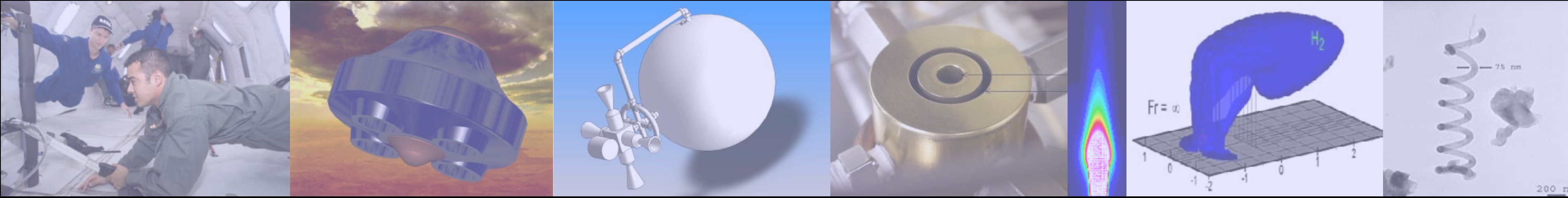

Effects of Combustion-induced Vortex Breakdown on Flashback Limits of Syngas-Fueled Turbine Combustors

DE-FG26-08NT0001719

Ahsan Choudhuri, PhD
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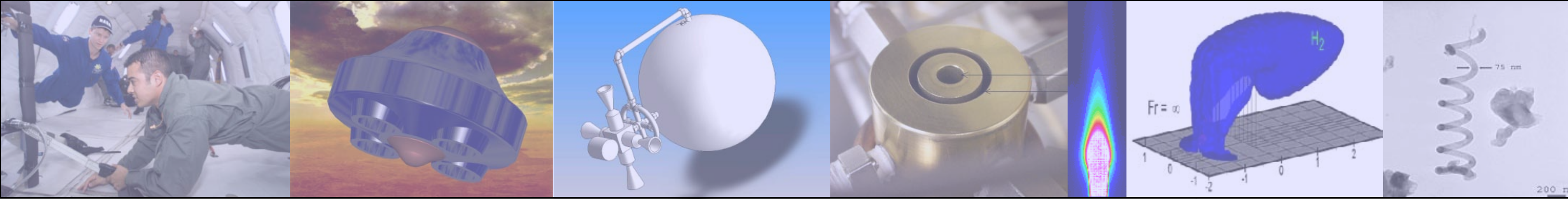
The University of Texas at El Paso

June 2-3
2010 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



Project Information

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

- **DOE Project Manager:**
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- **Duration:** 04/01/8-03/31/11
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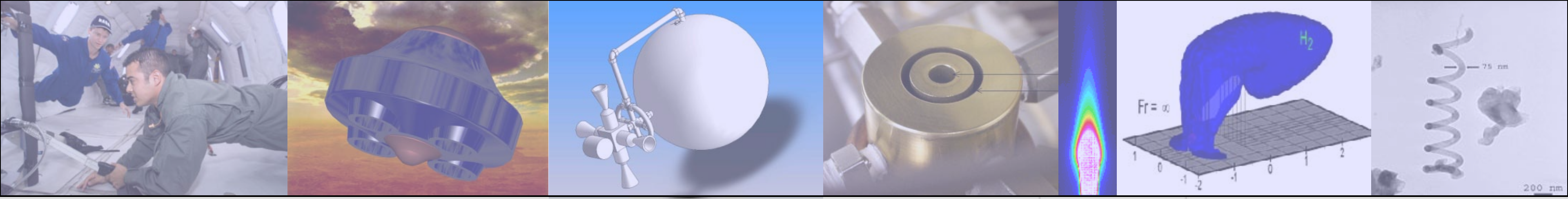
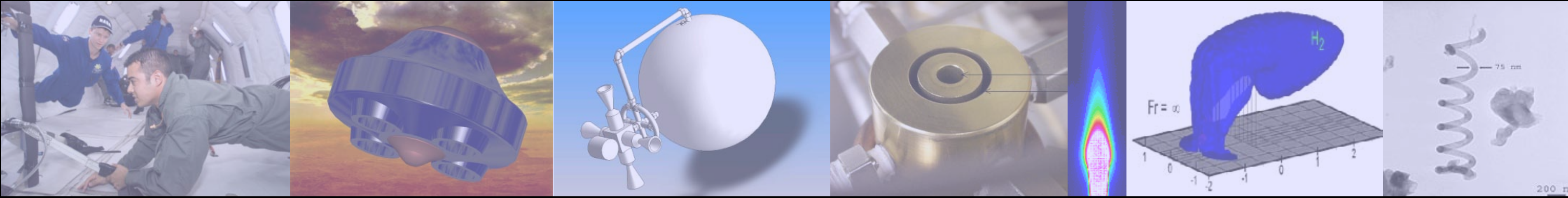


Project Objectives

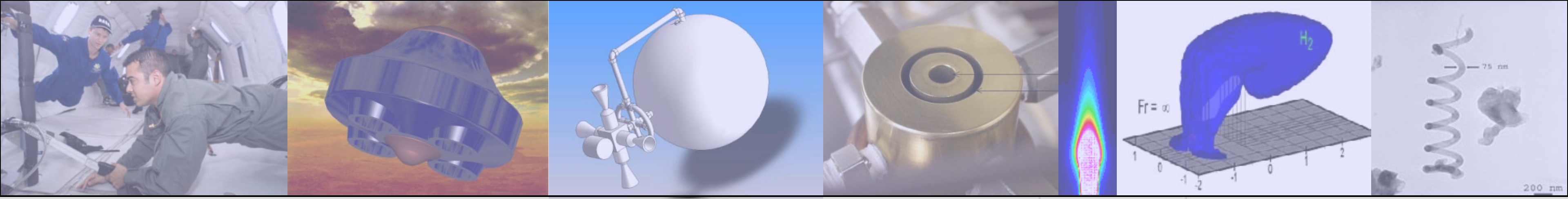
- **To study the effects of syngas fuel compositions on flame flashback due to CIVB**
  - Flow-field Parameters [Swirl Number]
  - Fuel Compositions [% H_2]

- **To explore passive modification of combustor aerodynamics**
  - Development of a parametric model
  - Asymmetric burner exit profiles



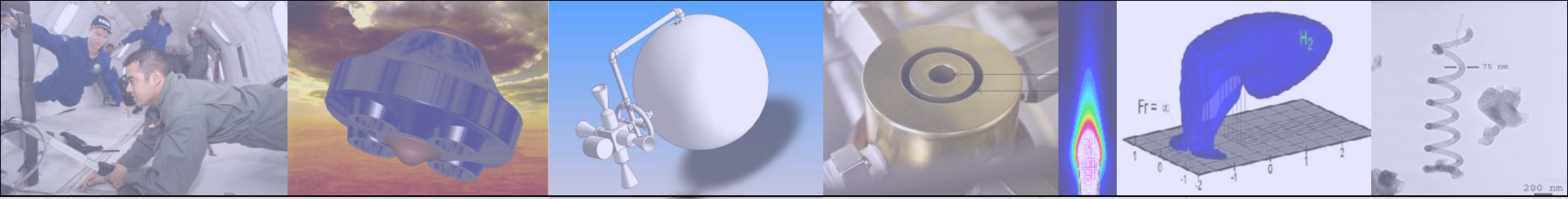
Flame Flashback

- Flame propagates upstream against the gas stream into the burner tube
- Flashback causes hardware damage and creates unsafe operating conditions
- Flashback occurs due to:
  a. boundary layer flame propagation
  b. turbulent flame propagation in core flow
  c. combustion instabilities
  d. combustion induced vortex breakdown (CIVB)
     ✓ Prevailing mechanism for swirl stabilized flames



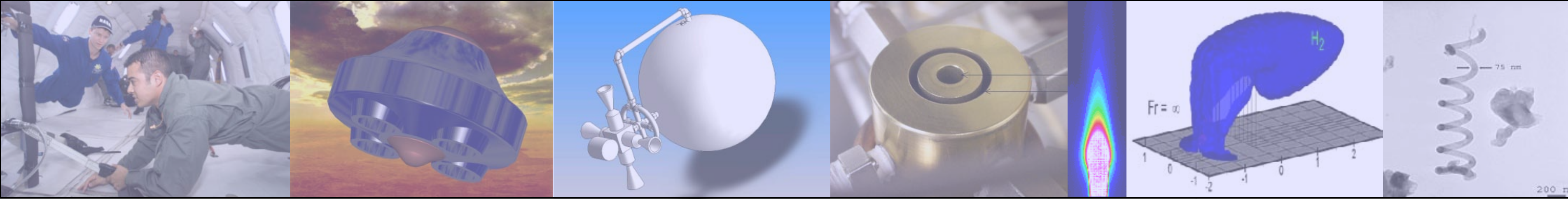
Combustion Induced Vortex Breakdown

- Vortex Breakdown (VB): “Change in structure of a vortex initiated by a variation in the characteristics ratio of tangential to axial velocity components.” (Leibovich ,1978)
- CIVB flashback occurs due to complex interactions of
  - Flow-field
  - Heat release processes: fuel compositions; unburnt mixture conditions; local stoichiometry
- CIVB Flashback is initiated by the expansion of the hot gas.
  - The low velocity regime of the VB pushes the flame front upstream.
  - The expansion of the hot gas pushes the VB location further upstream.

