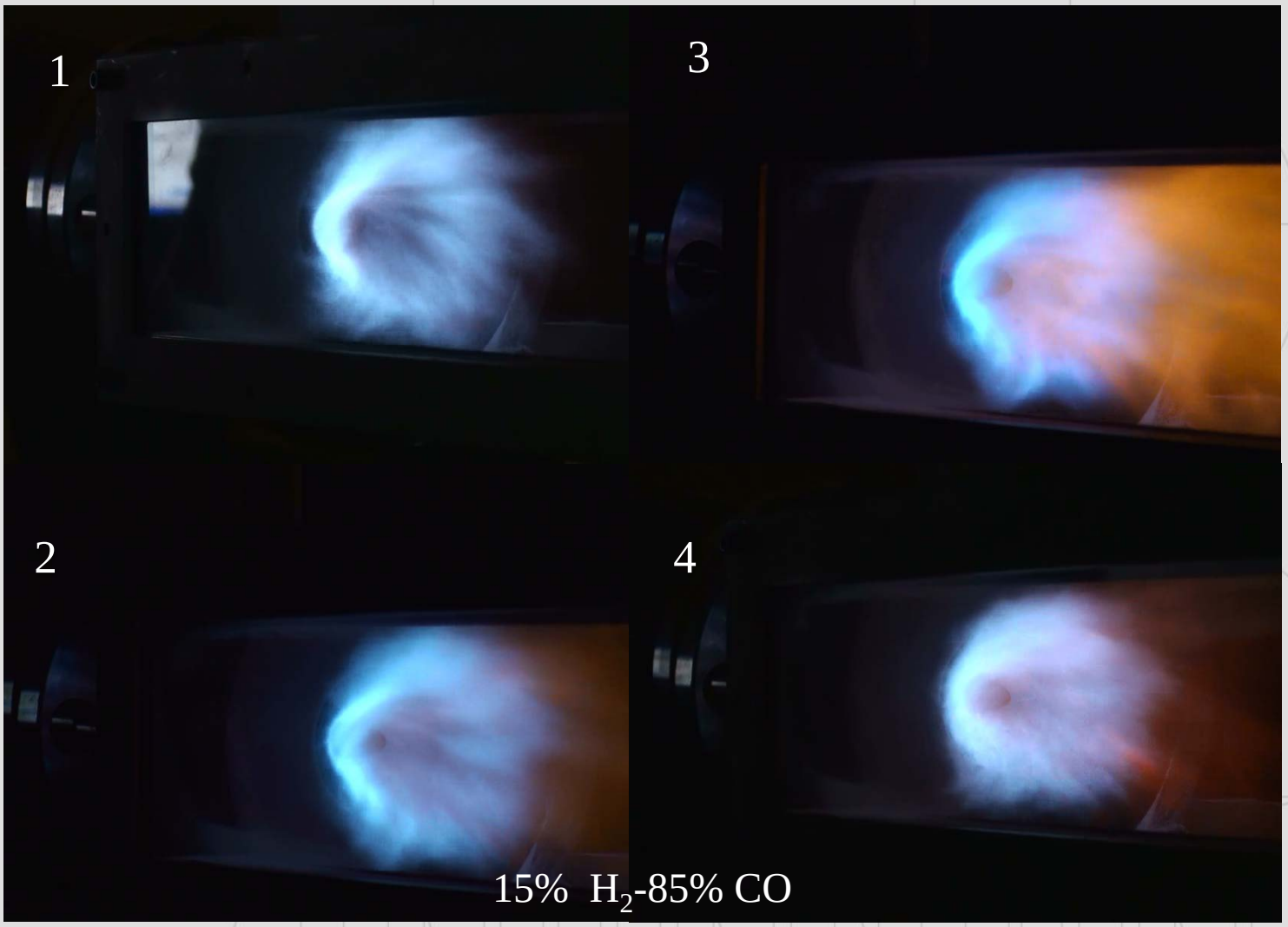


PIV Setup for Streamwise Plane

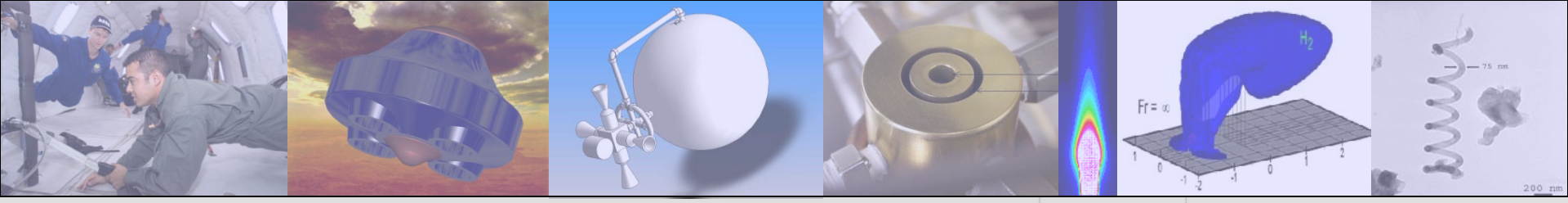
- Stereo PIV
- Phase Locked High Speed PIV and OH Chemiluminiscence

