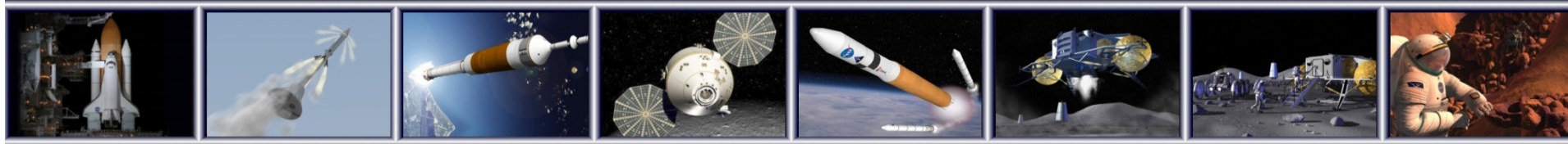


# **An approach to the flammability testing of aerospace materials**

**A compendium of presentations provided at  
International Conferences on Spacecraft  
Environmental Systems in Rome, Italy, 2008;  
Barcelona, Spain, 2010, and Portland, Oregon,  
USA 2011**

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NASA/Hokkaido Univ/JAXA Technical Interchange Meeting  
NASA WSTF  
Las Cruces, NM USA  
June 5, 2012



# Agenda



- Current approach to evaluation of spacecraft materials flammability
- The need for and the approach to alternative routes
- Examples of applications of the approach recommended
  - Crew Module splash down
  - Crew Module depressurization
  - Applicability of NASA's flammability test data to other sample configurations
  - Applicability of NASA's ground flammability test data to spacecraft environments



# Spacecraft fire safety



- General strategy: prevent fires
  - Materials control
  - Minimizing potential ignition sources and materials that can propagate a fire
  - Controlling the quantity and configuration of flammable materials to eliminate fire propagation paths



# Materials flammability test



- Major flammability test – NASA STD 6001 Test 1
- Upward flame propagation
- Conducted under worse expected spacecraft conditions – mostly in 30% oxygen at 10.2 psia
- Pass/fail test logic
- Current data usage
- Epistemic uncertainty related to data usage: data applicability issues



# Probabilistic uncertainties with attribute-type data



- Uncertainties associated with attribute (pass/fail) data: Binomial cumulative probability  $P$  of  $k$  samples failing in  $n$  tests for a material with a  $p$  failure probability

| Probability of at least one sample failing under a set of conditions (%) | Probability of no failures observed in $n$ tests under the same conditions (%) |    |    |    |
|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|----|----|----|
|                                                                          | $n = 3$                                                                        | 5  | 10 | 20 |
| 10                                                                       | 73                                                                             | 59 | 35 | 12 |
| 5                                                                        | 86                                                                             | 77 | 60 | 36 |
| 1                                                                        | 97                                                                             | 95 | 90 | 82 |





# Alternative route to the pass/fail approach



- To address the systemic uncertainty associated with the ground test-spacecraft environment flammability correlation, evaluation of flammability threshold has been investigated
- NASA recognized the merits of the flammability threshold approach (JSC-63309, Recommendations for Exploration Spacecraft Internal Atmospheres, 2006; ...this information will allow NASA to identify materials with increased flammability risk from oxygen concentration and total pressure changes, minimize potential impact, and allow for development of sound requirements for new spacecraft and extravehicular landers and habitats...)
- International Technical Specification ISO 16697 was drafted in 2010 and approved by the 14 aerospace countries of the TC20, SC 14 on Space Systems and Operations based on an earlier approach suggested by WSTF (J. Testing and Evaluation, Vol. 30, March 2002)



# General approach



- Determine the self-extinguishment oxygen concentration limits at constant pressures following NASA STD 6001 Test 1 (or Test 4)
- Experimental approach consists of concentrating the testing in the flammability transition zone following the Bruceton Up-and-Down method. For attribute data the method has been shown to be very repeatable and most efficient . Other methods for characterizing of critical levels (Karber and Probit) were also considered



## Approach (continued)



- Bruceton is from 30 to 50% more efficient than Probit for the same accuracy
- The method is widely used for determining the limiting oxygen index as defined and accepted by the combustion community
- Conduct a number of tests  $N$  at the highest oxygen concentration at which the material passes (MOC) (the material would fail in an environment with 1% oxygen higher)





## Examples of applications: 1. Crew Module splash down



- Crew Module splash down on re-entry: humid air getting in and damaging components
- Need to maximize the time the crew is able to breathe cabin air before the snorkel is activated
- It is considered to raise the partial pressure of oxygen in the CM immediately before reentry while maintaining the total cabin pressure at 14.7 psia