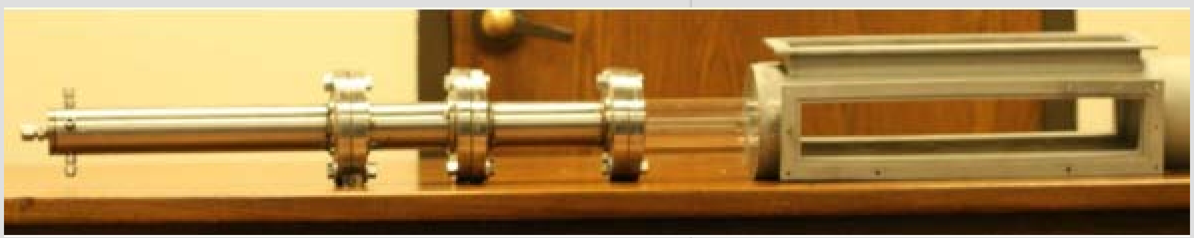


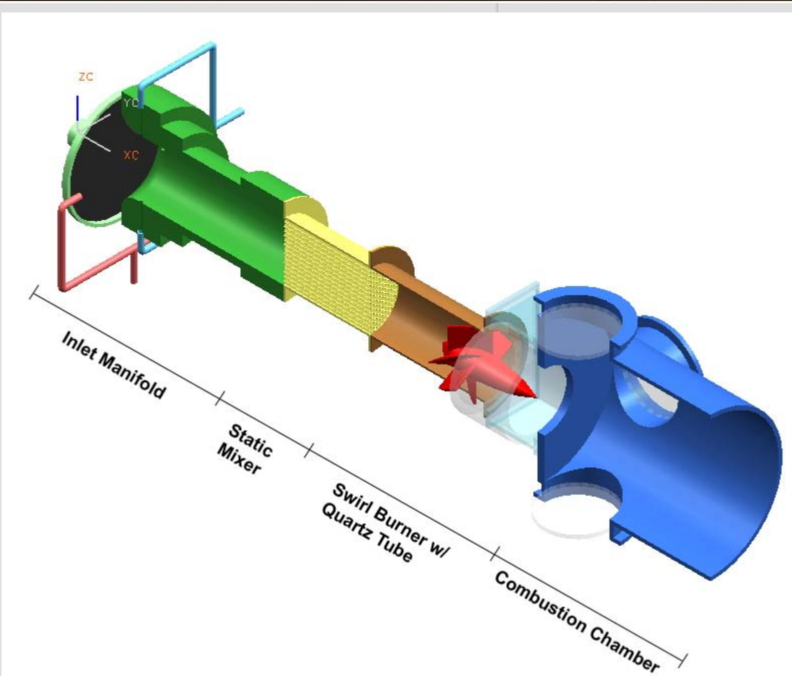
Combustion Induced Vortex Breakdown

- The swirl generator strongly influences the CIVB flashback behavior
- Past CIVB flashback investigations primarily focused on mixing tube type configurations
- Most previous investigations are limited to Methane (CH_4) combustion.



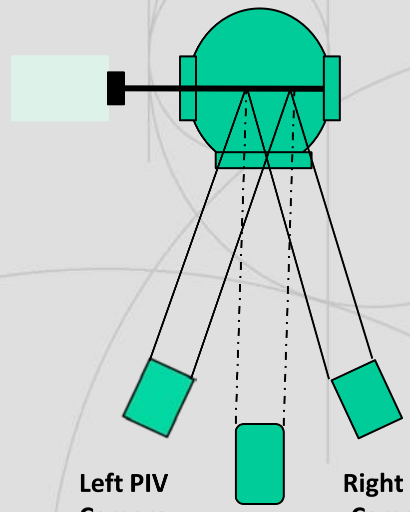
Experimental Set-up and Technique

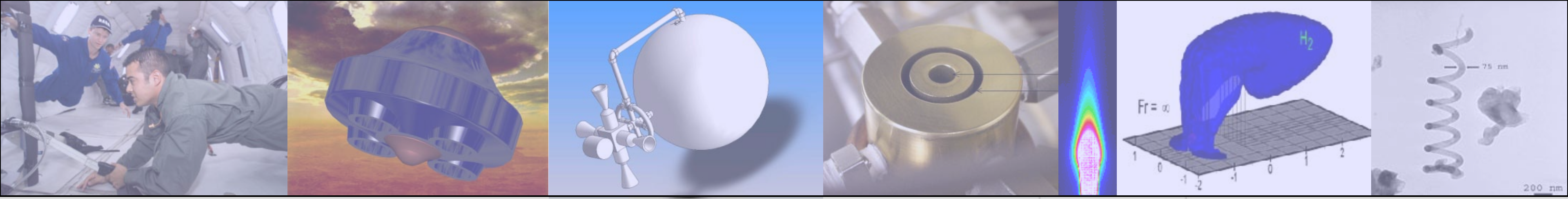




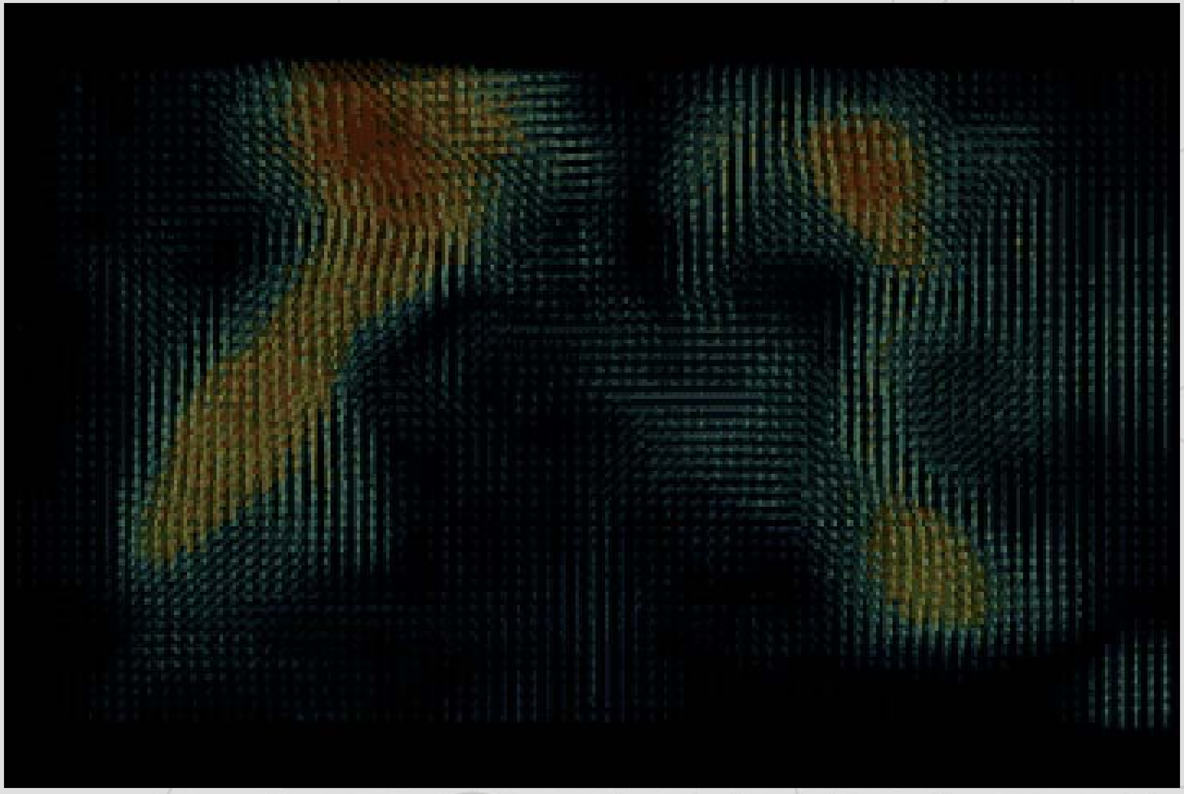
Experimental Set-up and Technique

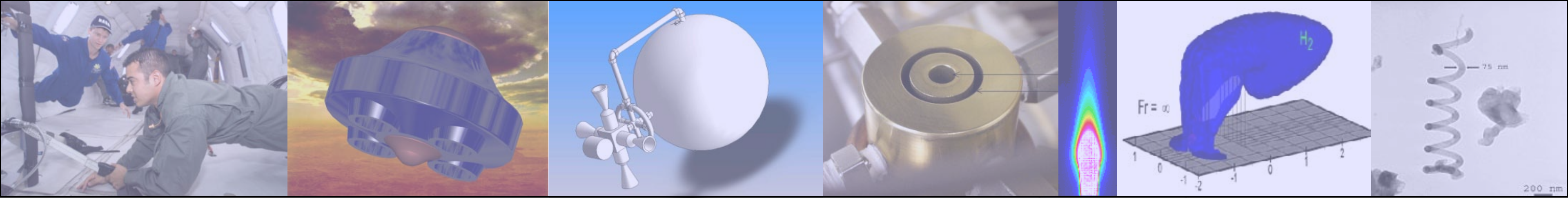
- 2KHz in Stereo PIV Mode
- High Resolution CCD Camera





