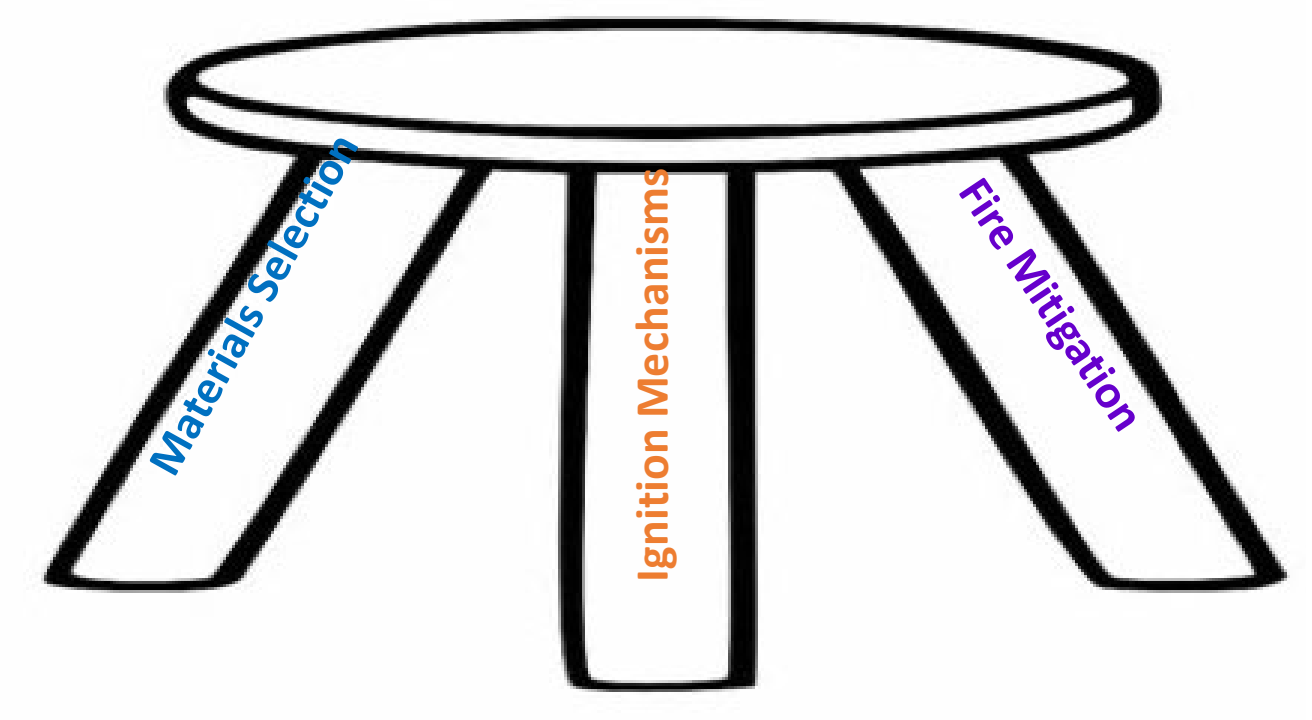
A Refined Mechanical Impact (G86) Test and Data Analysis Strategy for Composites LOX Compatibility Evaluation

Susana A. Harper, Alfredo Juarez, Roberto Robles, Brenton Woods

NASA Fire Safety Approach

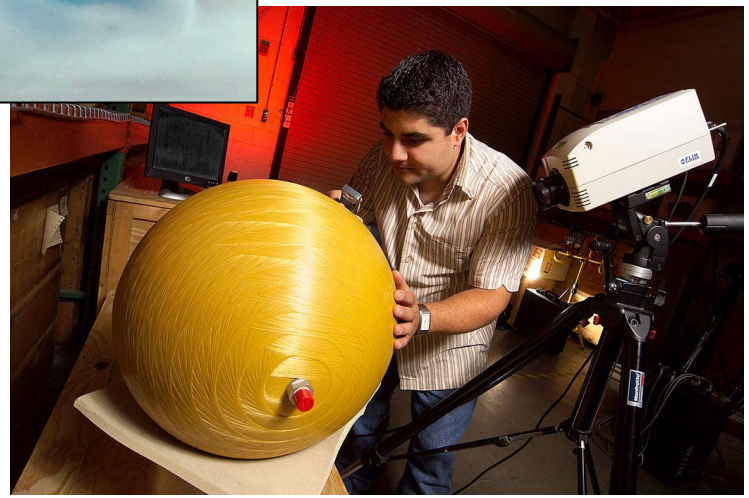
- Three-legged approach provides a robust spacecraft fire safety management plan in which **misses or weaknesses on one leg are compensated for on others**, safeguarding against an overall system failure.
- Each leg is intended to be fully independent and **should not be waived based on the execution of other legs**.



