Spacecraft fire safety and microgravity combustion research: an enabler for human space exploration

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THE APOLLO TRAGEDY
PORT WASHINGTON
JAN
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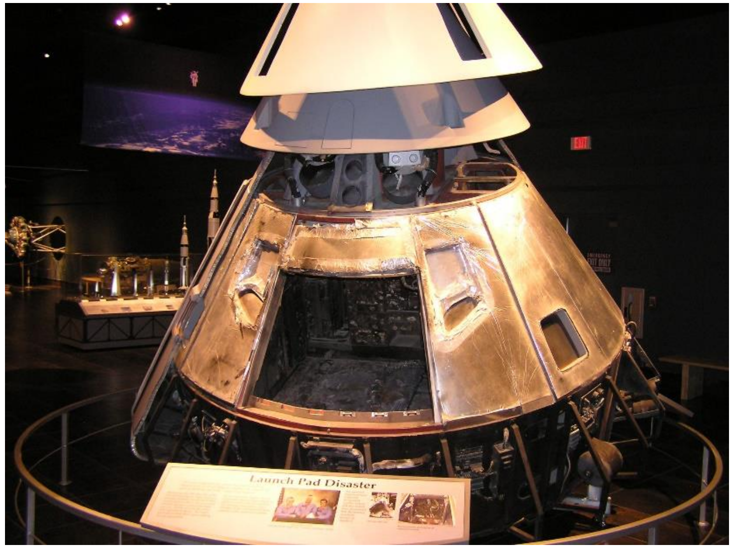
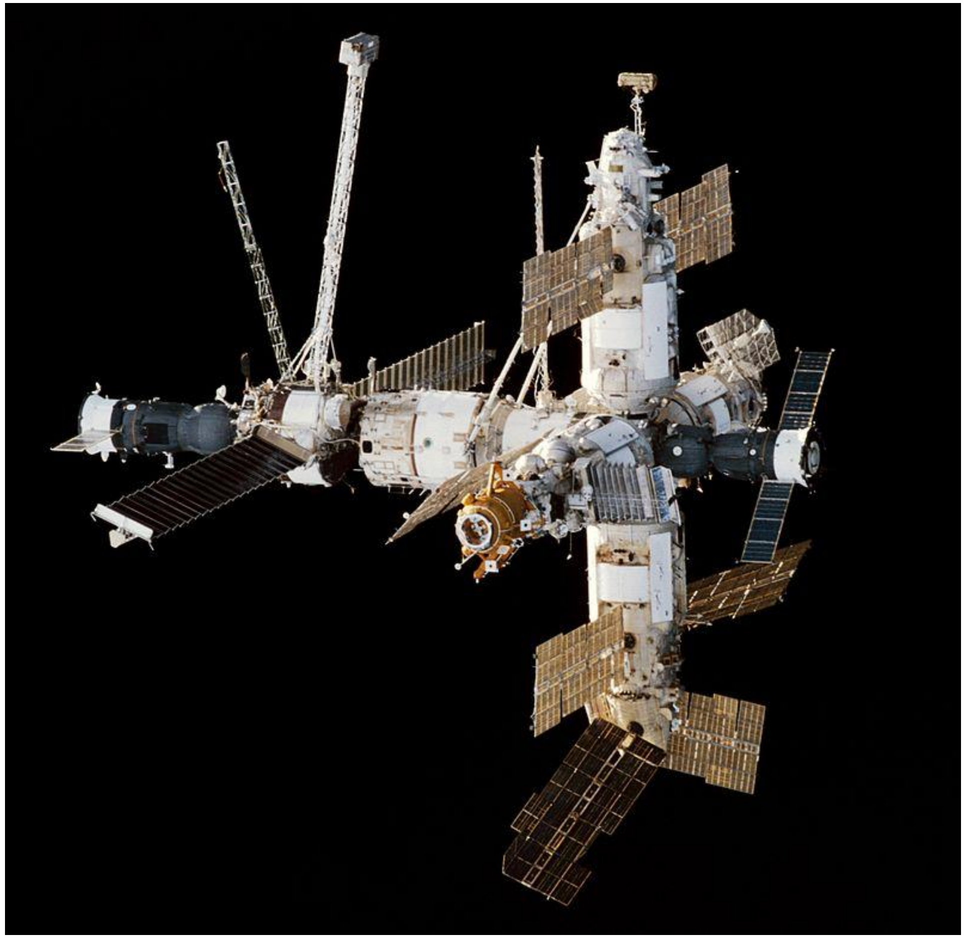
1967
N. Y.
5¢
The three-man crew of astronauts for the Apollo 1 mission, were killed today, in a flash fire, igniting the all oxygen atmosphere, in a simulated test aboard the huge spacecraft, designed to take the first Americans to the moon.
Astronauts Grissom, White and Chaffee


Launch Pad Disaster

Oxygen candle fire in MIR February 24, 1997

American astronaut Jerry Linenger:
As the fire spewed with angry intensity, sparks
– resembling an entire box of sparklers ignited
simultaneously
– extended a foot or so beyond the flame’s
furthest edge

MIR space station



What are special about fire in Spacecraft and/or extra-terrestrial habitats?

- You cannot go outside (escape options are limited)
- You are in a very small volume (survival options are limited).
- Spacecraft can tolerate a much smaller fire than you can tolerate in our home. Pressure and temperature can increase quickly.
- Toxic products accumulate quickly.
- Rescue is not available

But,

you can select materials to be used in spacecraft. So, in additional to detection and suppression as fire fighting tools, fire prevention by screening materials has become an important first line of defense against fire.

-Thousands of material samples needed to be screened

-Practically they have to be done on earth under normal gravity

One such a test:

NASA std (I) 6001A

Upward flame spread

Go-No go: pass if flame extinguishes and burn length is less than 6 inches

Question:

Is this test adequate in microgravity?

