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Space Experiment Concepts: Cup-Burner Flame Extinguishment

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GBEX-Gaseous Burner Extinguishment Experiment		Scott Numbers
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Physical and Chemical Aspects of Fire Suppression in Extraterrestrial Environments	*ISSI*	Viswanath Katta (co-I)

Background

◆ NASA's Fire Safety Approach

- *Fire prevention plays a key role*

⇒ fire safety program for manned space flight has been based on controlling the materials flammability and eliminating ignition sources

- *Space exploration expands platform*

⇒ longer duration missions to the moon, Mars, or aboard the International Space Station (ISS) increase the likelihood of fire events

⇒ various gravity levels affect fire behavior ISS: μ*g*, lunar: 1/6*g*, Martian: 1/3*g*

Objectives

◆ **Space Fire Suppression Processes & Technology**

- *Be prepared for space fire suppression!*

⇒ need better understanding of physical and chemical suppression processes in reduced gravity environments simulating various missions

- *Develop space fire suppression technology*

⇒ the results must provide useful data leading to technology development of fire suppression systems in various platforms

Organizing Questions *Fire Suppression*

- *Fire-Extinguishing Agent Effectiveness in Space Environments*

1. What is the relative effectiveness of candidate suppressants to extinguish a representative fire in reduced gravity, including high-O_2 mole fraction, low-pressure environments?
2. What are the relative advantages and disadvantages of physically acting and chemically acting agents in space fire suppression?
3. What are the O_2 mole fraction and absolute pressure below which a fire cannot exist?
4. What effect does gas-phase radiation play in the overall fire and post-fire environments?
5. Are the candidate suppressants effective to extinguish fires on practical solid fuels?

- *Space Fire Suppression Technology Development*

7. How can idealized space experiment results be applied to a practical fire scenario?
8. What is the optimal agent deployment strategy for space fire suppression?

Agent Effectiveness

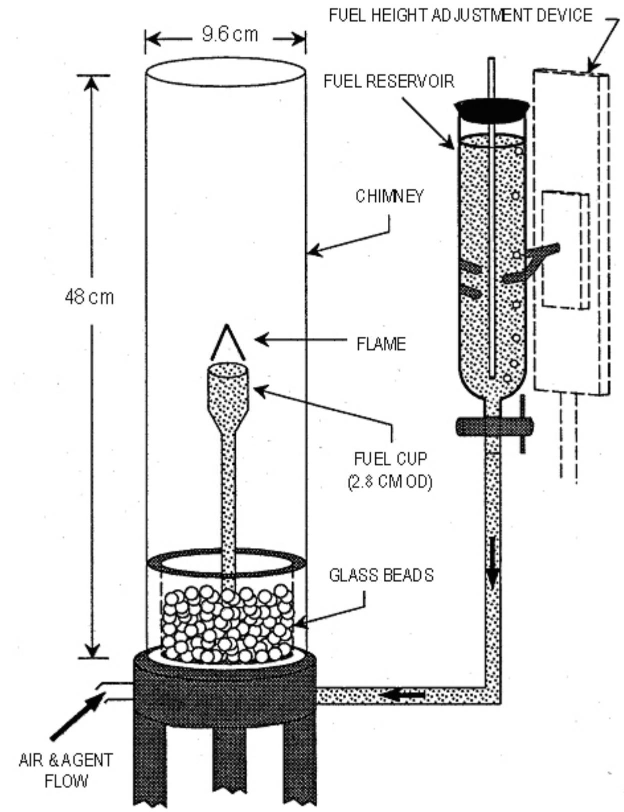
- **Cup-Burner Method:** dynamic co-flow diffusion flame
  - *Standard Test*

⇒ the most widely used test specified in national and international standards (NFPA 2001, AS 4214, ISO 14502)

⇒ measure the minimum extinguishing concentration (MEC) which renders the "inhibited" air <u>incapable</u> of supporting diffusion flame combustion

