CREW LAUNCH VEHICLE MOBILE LAUNCHER SOLID ROCKET MOTOR PLUME INDUCED ENVIRONMENT

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ABSTRACT

The plume-induced environment created by the Ares 1 first stage, five-segment reusable solid rocket motor (RSRMV) will impose high heating rates and impact pressures on Launch Complex 39. The extremes of these environments pose a potential threat to weaken or even cause structural components to fail if insufficiently designed. Therefore the ability to accurately predict these environments is critical to assist in specifying structural design requirements to insure overall structural integrity and flight safety.

INTRODUCTION

This paper presents the predicted thermal and pressure environments induced by the launch of the Crew Launch Vehicle (CLV) from Launch Complex (LC) 39. Once the environments are predicted, a follow-on thermal analysis is required to determine the surface temperature response and the degradation rate of the materials. An example of structures responding to the plume-induced environment will be provided.

LAUNCH ENVIRONMENT

The following factors are considered for the predictions of CLV ML plume induced environments: coordinate systems, lift-off trajectory, ML configuration, and SRM engine performance. The 5-segment reusable solid rocket motor (RSRMV) with propellant mixture provided by ATK is used in the simulation of nozzle condition. The nozzle and plume calculations for the RSRMV were generated with a chamber pressure of 905 psia. The computational codes used to produce the plume flow field solutions include Chemical Equilibrium Code (CEC/TRAN72), Reacting Multi-Phase Program (RAMP2), and Standard Plume Flow Field (SPF3). At the end of SPF calculations, the exhaust plume is calculated and consists of the following flow variables: Mach number, velocity, static temperature, static pressure, flow angle, particle mass flux, particle momentum flux, particle kinetic energy, particle thermal energy flux, particle flow angle, and N2 mole fraction. As an example, the near-field plume Mach number is shown in Figure 1.

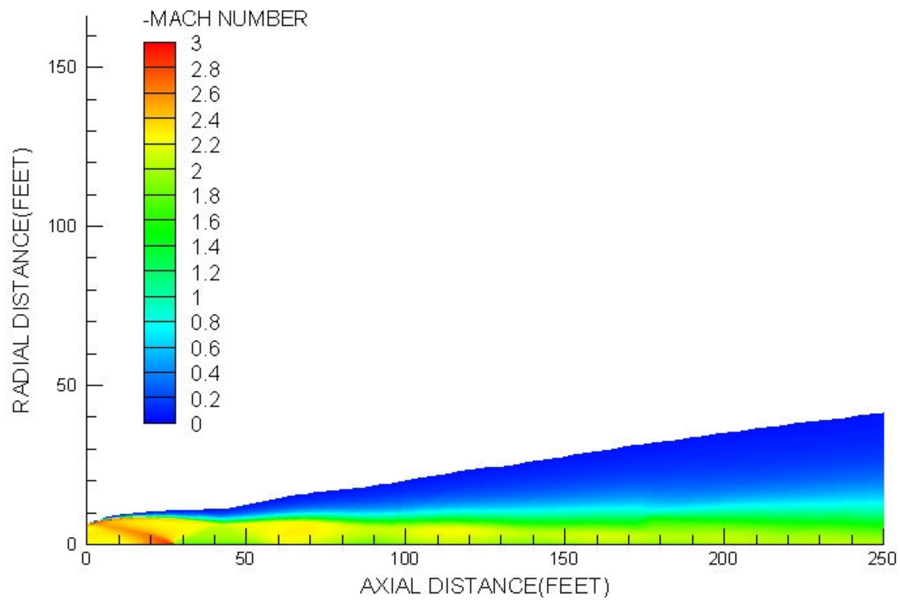
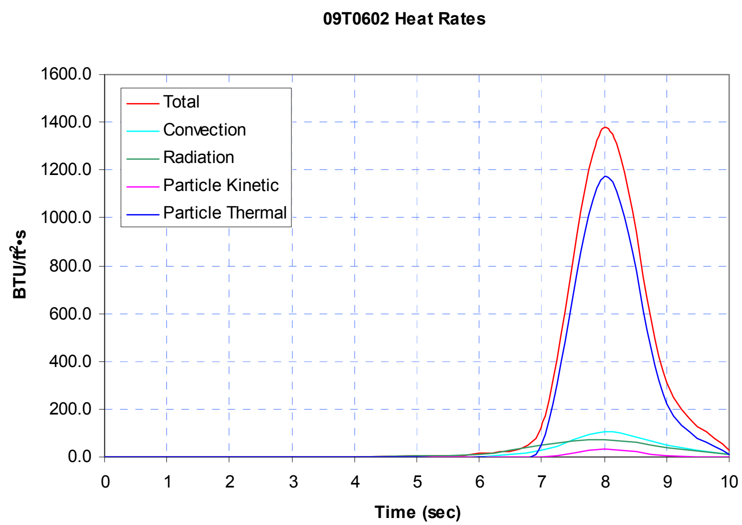