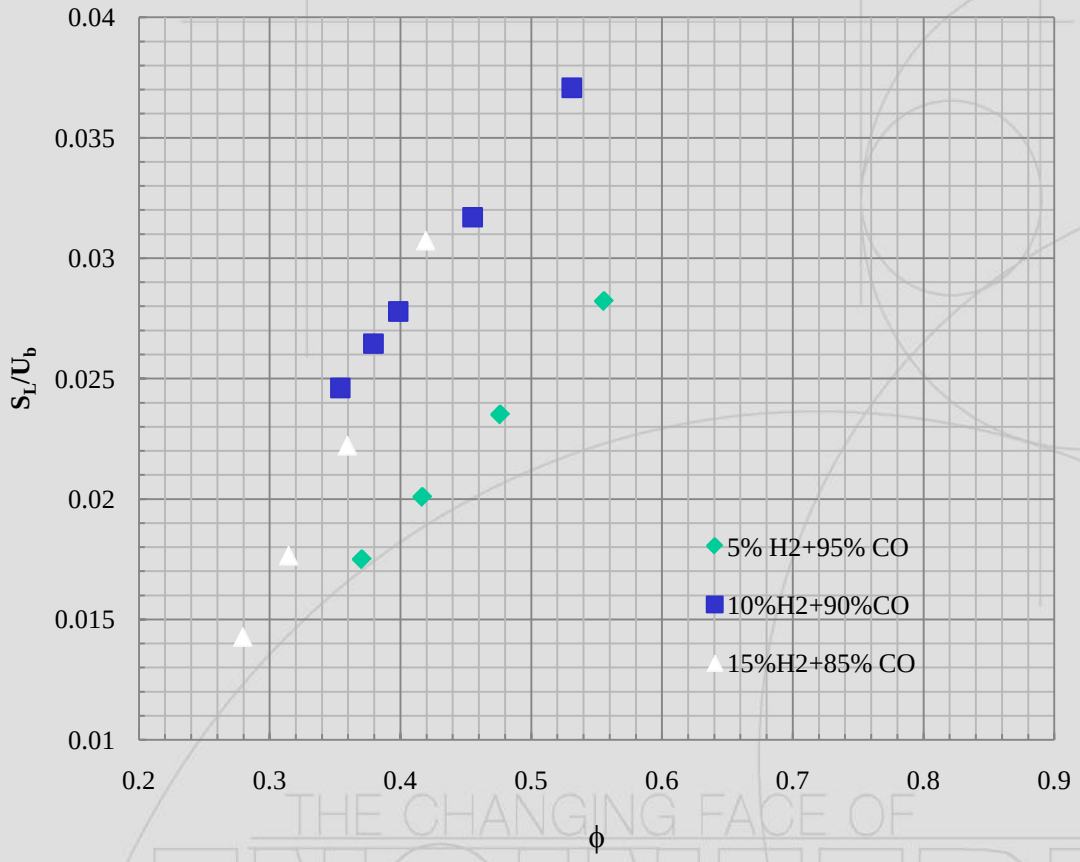






15% H_2-85% CO





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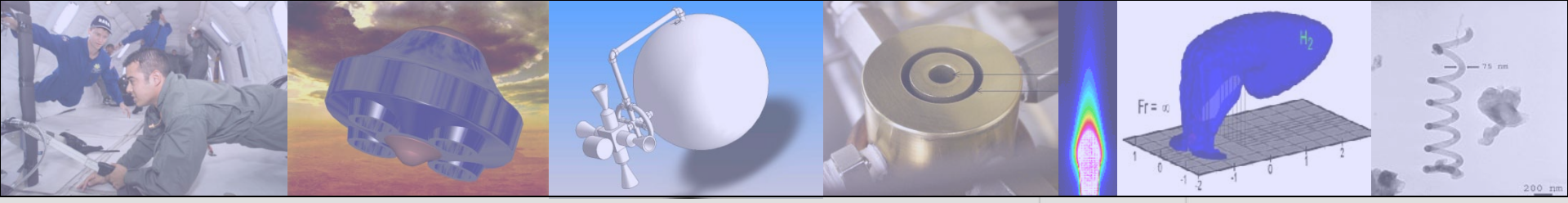

