

AN EXPERIMENTAL STUDY OF LAUNCH VEHICLE PROPellant TANK FRAGMENTATION

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OVERVIEW

- Purpose
- Test apparatus
- Results
- Conclusion



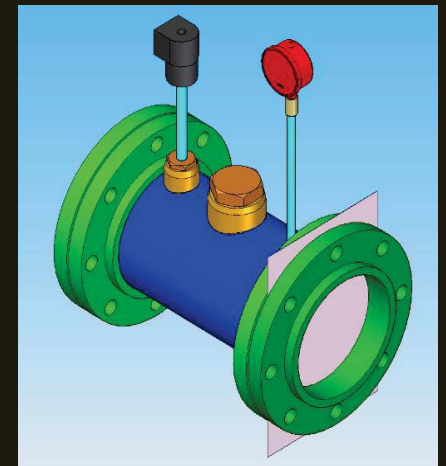


PURPOSE

- 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

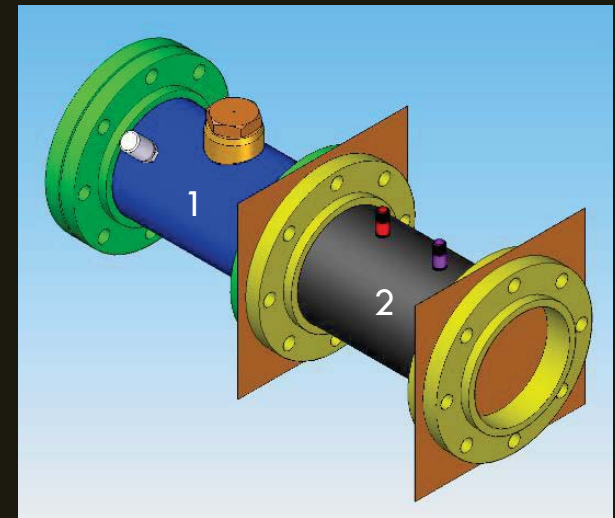
TEST APPARATUS: SINGLE-STAGE CANNON

- Initial design emphasized cost-effective for path-finding testing
 - Fail materials under appropriate conditions (< 480-psig)
- Single length of 6-in OD, 1/2-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, 1/2-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, cryogenics**
- Blast wave generated \sim 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							Al 2024 T3						
Test	t (mil)	rupture (psi)	init frag	final frag	impact frag	init rips	Test	t (mil)	rupture (psi)	init frag	final frag	impact frag	init rips
49	7	248.1	1	1	0	0	47	16	259.4	1	1	0	2
55	7	212.7	1	1	0	2	52	16	192.5	1	1	0	0
60	7	287.7	1	2	1	2	57	16	237.8	1	1	0	0
64	7	155.4	1	2	1	2	61	16	202.2	1	1	0	0
50	10	373.9	1	1	0	1	48	20	301.4	1	7	6	0
54	10	278.3	2	4	2	1	51	20	292.3	1	7	6	0
59	10	392.7	3	4	1	2	65	20	190.4	1	1	0	0
62	10	531.5	3	7	4	1	66	20	#N/A	1	1	0	0
53	15	576.2	2	11	9	3	67	32	414.5	1	1	0	0
56	15	385.4	3	4	1	1	68	32	384.3	1	1	0	0
58	15	572	4	0	4	3	69	32	426.4	1	1	0	0
63	15	586.5	3	12	9	3	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



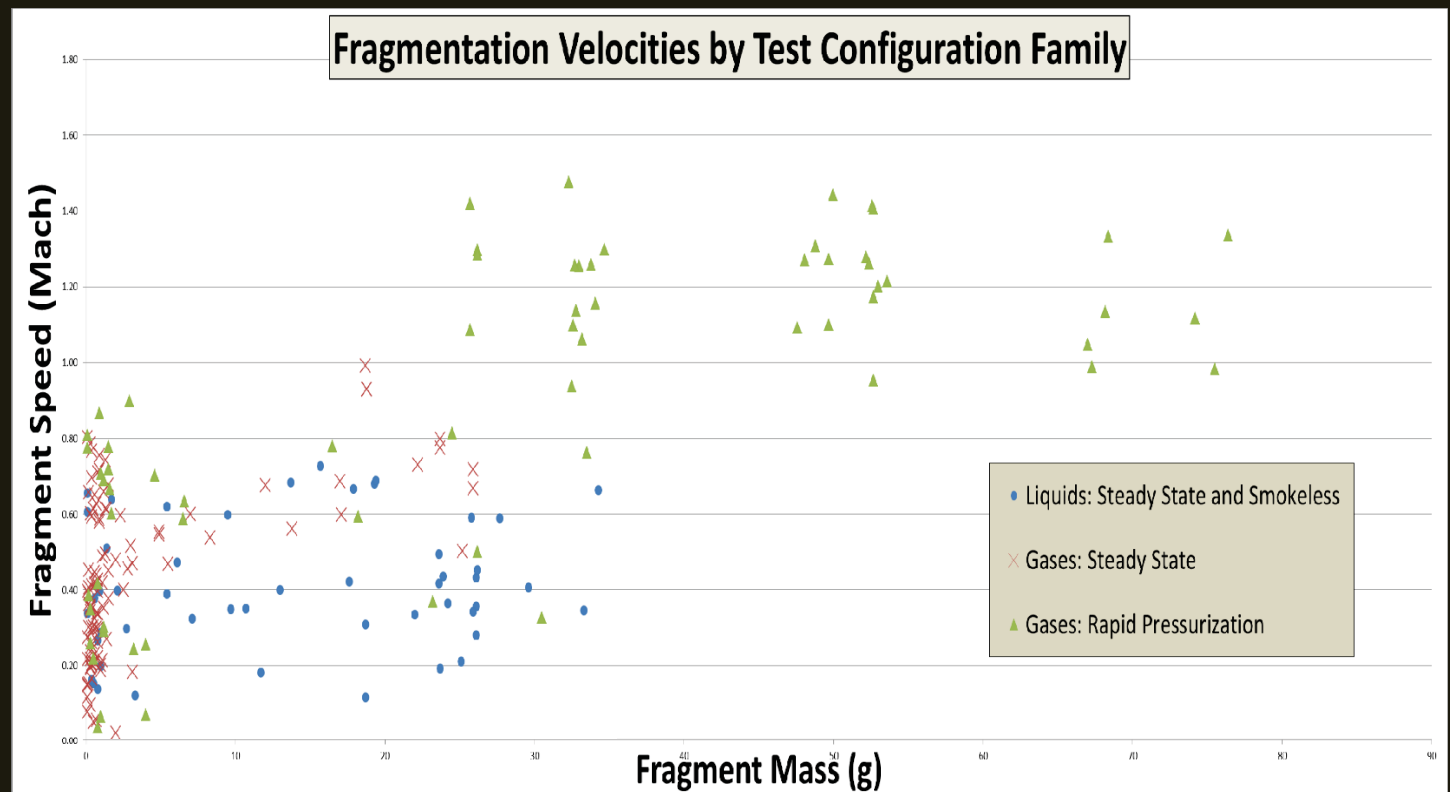
Smooth tears result from the flower petal ripping up mid-flight due to aerodynamic and inertial forces.