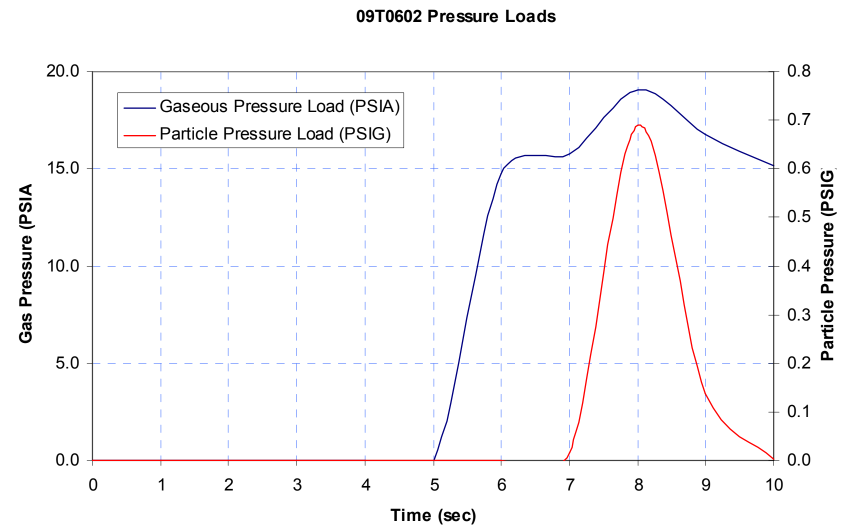
Figure 1: Near Field Plume Mach Number

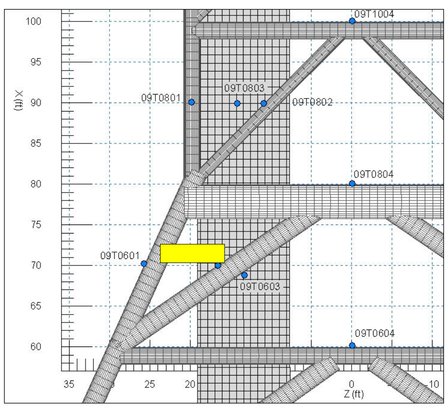
The exhaust plume, coupled with the vehicle trajectory, is then used to predict the launch-induced environments at specified locations on the ML and Ground Support Equipments (GSE) mounted on the ML. The plume-induced environments were predicted for the following modeled launch complex components:

- RSRBV Exhaust Deflectors
- RSRBV Hold-down Posts
- RSRBV Aspirator Opening Blast Shields
- GN2 Purge Line & Heater Unit
- MLB Deck
- Launch Tower Floors & Roof
- Elevator Shaft
- Elevator Shaft Blast Diverter
- Sound Suppression Water Jets & Pipes

A typical output showing the predicted environment on a cross beam is shown in Figure 2. The tabulated values will then be used as the input conditions to calculate the thermal responses of GSE components mounted on the ML.







Time	*Qc*	*Qr*	*Tr*	*Mdot*	*Qpke*	*Qpte*	*Pimp*	*Pimppar*	*Qtotal*
sec	BTU/ft^2·s	BTU/ft^2·s	R	lbm/ft^2·s	BTU/ft^2·s	BTU/ft^2·s	Psia	Psig	BTU/ft^2·s
0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
5	0.0	2.9	0.0	0.00	0.0	0.0	0.0	0.0	2.9
6	1.2	12.1	804.4	0.01	0.0	0.7	14.8	0.0	14.1
7	25.9	50.4	2560.1	0.17	0.2	47.2	15.8	0.0	123.7
8	102.9	69.9	4508.2	2.21	33.2	1171.6	19.0	0.7	1377.6
9	49.8	38.3	3306.1	0.80	3.7	219.9	16.7	0.1	311.8
10	9.7	9.4	1581.8	0.05	0.0	9.0	15.2	0.0	28.1

Figure 2: Thermal and Pressure Predictions for Body Point 09T0602 Using a North Drift Trajectory

PLUME-INDUCED THERMAL ENVIRONMENTS (THERM1D)

The THERM1D code is a one dimensional heat conduction code designed specifically for launch and test stand design problems. It was developed from a thermal analyzer code developed by Pond (Reference 1) to support the Space Shuttle development program. Convective, radiative and particulate surface heating options are included in the model. The THERM1D code also accounts for melting or ablation of the material surface as well as the deposition of aluminum oxide or carbon based soot. Details of the theory used in THERM1D can be found in References 1 and 2. The code features fully interactive input and output on a Windows 95/98/NT/2000/XP environment. Materials and material properties for THERM1D structures are provided via a data file which can be edited and updated. Graphical outputs of deposition, melting and temperature at different depths in the structure are provided at the end of each THERM1D case run.