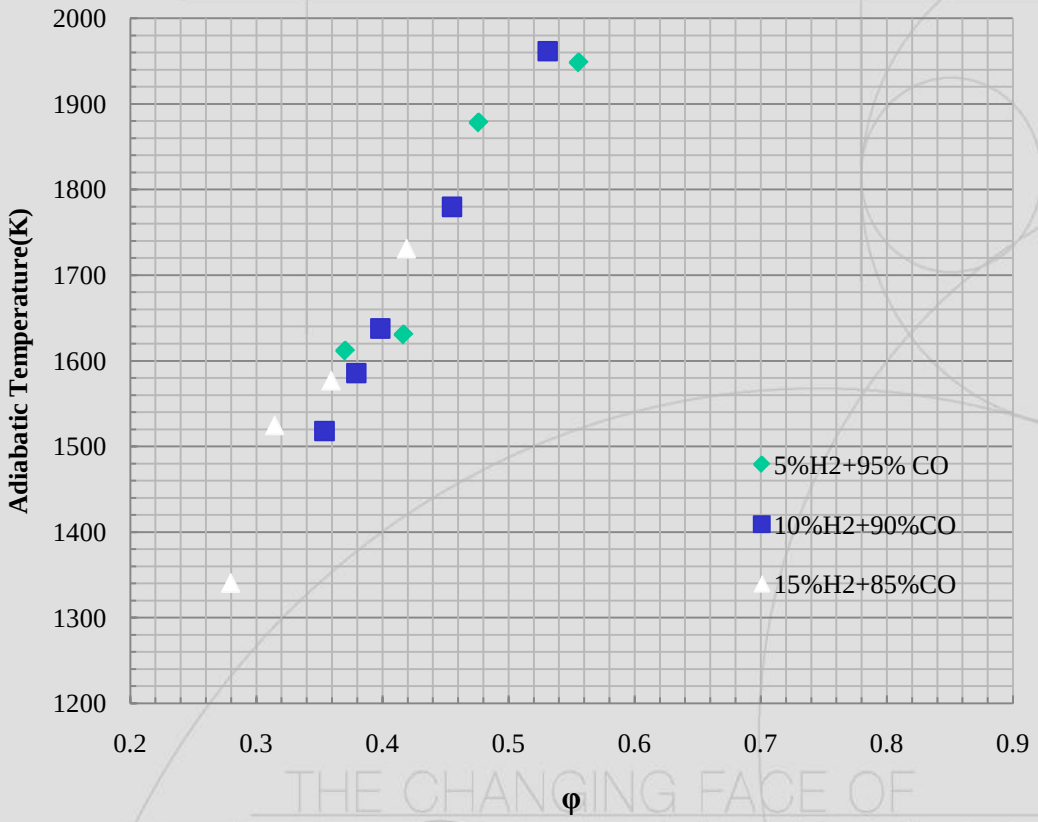

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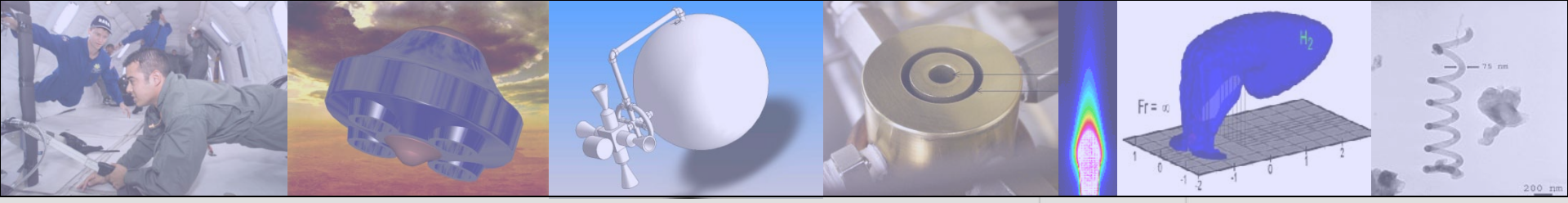

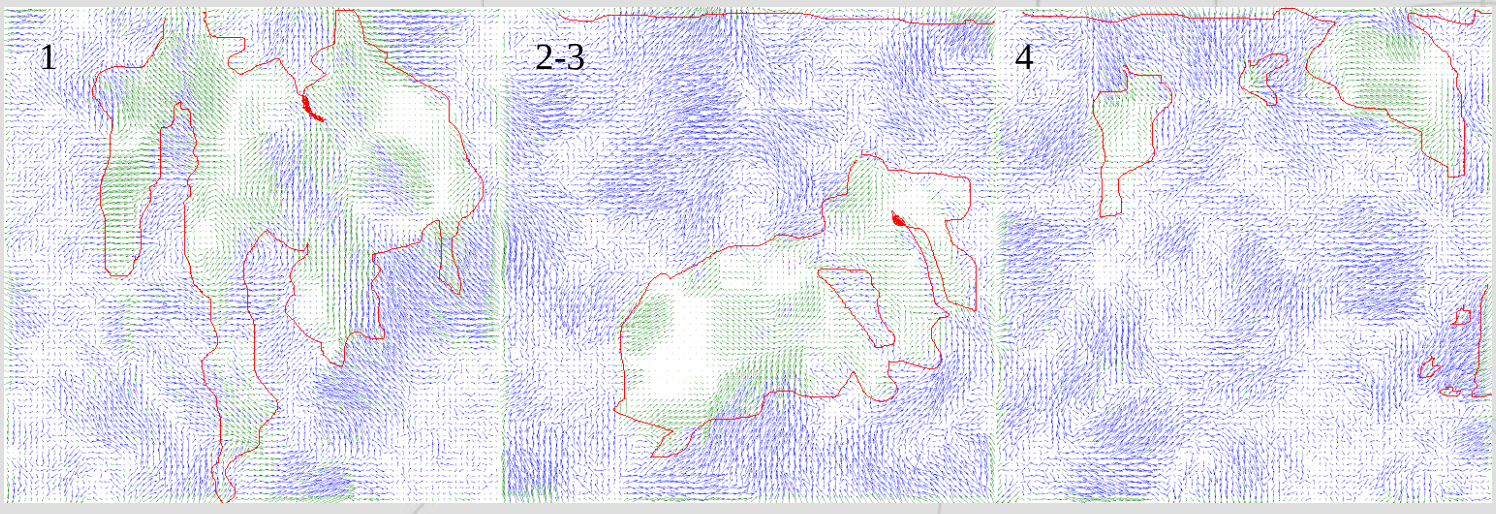

15% H_2-85% CO

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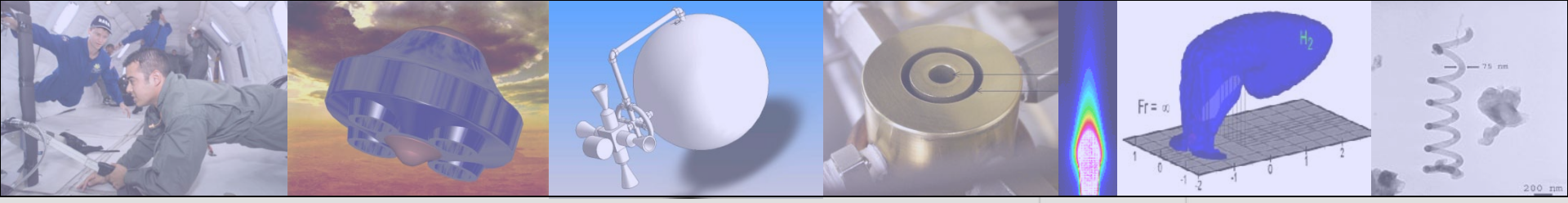