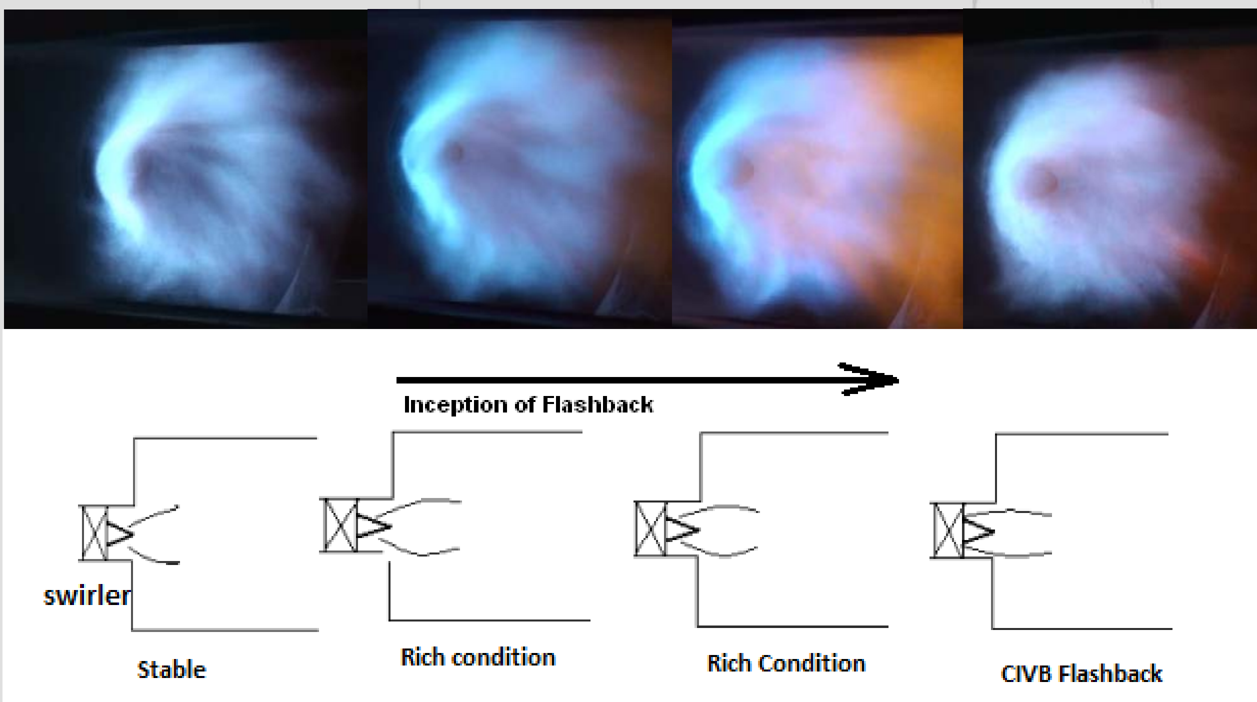
Cold flow visualization using PIV

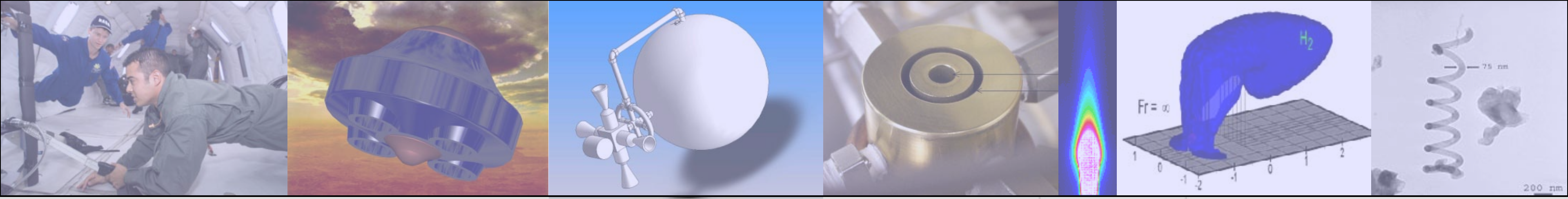




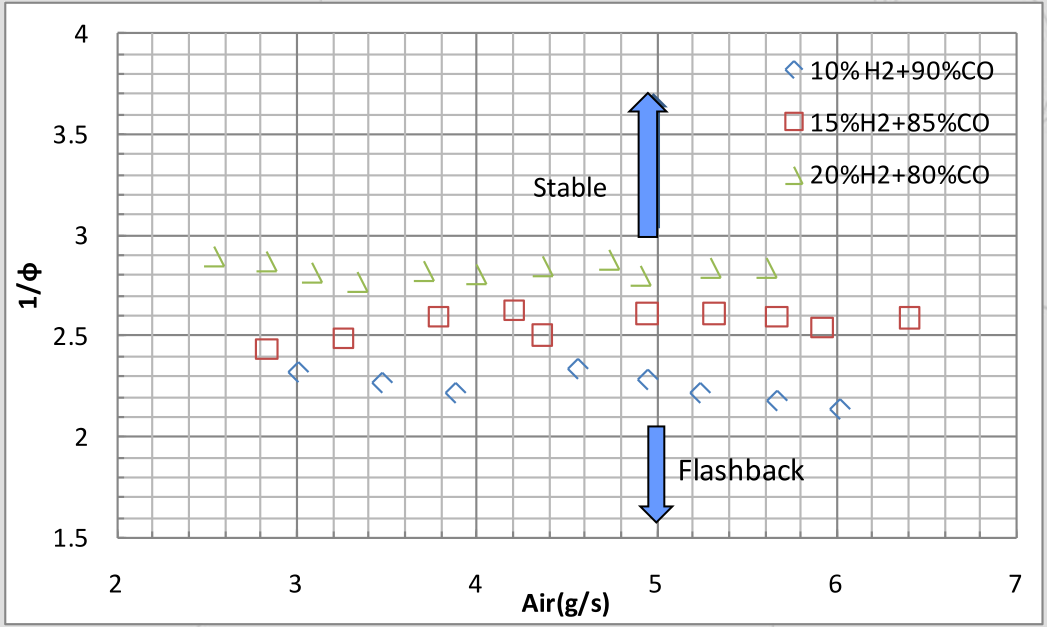
Results

Sequence of a typical CIVB flashback



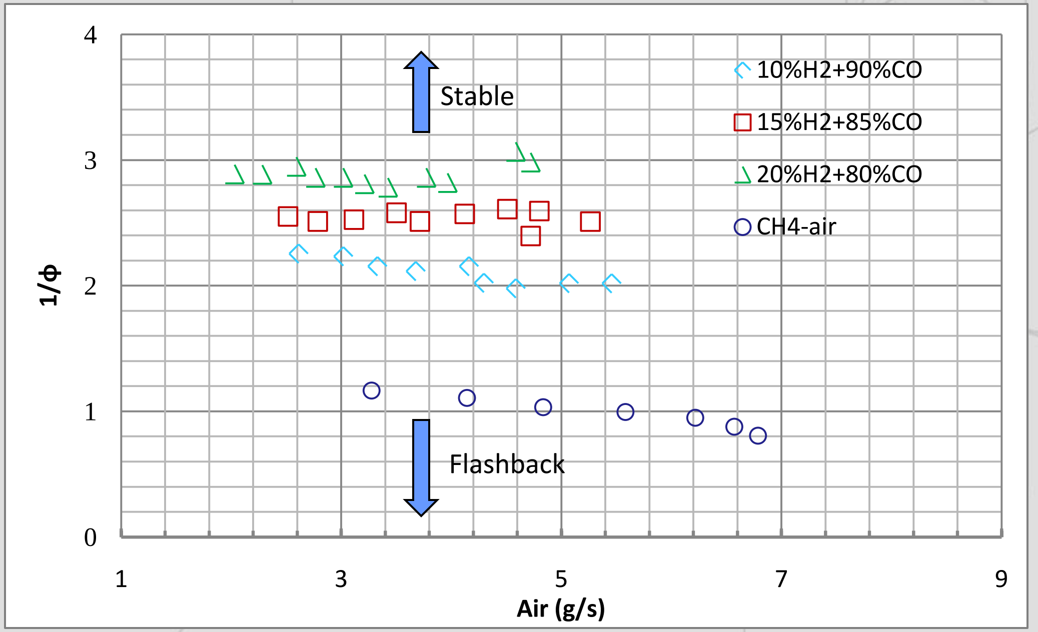


Flashback Map: H_2-CO Mixtures
S = 0.71



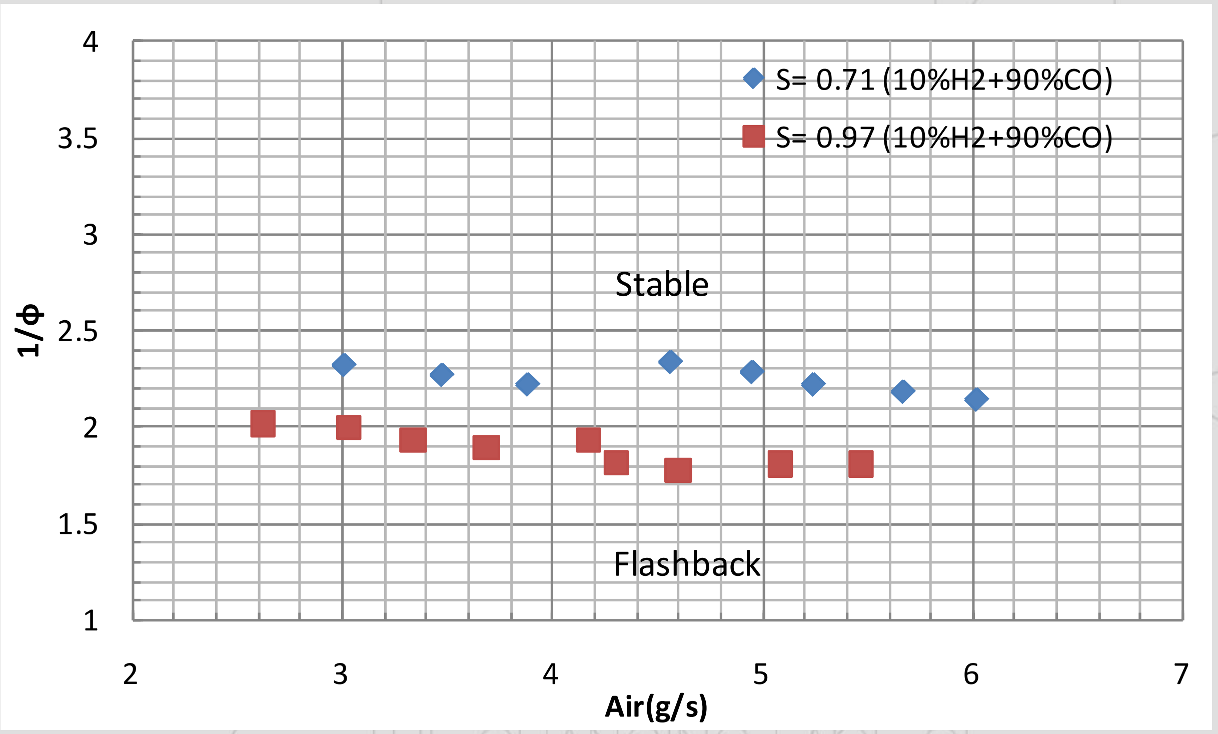
Estimated Measurement Uncertainties = ±1.5 % of the Mean Value