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

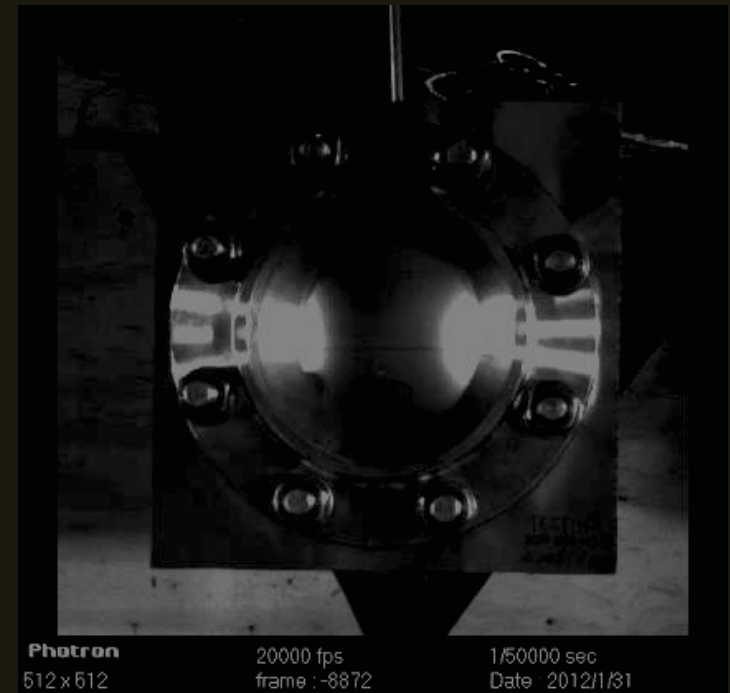
RESULTS: VELOCITY

- 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



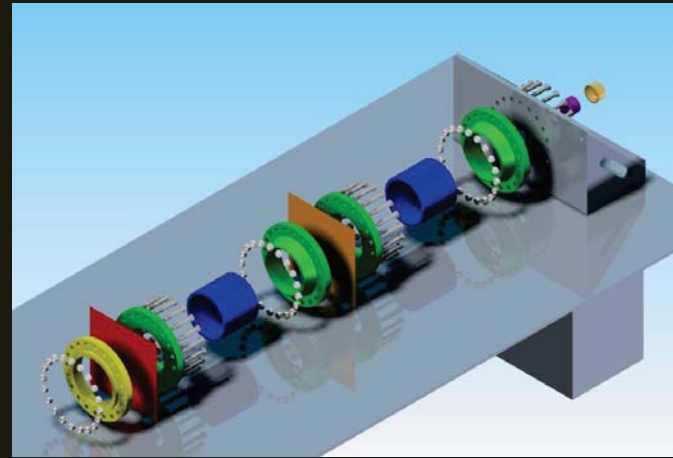
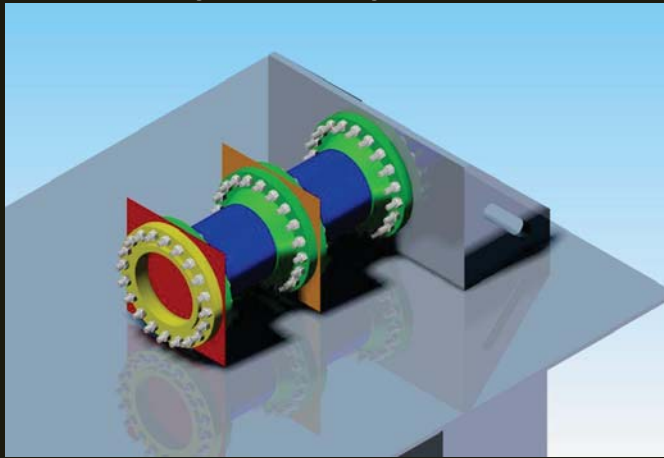
RESULTS: LIQUID LOADING

- Presence of liquid (LN_2 or H_2O) **reduces the number and speed** of fragments
- Early tests indicate effect is not temperature-driven
 - Cryocooled 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