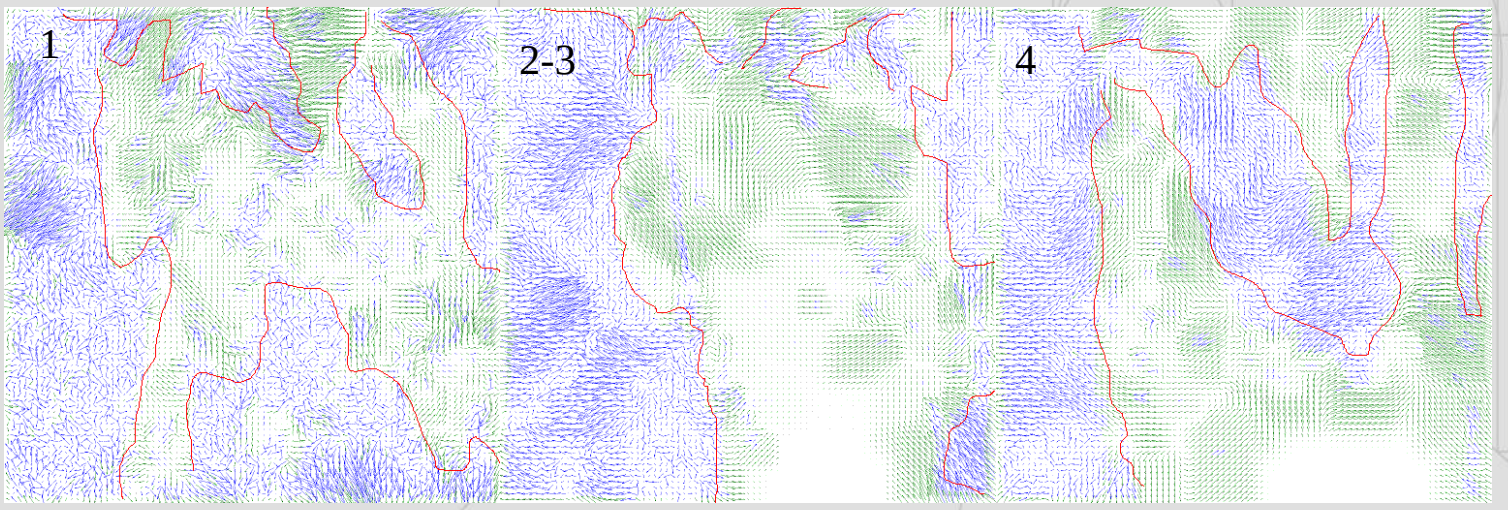

5% H_2-95% CO

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