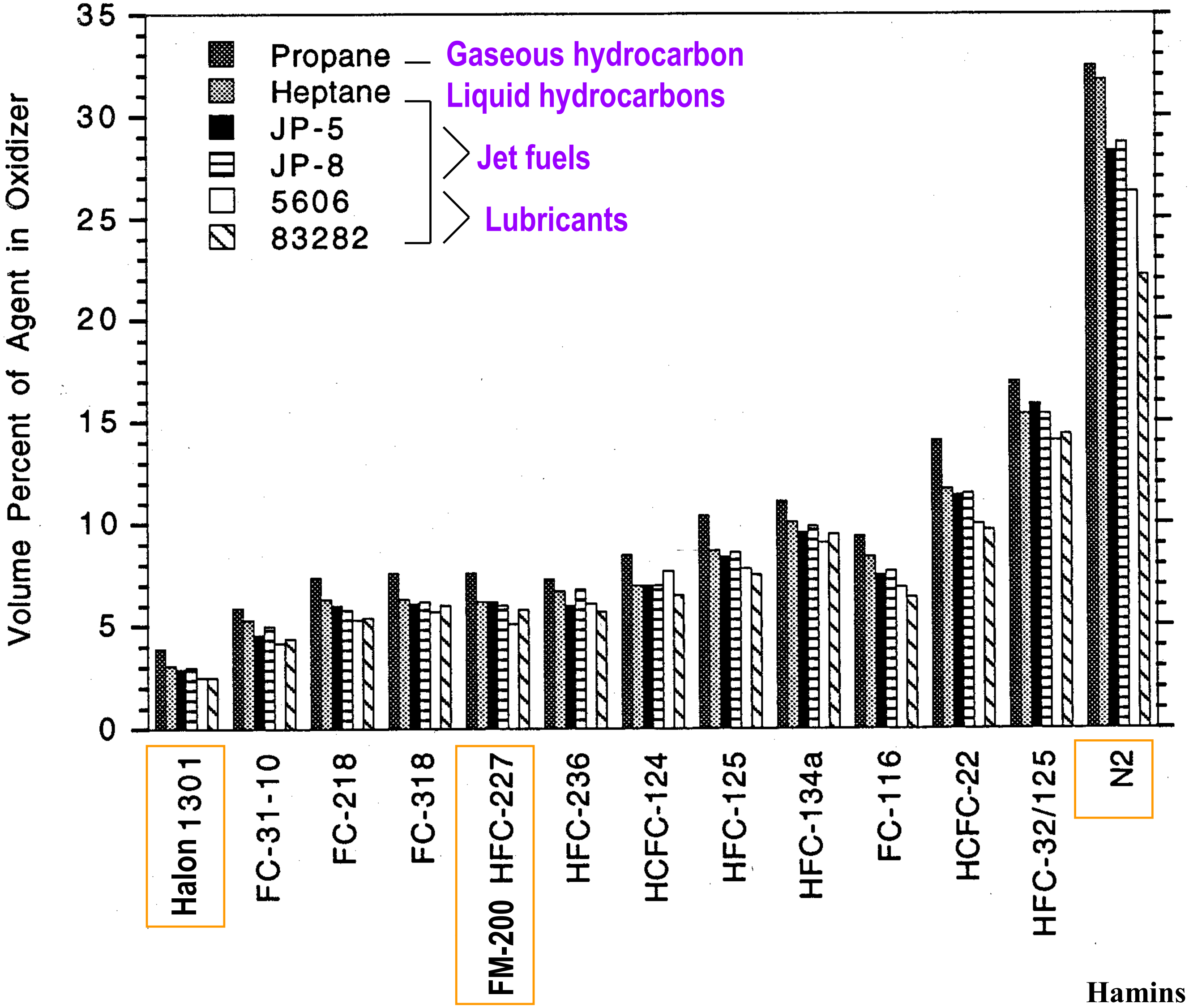
⇒ the minimum design concentration of a gaseous ***agent*** for a fire protection system is determined by adding at least 30% to the cup-burner MEC value by manufacturer

⇒ the third party approval (e.g., UL, Factory Mutual) of a fire extinguishing ***system*** requires large-scale pan fire tests in relation to the cup-burner MEC values



Hamins et al. (1994)

MEC Minimum Extinguishing Concentration



Hamins et al. (1994)

Laboratory Flame vs. Real Fire

◆ Cup- Burner Flame Behavior:

- *Relatively system independent:*

⇒ the MEC is nearly independent of the fuel cup size, chimney size, fuel velocity, and oxidizer velocity

⇒ the cup-burner MEC values are nearly equal to those for low strain rate counterfow diffusion flames

- *Scale model of a real fire:*

⇒ flame segments subjected to various strain rates, including stabilized/spreading edge diffusion flames

⇒ flame flickering and separation in 1*g*, affecting the air and agent entrainment into fire zone

⇒ extinguishment occurs via ***dynamic*** blow-off process rather than global extinction typical of counterflow diffusion flames

