Hypervelocity Impact of Composite Overwrapped Pressure Vessel (COPV) and Comparison to a Numerical Model

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Objectives

- Expose COPV to hypervelocity impact (HVI) testing in pressurized and unpressurized condition.
- Assess overall COPV damage incurred by HVI.
- Identify impact conditions likely to result in catastrophic rupture.
- Broaden the conclusions made from experiment by numerical analysis.

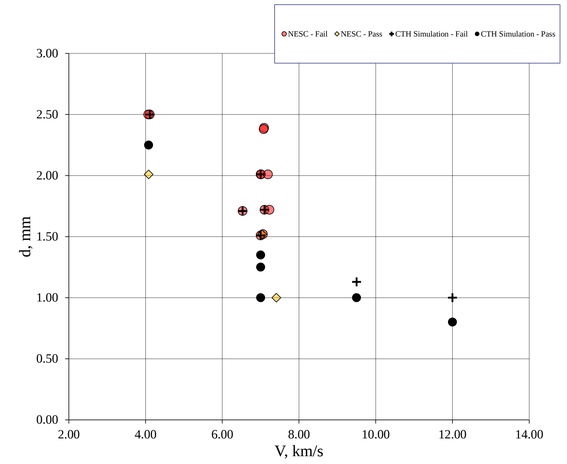
Model

- CAD model based on CT scan

	Material	Model
EOS	Aluminum 6061-T6, COPV liner	**Mie-Gruneisen analytic**
	Composite overwrap	**Mie-Gruneisen, user option**
	Aluminum projectile	**Sesame tabulated**
Elastic-plastic	Aluminum 6061-T6, COPV liner	**Elastic perfectly plastic, user option**
	Composite overwrap	**Elastic perfectly plastic, user option**
	Aluminum projectile	**Johnson-Cook**

EOS	Parameter	Value	Units
Composite Overwrap	Density	1.54	**g/cm^3**
	Sound speed	2.34e05	**cm/s**
	Hugoniot linear coeff.	1.5	**-**
	Gruneisen parameter	2.0	**-**
	Specific heat	1.98e-2	**J/(kg-k)**

Elastic-plastic model	Parameter	Value	Units
Aluminum 6061-T6	Yield strength	2.55e09	**MPa**
	Poisson's ratio	0.35	**-**
Composite Overwrap	Yield strength	2.21e09	**MPa**
	Poisson's ratio	0.36	**-**

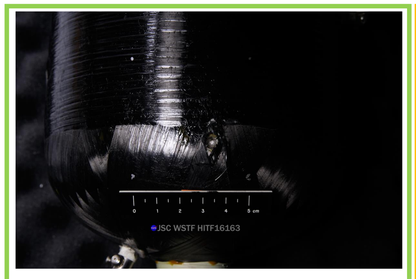


Hypervelocity Impact Testing

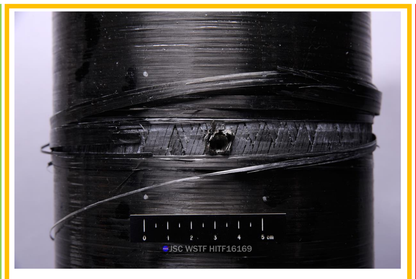
- Testing occurred at NASA White Sands test Facility (WSTF) Remote Hypervelocity Test Laboratory (RHTL) in Las Cruces, New Mexico.
- Test Matrix