EXAMPLES

Shuttle Range Safety Cable

There was a concern that the Shuttle Range Safety Cable might have survived the rocket exhaust plume and became debris. It was recommended that more accurate environments be used in the analysis to include the protective Al2O3 buildup on the cable.

The cable is made of a combination of Teflon (outer jacket and core) and Copper (braid and conductor), as shown in Figure 5. Five inner locations have been identified along the radial direction of the cable. Figures 6 and 7 show the thermal response and material degradation, for body point 14, as a result of THERM1D calculation. Similar results for body point 14a are shown in Figures 8 and 9. It is noticed that for both body points 14 and 14A, the jacket melts at 1.02 sec and cable burns through at 1.3 sec. Although there are some solid particle buildups, but they are not enough to keep the cable from melting.

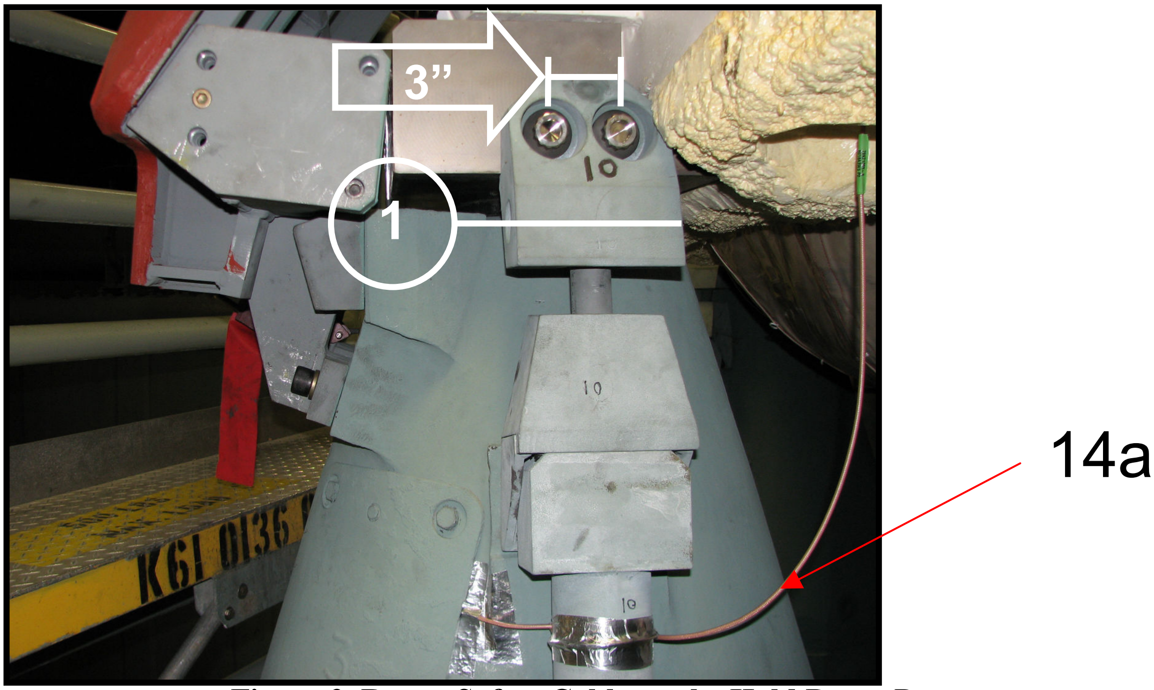


Figure 3. Range Safety Cable on the Hold Down Post

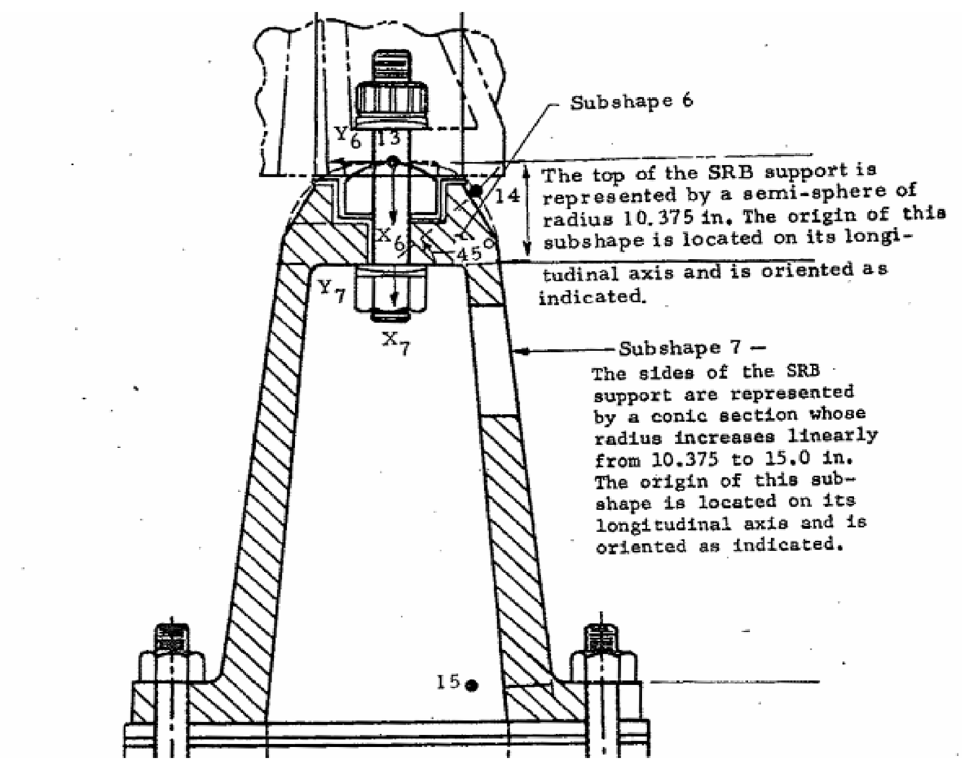


Figure 4. Shuttle Environment Prediction