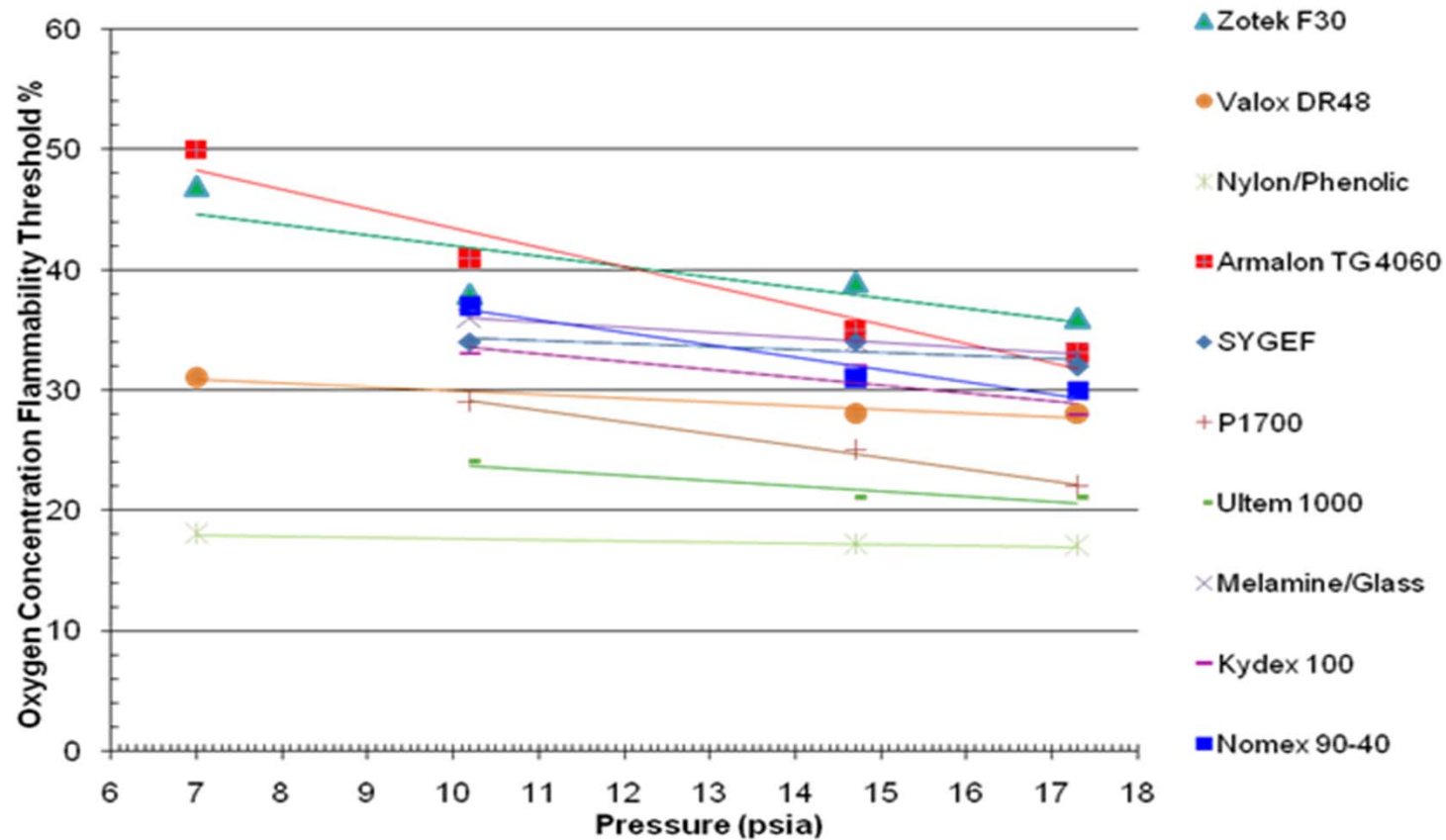
## Applications: 1. Crew Module splash down



- Large data base with pass/fail logic in 30% oxygen, 10.2 psia
- What is the maximum oxygen concentration at 14.7 psia where materials certified in 30% oxygen at 10.2 psia would still be self-extinguishing?
- Orion CM was planned to be leak tested using ambient air at 17.3 psia. Would materials certified in 30% oxygen at 10.2 psia be still non-flammable under these conditions?



