

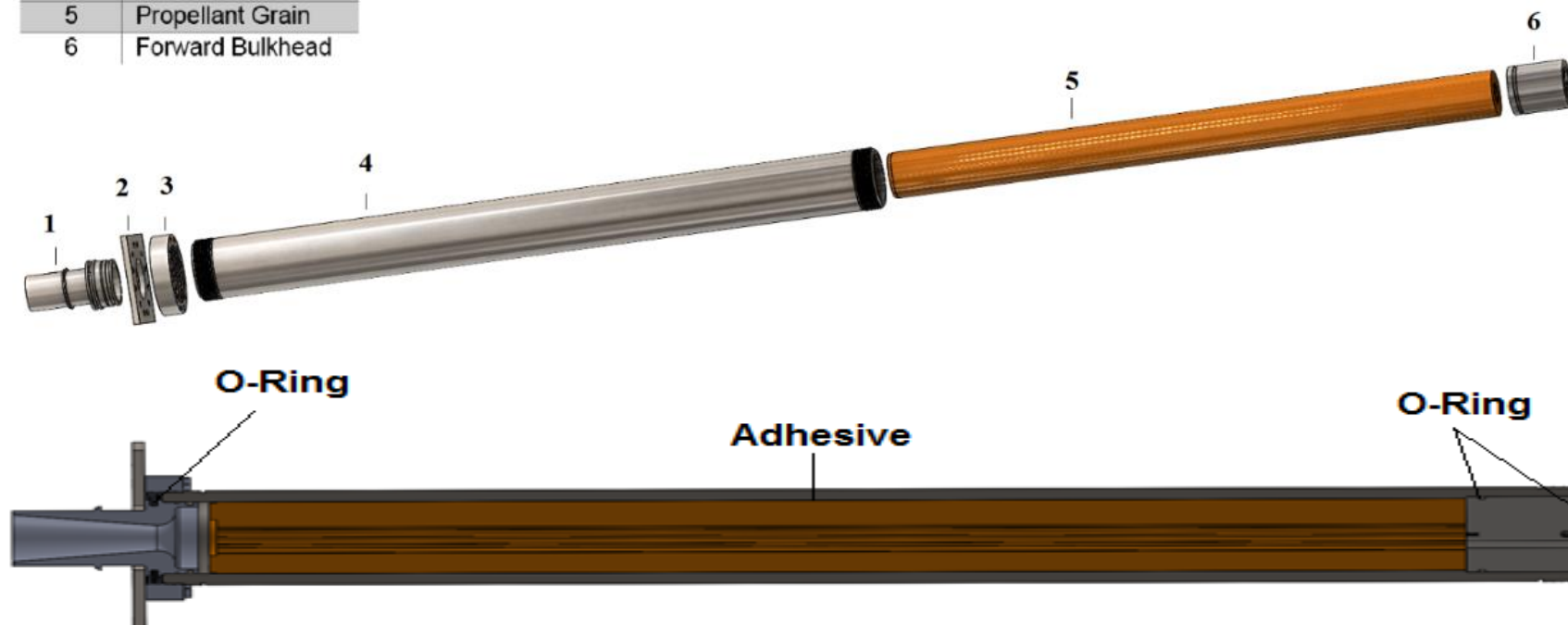


# Advanced Technology Demonstration Motor: Case-Bonded Extruded Double-Base Grain

Joseph Hong  
Rocket Development Engineer  
BAE Systems, Inc.  
Radford, VA, USA  
October 24, 2019

# Motor Assembly

Index	Part
1	Nozzle
2	Aft Plate
3	Aft Collar
4	Motor Case
5	Propellant Grain
6	Forward Bulkhead