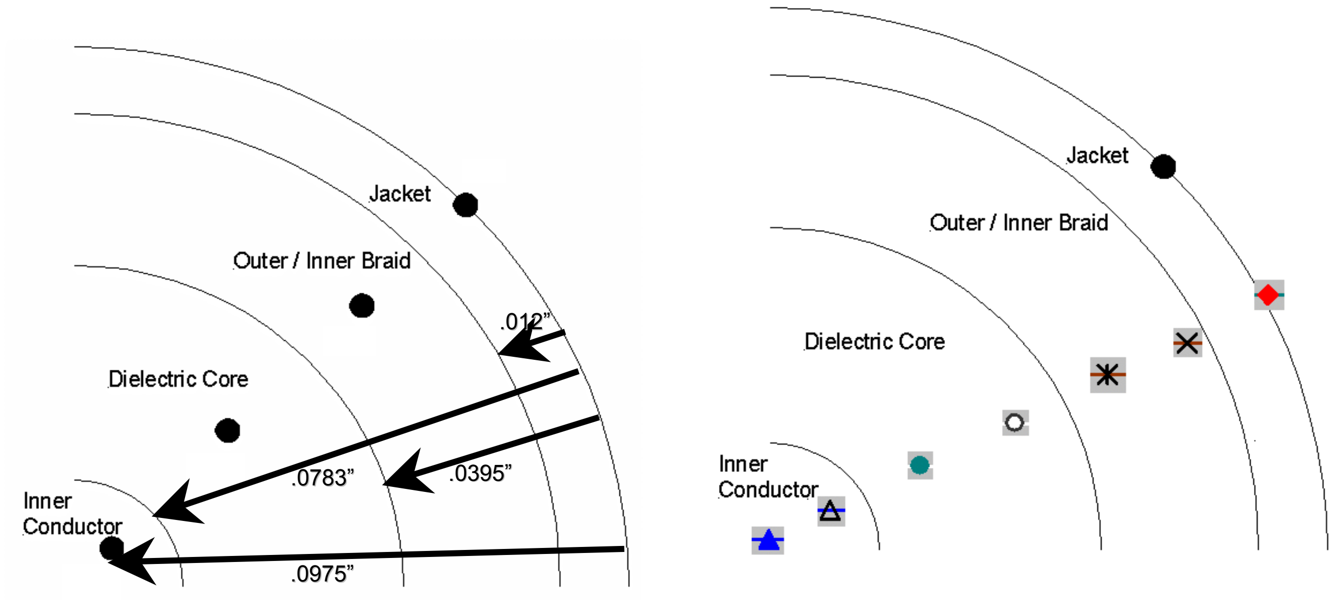


Figure 5. Cable Cross Section

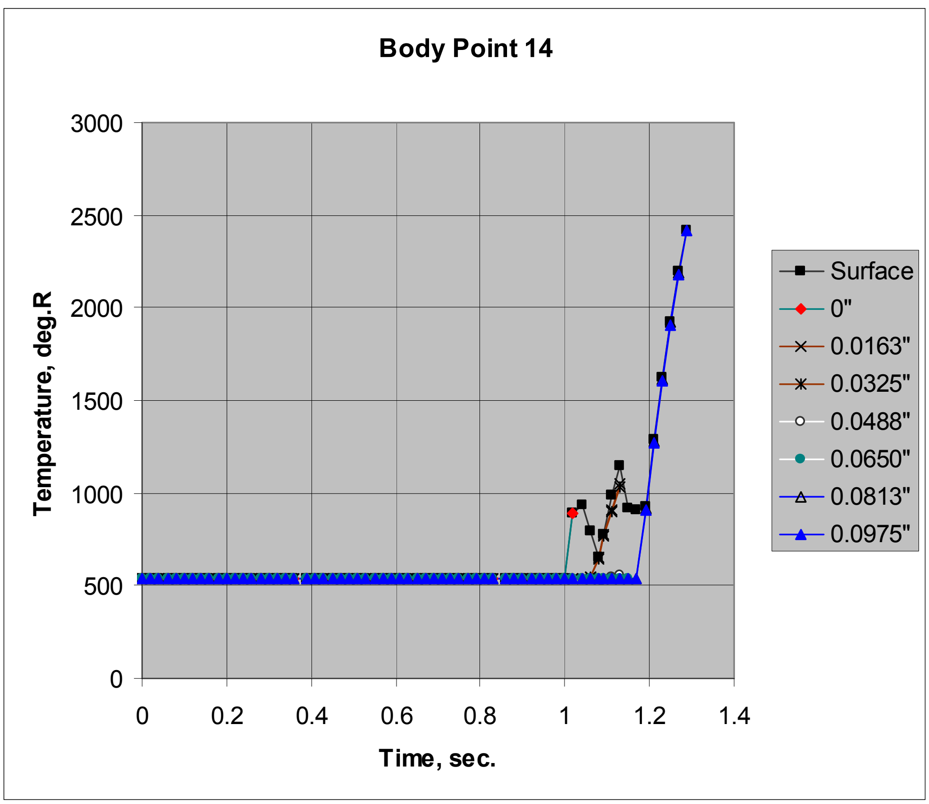


Figure 6. Thermal Response

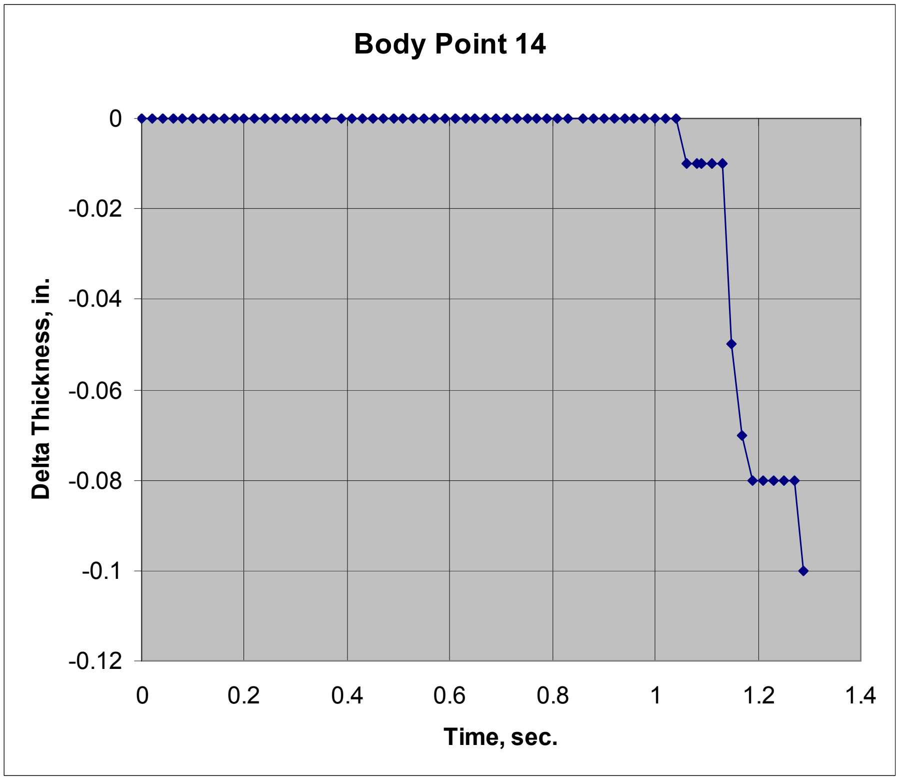


Figure 7. Material Loss

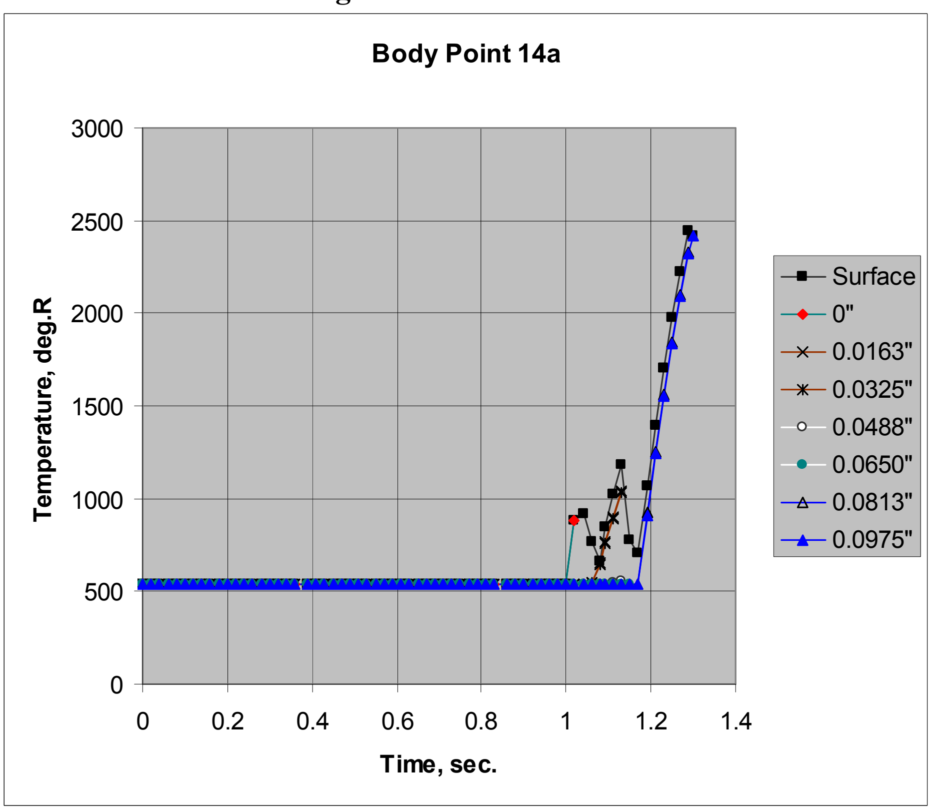


Figure 8. Thermal Response

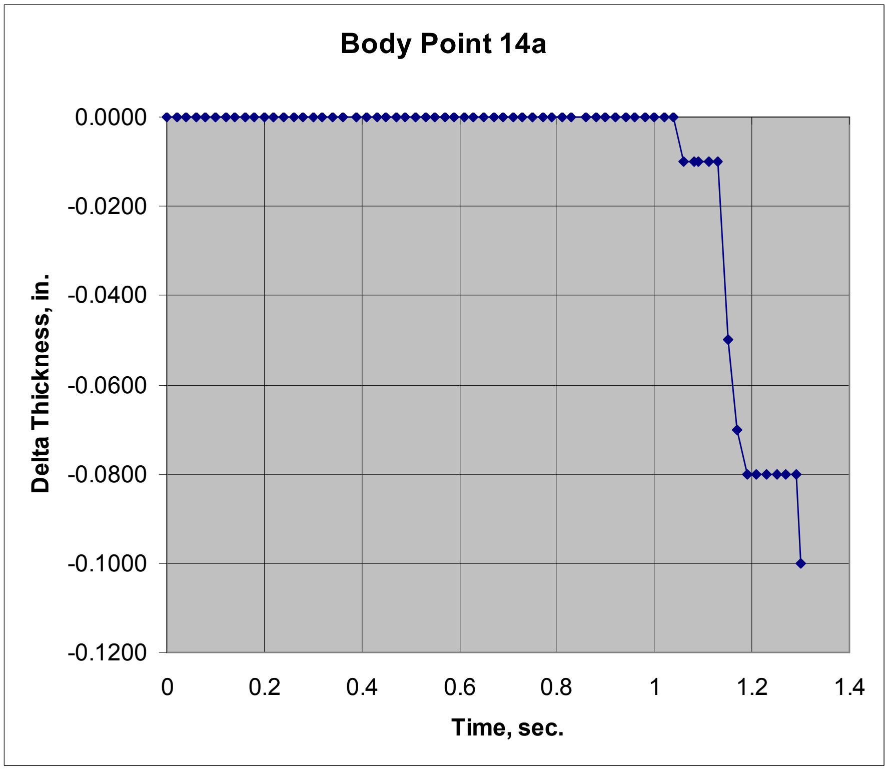
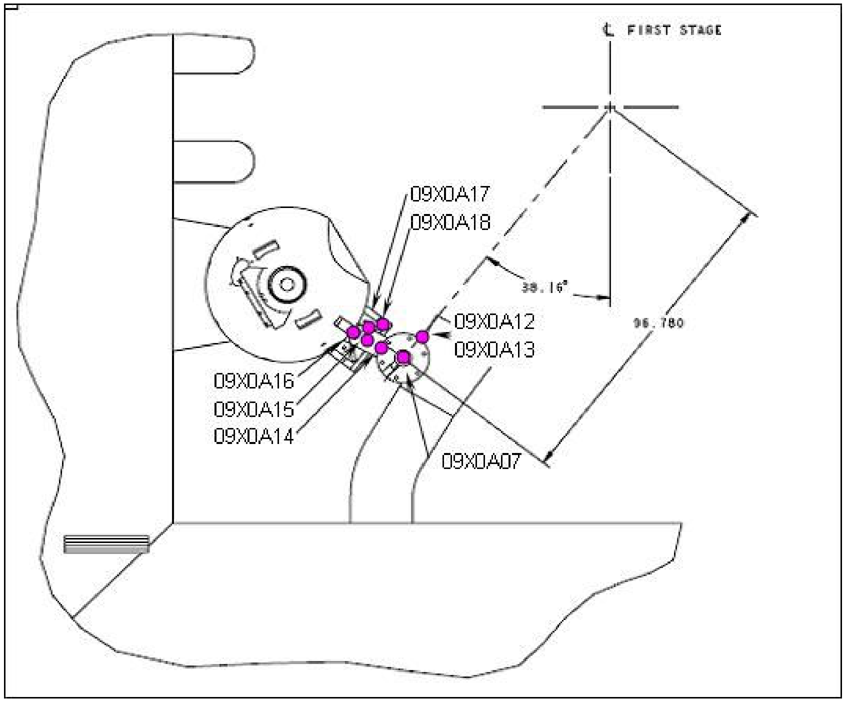