Flashback Map: H_2-CO Mixtures
S = 0.97

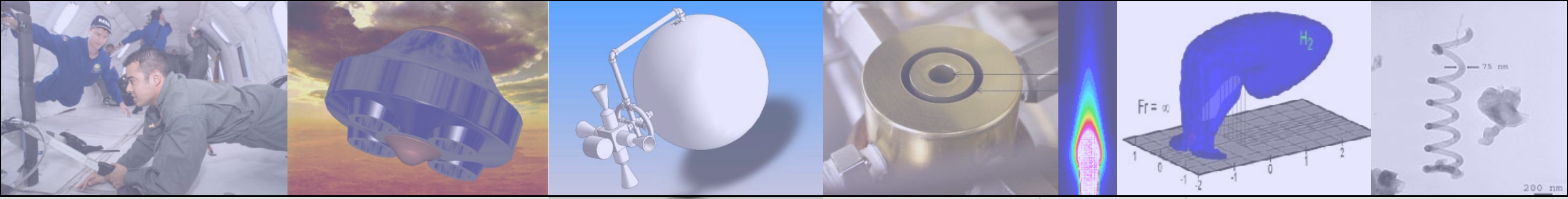


Estimated Measurement Uncertainties = ±1.5 % of the Mean Value

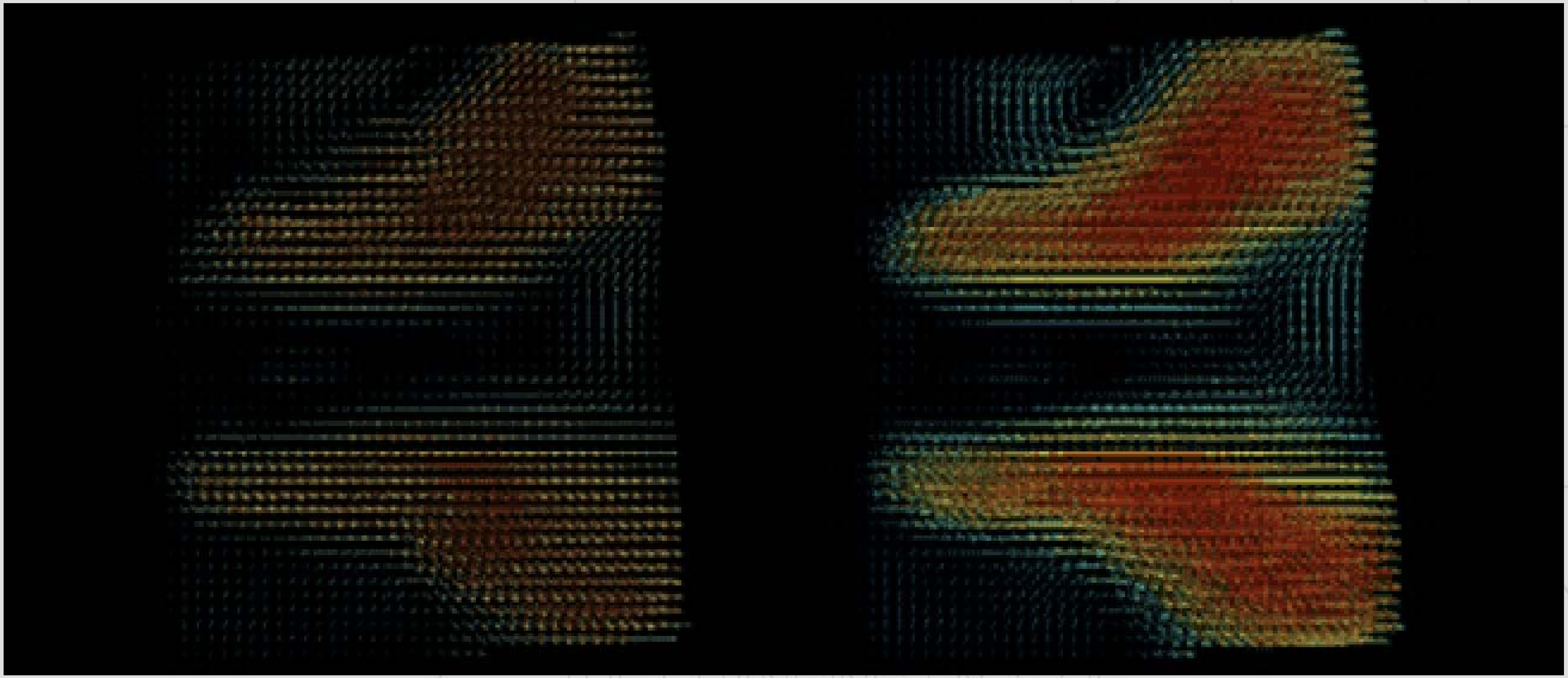
Flashback Map: H_2-CO Mixtures
S = 0.71 vs. 0.97



Estimated Measurement Uncertainties = ±1.5 % of the Mean Value

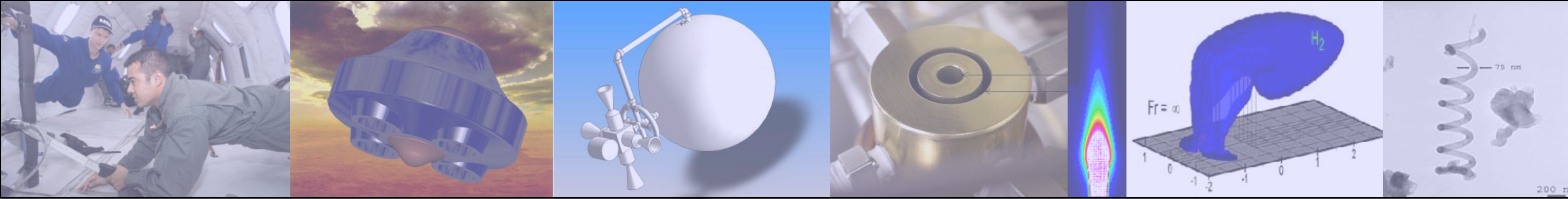


Sample PIV flow-visualization videos using Methane, with and without POD

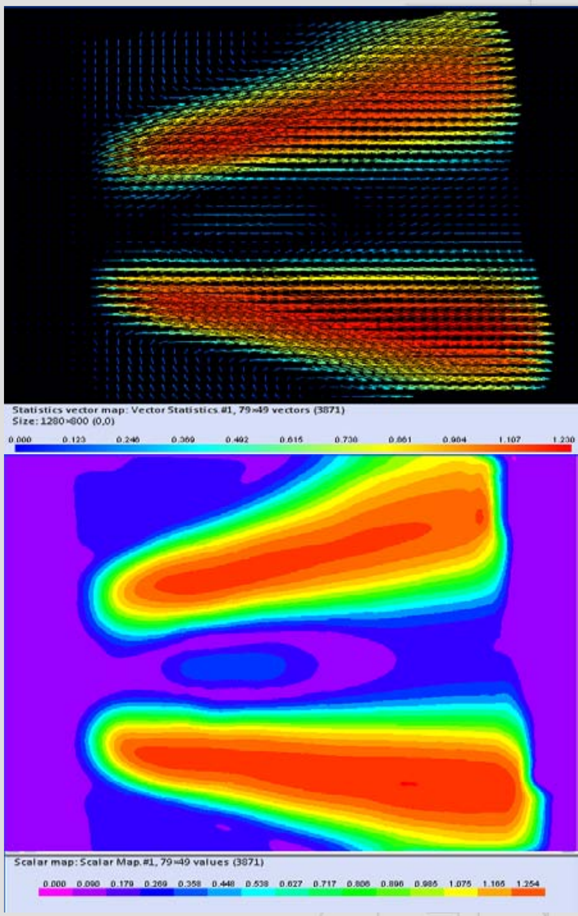


Methane without POD

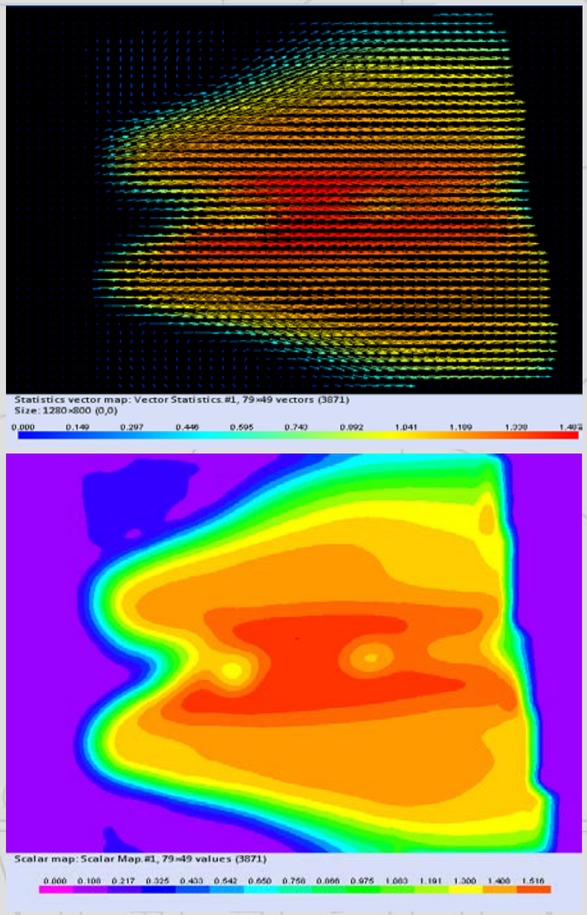
Methane with POD



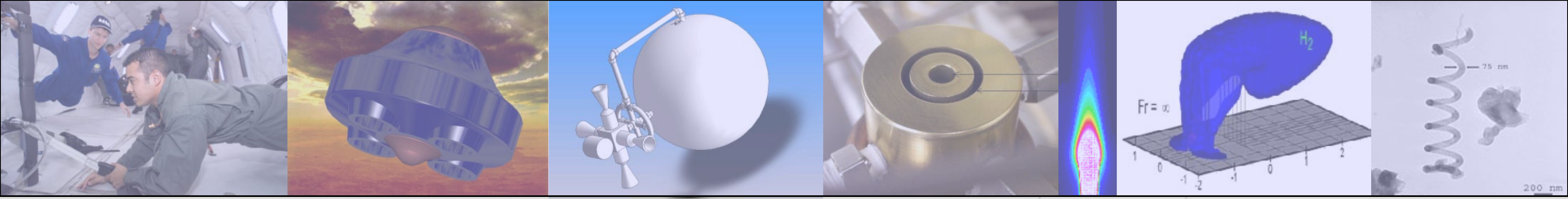
Reaction flow-field for CH_4-air mixture (experimental baseline) with S = 0.97