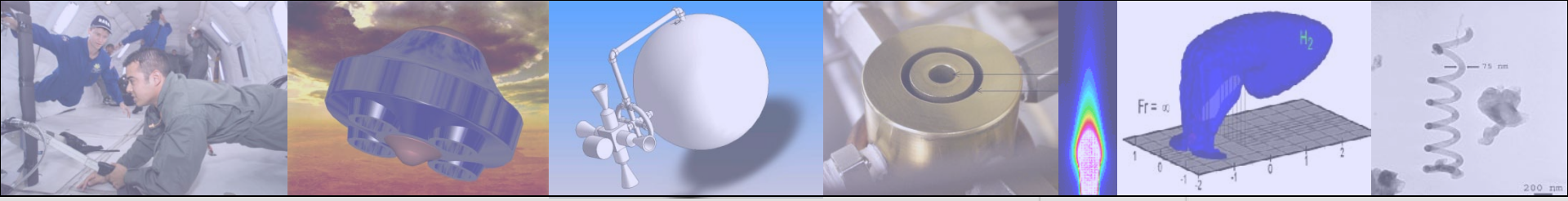
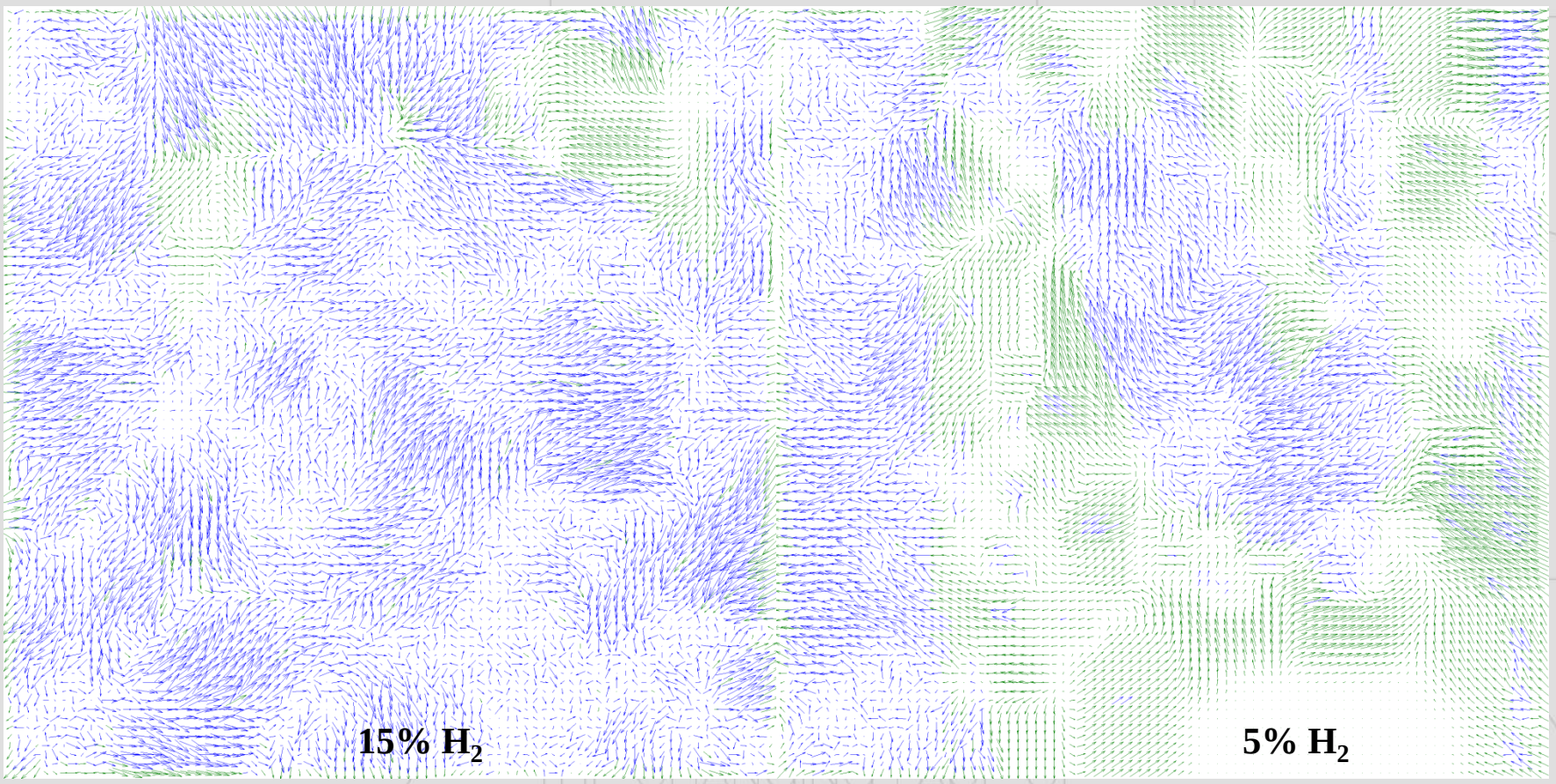