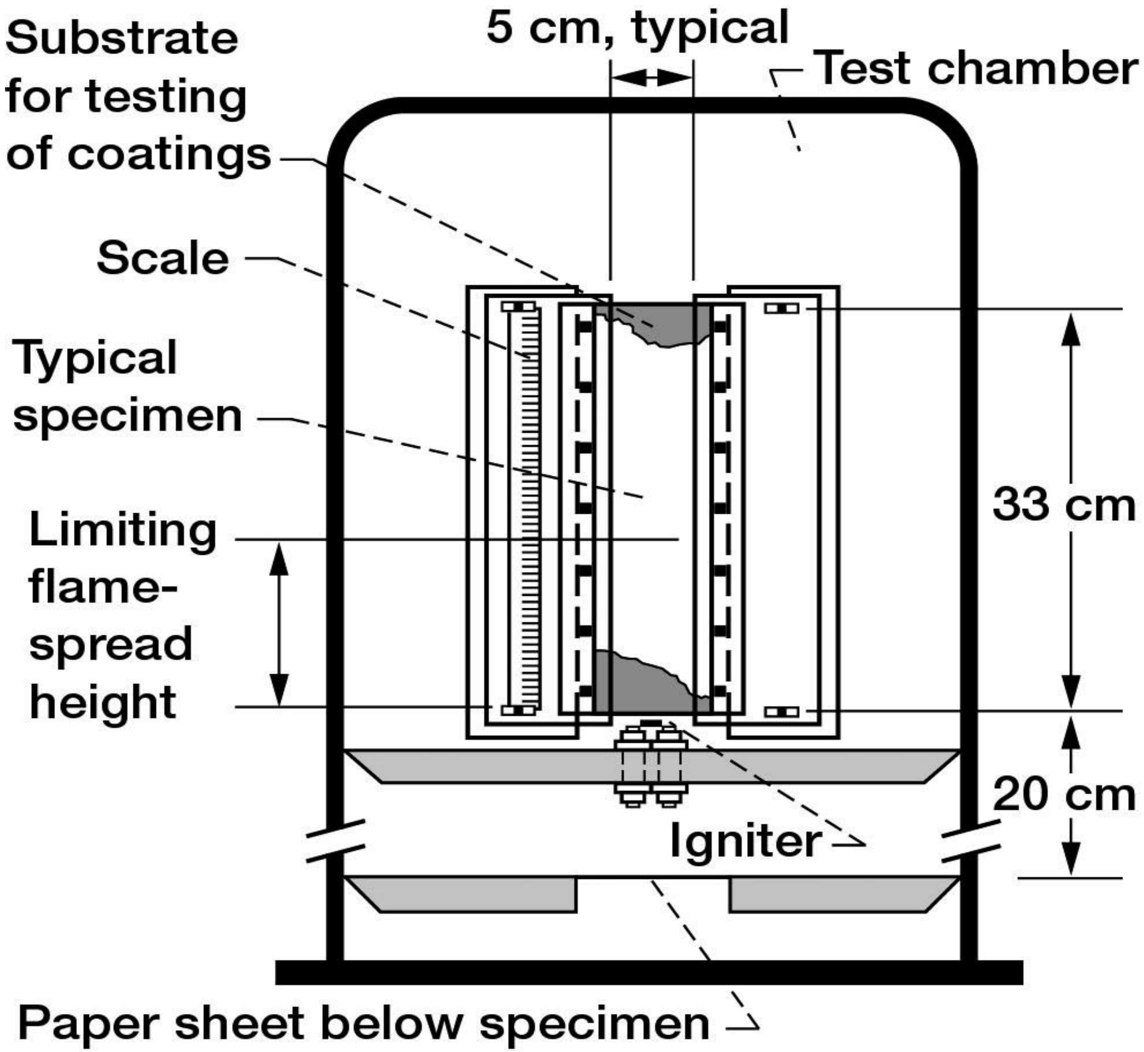
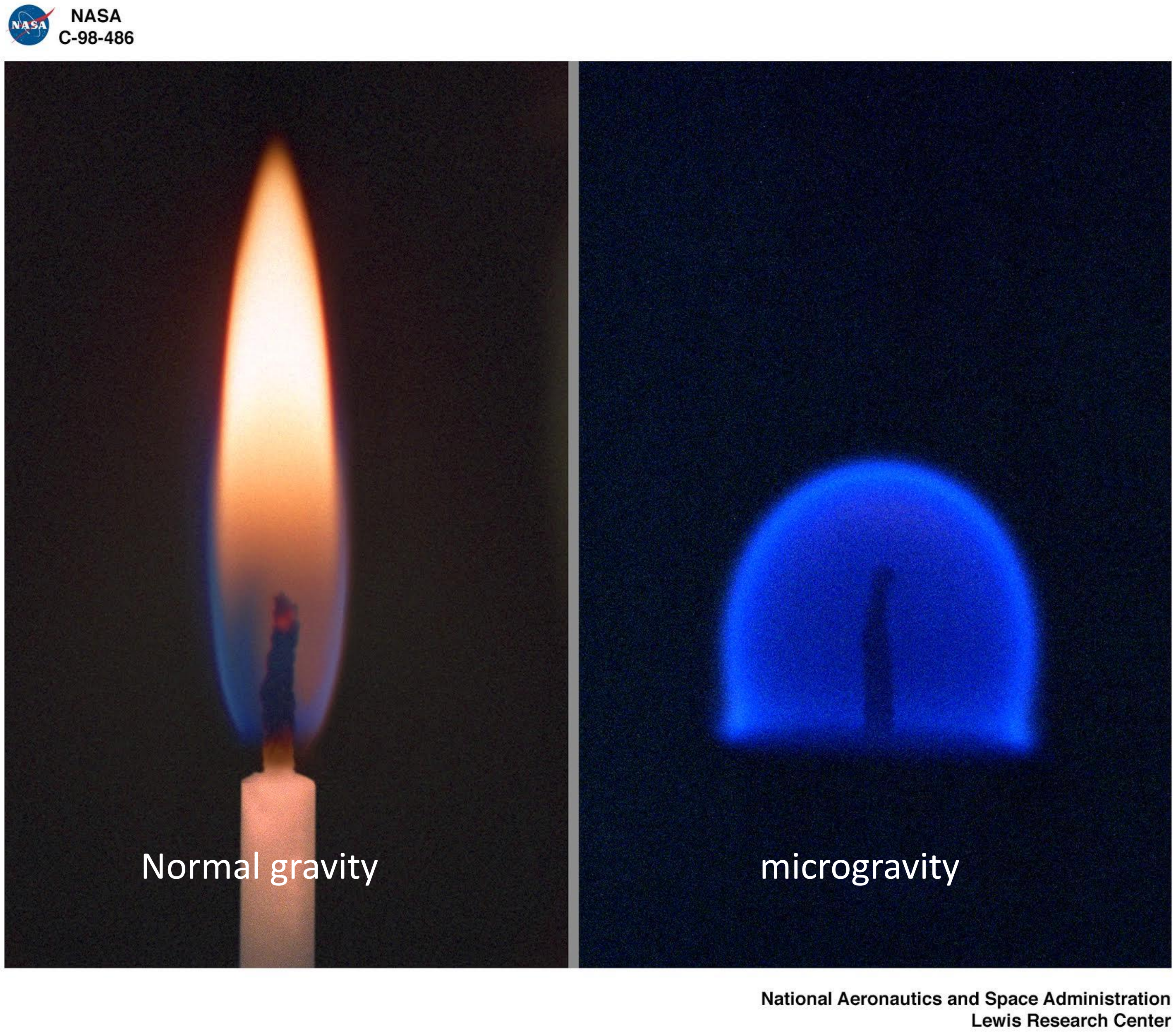