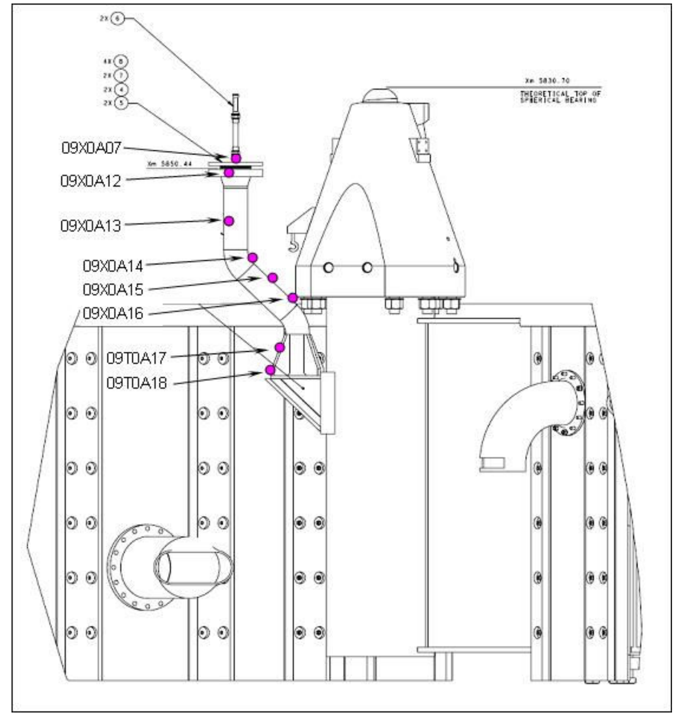
Figure 9. Material Loss

CLV Aft Skirt Umbilical

The aft skirt umbilical (ASU), previously know as the GN2 purge line, is subject to the direct impingement of the Crew Launch Vehicle (CLV) solid rocket exhaust plume (Figure 10). THERM1D has been used to calculate the thermal responses of the ASU during Ares-I launch. The launch-induced environments predicted at a body point 09XDA14 on the ASU are shown in Figure 11. The line is assumed to be made of 1.5-inch stainless steel.

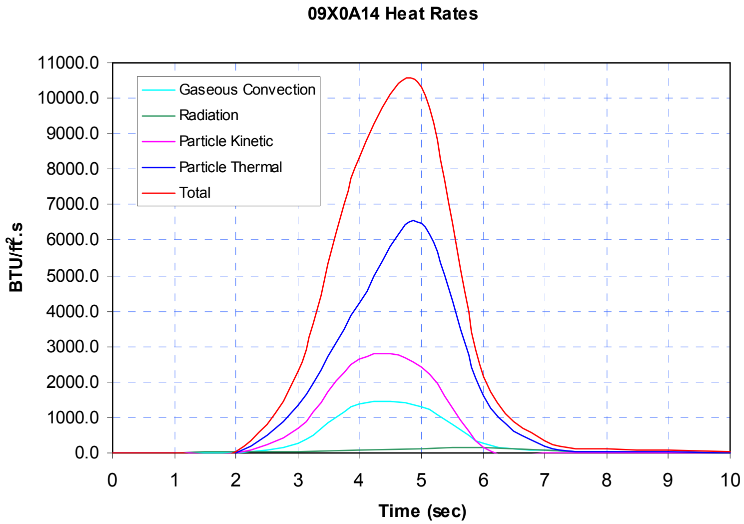
The thermal responses and material degradation of the ASU structure as predicted by THERM1D are shown in Figures 12 and 13, respectively. It is apparent that the top surface will reach steel melting temperature and will melt away at 4.2 seconds. The layers at 0.25" and deeper will never reach the melting temperature and will survive the rocket exhaust plume. In addition, there is an Aluminum Oxide particle buildup on the top surface. This particle layer can be considered as a protective coating and it helps slow down the melting and material degrading process. Figure 12 shows the thermal response of the particle layer.