# Applications: 1. Crew Module splash down



## Applications: 2. Crew Module depressurization



- Leak rate design of CM ECLSS
- Scenario for Crew Module (CM) depressurization
- Issue: Flammability in low-pressure oxygen of materials qualified in 30% oxygen at 10.2 psia





# Applications: 2. Crew Module depressurization



- Self-extinguishment total pressure limits were determined in oxygen following NASA STD 6001 Test 1
- The data yielded the upward limiting pressure index (ULPI), the pressure level where approximately 50% of materials self-extinguish in a given environment (ULPI is the pressure equivalent for ULOI)
- Furthermore, we conducted a number of tests N at the highest total pressure the material passes (MTP) (the material would fail in an environment with 0.1 psia higher) to determine the maximum total pressure (MTP) - defined as the maximum total pressure where all samples tested (at least five) self-extinguish following the NASA STD 6001 failure criteria (Note that MTP is the pressure equivalent for MOC)



## Applications: 2. Crew Module depressurization



| Material        | ULPI | MTP | ULOI | MOC |
|-----------------|------|-----|------|-----|
| Epoxy/glass     | 0.9  | 0.8 | 28.6 | 24  |
| Udel P1700      | 1.0  | 0.9 | 31.7 | 29  |
| Kydex 100       | 1.8  | 0.6 | 33.5 | 32  |
| Solimide TA-301 | 0.7  | 0.5 | 29.3 | 28  |
| Melinex 515     | 0.9  | 0.4 | 21.2 | 20  |
| Nomex HT90-40   | 0.6  | 0.5 | 28.5 | 25  |
| Ultram 1000     | 1.5  | 0.9 | 26.5 | 24  |



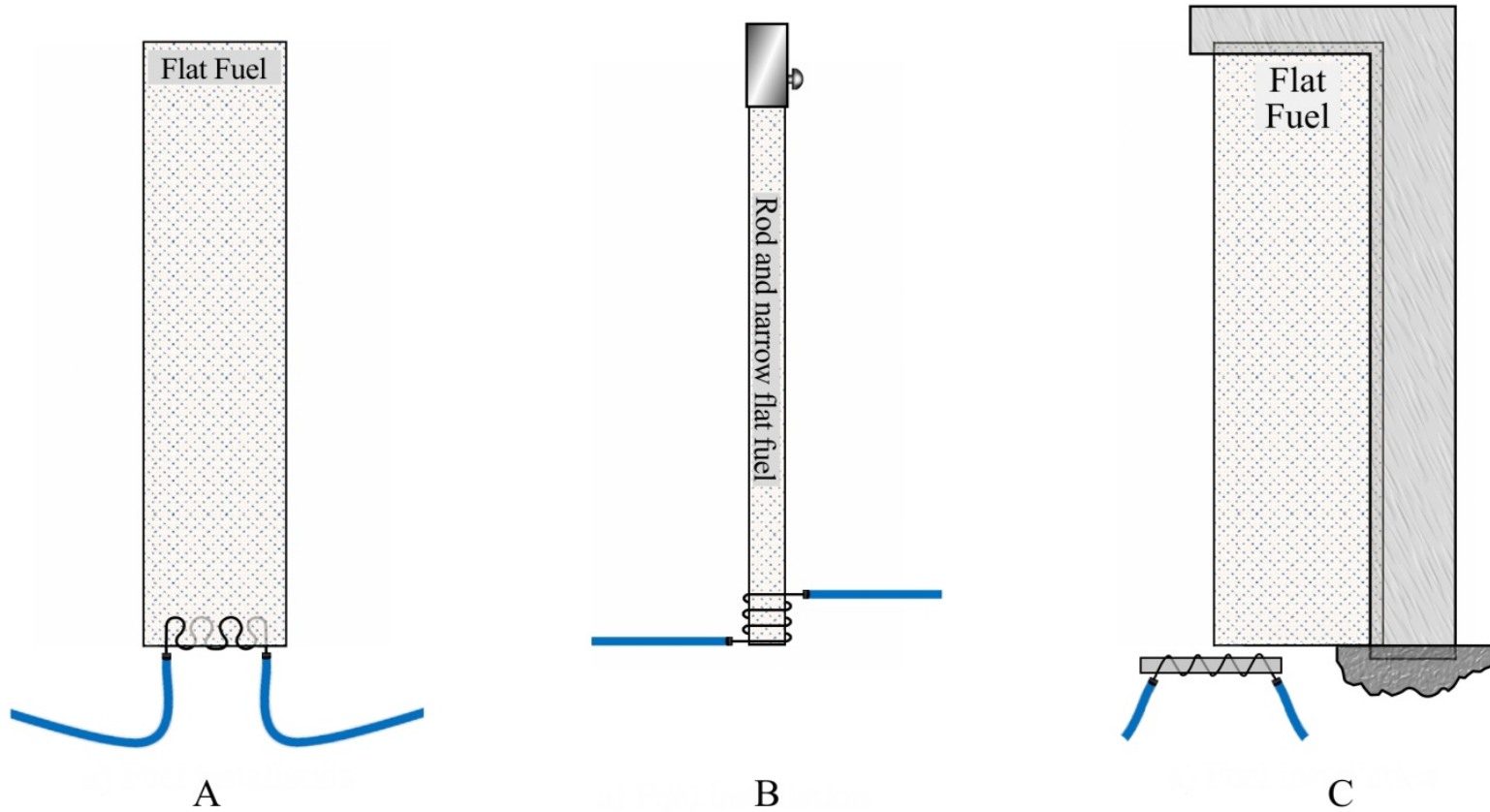
## Applications: 3. Applicability of NASA's ground test data to other configurations



- The approach suggested to the flammability test logic allows evaluation of the applicability of NASA's ground testing to other conditions or configurations
  - Material thickness
  - Mode of ignition
  - Sample geometry
  - Exposed edges vs. standard sample mounting
  - Pass/fail criteria.