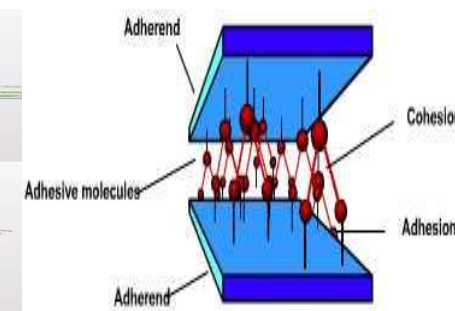
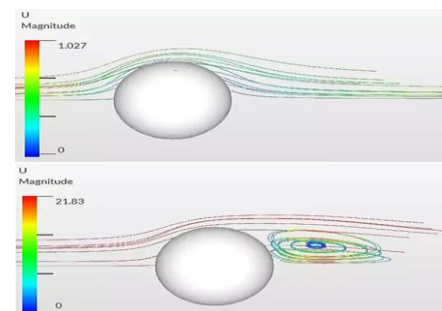
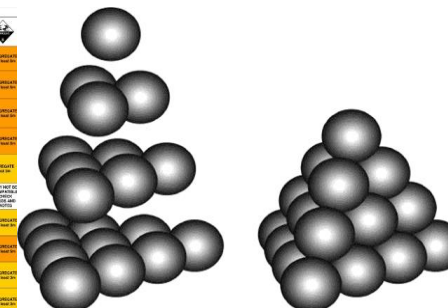


# Adhesive Selection

- Energetic Compatible
- Maximum Propellant Loading
- Withstand Firing Forces
- Single Component
- Fast, Room Temperature Curing

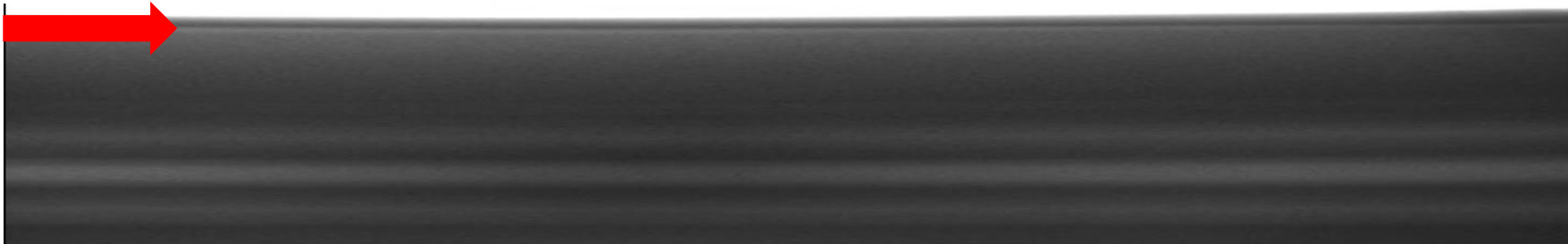
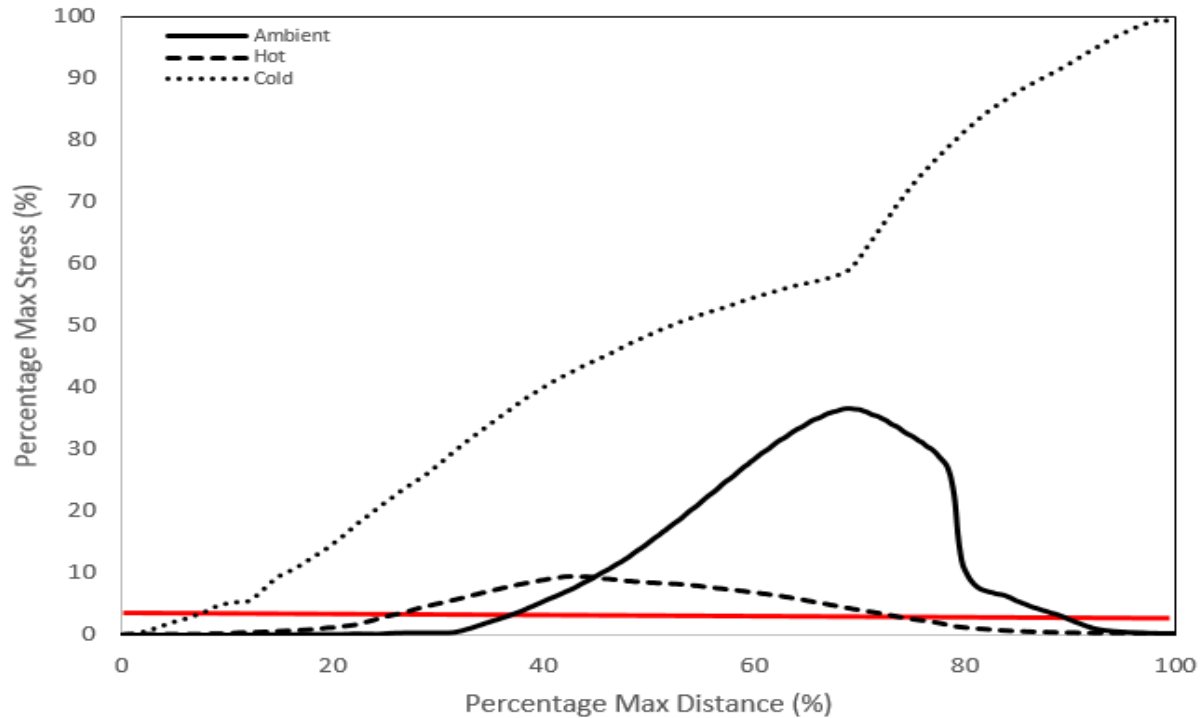
**DANGEROUS GOODS & COMBUSTIBLE LIQUIDS STORAGE COMPATIBILITY CHART**