Click here to play movie

Cup Burner

Pool Fire

http://www.me.uwaterloo.ca/~ew eckman/fire/firehome.htm

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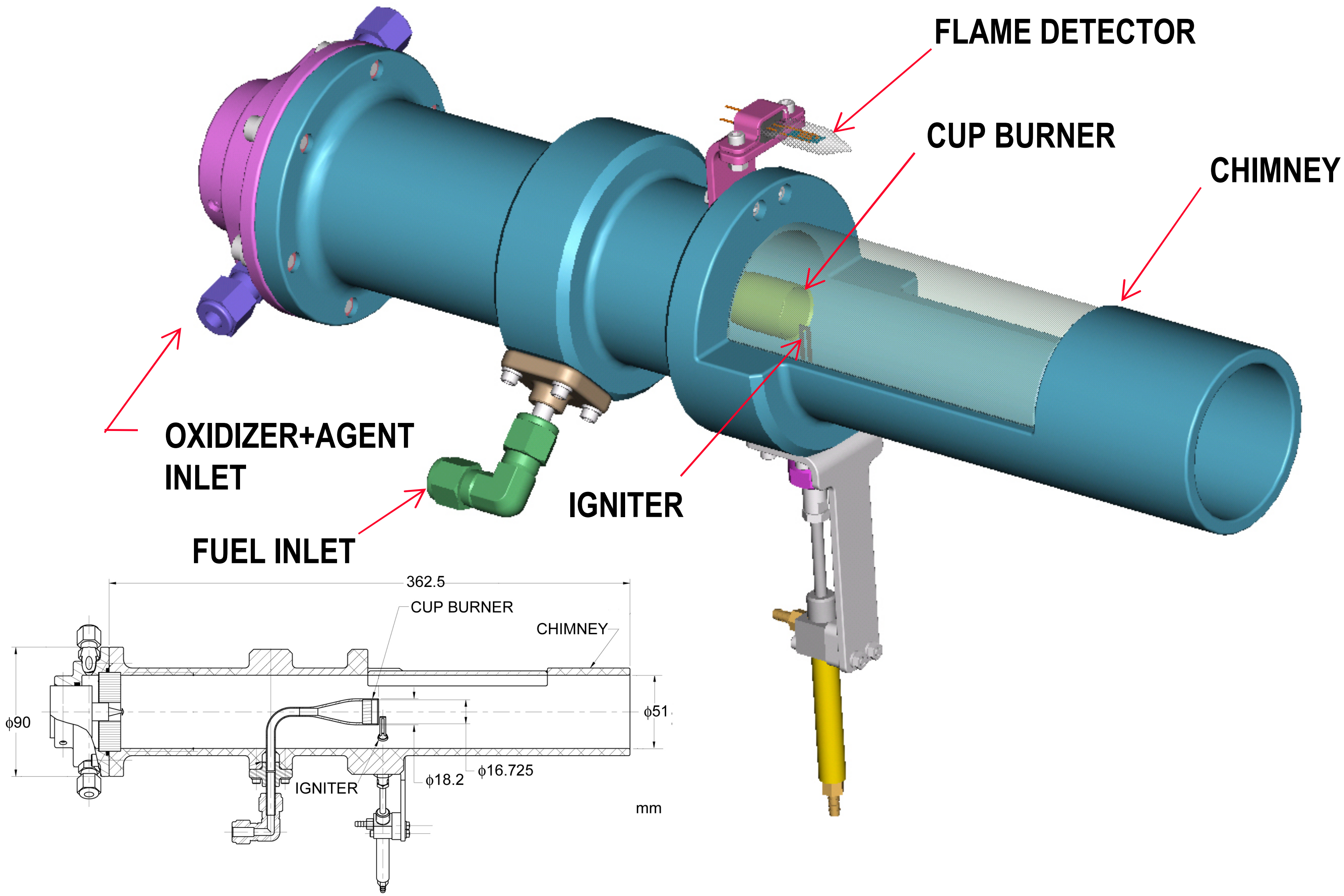
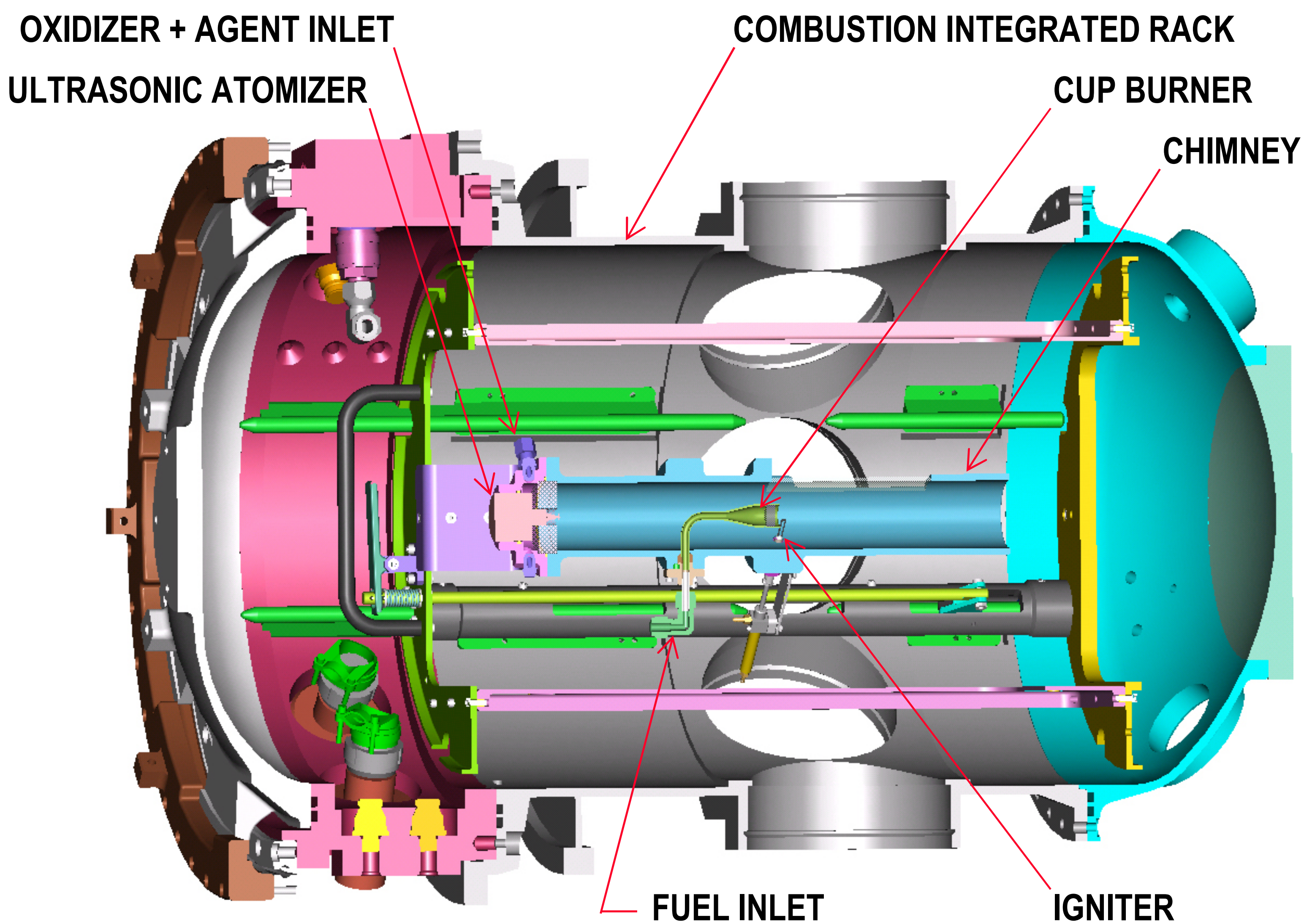
GBEX Gaseous Burner Extinguishment EXperiment