Test Id	Target Location	COPV Pressure (MPa)	COPV temperature (°C)	Projectile Material	Projectile Diameter (mm)	Projectile Mass (g)	Impact Angle (deg)	Velocity (km/s)	Damage Result
HITF16159	Cylinder	29.2	50.5	Al 2017-T4	1.00	0.00146	45	7.41	Pass*
HITF16160	Cylinder	28.8	35	Al 2017-T4	1.52	0.00510	45	7.06	Vent
HITF16274	Cylinder	0	-	Al 2017-T4	1.51	0.00505	45	7.00	Perforation
HITF16161	Cylinder	27.7	41.7	Al 2017-T4	2.38	0.01975	45	7.08	Rupture
HITF16178	Cylinder	0	-	Al 2017-T4	2.38	0.01974	45	7.09	Perforation
HITF16162	Cylinder	29.1	29.4	Al 2017-T4	2.01	0.01191	45	7.01	Rupture
HITF16211	Cylinder	0	-	Al 2017-T4	2.01	0.01196	45	7.00	Perforation
HITF16163	Shoulder	29.0	38.9	Al 2017-T4	1.52	0.00514	45	7.04	Pass*
HITF16212	Shoulder	0	-	Al 2017-T4	1.52	0.00509	45	6.86	Crater*
HITF16164	Shoulder	29.1	50.5	Al 2017-T4	2.01	0.01190	45	7.19	Vent
HITF16327	Shoulder	0	-	Al 2017-T4	2.01	0.01191	45	7.05	Perforation
HITF16165	Cylinder	29.1	35.5	Al 2017-T4	1.72	0.00741	45	7.23	Vent
HITF16275	Cylinder	0	-	Al 2017-T4	1.71	0.00736	45	6.53	Perforation
HITF16331	Cylinder	0	-	Al 2017-T4	1.72	0.00746	45	7.10	Perforation
HITF16166	Cylinder	28.1	29.4	Al 2017-T4	1.51	0.00505	0	7.24	Vent
HITF16328	Cylinder	0	-	Al 2017-T4	1.51	0.00505	0	6.65	Perforation
HITF16332	Cylinder	0	-	Al 2017-T4	1.51	0.00506	0	7.32	Perforation
HITF16167	Cylinder	29.1	44.4	Al 2017-T4	1.72	0.00741	0	7.01	Rupture
HITF16329	Cylinder	0	-	Al 2017-T4	1.72	0.00740	0	7.11	Perforation
HITF16168	Cylinder	29.1	42.7	Al 2017-T4	2.31	0.01176	60	7.03	Rupture
HITF16393	Cylinder	0	-	Al 2017-T4	2.31	0.01175	60	7.20	Perforation
HITF16169	Cylinder	29.1	42.7	Al 2017-T4	2.01	0.01191	60	7.08	Vent
HITF16394	Cylinder	0	-	Al 2017-T4	2.01	0.01196	60	7.01	Perforation
HITF16170	Cylinder	29.1	40.5	Al 2017-T4	2.50	0.02290	45	4.07	Rupture
HITF16395	Cylinder	0	-	Al 2017-T4	2.50	0.02289	45	4.11	Perforation
HITF16171	Cylinder	29.4	44.4	Al 2017-T4	2.01	0.01194	45	4.08	Pass*
HITF16504	Cylinder	28.8	20	440C SS	1.09	0.00525	45	7.10	Vent
HITF16513	Cylinder	0	-	440C SS	1.09	0.00528	45	7.03	Perforation
HITF16505	Cylinder	28.7	10.5	440C SS	1.29	0.00861	45	7.10	Rupture
HITF16514	Cylinder	0	-	440C SS	1.29	0.00861	45	7.01	Perforation

Experimental and Modeling Results



- HITF16163, Pressurized test, Pass



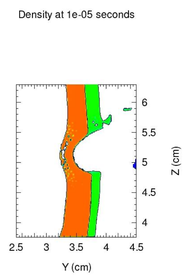
- HITF16169, Pressurized test, Venting failure

- HITF16162, Pressurized test, Rupture failure

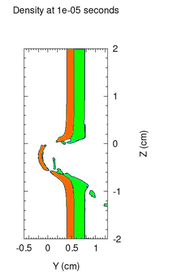
- HITF 16212, Unpressurized test, Pass

- HITF 16394, Unpressurized test,, Perforation

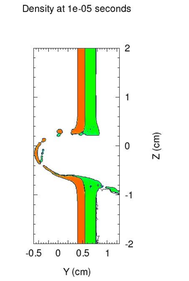
- HITF 16211, Unpressurized test, Perforation



- CTH simulation of HITF16212; Result: Pass



- CTH simulation of HITF 16394, Result: Fail



- CTH simulation of HITF16212; Result: Fail

Conclusions

- Experiments demonstrate COPV has capacity to withstand hypervelocity impact.
- Failure mode appears to be related to impact energy.
- A numerical model was designed to broaden the scope of this effort.
- Pressurizing of COPV in numerical impact simulations will be the next effort.

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