AN EXPERIMENTAL STUDY OF LAUNCH VEHICLE PROPELLANT TANK FRAGMENTATION

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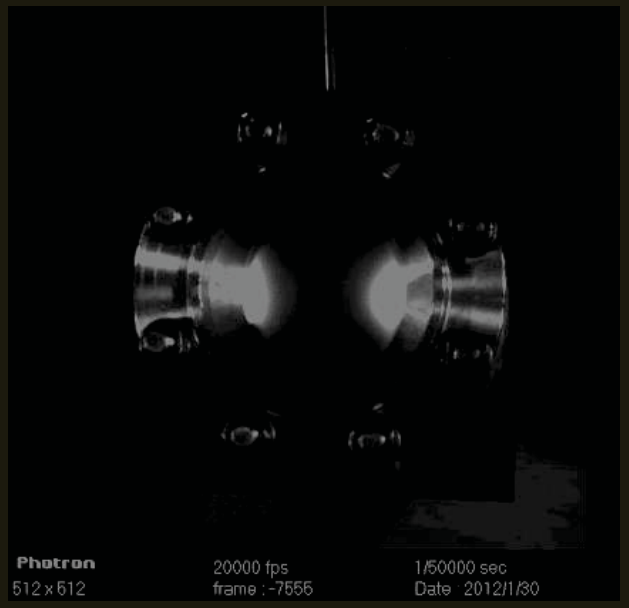
OVERVIEW

- Purpose
- Test apparatus
- Results
- Conclusion

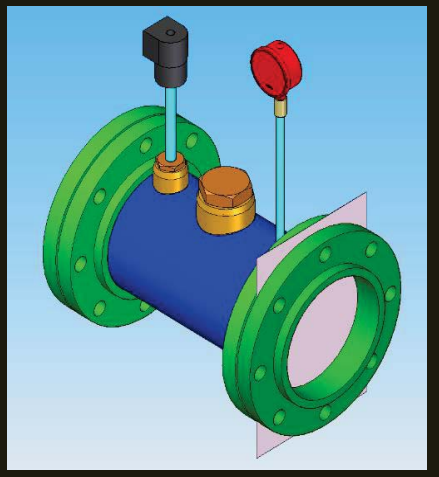


PURPOSE

- BEi attempting to develop comprehensive launch vehicle failure model
  - Fragments
  - Overpressure
  - Fireball
- Not a lot of fragment data out there
  - Some accidents – incomplete data collection
  - Some tests – incomplete data collection
  - Unclear on tiny fragment generation

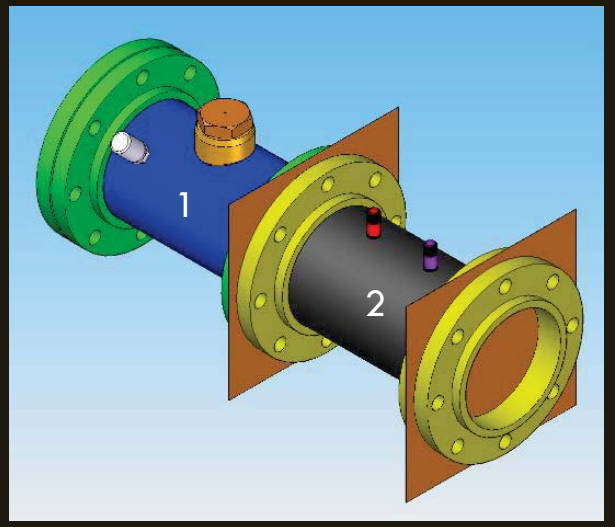
TEST APPARATUS: SINGLE-STAGE CANNON

- Initial design emphasized cost-effective for path-finding testing
  - Fail materials under appropriate conditions (< 480-psig)
- Single length of 6-in OD, ½-in thick pipe; flanges on either end
- Large mass on one end, sample on the other
- Port for gaseous fills and for liquid fills
  - "Quasi-steady state" testing fails samples with slow pressurization
- Samples were primarily Al 2024 and 300 Series SS
  - Available COTS
  - Close corollary to popular launch vehicle tank materials
- Concept proven, results analyzed; a new test apparatus was built



TEST APPARATUS: THE TWO-STAGE CANNON

- Also referred to as “smokeless powder testing”
- Two lengths of 6-in OD, ½-in pipe
- Large mass on one end
  - Sample on the other end, burst disc in the middle
  - Sample on the other end, sample in the middle
- Smokeless powder charge in the first chamber
  - Rapid pressurization to failure of burst disc or first sample (shock tube)
  - Second chamber pressurized (ullage) or filled with fluids, cryogens
- Blast wave generated ~ Mach 1, representative of acoustic event