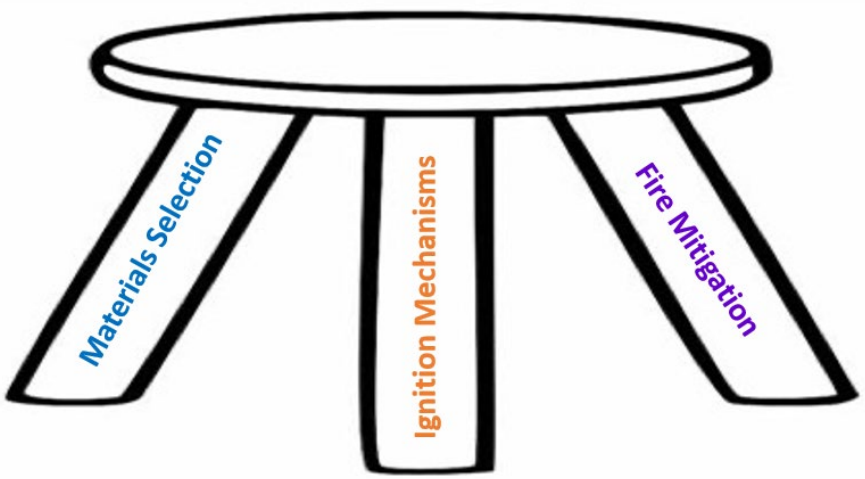
The Composites Challenge

- Composites are often used with liquid oxygen
  - Requiring ASTM G86 Testing
  - One of few LOX compatibility tests available
- ASTM G86-17, requirements for acceptability
  - No reactions/20 impacts @ 98-J (72 ft-lbf) or,
  - Max 1 reaction / 60 impacts @98 J (72 ft-lbf)
- Reactions defined as
  - Audible Report
  - Observable Flash
  - Charr/Scorch
- **Standard ASTM G86-17 LOX Mechanical Impact acceptance criteria does not discriminate between highly and mildly reactive composites.**





Materials Selection?







Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance (ASTM MNL 36)

"Though it is understood that it is not always possible to use materials that do not ignite under operating condition, it is generally understood that the ***most ignition-resistant materials are preferred for any design.***"

Re-examining Acceptance Criteria

- When a composite must be used, it is important to select the **least reactive options.**
- Examine historical data.
- **Audible reports & flashes observed to be most indicative of energetic material response.**
- Evaluated data obtained with use of Rebound Catcher (STP1596-2015-0087)

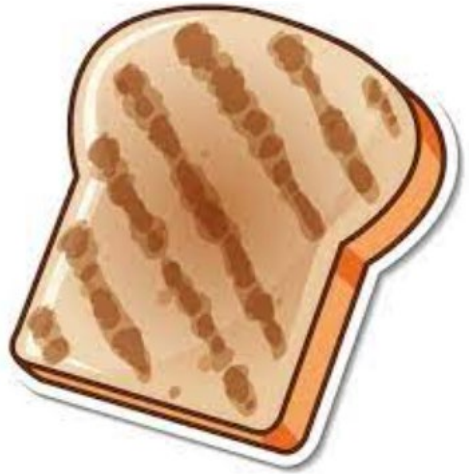
Audible Reports



Observable Flashes



Scorch/Charr



Review of Historical Reactivity Data







- Data from 19 composite tests evaluated.
- Not all composites fail in the same manner.
- **Audible reports & flashes observed to be most indicative of energetic material response.**