Class of Subcategory Risk	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
FLAMMABLE GASES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
NON-TOXIC NON-FLAMMABLE GASES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
TOXIC GASES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
OXIDIZING GASES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
FLAMMABLE LIQUIDS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
COMBUSTIBLE LIQUIDS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
FLAMMABLE SOLIDS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
SPONTANEOUSLY COMBUSTIBLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
DANGEROUS WHEN MIXED	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
OXIDIZING AGENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
ORGANIC PEROXIDE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50



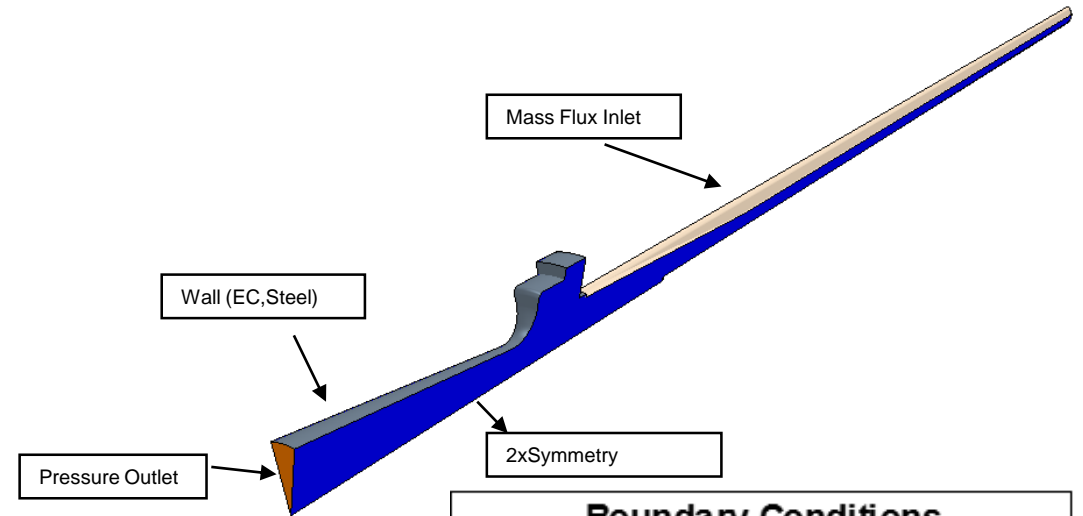
# Adhesive Testing

- Laboratory Testing
  - Shear
  - Tension
- Full-Scale Prototype
  - Real-Time Radiography