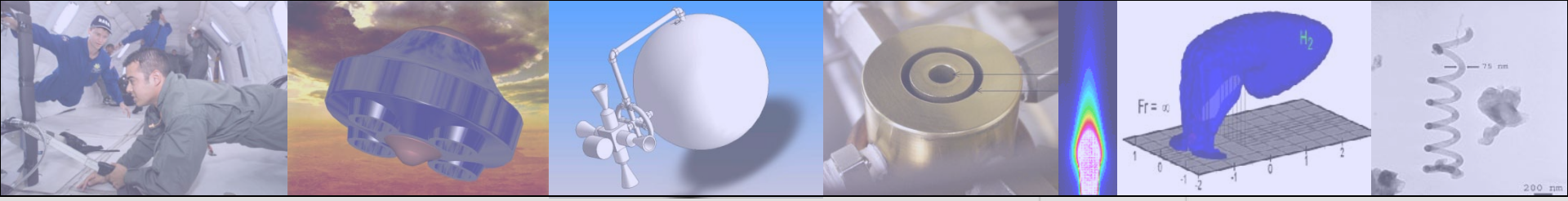
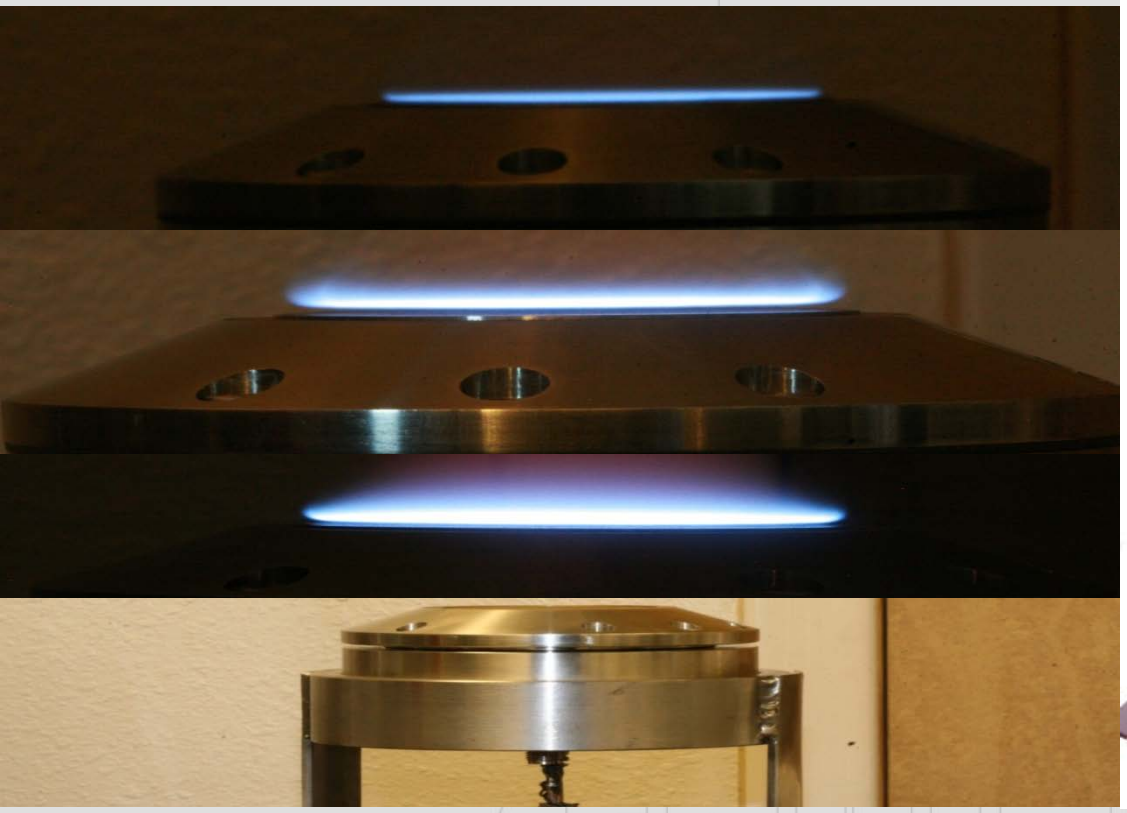
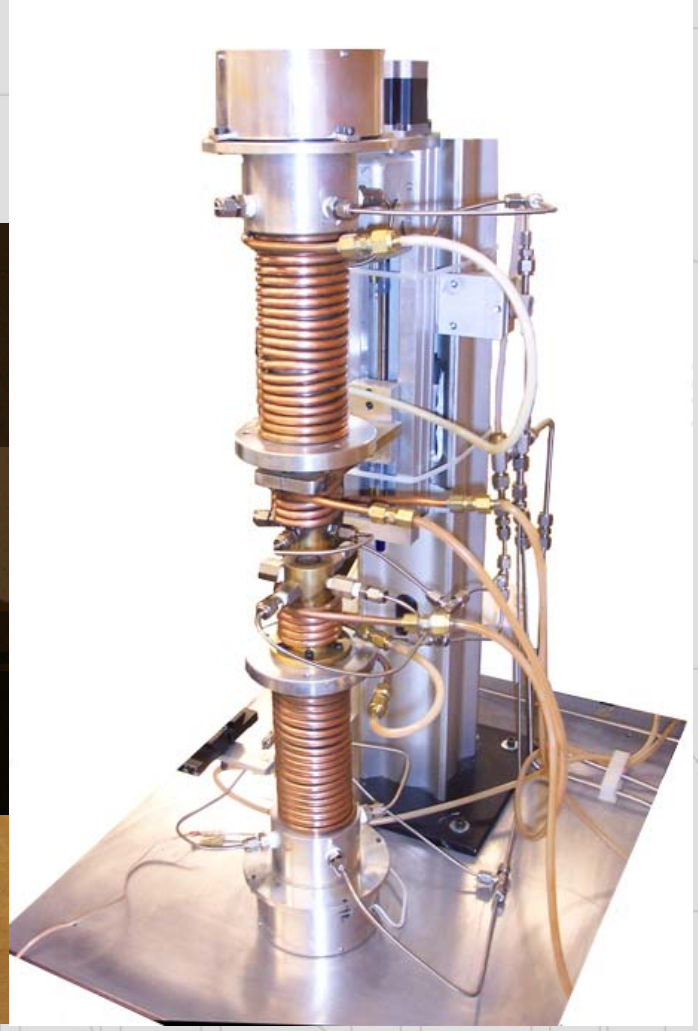