GBEX in CIR


OXIDIZER + AGENT INLET
ULTRASONIC ATOMIZER
COMBUSTION INTEGRATED RACK
CUP BURNER
CHIMNEY
FUEL INLET
IGNITER

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GBEX Gaseous Burner Extinguishment EXperiment

- **Dimensions:** 5/8 Scale

  Burner : 17 mm ID

  Chimney: 51 mm ID × 350 mm length

- **Test Matrix:**

  Fuel: CH_4

  Oxidizer: O_2-N_2 mixture

  Oxygen mole fraction: 0.21, 0.3

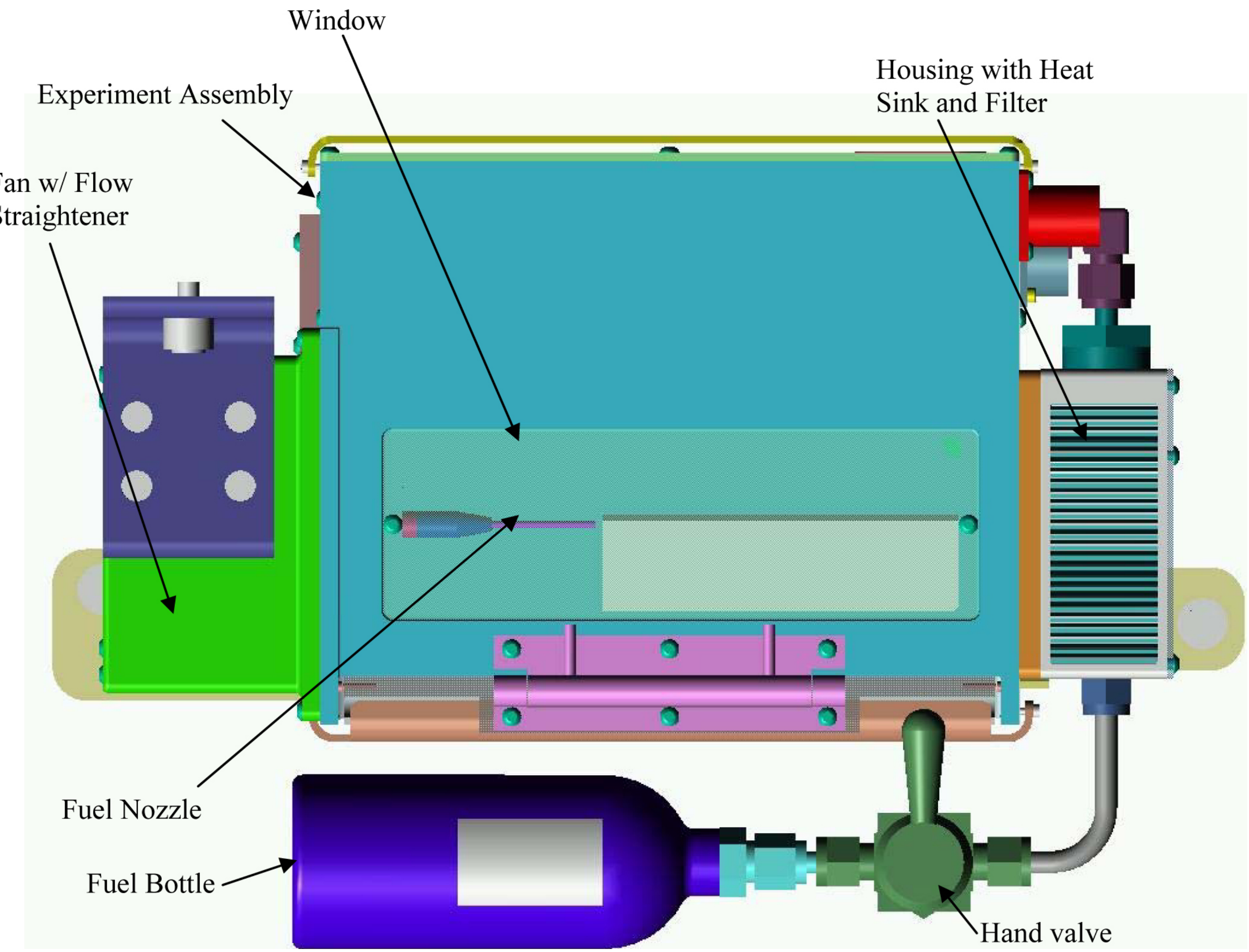