Figure 5.—Sketch of apparatus for NASA STD-6001 Test 1, upward flammability test.

Candle flames

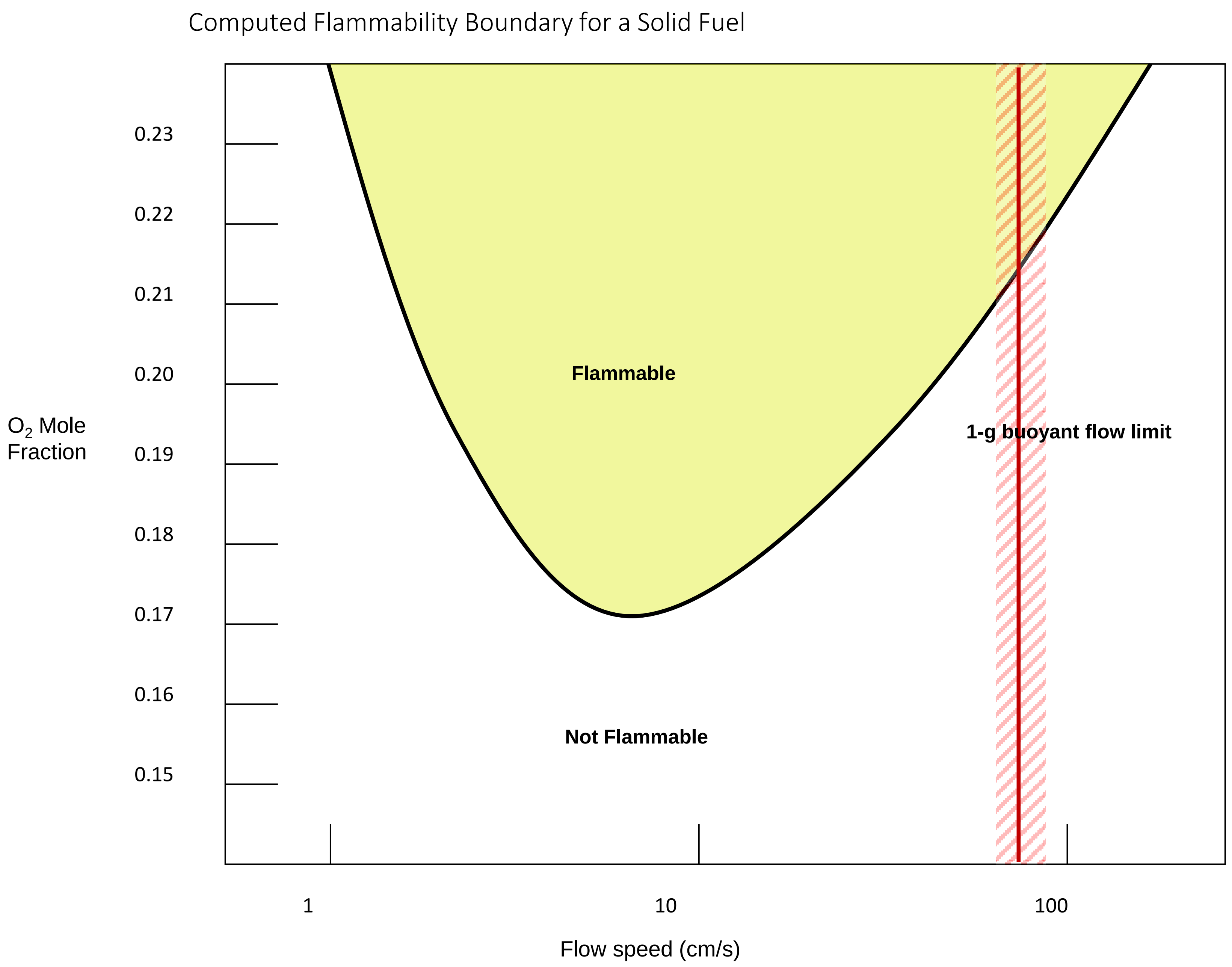
Big differences between flames in normal gravity and Quiescent microgravity atmosphere!