TEST APPARATUS: FRAGMENT COLLECTION

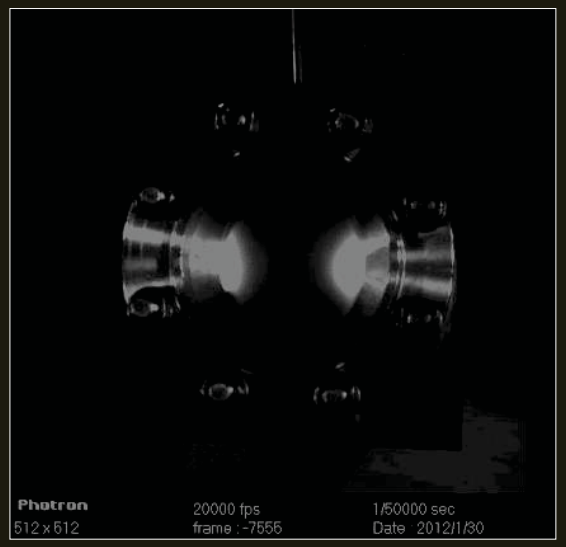
- Previous testing/accident data didn't account for 100% of fragments

- A method was developed to attempt to capture all fragments
  - Plywood wall with insulating foam to stop/capture fragments
  - Kevlar used when breakthrough began occurring regularly
  - Total fragment collection greater than 97%

- High speed cameras for multiple angles on most tests
  - 10-20,000 fps
  - Allows for fragment velocity calculation
  - Allows for shockwave visualization (when present)
  - Aids in sample reconstruction

RESULTS: FAILURE MODE

"Smooth/Punch Out" Failure
- Typical on aluminum
- Occasional on thin steel
- One piece, easy cleanup



"Tearing" Failure
- Typical on steel
- Multiple fragments
- Typically begin in center of sample
- "Flower petal" and "barn door"

RESULTS: FRAGMENTS

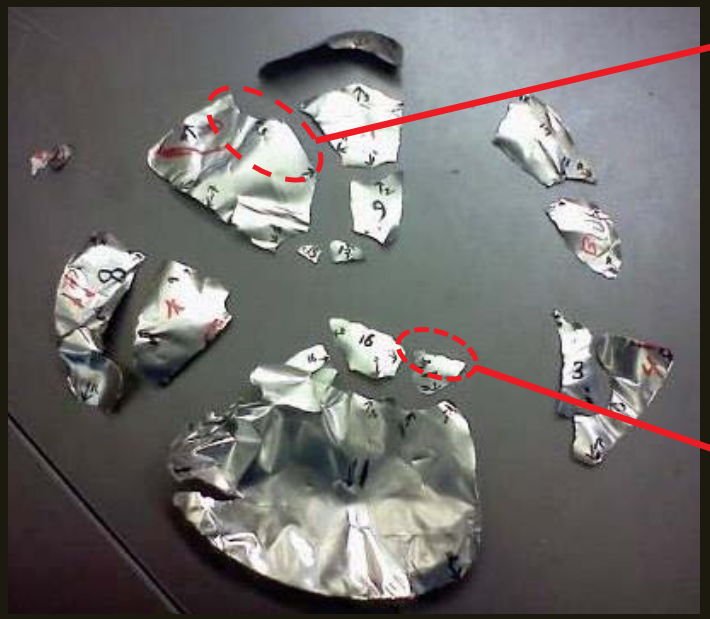
- DOE test series to determine if steel or aluminum produced more fragments
- Impact fragments can be identified after collection
- Steel fragments significantly more than aluminum on impact
- No "tiny fragments" found in initial tests

300 Series Steel						
Test	t (mil)	rupture (psi)	init frag	final frag	impact frag	init rips
49	7	248.1	1	1	0	0
55	7	212.7	1	1	0	2
60	7	287.7	1	2	1	2
64	7	155.4	1	2	1	2
50	10	373.9	1	1	0	1
54	10	278.3	2	4	2	1
59	10	392.7	3	4	1	2
62	10	531.5	3	7	4	1
53	15	576.2	2	11	9	3
56	15	385.4	3	4	1	1
58	15	572	4	0	4	3
63	15	586.5	3	12	9	3

Al 2024 T3						
Test	t (mil)	rupture (psi)	init frag	final frag	impact frag	init rips
47	16	259.4	1	1	0	2
52	16	192.5	1	1	0	0
57	16	237.8	1	1	0	0
61	16	202.2	1	1	0	0
48	20	301.4	1	7	6	0
51	20	292.3	1	7	6	0
65	20	190.4	1	1	0	0
66	20	#N/A	1	1	0	0
67	32	414.5	1	1	0	0
68	32	384.3	1	1	0	0
69	32	426.4	1	1	0	0
70	32	385.3	1	1	0	0
71	40	441	1	2	1	0
72	40	449.7	1	1	0	0
73	40	429.1	1	1	0	0
74	40	401.5	1	1	0	0

RESULTS: FRAGMENTATION

- Aerodynamic and impact fragmentation occurs as a ductile failure
- Informs computational modeling
- Allows for educated guess at fragment genesis after failure



Smooth tears result from the flower petal ripping up mid-flight due to aerodynamic and inertial forces.