  Velocity : 1 – 12 cm/s

  Agent: CO_2, N_2, He, Water Mist, Inert Gas/Water Mist

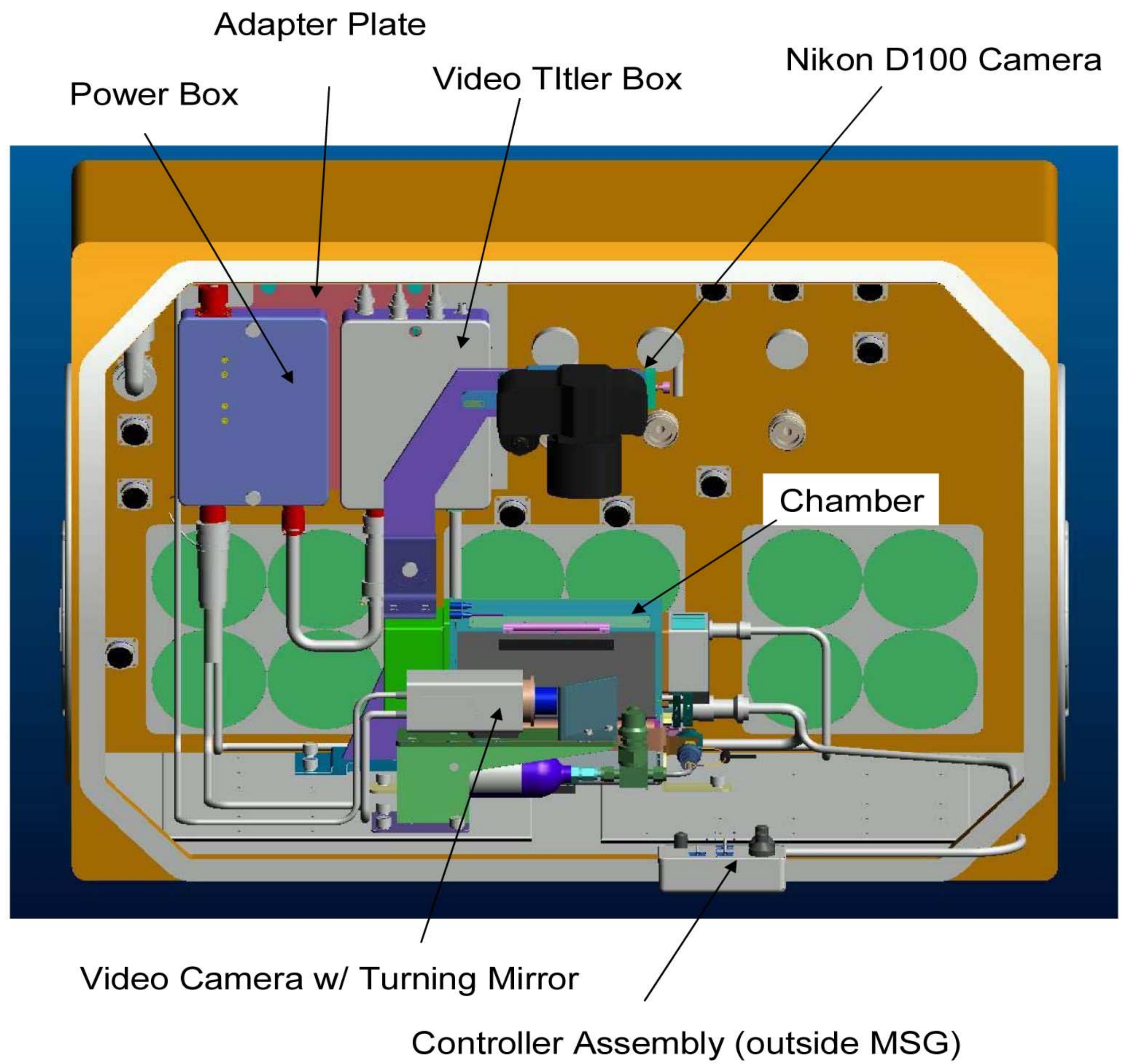
  Gravity: μg

  Pressure: 1 atm, 0.7 atm

MSG Microgravity Science Glovebox



MSG Microgravity Science Glovebox



MSG Microgravity Science Glovebox

- **Dimensions:**

Burner:	12 mm ID
Chimney:	79 mm square × 187 mm length

- **Test Matrix:**

Fuel:	CH_4
Oxidizer:	Air
	Velocity : 1 – 50 cm/s
Agent:	N_2
Gravity:	μg
Pressure:	1 atm