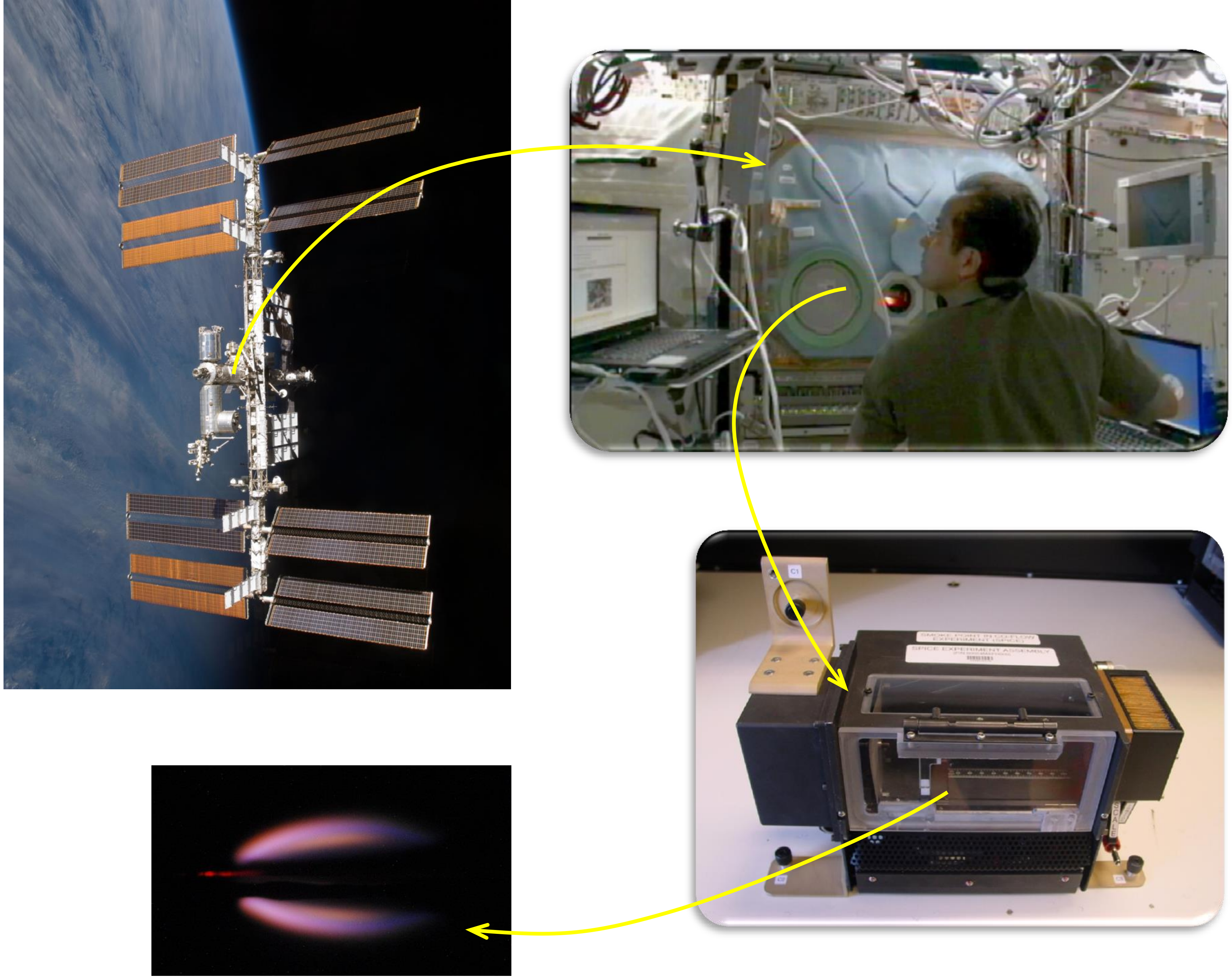
Drop tower experiment:
2-cm diameter plexi-glass sphere burning in 17% O_2 air

Buoyant + 2cm/s forced flows | 2cm/s forced flow | 2cm/s forced flow

- In manned spacecraft, there is a low-speed ventilating purely forced air flow (several cm/s up to several tens cm/s)
- By comparison, on earth, even without a wind, we have a buoyant flow due to gravity which can reach several m/s around a small flame.
- In general, flow velocity around the flame in normal gravity is larger than those in spacecraft.
- Different flow magnitude and flow pattern alter heat and mass transfer of oxygen and fuel vapor, burning rate, flame temperature, reaction kinetics, shape and color. Consequently, the total heat release rate and the flammability of materials can be different.
- To accurately predict the combustion behavior of materials in microgravity, we need to study the flame structure under low-speed forced flow.



Computed Flammability Boundary for a Solid Fuel
O2 Mole Fraction
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
Flammable
Not Flammable
1-g buoyant flow limit
1
10
100
Flow speed (cm/s)