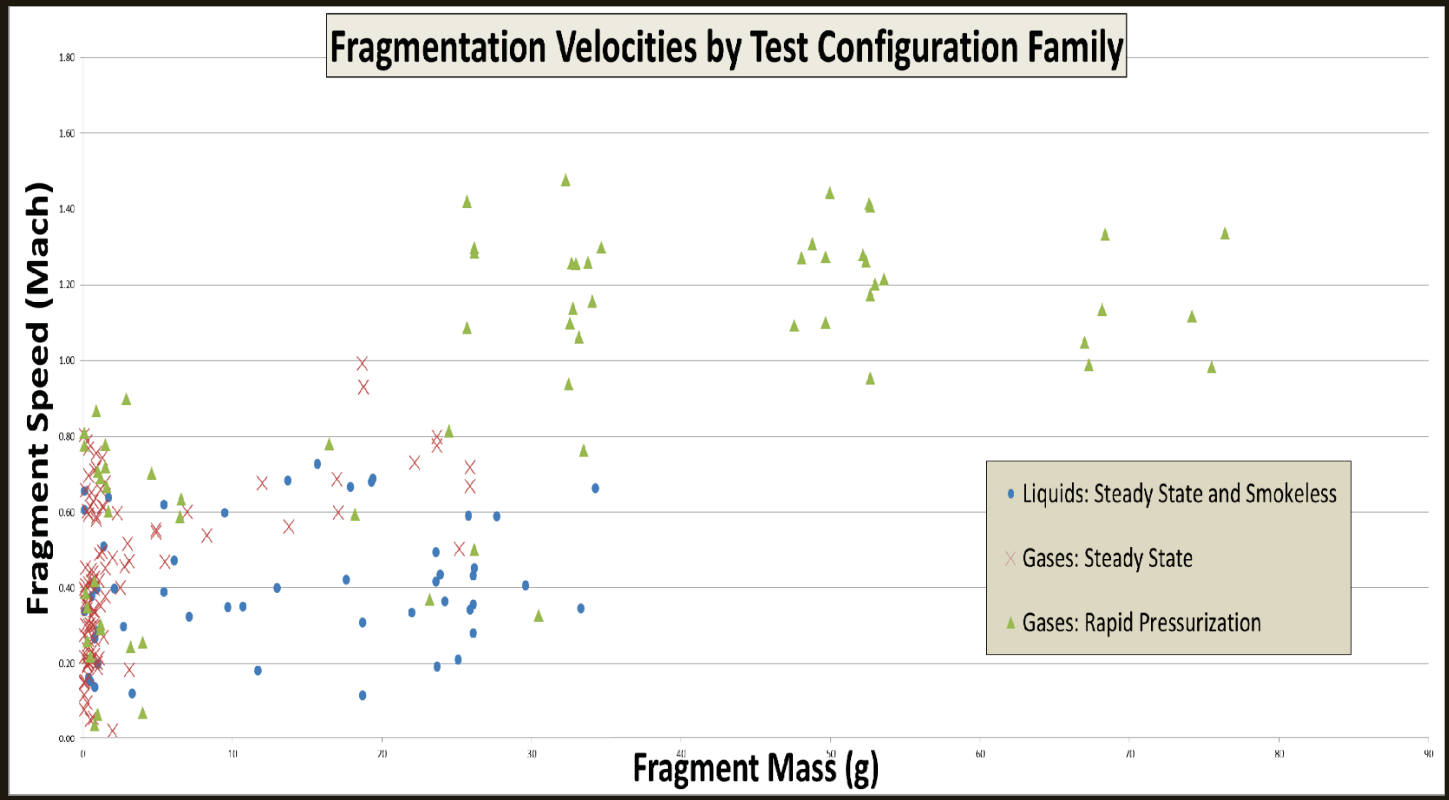
Jagged edges are found only on the outside edge of each flower petal

RESULTS: VELOCITY

- Varying test states produced repeatable and predictable results

- Average velocity of blast accelerated fragments matches known accident and test measurements