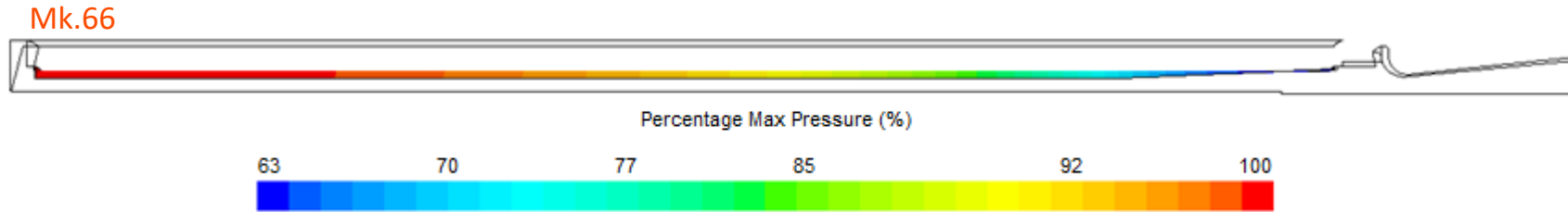
# CFD Analysis Description

- Methodology
  - Three dimensional, turbulent, Navier-Stokes analysis
  - Steady-state simulation @ +150°F
- Mesh
  - 1/16<sup>th</sup> symmetry model, hexahedral
- Assumptions
  - Static ambient pressure outlet
  - Isothermal walls
  - No erosive burning, burn augmentation rate factor, igniter mass flow

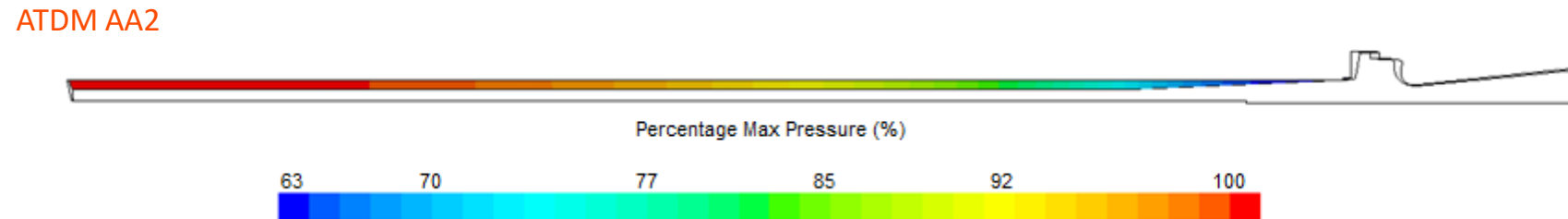


Boundary Conditions	
Regions	Static Temperature
Aft End Inhibitor	335
Wrap	
Salt Rod	
Case Wall	1000
Bulkhead	
Nozzle Wall	
Inlet	Mass Flux Inlet
Outlet	14.7 psi

# Pressure Drop Across Grain



- Force on Grain: 252lbf in Z-axis. Vector towards aft end.



- Force on Grain: 360lbf in Z-axis. Vector towards head end.

# Pressure Contour

Mk.66



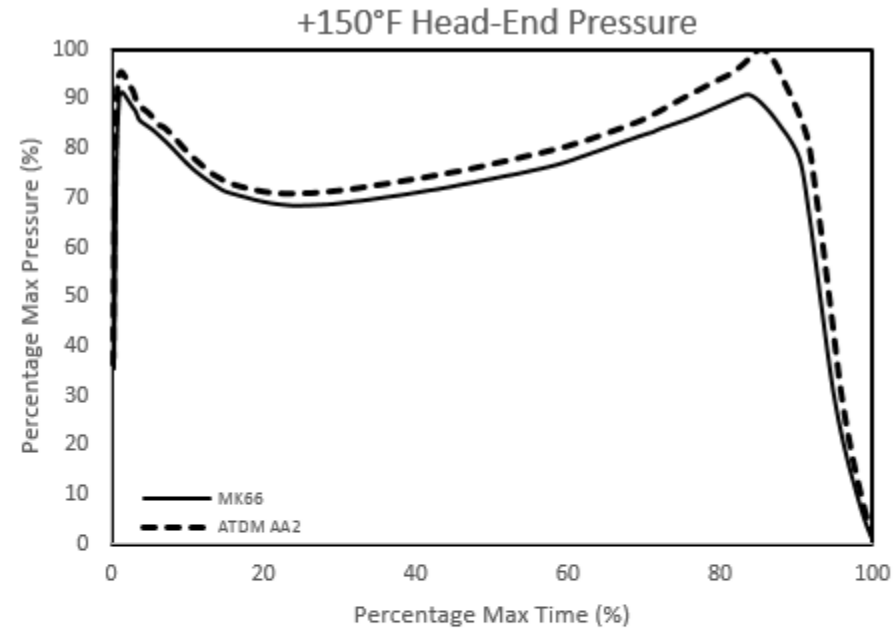
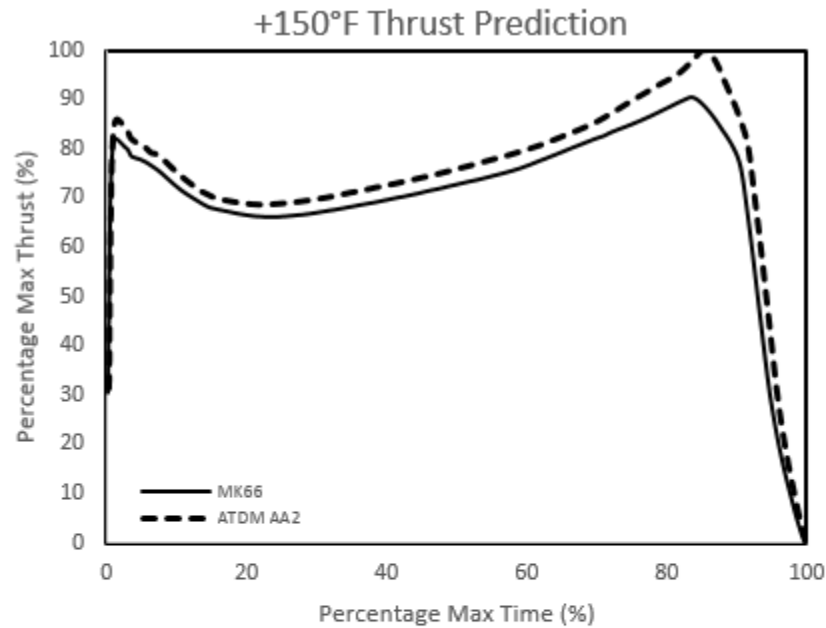
ATDM AA2