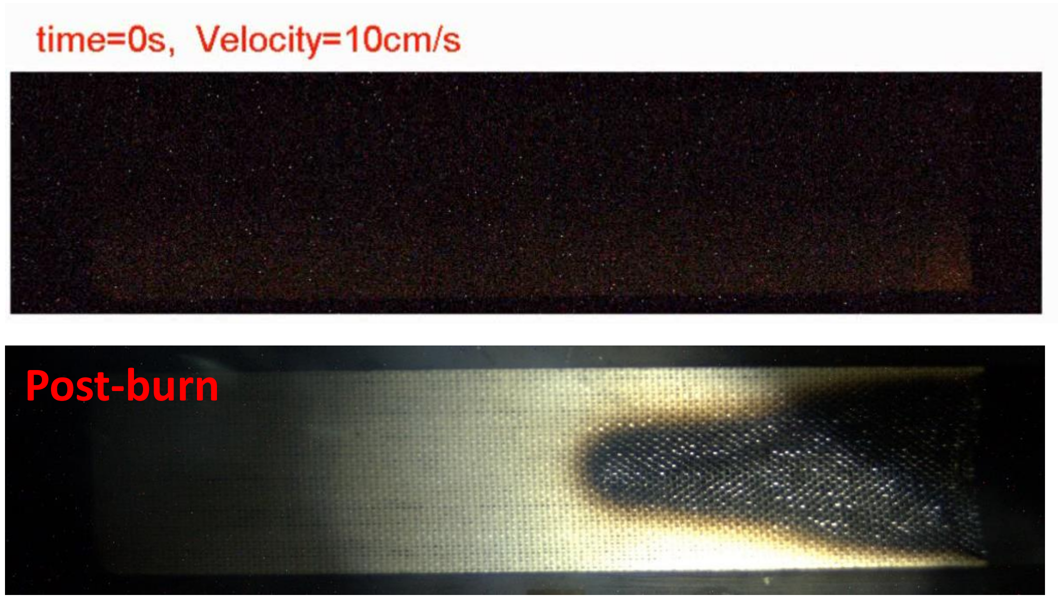

SPICE EXPERIMENT ASSEMBLY

ISS Glovebox 2015

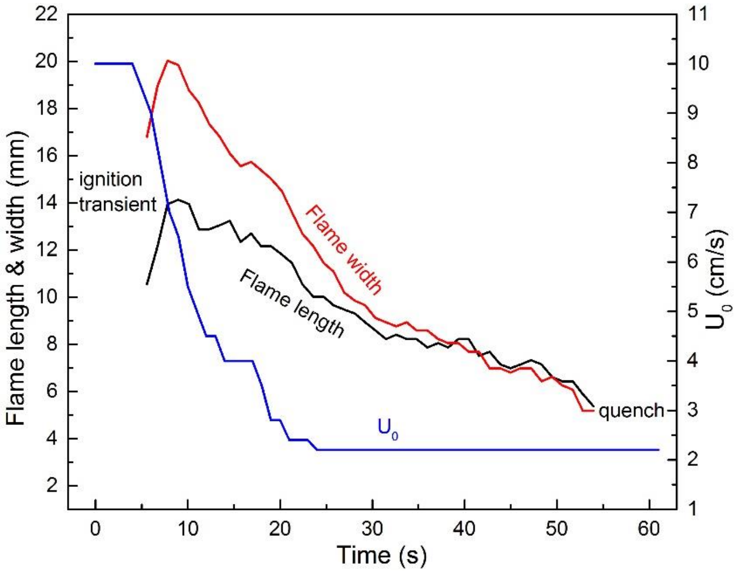
Quenching sequence:

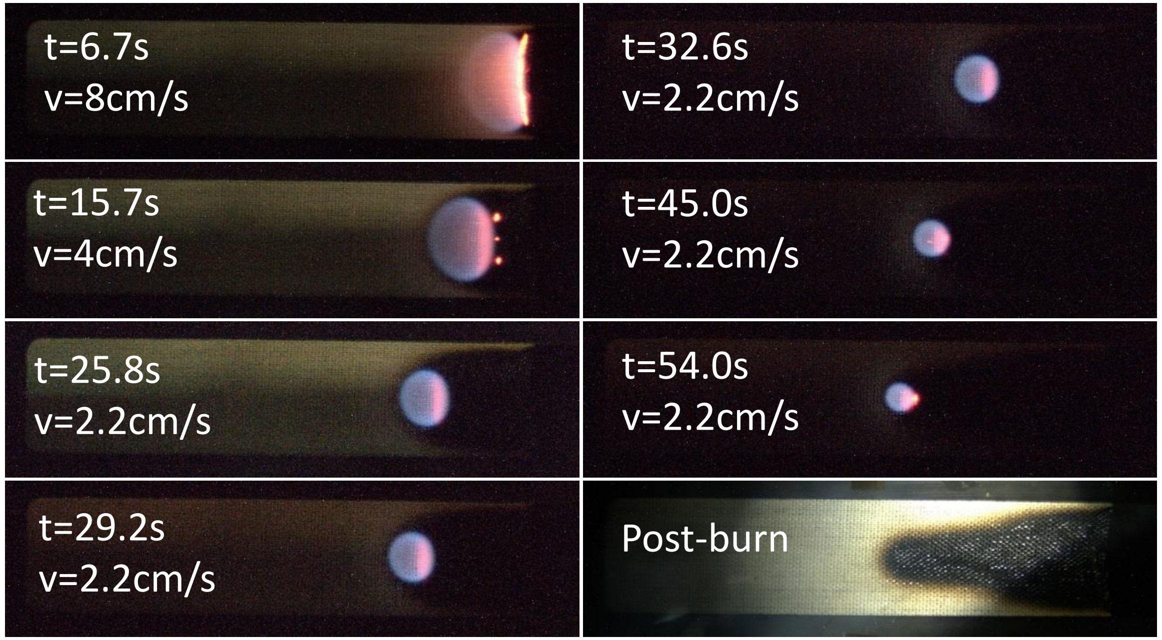
2.2cm SIBAL, 18.7% O2, Flow 10->2.2 cm/s