#	Material Type	Rebound Catcher Used	Audible Report Lowest Energy Detected		Flash Lowest Energy Detected		Charr/Scorch Lowest Energy Detected	
			J	Ft-lbs	J	Ft-lbs	J	Ft-lbs
1	Composite	Yes	None at 98	None at 72	98	72	98	72
2	Composite	Yes	None at 98	None at 72	None at 98	None at 72	64.5	47.6
3	Composite	Yes	None at 98	None at 72	98	72	27.1	20
4	Composite	Yes	None at 98	None at 72	98	72	20.3	15
5	Composite	Yes	None at 98	None at 72	85.3	62.9	85.3	62.9
6	Composite	Yes	None at 98	None at 72	48.7	35.9	48.7	35.9
7	Composite	Yes	None at 98	None at 72	47.5	35	33.9	25
8	Composite	Yes	None at 98	None at 72	47.5	35	27.1	20
9	Composite	Yes	None at 98	None at 72	36.9	27.2	36.9	27.2
10	Synthetic Polymer	Yes	98	72	64.5	47.6	64.5	47.6
11	Composite	Yes	85.3	62.9	74	54.6	74	54.6
12	Composite	Yes	74	54.6	55.5	40.9	55.5	40.9
13	Composite	Yes	36.9	27.2	36.9	27.2	36.9	27.2
14	Composite	Yes	36.9	27.2	24.3	17.9	24.3	17.9
15	Composite	Yes	27.8	20.5	24.3	17.9	24.3	17.9
16	Composite	Yes	24.3	17.9	24.3	17.9	24.3	17.9
17	Composite	Yes	21	15.5	21	15.5	21	15.5
18	Composite	Yes	27.8	20.5	13.6	10	13.6	10
19	Composite	Yes	18.3	13.5	13.8	10.2	13.8	10.2

Proposed Guidelines - Mildly Reactive

Discriminate between highly and mildly reactive composites/materials.

- **Mildly Reactive**
  - **No audible reports at 72 ft-lbs or below**
  - **No observable flashes at 65 ft-lbs or below**
- Charring/scorching commonly observed for even least reactive composites down to lowest energy levels. Not used as a selection driver.

#	Material Type	Rebound Catcher Used	Audible Report Lowest Energy Detected		Flash Lowest Energy Detected		Charr/ Scorch Lowest Energy Detected	
			J	Ft-lbs	J	Ft-lbs	J	Ft-lbs
1	Composite	Yes	None at 98	None at 72	98	72	98	72
2	Composite	Yes	None at 98	None at 72	None at 98	None at 72	64.5	47.6
3	Composite	Yes	None at 98	None at 72	98	72	27.1	20
4	Composite	Yes	None at 98	None at 72	98	72	20.3	15
5	Composite	Yes	None at 98	None at 72	85.3	62.9	85.3	62.9
6	Composite	Yes	None at 98	None at 72	48.7	35.9	48.7	35.9
7	Composite	Yes	None at 98	None at 72	47.5	35	33.9	25
8	Composite	Yes	None at 98	None at 72	47.5	35	27.1	20
9	Composite	Yes	None at 98	None at 72	36.9	27.2	36.9	27.2
10	Synthetic Polymer	Yes	98	72	64.5	47.6	64.5	47.6
11	Composite	Yes	85.3	62.9	74	54.6	74	54.6
12	Composite	Yes	74	54.6	55.5	40.9	55.5	40.9
13	Composite	Yes	36.9	27.2	36.9	27.2	36.9	27.2
14	Composite	Yes	36.9	27.2	24.3	17.9	24.3	17.9
15	Composite	Yes	27.8	20.5	24.3	17.9	24.3	17.9
16	Composite	Yes	24.3	17.9	24.3	17.9	24.3	17.9
17	Composite	Yes	21	15.5	21	15.5	21	15.5
18	Composite	Yes	27.8	20.5	13.6	10	13.6	10
19	Composite	Yes	18.3	13.5	13.8	10.2	13.8	10.2

Proposed Guidelines - Moderately Reactive

Discriminate between highly and mildly reactive composites/materials.

- **Moderately Reactive**
  - **No audible reports at 65 ft-lbs or below**
  - **No observable flashes at 30 ft-lbs or below**
- Charring/scorching commonly observed for even least reactive composites down to lowest energy levels. Not used as a selection driver.