Percentage Max Pressure (%)



# Initial Ballistic Analysis

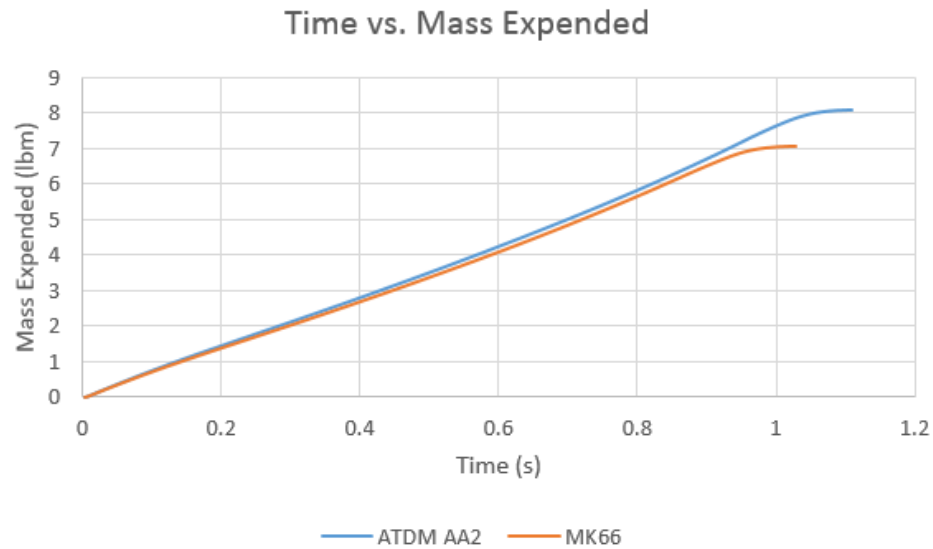


Ballistics Summary				
		+150F	+77F	-50F
ATDM AA2	Action Time (s)	+7.9%	+8.8%	+6.0%
	Impulse (lbf-s)	+14.3%	+14.4%	+14.5%
	Max Thrust (lbf)	+10.5%	+4.7%	+5.5%
	Max Pressure (psi)	+9.7%	+4.5%	+5.4%
HW MK66	Action Time (s)	100%	100%	100%
	Impulse (lbf-s)	100%	100%	100%
	Max Thrust (lbf)	100%	100%	100%
	Max Pressure (psi)	100%	100%	100%