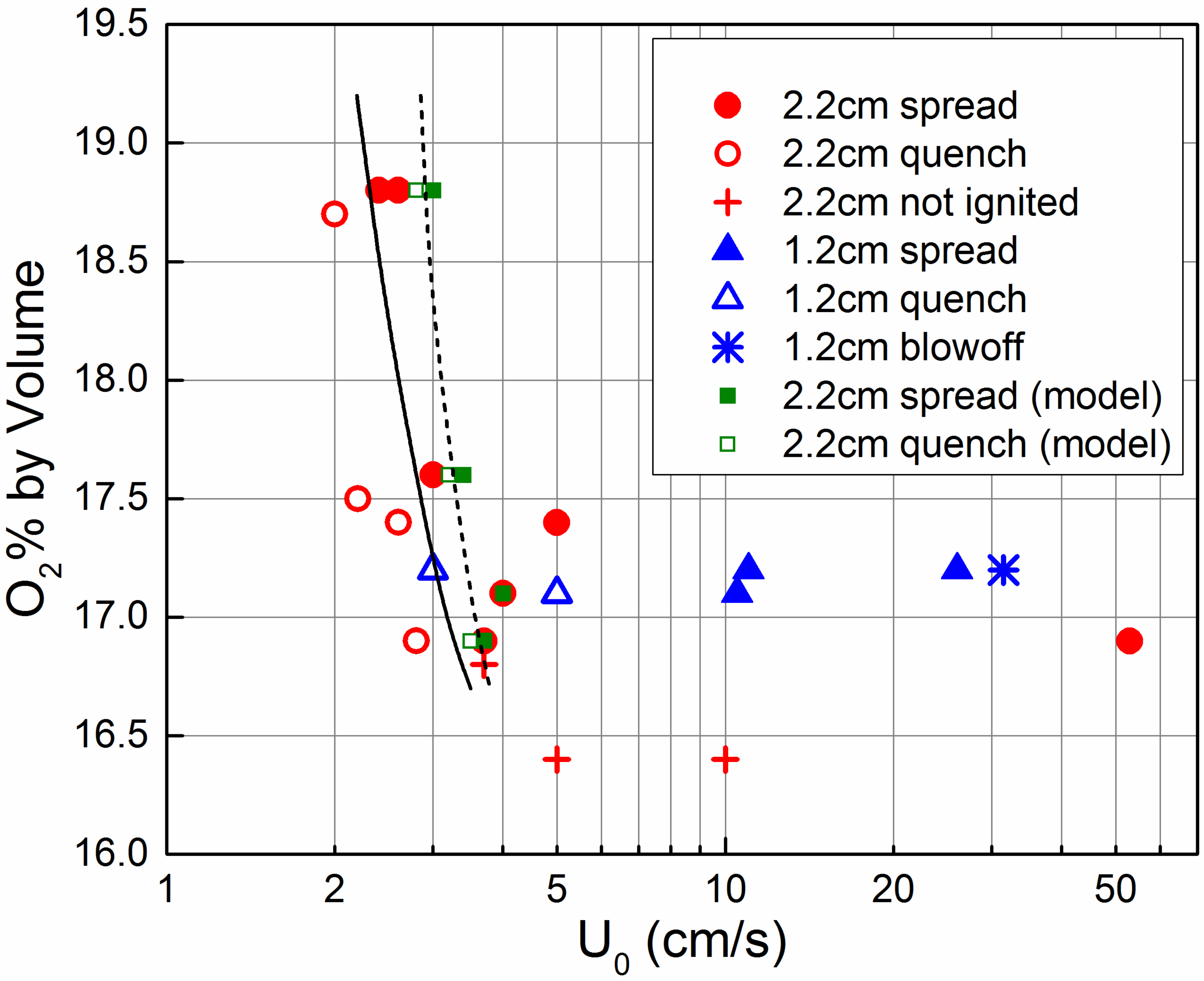
right: top image sequence
(2 x realtime)
time, velocity
Below left:
top flame tracking, forced vel.
Below right:
top image sequence