#	Material Type	Rebound Catcher Used	Audible Report Lowest Energy Detected		Flash Lowest Energy Detected		Charr/ Scorch Lowest Energy Detected	
			J	Ft-lbs	J	Ft-lbs	J	Ft-lbs
1	Composite	Yes	None at 98	None at 72	98	72	98	72
2	Composite	Yes	None at 98	None at 72	None at 98	None at 72	64.5	47.6
3	Composite	Yes	None at 98	None at 72	98	72	27.1	20
4	Composite	Yes	None at 98	None at 72	98	72	20.3	15
5	Composite	Yes	None at 98	None at 72	85.3	62.9	85.3	62.9
6	Composite	Yes	None at 98	None at 72	48.7	35.9	48.7	35.9
7	Composite	Yes	None at 98	None at 72	47.5	35	33.9	25
8	Composite	Yes	None at 98	None at 72	47.5	35	27.1	20
9	Composite	Yes	None at 98	None at 72	36.9	27.2	36.9	27.2
10	Synthetic Polymer	Yes	98	72	64.5	47.6	64.5	47.6
11	Composite	Yes	85.3	62.9	74	54.6	74	54.6
12	Composite	Yes	74	54.6	55.5	40.9	55.5	40.9
13	Composite	Yes	36.9	27.2	36.9	27.2	36.9	27.2
14	Composite	Yes	36.9	27.2	24.3	17.9	24.3	17.9
15	Composite	Yes	27.8	20.5	24.3	17.9	24.3	17.9
16	Composite	Yes	24.3	17.9	24.3	17.9	24.3	17.9
17	Composite	Yes	21	15.5	21	15.5	21	15.5
18	Composite	Yes	27.8	20.5	13.6	10	13.6	10
19	Composite	Yes	18.3	13.5	13.8	10.2	13.8	10.2

Proposed Guidelines - Highly Reactive

Discriminate between highly and mildly reactive composites/materials.

- **Highly Reactive**
  - **Audible reports at or below 65ft lbs**
  - **Observable flashes at or below 30ft lbs**
- Charring/scorching commonly observed for even least reactive composites down to lowest energy levels. Not used as a selection driver.

WSTF #	#	Material Type	Rebound Catcher Used	Audible Report Lowest Energy Detected		Flash Lowest Energy Detected		Charr/ Scorch Lowest Energy Detected	
				J	Ft-lbs	J	Ft-lbs	J	Ft-lbs
92-26543	1	Composite	Yes	None at 98	None at 72	98	72	98	72
92-26548	2	Composite	Yes	None at 98	None at 72	None at 98	None at 72	64.5	47.6
23-48385	3	Composite	Yes	None at 98	None at 72	98	72	27.1	20
23-48383	4	Composite	Yes	None at 98	None at 72	98	72	20.3	15
92-26555	5	Composite	Yes	None at 98	None at 72	85.3	62.9	85.3	62.9
92-26547	6	Composite	Yes	None at 98	None at 72	48.7	35.9	48.7	35.9
23-48386	7	Composite	Yes	None at 98	None at 72	47.5	35	33.9	25
23-48384	8	Composite	Yes	None at 98	None at 72	47.5	35	27.1	20
92-26556	9	Composite	Yes	None at 98	None at 72	36.9	27.2	36.9	27.2
6001 FY23	10	Synthetic Polymer	Yes	98	72	64.5	47.6	64.5	47.6
92-26544	11	Composite	Yes	85.3	62.9	74	54.6	74	54.6
92-26546	12	Composite	Yes	74	54.6	55.5	40.9	55.5	40.9
92-26550	13	Composite	Yes	36.9	27.2	36.9	27.2	36.9	27.2
92-26551	14	Composite	Yes	36.9	27.2	24.3	17.9	24.3	17.9
92-26552	15	Composite	Yes	27.8	20.5	24.3	17.9	24.3	17.9
92-26549	16	Composite	Yes	24.3	17.9	24.3	17.9	24.3	17.9
92-26545	17	Composite	Yes	21	15.5	21	15.5	21	15.5
23-48420	18	Composite	Yes	27.8	20.5	13.6	10	13.6	10
92-26553	19	Composite	Yes	18.3	13.5	13.8	10.2	13.8	10.2

Summary Selection Guidelines

- As new space vehicles push LOX system design limits, G86 is one of few LOX evaluation methods available.
- Audible reports & flashes observed to be most indicative of energetic material response.
- Charring/scorching commonly observed for even least reactive composites down to lowest energy levels. Not recommended for use as a selection driver.
- **Proposed Guidelines to discriminate between highly and mildly reactive composites/materials if material does not pass G86 Acceptance Criteria**
  - **Mildly Reactive**
    - No audible reports at 72 ft-lbs or below
    - No observable flashes at 65 ft-lbs or below
  - **Moderately Reactive**
    - No audible reports at 65 ft-lbs or below
    - No observable flashes at 30 ft-bls or below
  - **Highly Reactive**
    - Audible reports at or below 65ft lbs
    - Observable flashes at or below 30ft lbs
- Ensure use of plummet catcher for repeatability (STP1596-2015-0072).