Stable

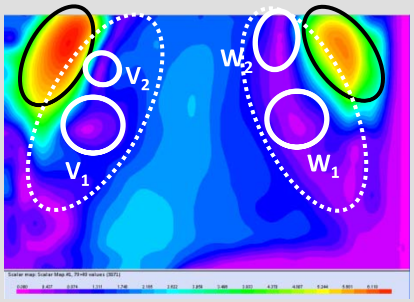


Flashback

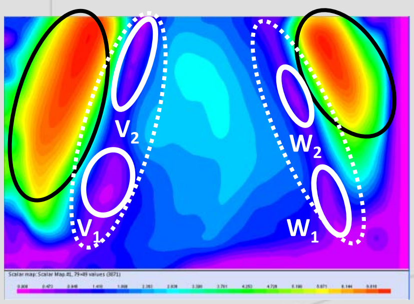


Sample flow-visualization for CIVB flashback sequence

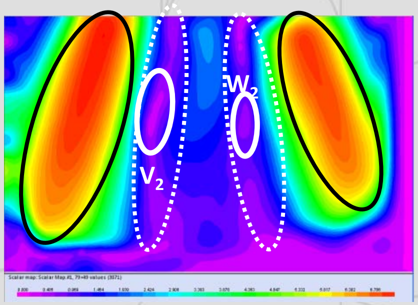
10% H_2 and 90% CO with S = 0.97



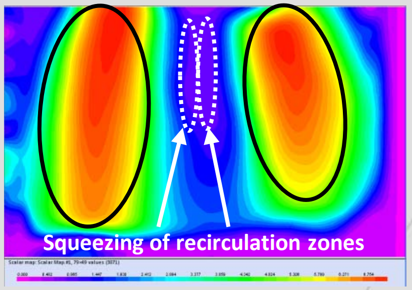
(a)



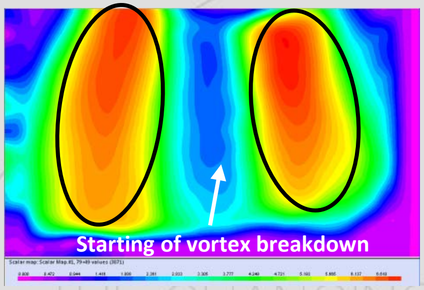
(b)



(c)



(d)



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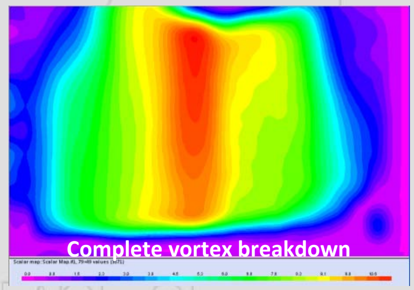
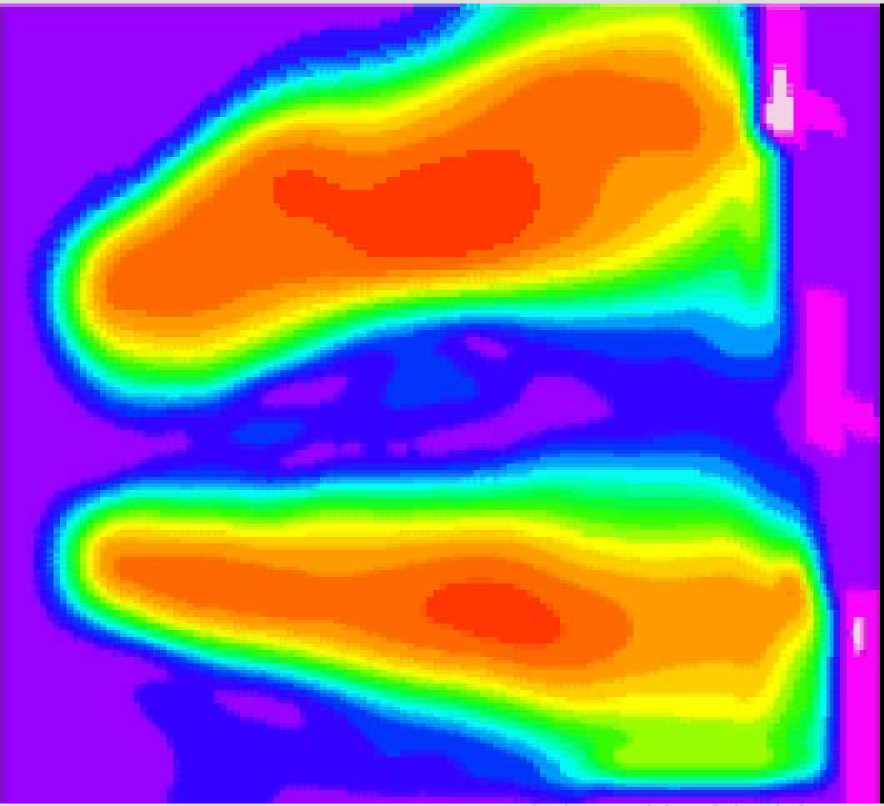
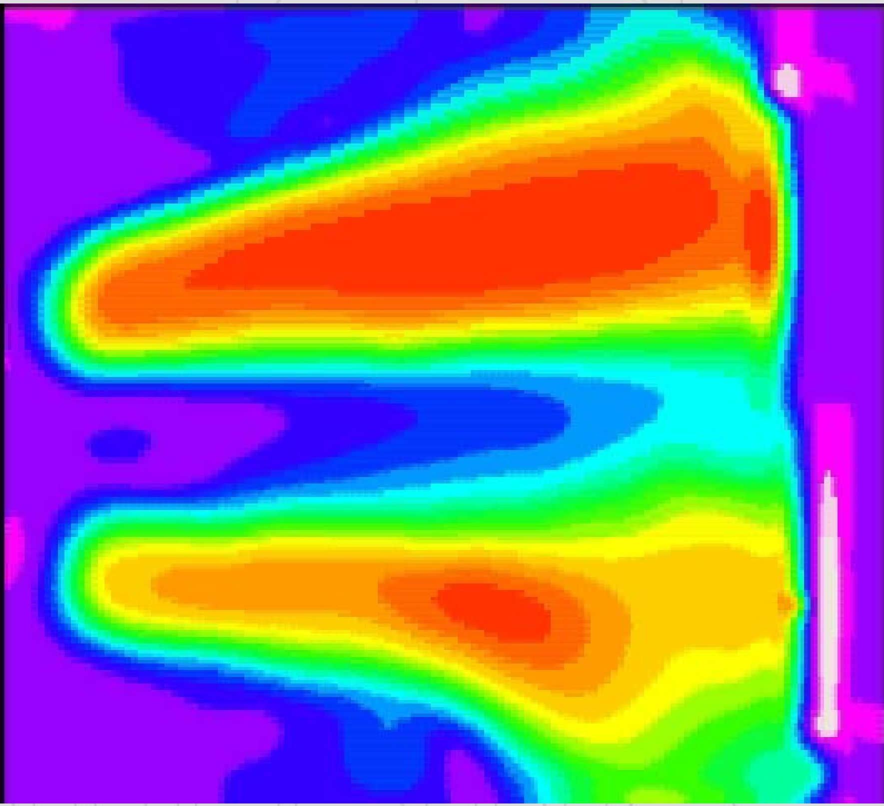


(f)

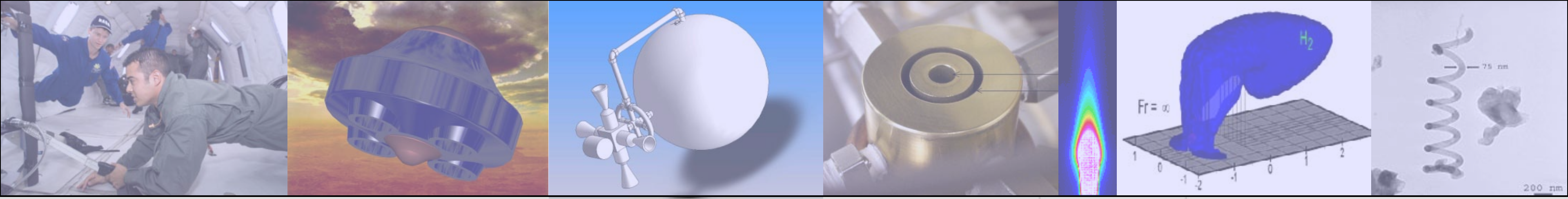
Scalar flow-visualization videos using POD with 20% H_2 – 80% CO for S = 0.97 and S = 0.71