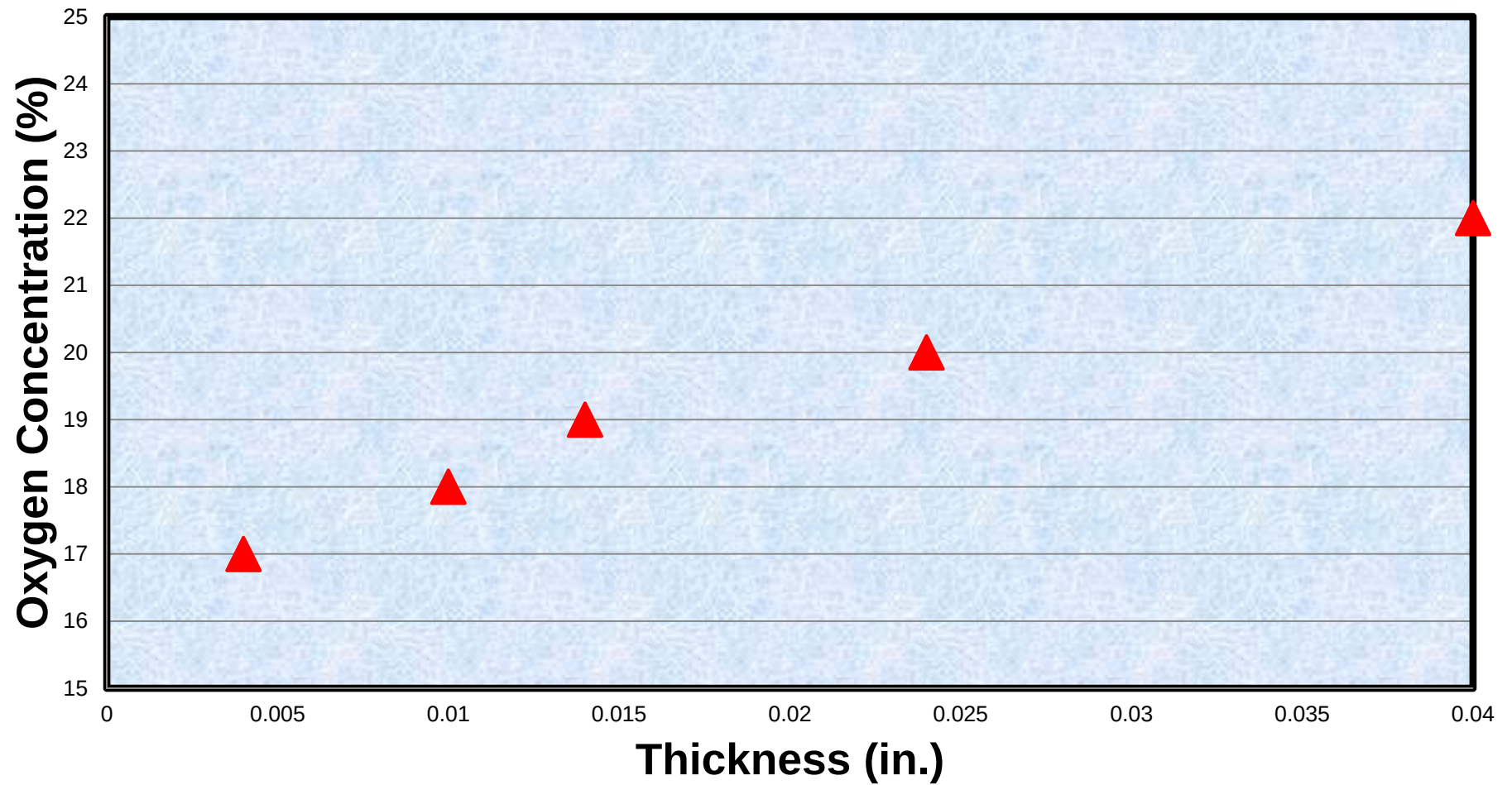
# Sample Mounting







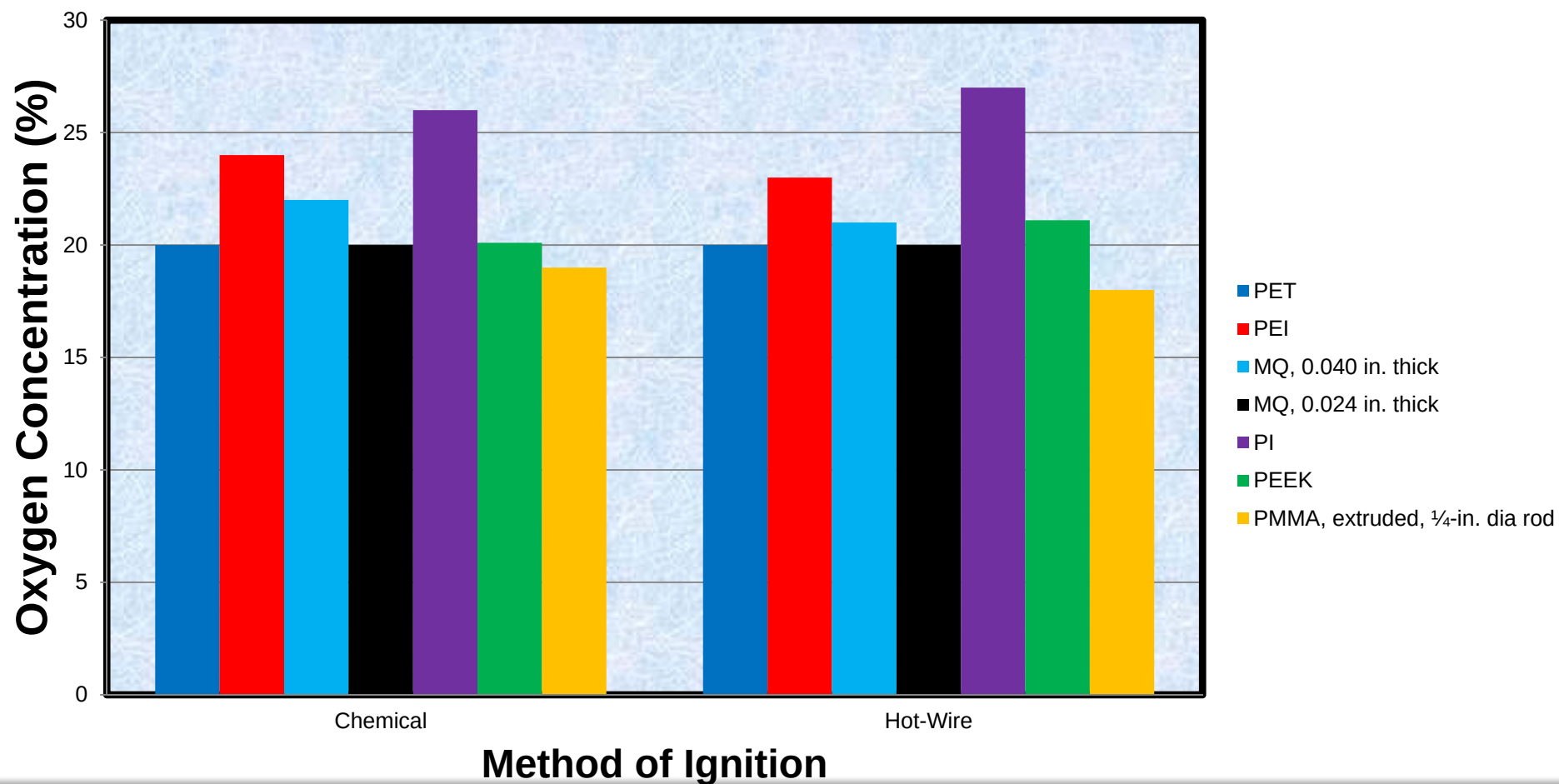
# MQ Thickness/MOC





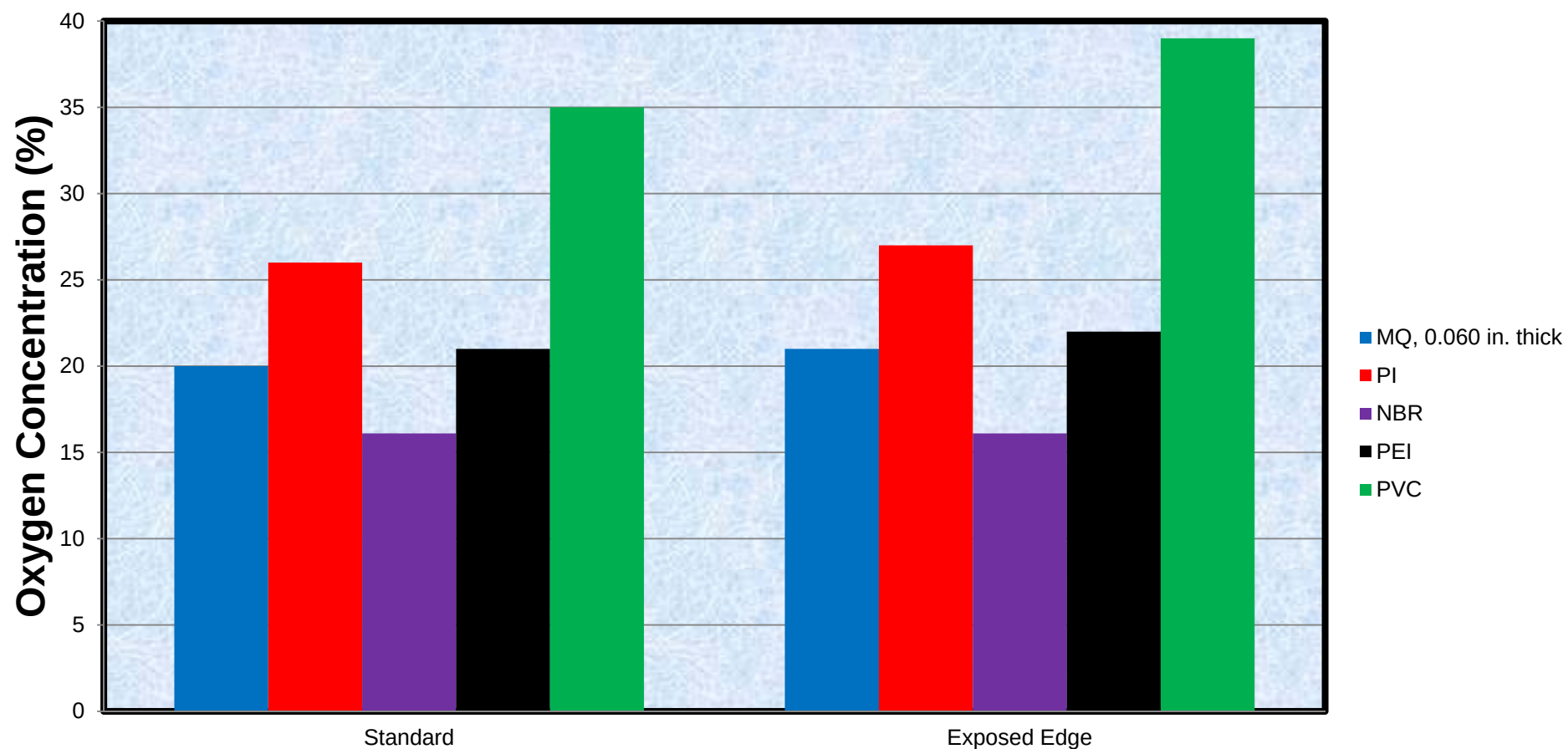