H2
Fr = ∞
75 nm
200 nm


15% H_2
5% H_2



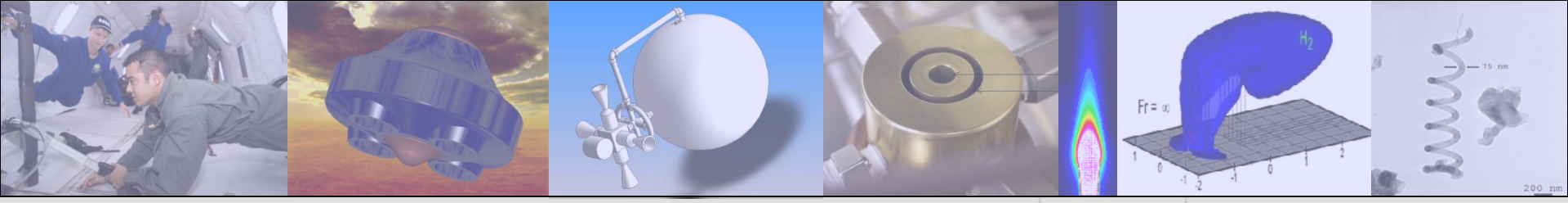
Experimental Setup: Laminar Flame Velocity

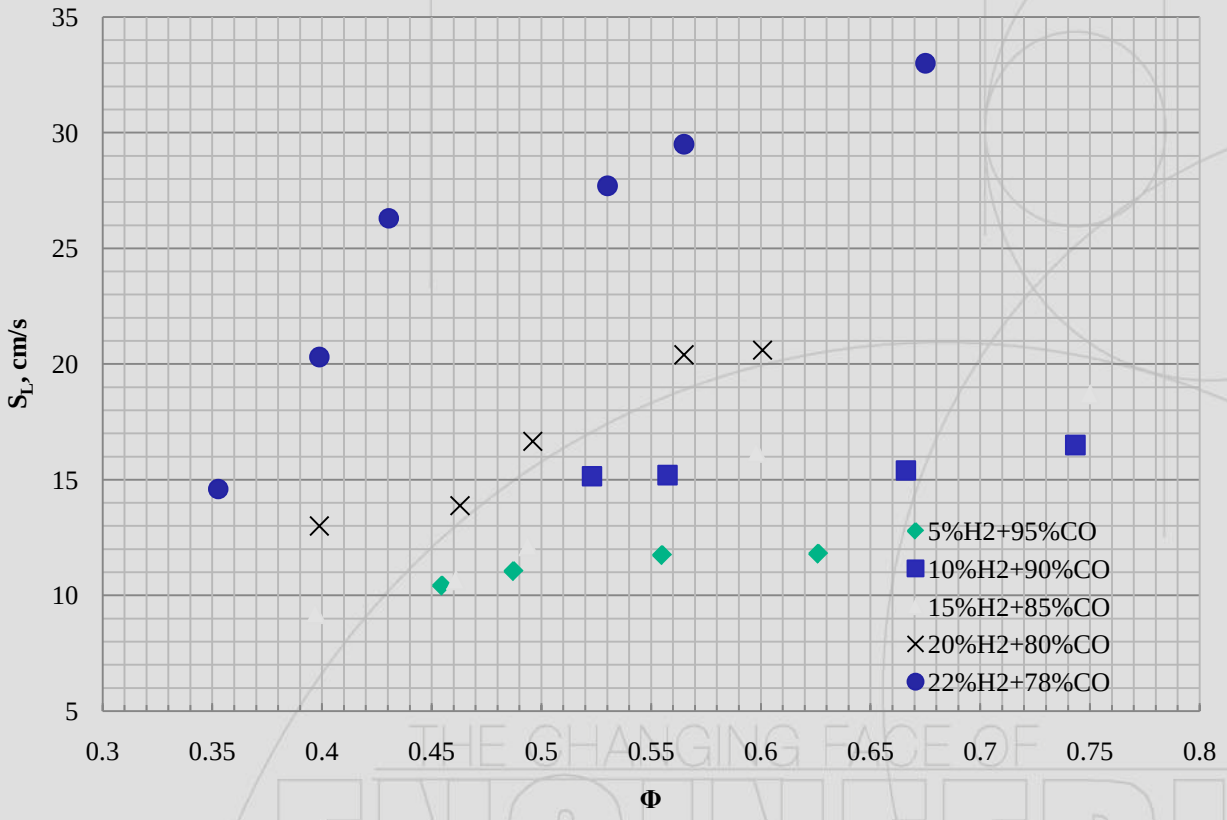




Flat Flame Burner

Twin Flame Counter Flow Burner





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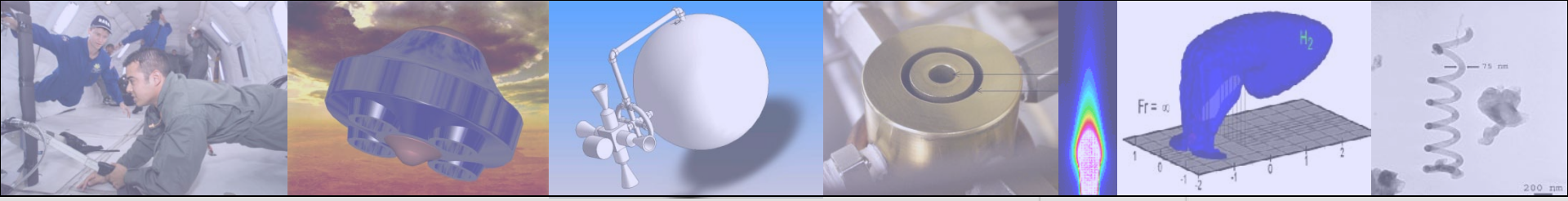
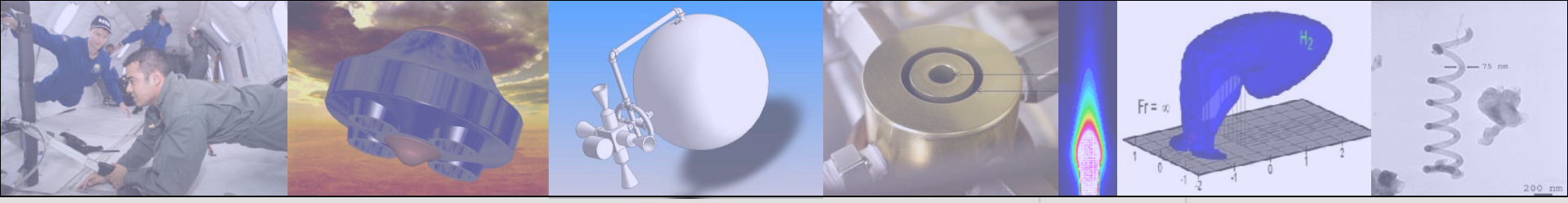


Accomplishments To date

Boundary Layer Flame Propagation

- The flashback behavior of H2-CO flames changes nonlinearly with the increase in H2 contents in the mixture.
- The critical velocity gradient (gF) values of 5%-95% and 15%-85% H2-CO mixtures somewhat agree with the scaling relation and yield an average c value of 0.035.
- the g_F values of 25%-75% H2-CO mixture show higher order variations with the SL2/α ratio (especially for SL2/α > 19,000 s-1).
- At a lower SL2/α ratio, burner diameters have small effects on critical velocity gradient measurements; however, the effect is significant at higher SL2/α ratio.
- The effect of external excitation on the flashback propensity of H2-CO flames with more than 5% H2 is not significant.



Combustion Induced Vortex Breakdown

- Flashback propensity of swirl stabilized H_2-CO flames driven by various mechanisms were mapped.
- Laminar Flame Velocities of lean H_2-CO mixtures were measured.
- PIV Images are acquired and are being analyzed to understand the Flame-Flow field interactions at near flashback conditions.