Not Export Controlled per PS-2019-DR-1158

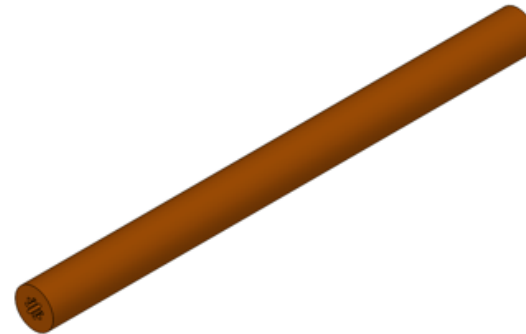


# Verification: Mass Expended



	ATDM AA2	MK66
SPP Total Mass Expended (lbm)	8.090	7.080
Theoretical Grain Weight (lbm)	8.081	7.073

- Assumption: Constant AA2 density of  $0.058 \text{ lbm/in}^3$

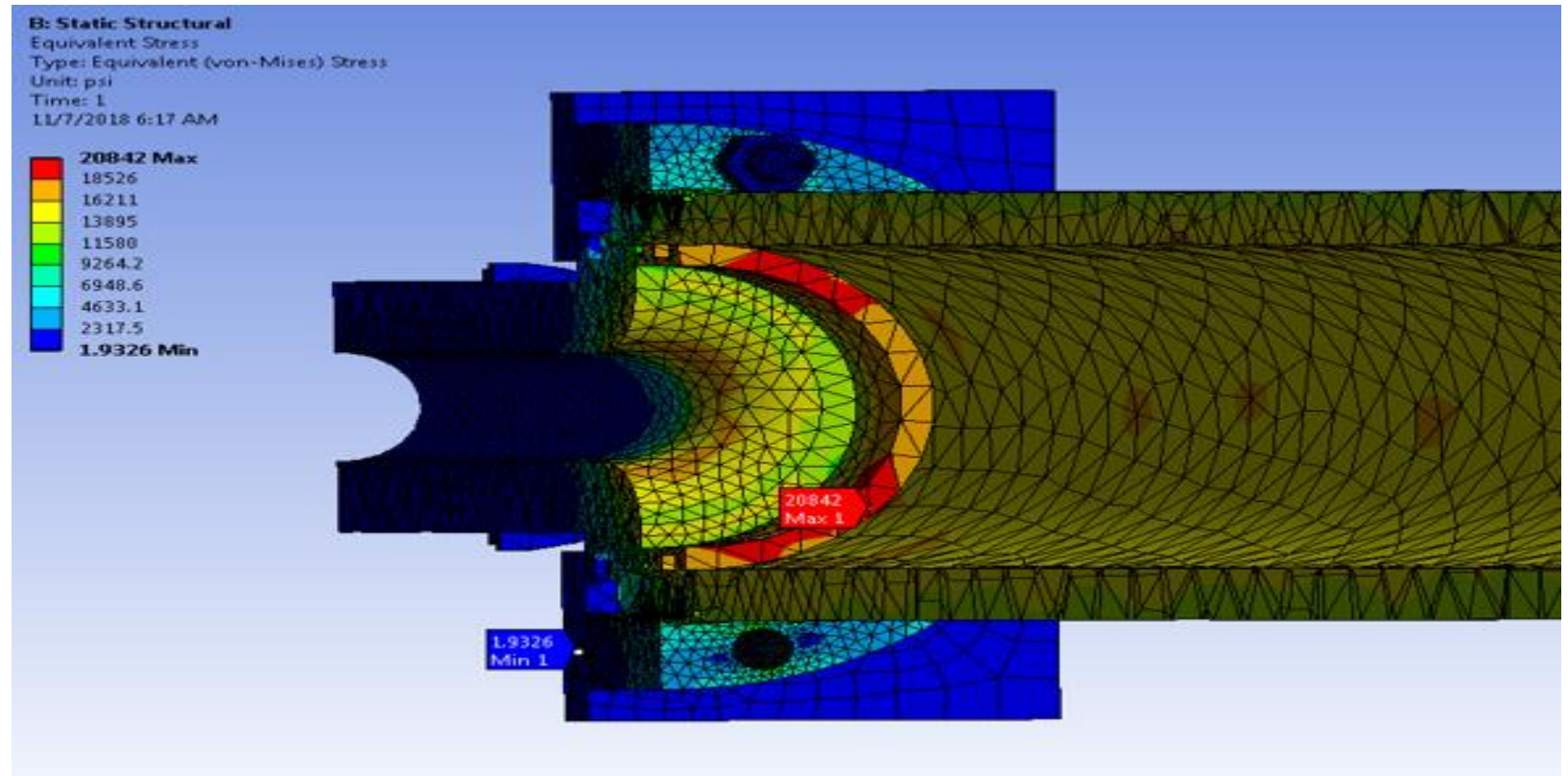


Initial Burn Surface Area-ATDM



# Structural Analysis

- Static Analysis
- Peak Stress
  - Nozzle Face
  - Bolt Holes
  - Aft Collars
- All Forces < Yield