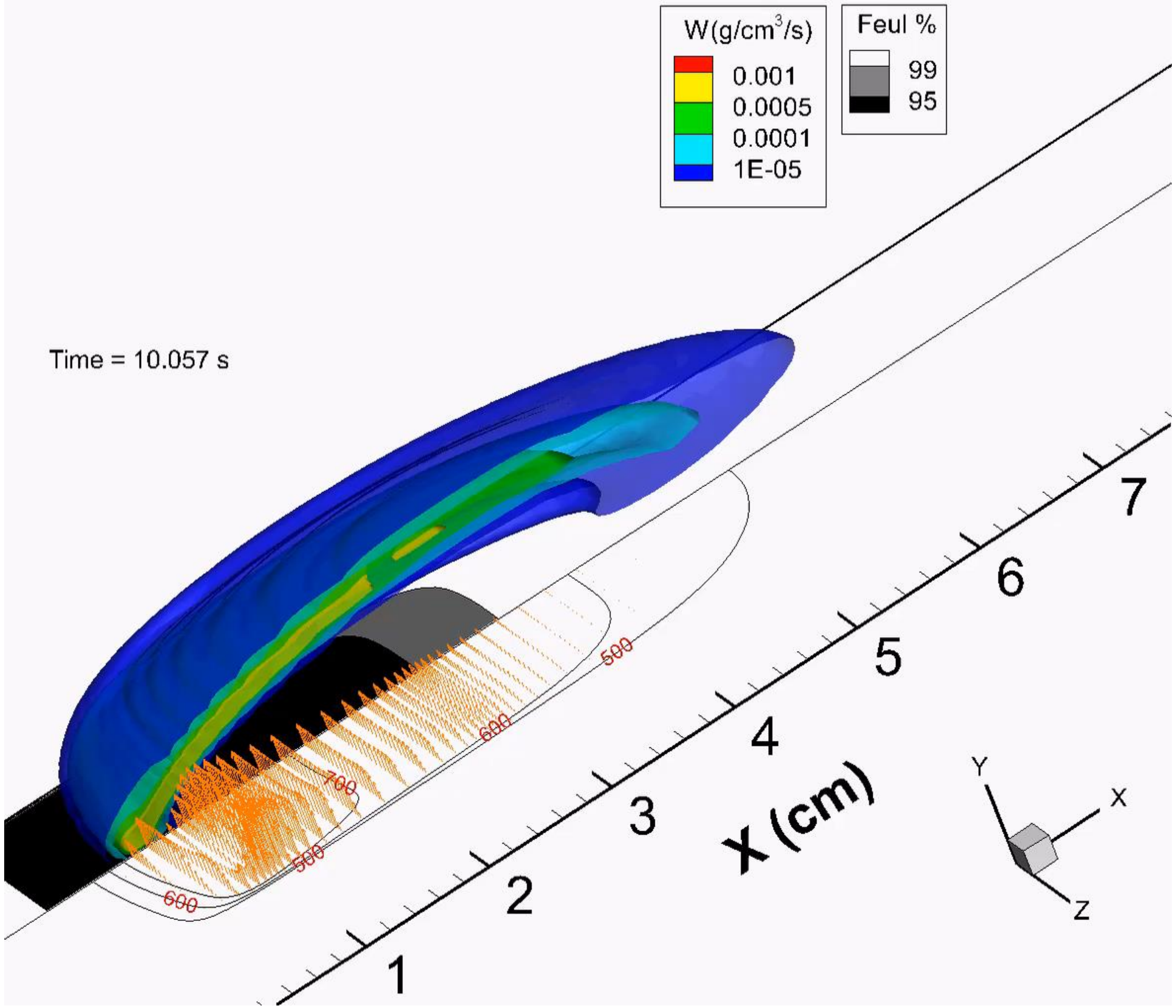
Flow





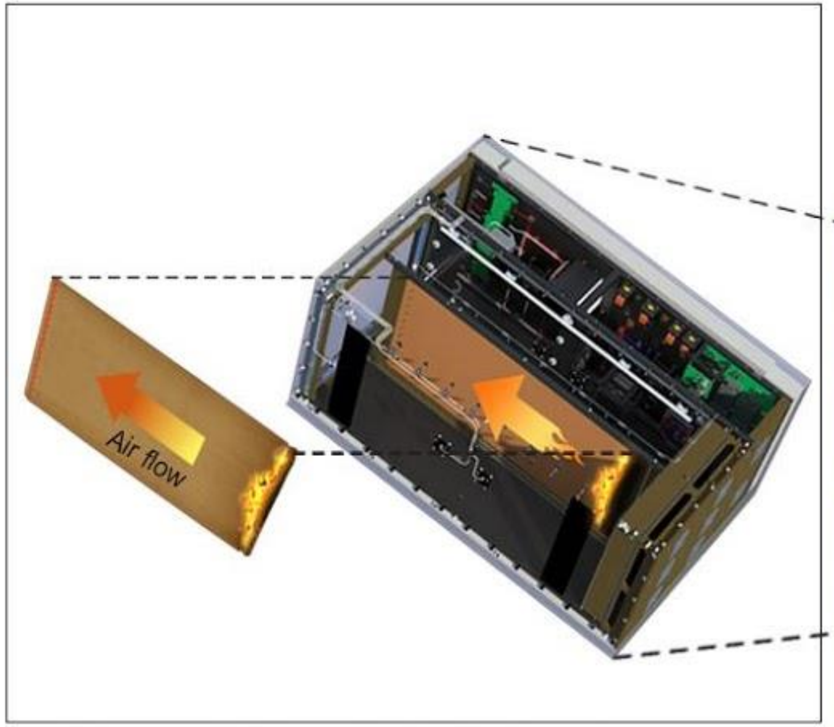


BASS Project
ISS Glovebox
2015

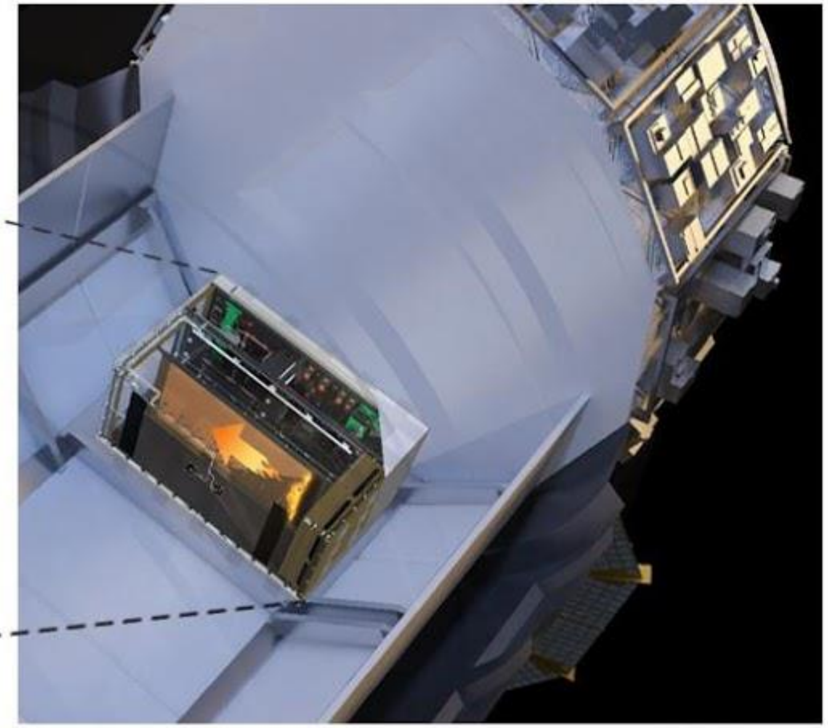

W(g/cm^3/s)
0.001
0.0005
0.0001
1E-05
Feul %
99
95
Time = 10.057 s
500
600
700
500
600
1
2
3
4
5
6
7
X (cm)
Y
X
Z

‘Large’ Scale fire experiment in automated transport vehicle (Saffire)