# Chemical Igniter v. Hot Wire





## Standard v. Exposed Edge

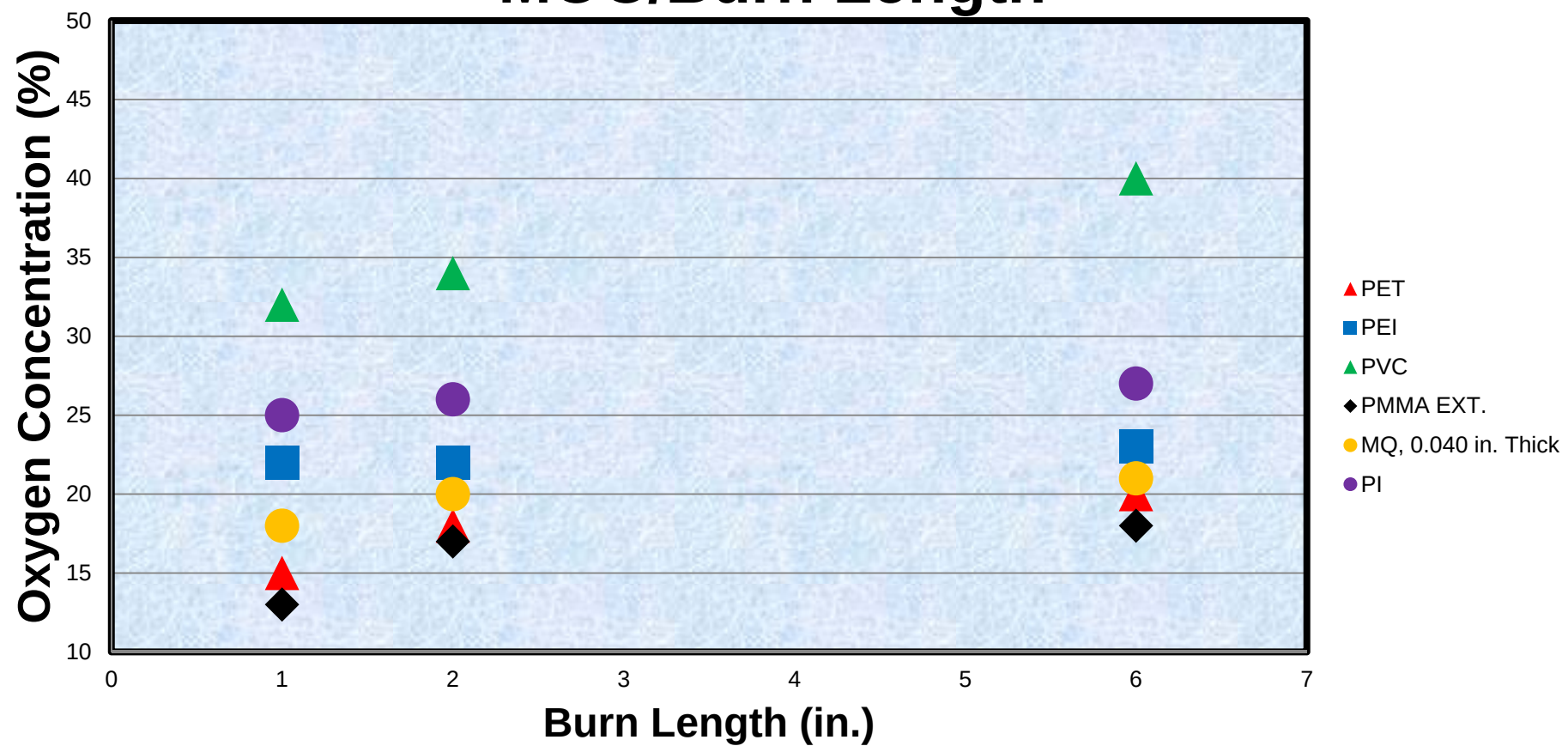


## Sample Configuration





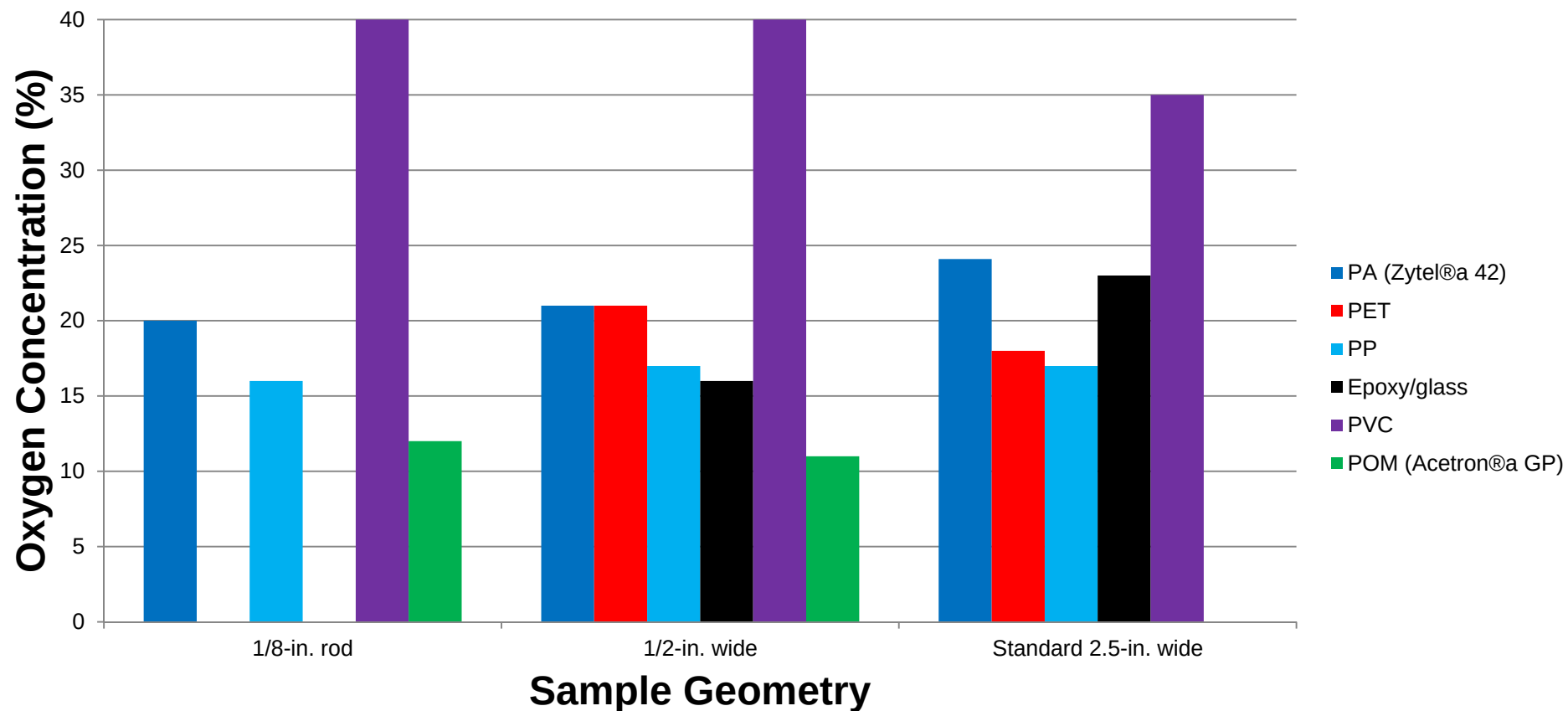
## MOC/Burn Length





# Sample