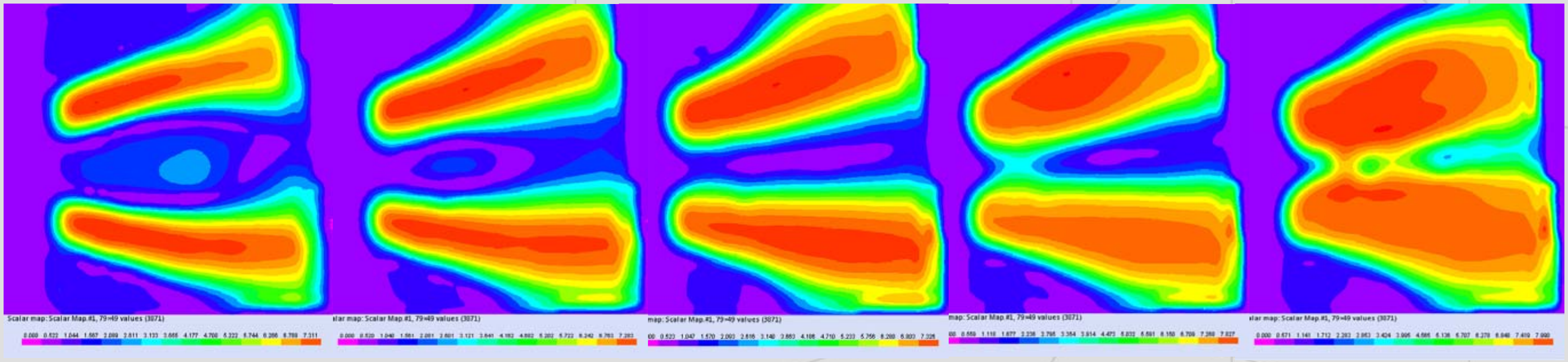
S = 0.97



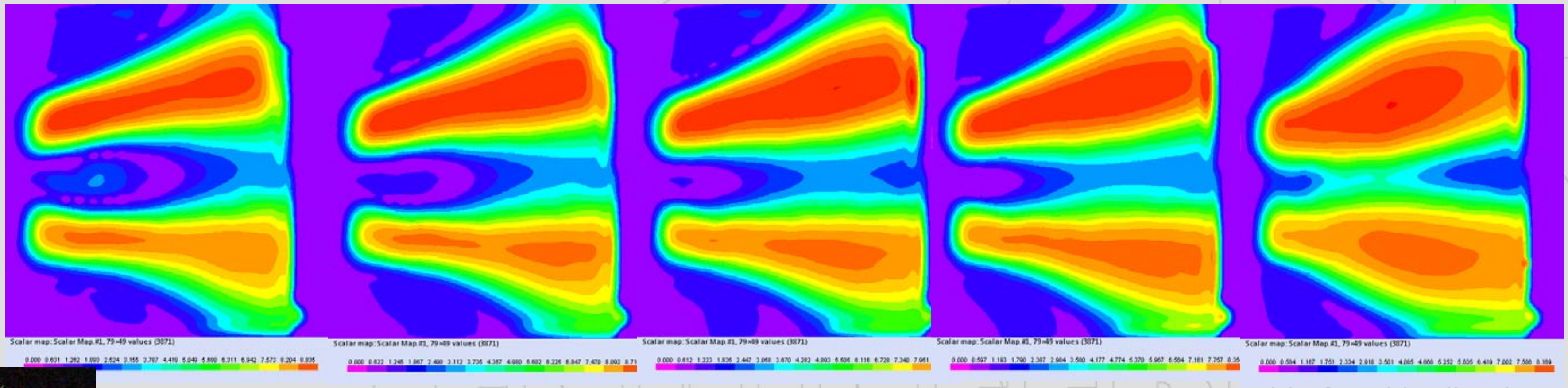
S = 0.71



Flashback sequence with S = 0.97 and S = 0.71 for 20% H_2 – 80 % CO

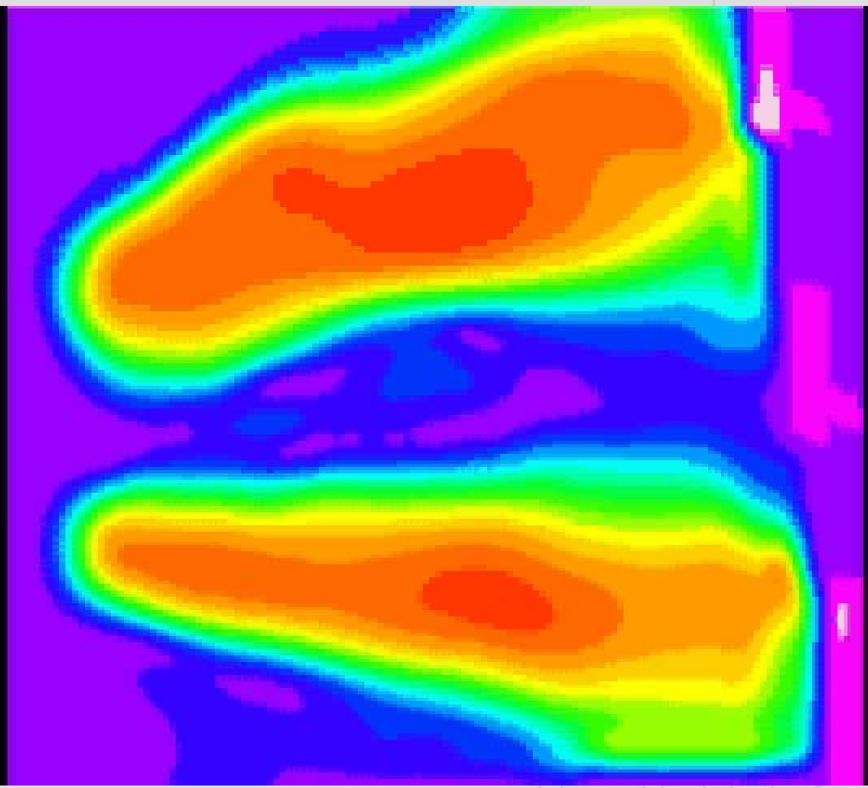


S = 0.97

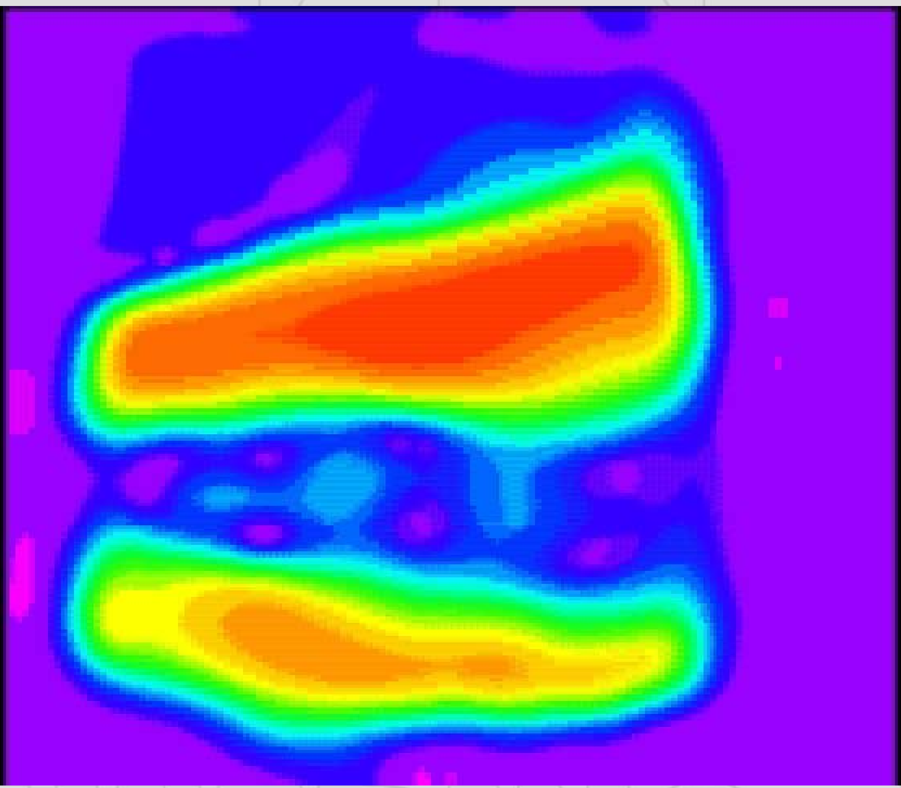


S = 0.71

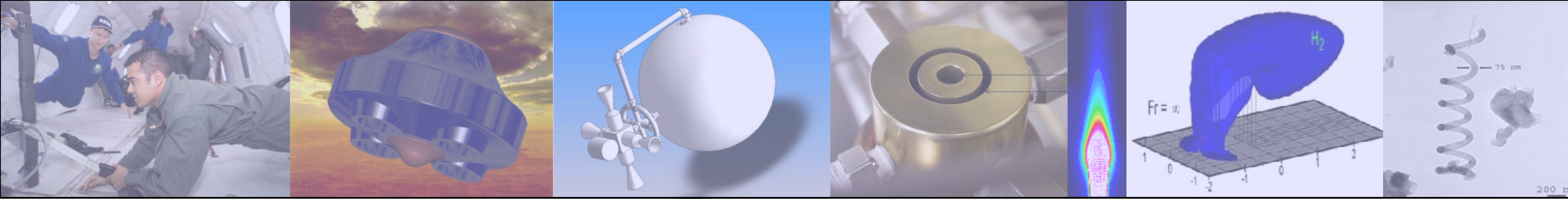
Scalar flow-visualization videos using POD with 20% H2 – 80% CO and 10% H2 – 90% CO for S = 0.97