FSEE Fire Suppression in Extraterrestrial Environments

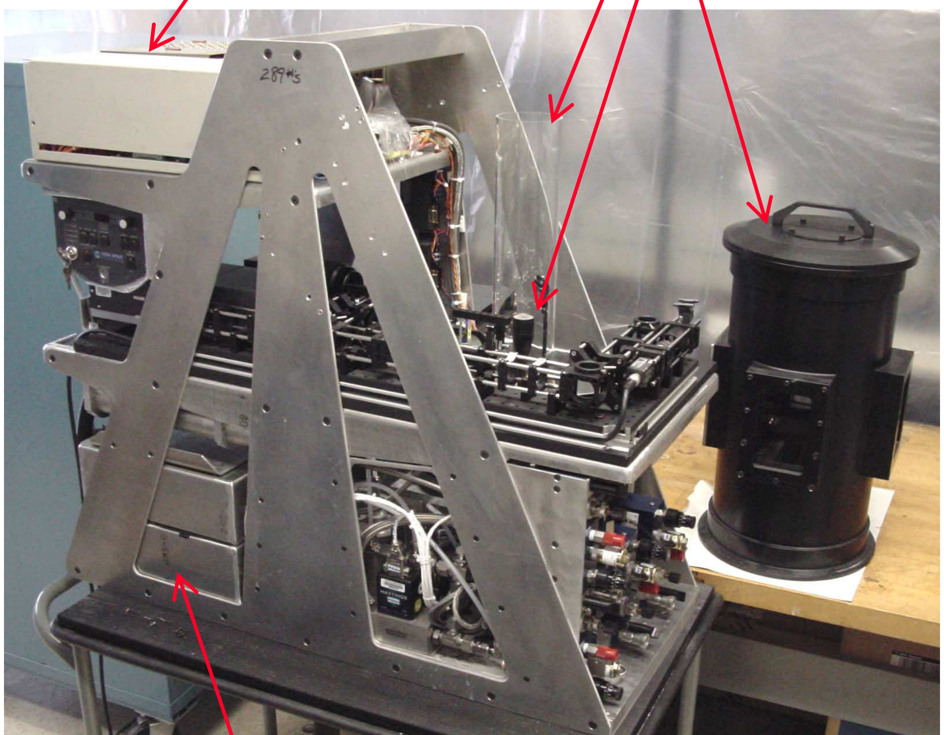
Drop/KC-135 Rig

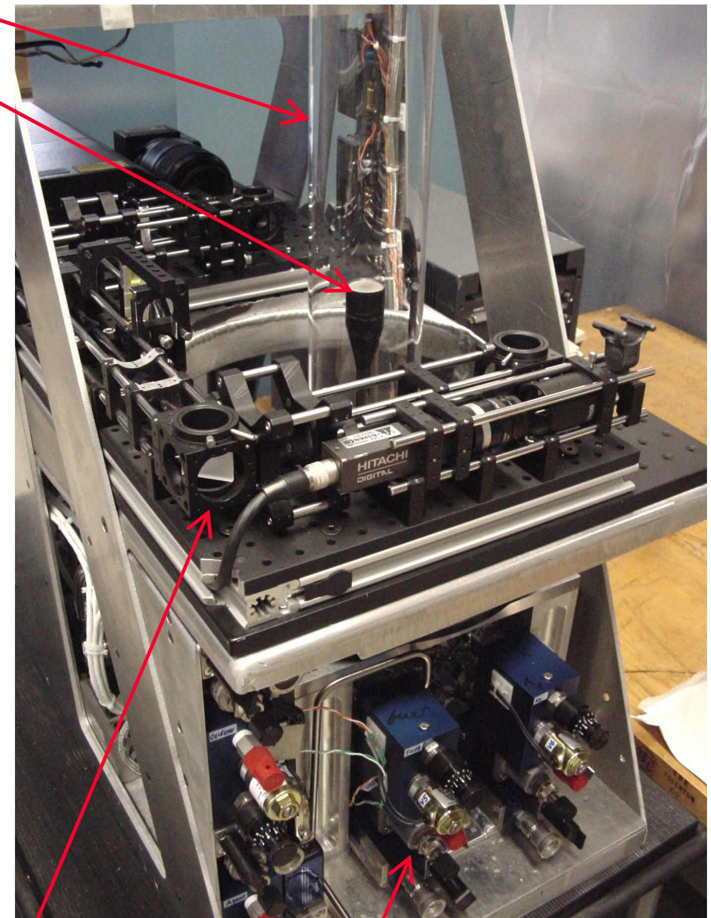
COMPUTER & I/O BOX

CHIMNEY

CUP BURNER

CHAMBER





BATTERIES

PIV-MZI OPTICS

FLOW MODULES

FSEE Fire Suppression in Extraterrestrial Environments

Dimensions: Full Scale

Burner : 28 mm ID

Chimney: 85 mm ID × 533 mm length

Test Matrix:

Fuel:	Gas:	CH_4, C_2H_6, C_3H_8
	Liquid:	n-C_7H_{16}, CH_3OH
	Solid:	trioxane (3[CH_2O]), PMMA

Oxidizer: O_2-N_2 mixture
Oxygen mole fraction: 0.21 – 0.3
Velocity: 3 – 20 cm/s

Agent: CO_2, N_2, He, Ar
CF_3H(HFC-23), C_3F_7H (HFC-227ea), CF_3Br (Halon 1301)
Water Mist, Inert/Water Mist, Microencapsulated Water

Gravity: μ*g*, lunar (1/6 *g*), Martian (1/3 *g*), 1*g*

Pressure: 0.7 – 1 atm

Dynamic Flame Extinguishment

Experiment (1g)

Methane

Air + 15.9%CO_2

U_{CH4}= 0.92 cm/s
U_{ox}= 6.7 cm/s

Click here to play movie

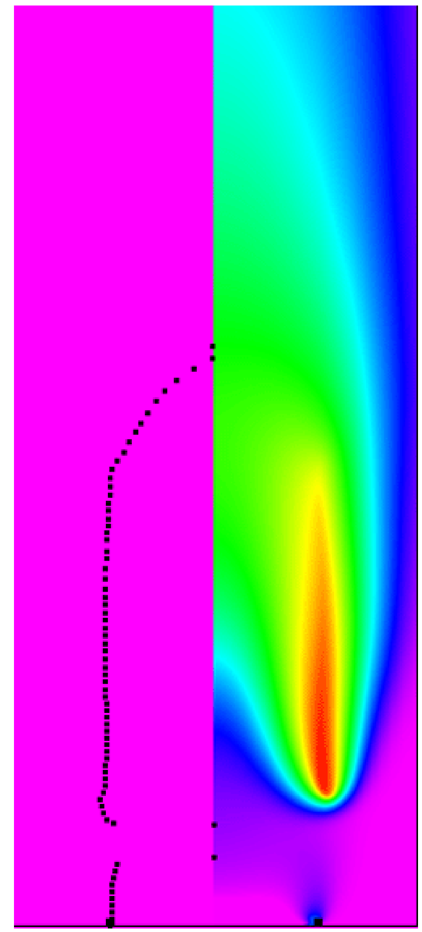
Direct Numerical Simulation (0g)