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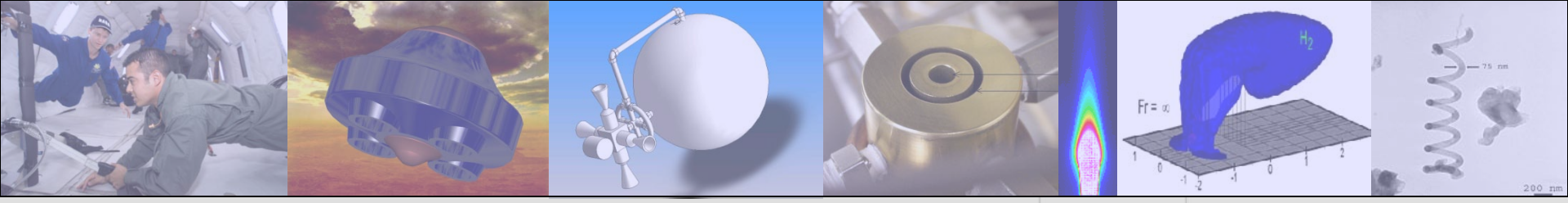
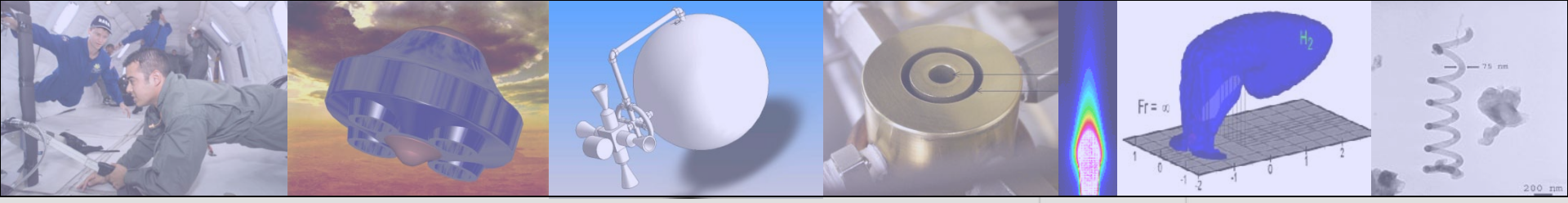


Students

- Bidhan Dam (Graduate: MS)
- Gerardo Vargas (Graduate: MS)
- Vishwanath Adrha (Graduate: PhD)
- Gilberto Corona (Undergraduate: Senior)
- Federico Esquivel (Undergraduate: Junior)

Conference Article

Dam, K., Choudhuri, A., and Lewis, R., (2009) “Flashback Propensity of Syngas fuels,” Proceedings of POWER2009, ASME Power 2009, POWER2009-81011.



Questions?????

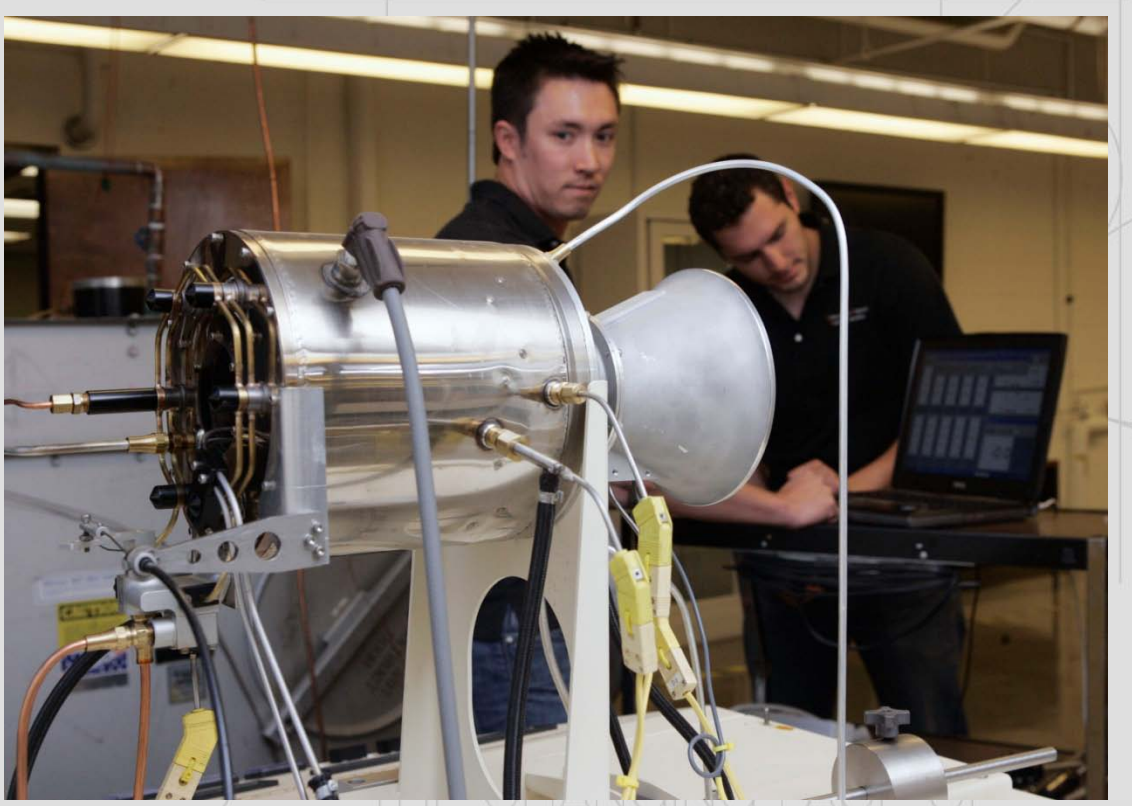


Photo: Jonathon Bice (Left), Federico Esquivel (Right)
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