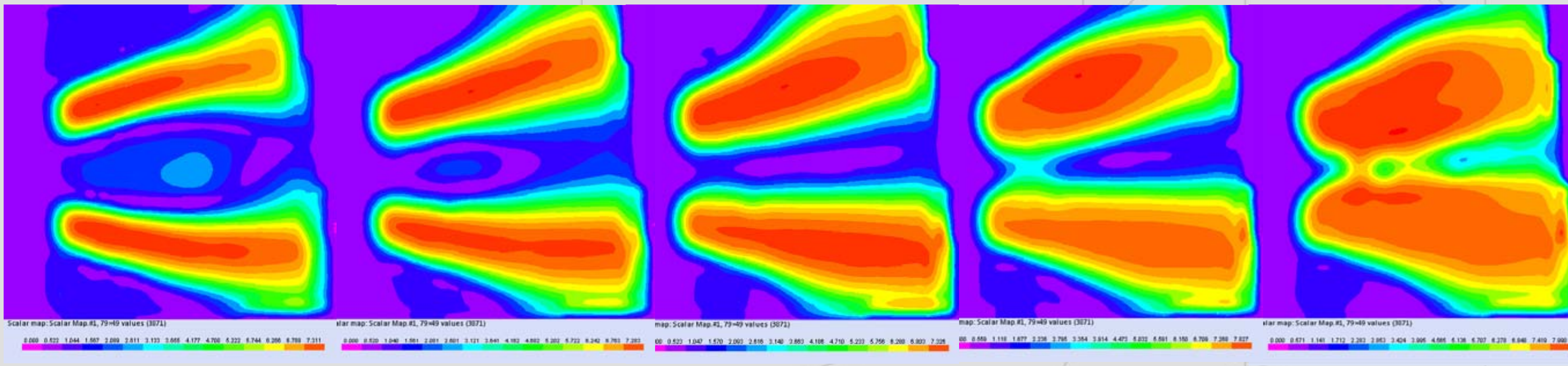
20 % H_2 – 80% CO



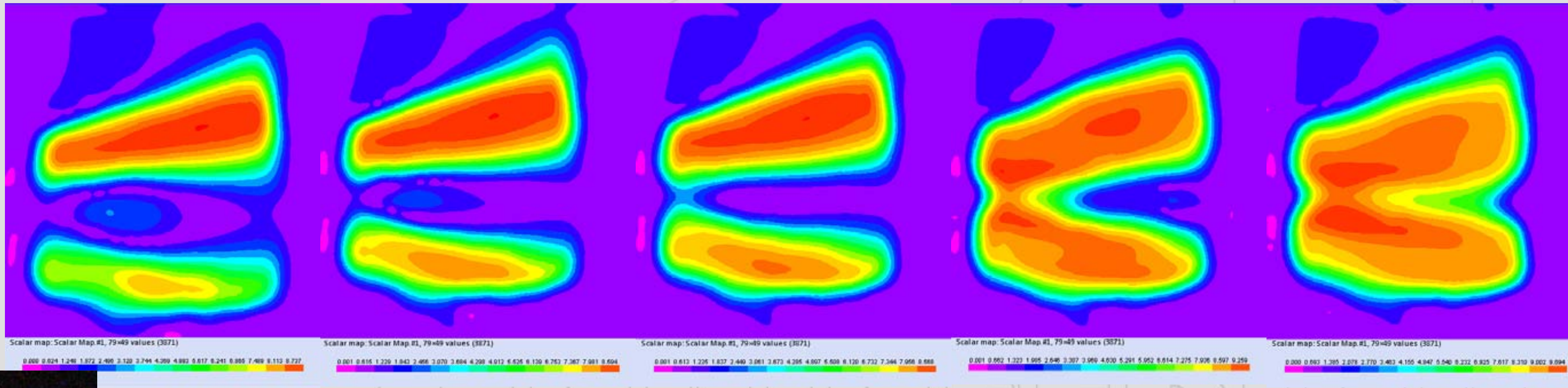
10 % H_2 – 90% CO



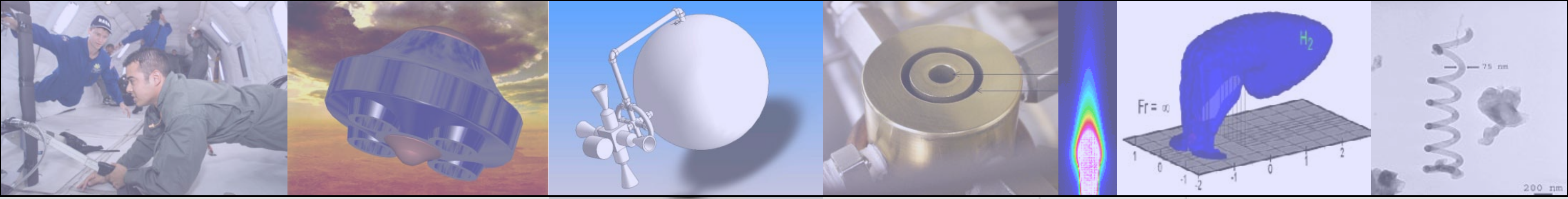
Flashback sequence with 20% H_2 – 80 % CO and 10 % H_2 – 90% CO for S = 0.97



20 % H_2 – 80% CO

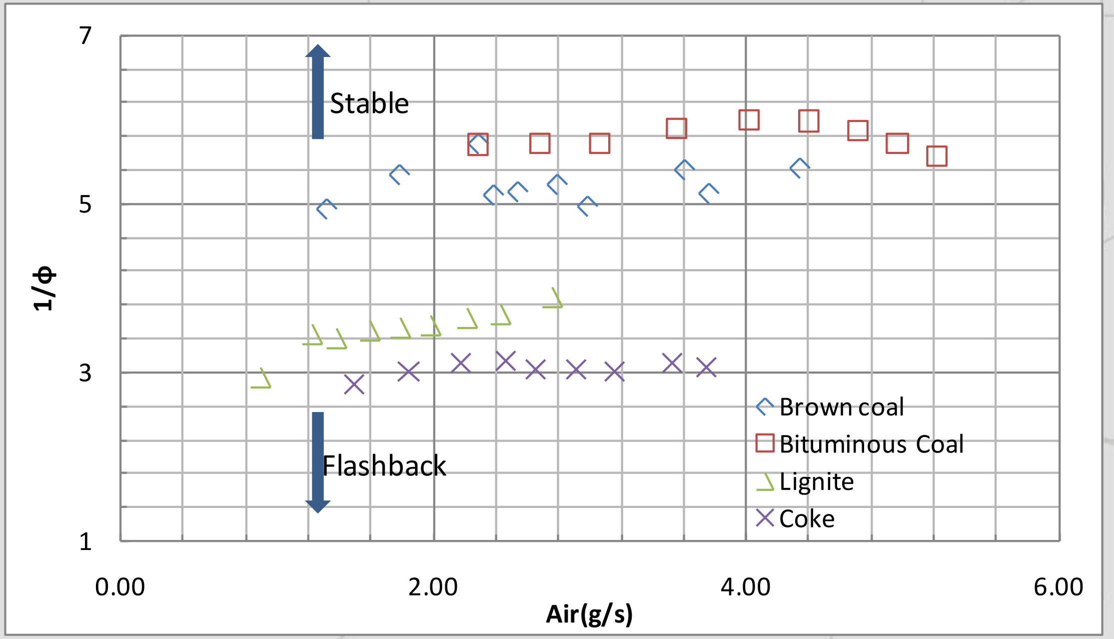


10 % H_2 – 90% CO



Flashback Map: Syngas Compositions

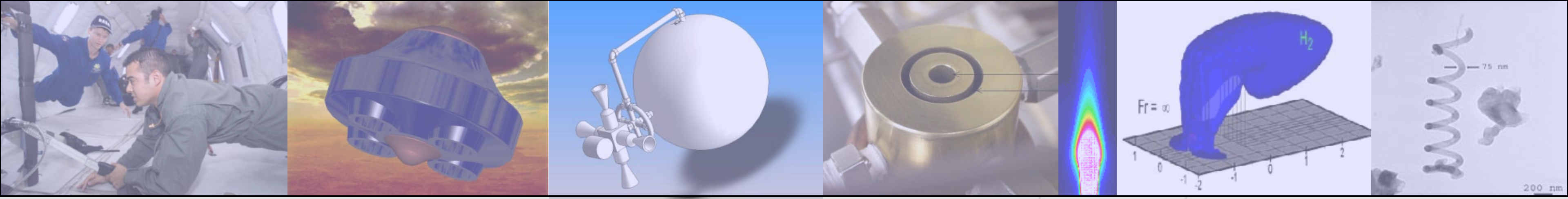
S = 0.97



Estimated Measurement Uncertainties = ±1.5 % of the Mean Value

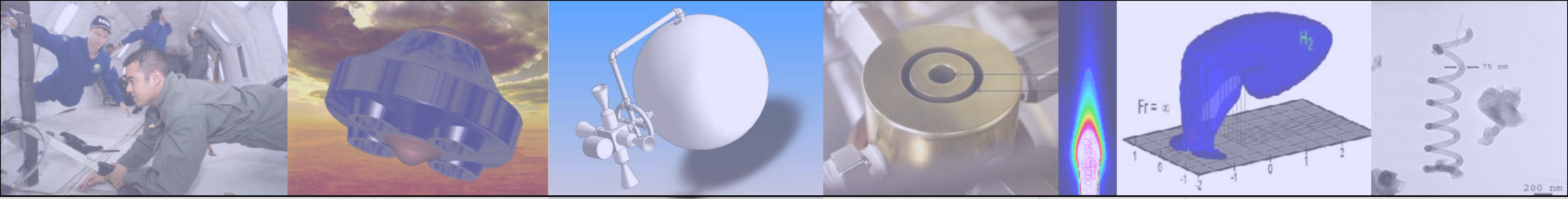
Table 1: Compositions of Synthesized Gases

Gasification	Type of coal	CO (%)	H_2 (%)	CH_4 (%)	N_2 (%)	CO_2 (%)	Calorific Value (MJ/m^3)
Coal	Brown coal	16	25	5	40	14	6.28
	Bituminous	17.2	24.8	4.1	42.7	I1	6.13
	Lignite	22	12	I	55	10	4.13
	Coke	29	15	3	50	3	6.08
Wood		2.1	21	1.83	43	12	7.07



Accomplishments to date

- Experimental measurements of the swirl stabilized flame were conducted for a wide range of mixture compositions, equivalence ratios, and bulk velocities with S = 0.71 and 0.97.
- Mapping and PIV measurements for reacting flow field with CH_4-air mixture were performed initially to use as the baseline for the rest of the experiments.
- Results with various H_2 - CO mixtures:
  - For a given mass flow-rate the CIVB flashback ϕ decreases with the increase in H_2 concentration in fuel mixtures.
  - For a given mass flow-rate the CIVB flashback ϕ increases with the increase of Swirl Number.