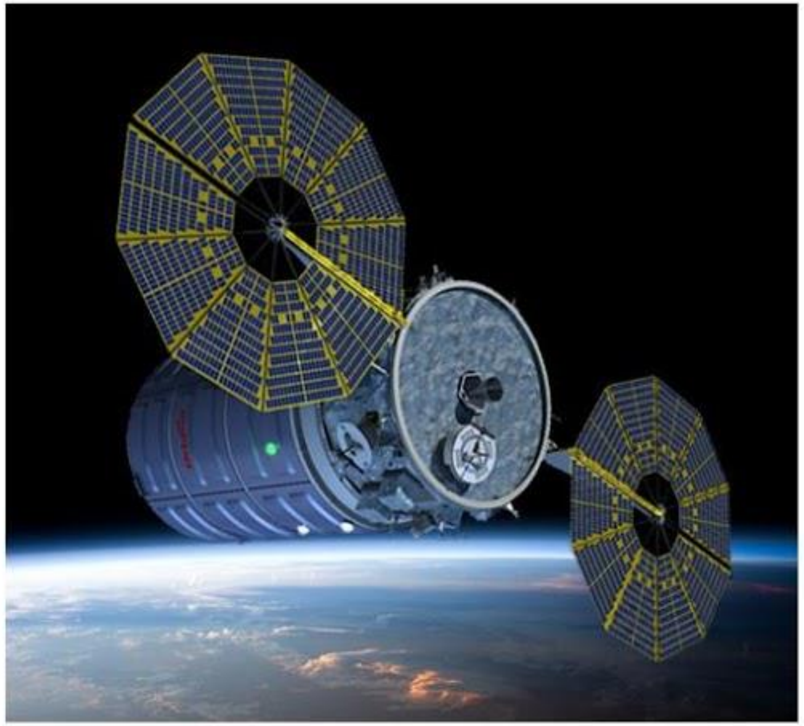
The **Saffire** flow duct is mounted in the Cygnus spacecraft. Within the flow duct, a large fabric sample is ignited. The first panel shows the flame shortly after ignition for the first test. For the second test, the igniter on the left of the sample (shown in red) is used to produce an opposed-flow flame, that is, one that spreads from left to right into the approaching flow.



Test sample inserted into hardware.

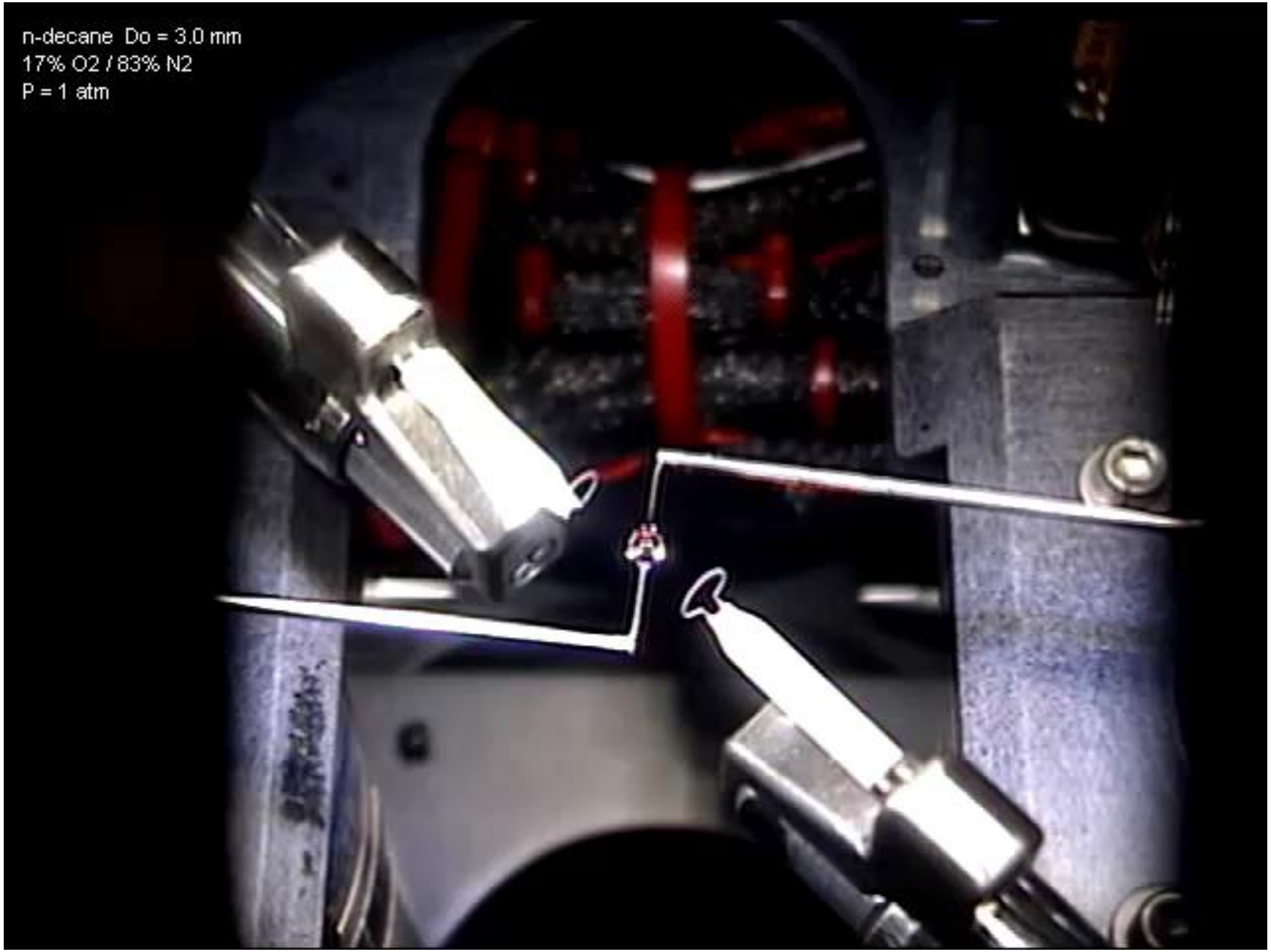


Hardware installed on Cygnus vehicle.



Cygnus vehicle with hardware installed.

Curtesy from Ferkul, Urban, Ruff and international team members


n-decane Do = 3.0 mm
17% O2 / 83% N2
P = 1 atm

Summary

- Space fire safety and combustion research is an enabler for safe human exploration in space

- Fundamental research is required to answer many questions in microgravity combustion

- Combined experimental and numerical modeling is the most fruitful approach

- Long duration experiments aboard ISS and other spacecraft provided valuable information on solid material combustion which is crucial to spacecraft fire safety

- Many unanswered questions remain. Little information on partial gravity combustion