Geometry/MOC

Hot-Wire Ignition



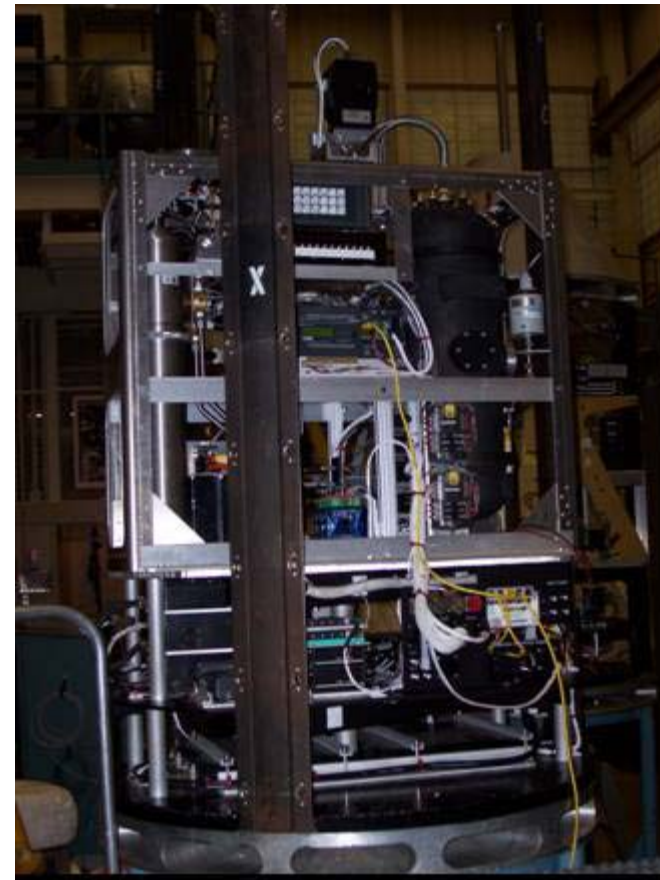


# Applications: 4. Correlation of ground test data with spacecraft environments

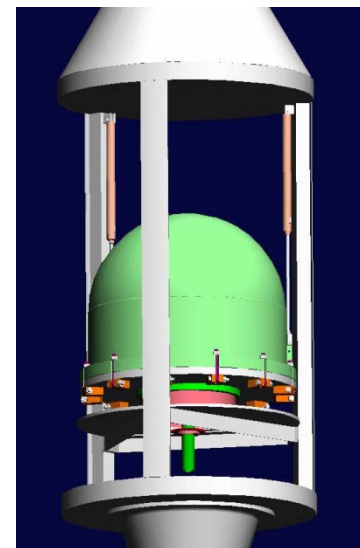
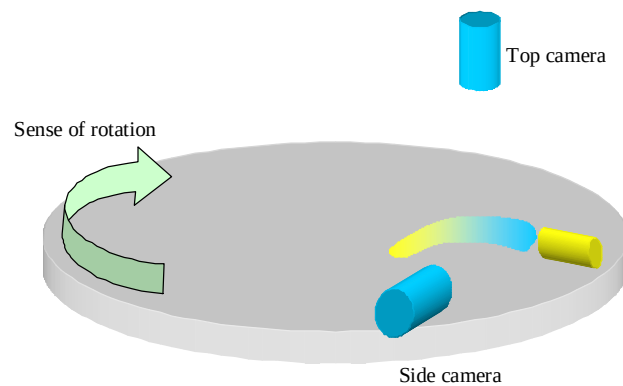


NASA Glenn Research Center microgravity wind tunnel capabilities:

- Flow velocities: 0 to 30 cm/s
- Total pressure: 0 to 14.7 psia
- Oxygen concentration: 0 to 100%



# Partial gravity centrifuge installed in the NASA GRC Zero Gravity Facility drop bus



# Applications: 4. Correlation of ground test data with spacecraft environments