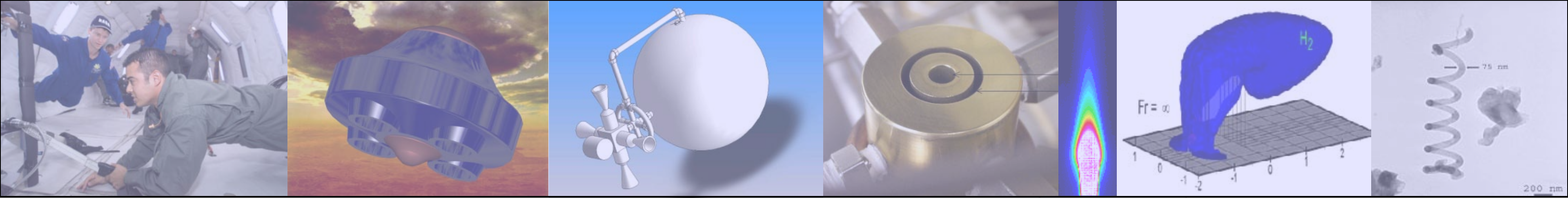


Students Supported through the Grant

- Federico Esquivel (Undergraduate)
- Gilberto Corona (Graduate: MS)
- Bidhan Dam (Graduate: PhD)

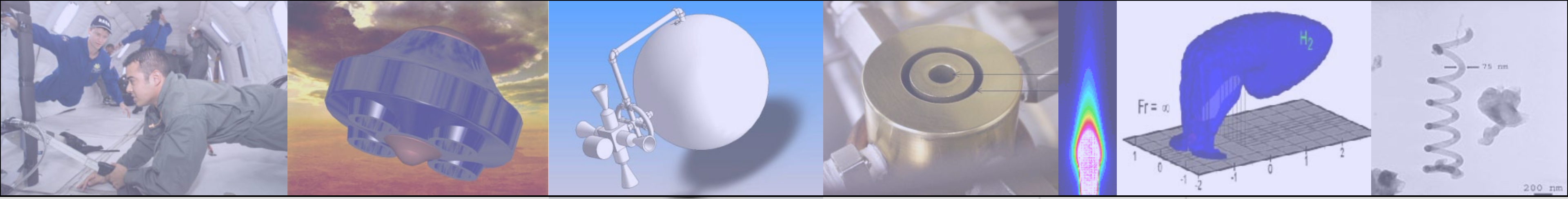
Other Participants

- Raufur Rahim Choudhury (Undergraduate)
- Vish Ardha (Graduate: PhD)
- M. Hayder (Post Doctoral)

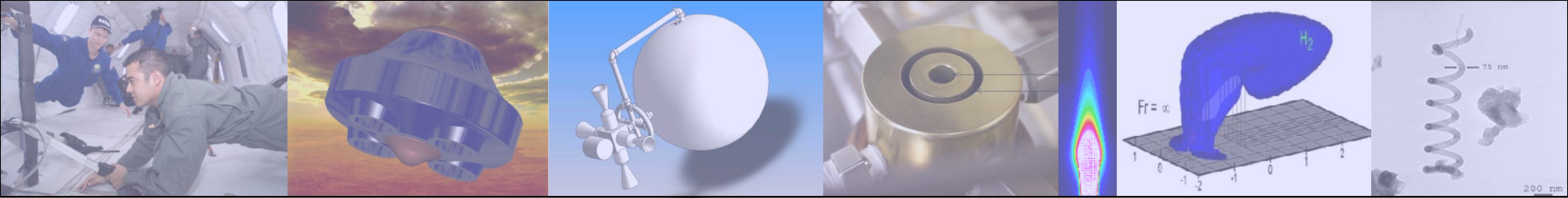


Publications

- Dam, B., Love, N., and Choudhuri, A., 2010, “Flashback Propensity of Syngas Fuels,” *Fuel*, *in review*.
- Ardha, V., Dam, B., and Choudhuri, A., *Burning Velocity of Syngas Fuels*, 2010, ASEM JERT, *in review*.
- Choudhuri, A. Dam, B., and Corona, G., *Flashback Propensity in Swirl Stabilized Burner with Syngas Fuels*, 2010, ASME POWER Conference, Paper No. POWER). 2010-27137.
- Dam, B., Ardha, V., and Choudhuri, A., *Laminar Flame Velocity of Syngas Fuels*, 2010, ASME POWER Conference.
- Dam, B., Corona, G., and Choudhuri, A., *Investigation of Flashback Propensity in Turbines with Syngas Fuels*, 2010, AIAA Conference, Paper No. 2010-1172
- Dam, B., Ardha, V., and Choudhuri, A., *Flashback Propensity of Syngas Fuels*, 2009, ASME POWER Conference, Paper No. POWER2009-81011.
- Ardha, V., Esquivel, F., and Choudhuri, A., *Laminar Flame Speeds of Hydrogen Fuel Blends Measured with the Heat Extraction Method*, 2009, ASME International Mechanical Engineering Congress, Paper No. IMECE2009-11846.



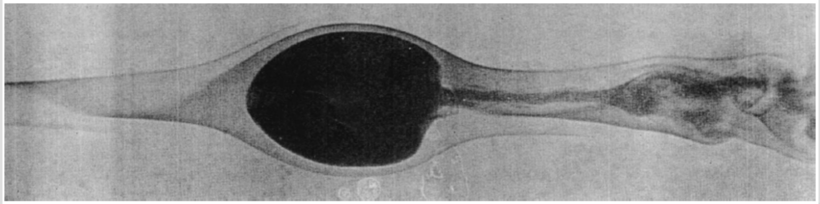
Back up Slides



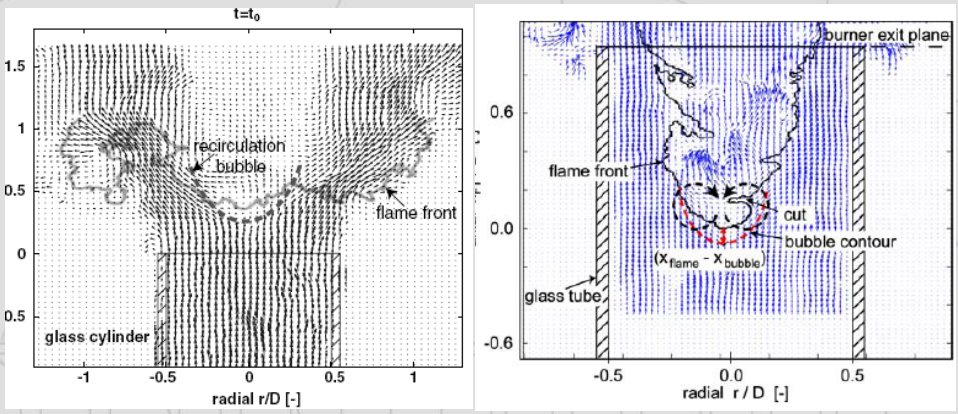
Background

i. Vortex Breakdown (VB): "Change in structure of a vortex initiated by a variation in the characteristics ratio of tangential to axial velocity components."Leibovich (1978)

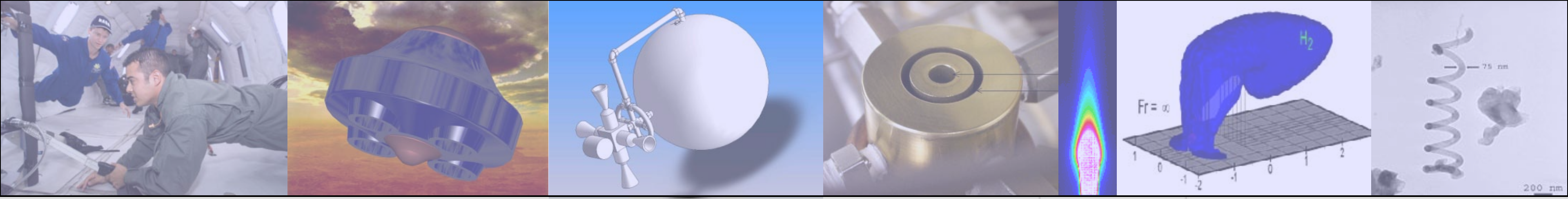
i. CIVB Flashback occurs due to the expansion of the hot gas.
   i. The low velocity regime of the VB pushes the flame front upstream.
   ii. The expansion of the hot gas pushes the VB location further upstream.



Sarpkaya (1971)

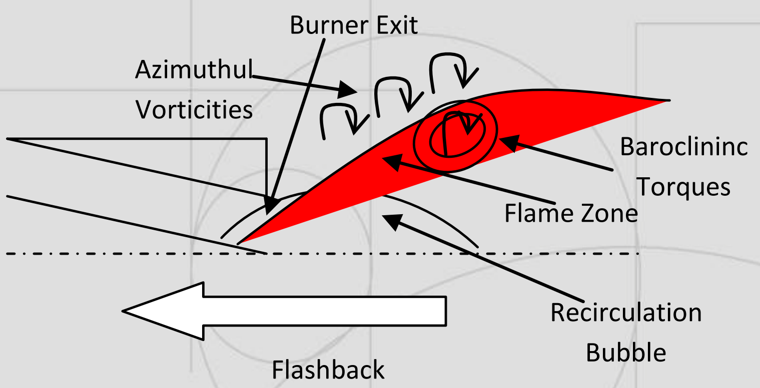


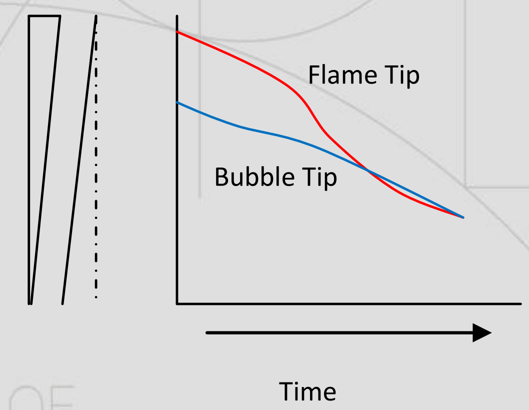
Konle et al. (2008)

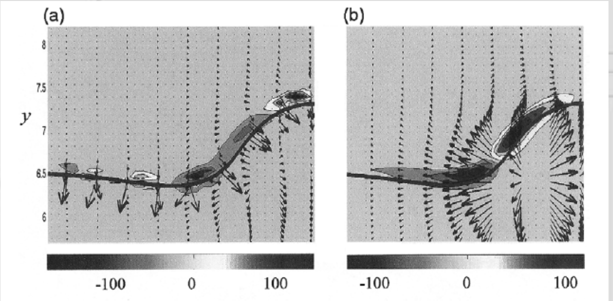


CIVB Flashback Process

1. Flame stabilizes slightly upstream of the recirculation zone.
2. As the flame approaches the CIVB limit combined effects of baroclinic torque within the reaction zone and azimuthul vorticities pushes the recirculation tip slightly upstream.
3. The flame position also moves upstream and stabilizes in a new location.
4. Further increase in the equivalence ratio increases the negative axial velocity generation through flame vortex interactions and pushes the recirculation tip further upstream. However, the difference between the recirculation tip and flame stabilization points decreases.
5. Once the equivalence ratio exceeds a critical value, flame becomes unstable and flashback occurs.







Pan et al. (2002)