- Stainless steel and aluminum are similarly accelerated in blast loading

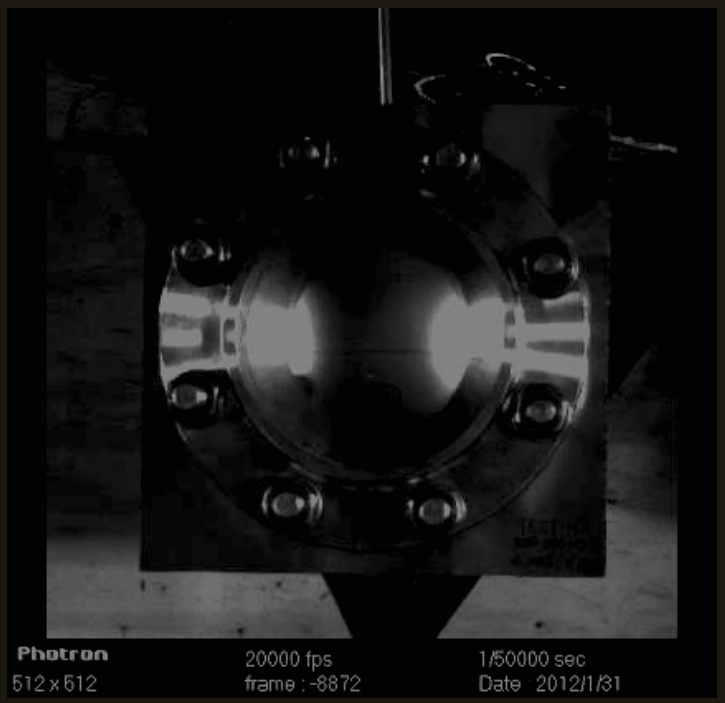


RESULTS: LIQUID LOADING

- Presence of liquid (LN_2 or H_2O) reduces the number and speed of fragments

- Early tests indicate effect is not temperature-driven
  - Cyrocooled samples failed normally without liquid loading

- More propellant in tank means fewer, less energetic fragments

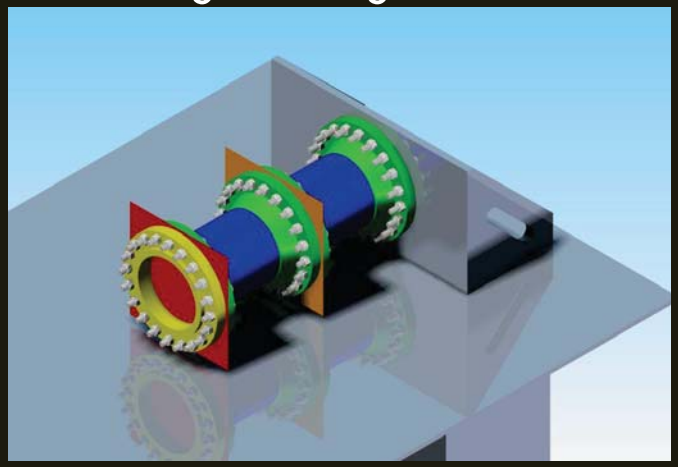


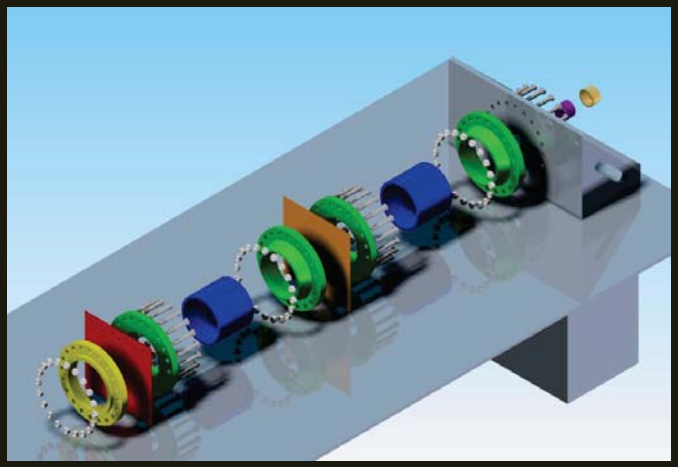
FUTURE WORK

- A 14-in pipe cannon will rupture flight-thickness material at the estimated appropriate blast pressure

- This will answer the question of scale left unresolved by the 6-in cannon

- Orthogrid iso-grid structures can also be tested





CONCLUSION

- Cost effective path-finding test program completed

- Initial findings show promise for future work and inform modeling efforts
  - Steel produces more ‘impact’ fragments
  - Steel and aluminum accelerated similarly
  - Fragment characteristics can indicate formation
  - Liquid loading decreases fragmentation

- 14-in cannon is built and ready to go