Methane

Air + 30.7% He

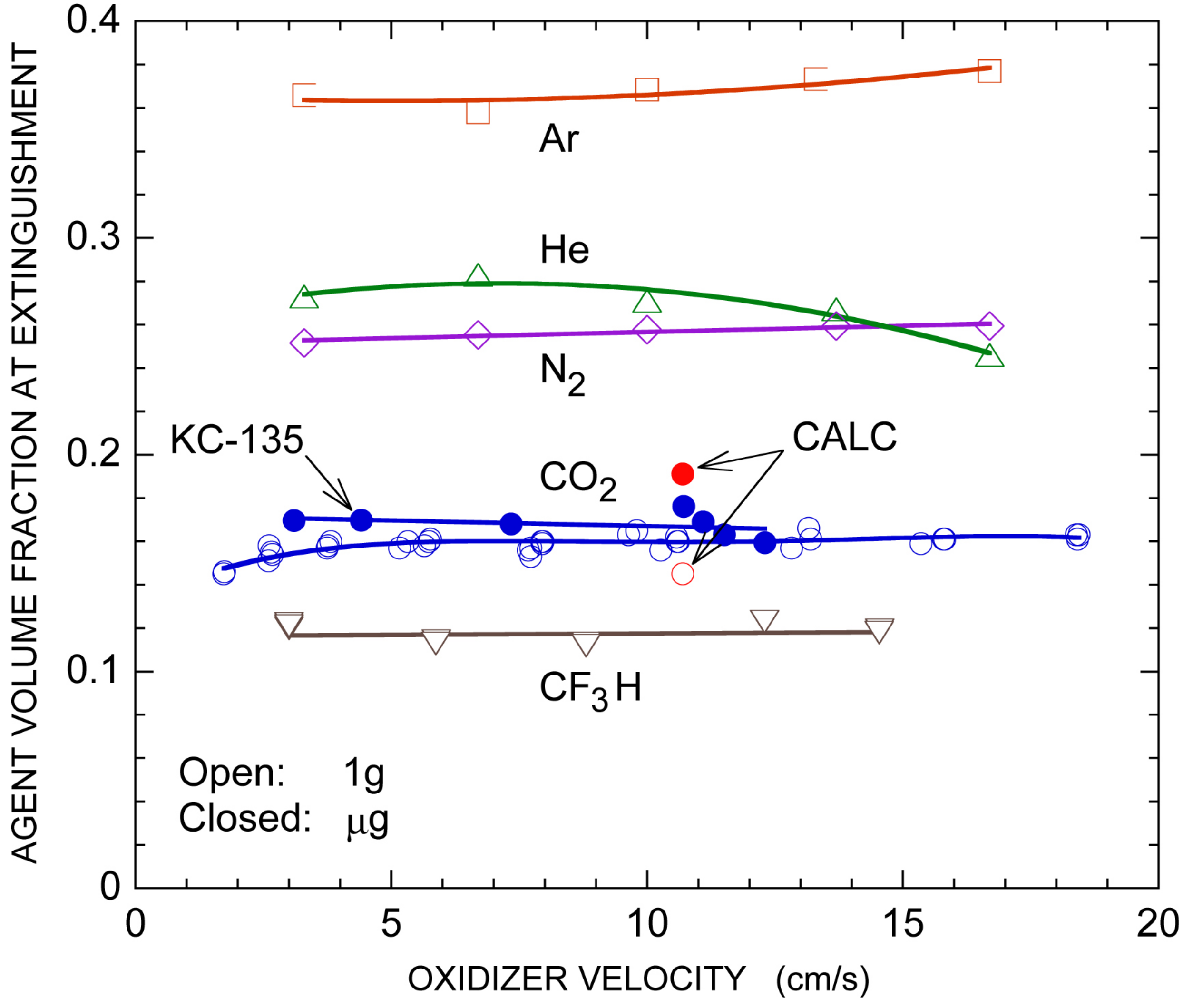
U_{CH4}= 0.92 cm/s
U_{ox}= 10.7 cm/s

- Full chemistry (GRI Mech 1.2)
- Radiative loss
- Mixture rules



Takahashi, Linteris, and Katta, AIAA Paper No. 2004-0957, January 2004

Extinguishment Limits



Takahashi, Linteris, and Katta, AIAA Paper No. 2004-0957, January 2004

Answering to Organizing Questions

- *Cup-burner flame extinguishment experiment can:*

1. measure the relative effectiveness (MEC) of candidate suppressants in low-*g*, including high-O_2, low-P environments
2. determine the X_{O2} (LOI) below which a fire cannot exist
3. examine the effect of radiation in fire and post-fire environments
4. reveal advantages/disadvantages of physical/chemical agents
5. measure the agent effectiveness for practical solid fuels

7. provide an idealized space experiment applicable to a practical fire scenario
8. produce useful data in relation to agent deployment strategy

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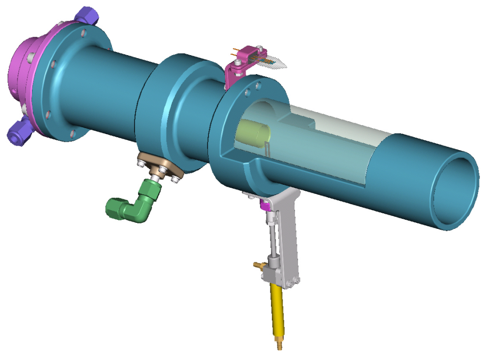
Conclusions

- **Space Fire Suppression Processes & Technology**



⇒ Space experiment concepts of cup-burner flame extinguishment have been conceived to address to the key issues (i.e., organizing questions) in space fire suppression

⇒ Cup-burner flame extinguishment experiment can reveal physical and chemical suppression processes and provide agent effectiveness data useful for technology development of space fire suppression systems in various reduced-gravity platforms