# Motor Test Assembly

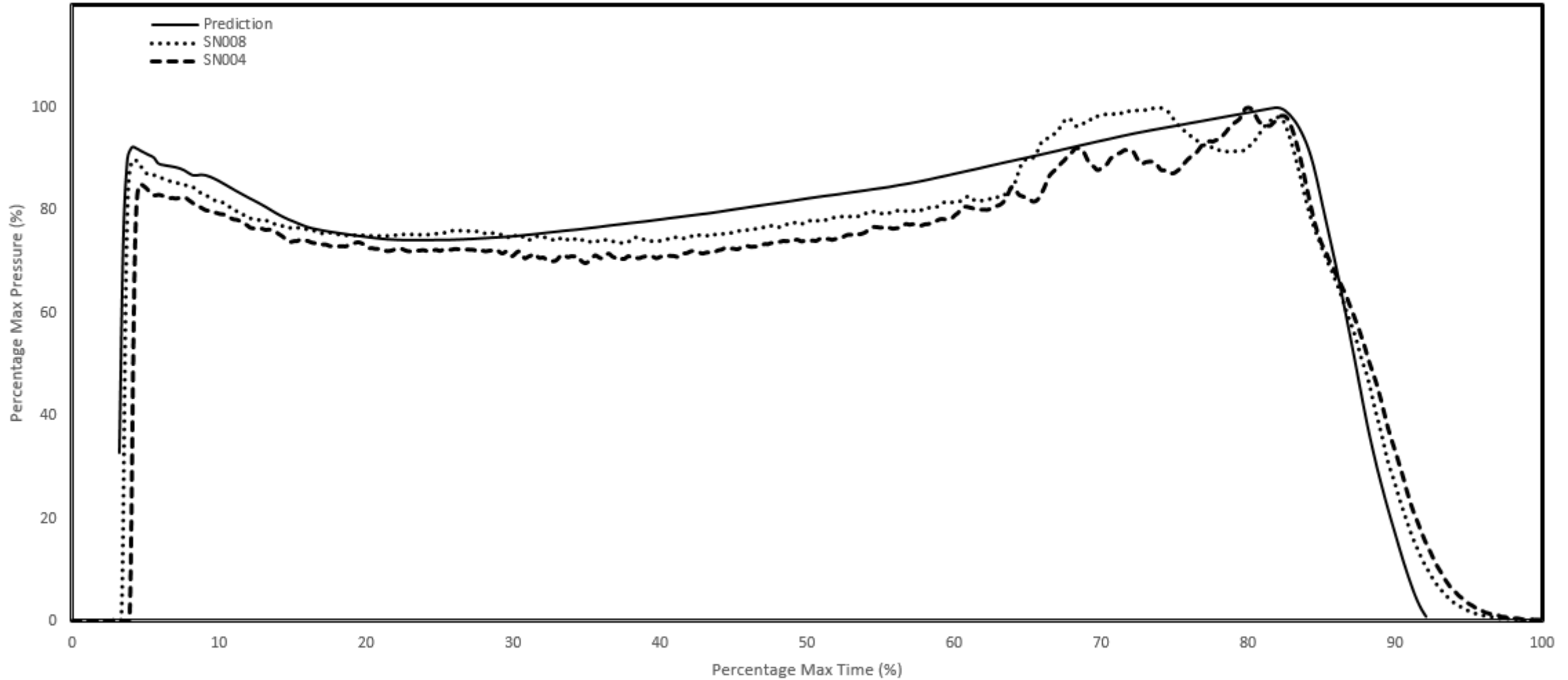


Not Export Controlled per PS-2019-DR-1158

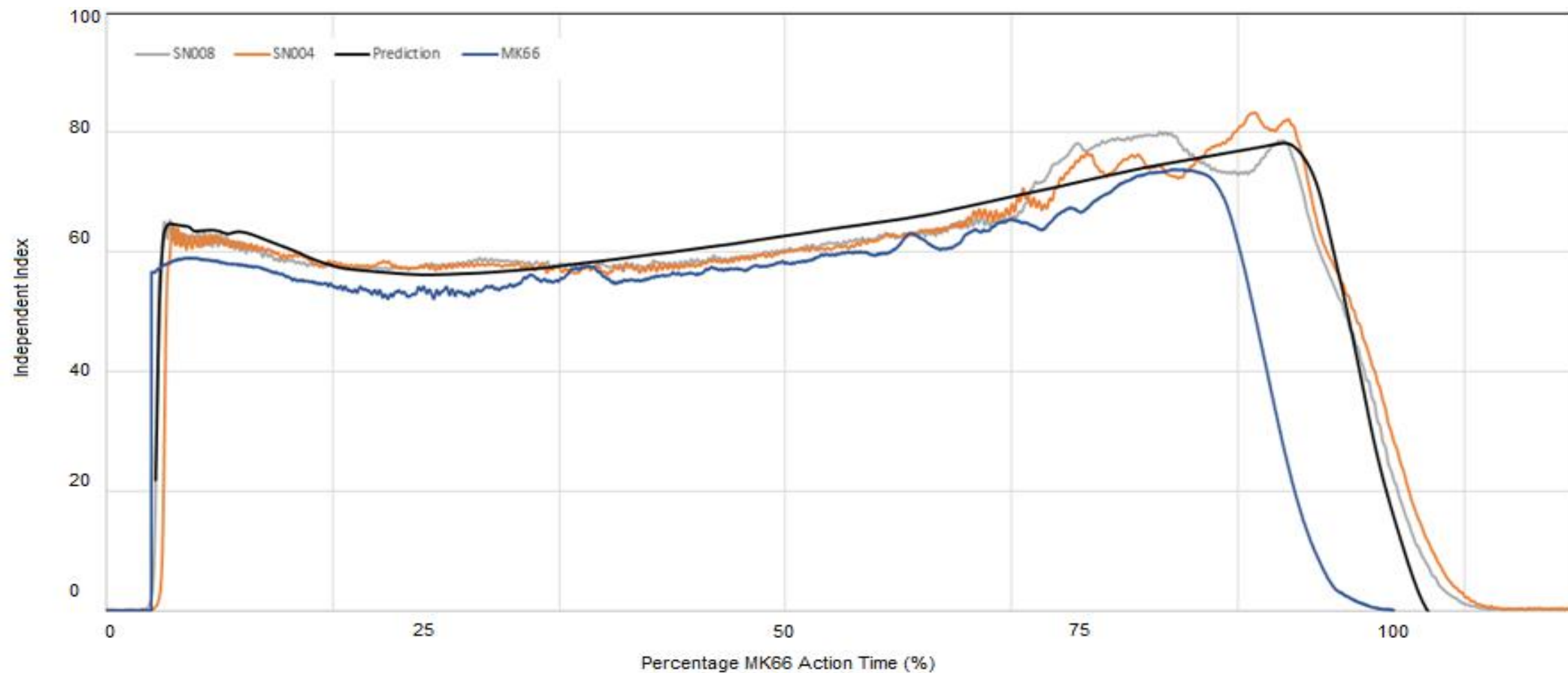
# Static Test Firing



# Static Test Firing – Head End Pressure



# Static Test Firing - Thrust





## Post-Firing Motor Interior



Motor Forward End



Motor Aft End

## ■ Component Deterioration - Nozzle





## ■ Component Deterioration – Nozzle Seal Ring



# Component Deterioration – Resonance Rod



# Conclusions and Future Work

- BAE Systems, OSI successfully demonstrated test firing of case-bonded, extruded double-base rocket grain
- Motor impulse increase of 12% over baseline
- Adjustments for temperature conditioned testing
- Additional technologies under development to further performance