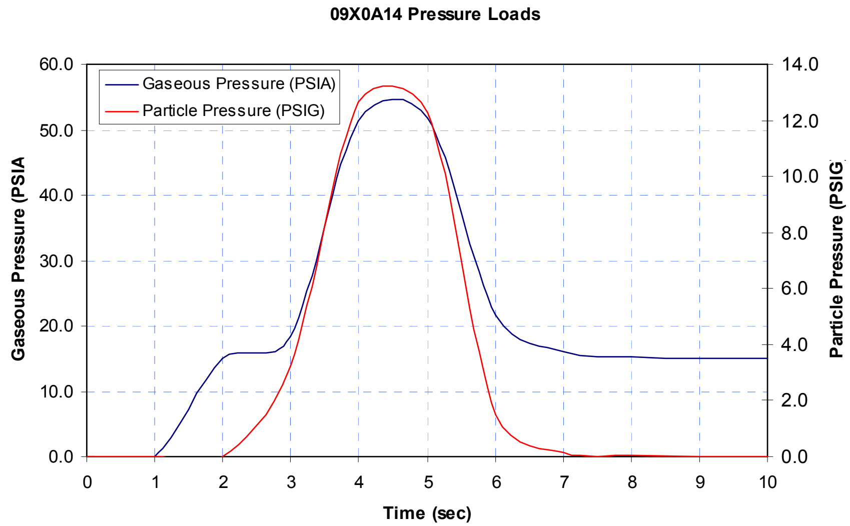




Body Point	Description	PLIMP Coordinate Frame (FT)			Launch Complex Coordinate Frame (IN)		
		X	Y	Z	X	Y	Z
09X0A07	GN2 Purge Line Top	12.50	-6.34	4.98	5850.0	-1300.1	-59.8
09X0A12	GN2 Purge Line Duct	12.13	-6.14	4.78	5854.4	-1297.6	-57.4
09X0A13	GN2 Purge Line Duct	11.27	-6.14	4.78	5864.8	-1297.6	-57.4
09X0A14	GN2 Purge Line Duct	10.32	-6.13	5.60	5876.1	-1297.5	-67.2
09X0A15	GN2 Purge Line Duct	9.84	-5.91	6.00	5882.0	-1294.9	-72.0
09X0A16	GN2 Purge Line Duct	9.29	-5.67	6.45	5888.6	-1292.1	-77.4
09X0A17	GN2 Purge Line Base	8.22	-5.66	5.64	5901.4	-1291.9	-67.7
09X0A18	GN2 Purge Line Base	7.55	-5.74	5.40	5909.4	-1292.9	-64.8

Figure 10. GN_2 Purge Line Geometry and Body Point Locations





Time	*Qc*	*Qr*	*Tr*	*Mdot*	*Qpke*	*Qpte*	*Pimp*	*Pimppar*	*Qtotal*
sec	BTU/ft^2·s	BTU/ft^2·s	R	lbm/ft^2·s	BTU/ft^2·s	BTU/ft^2·s	Psia	Psig	BTU/ft^2·s
0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0
2	8.8	31.0	1305.4	0.00	0.0	0.0	15.1	0.0	39.8
3	252.6	41.8	5414.1	2.76	687.4	1322.6	18.4	3.2	2304.3
4	1384.2	81.7	6035.0	8.90	2643.8	4199.2	51.3	12.7	8308.9
5	1284.6	126.0	6042.2	9.12	2422.7	6477.8	51.7	12.3	10311.1
6	255.7	146.8	5394.4	2.33	145.9	1603.9	21.6	1.5	2152.3
7	70.0	60.2	3386.7	0.55	5.8	197.5	16.0	0.1	333.5
8	29.6	36.6	2235.7	0.23	0.8	55.7	15.3	0.0	122.7
9	16.5	19.1	1712.5	0.13	0.2	23.3	15.1	0.0	59.0
10	10.5	2.3	1422.5	0.08	0.1	11.7	15.0	0.0	24.5

Figure 11. Body Point 09X0A14 Environments

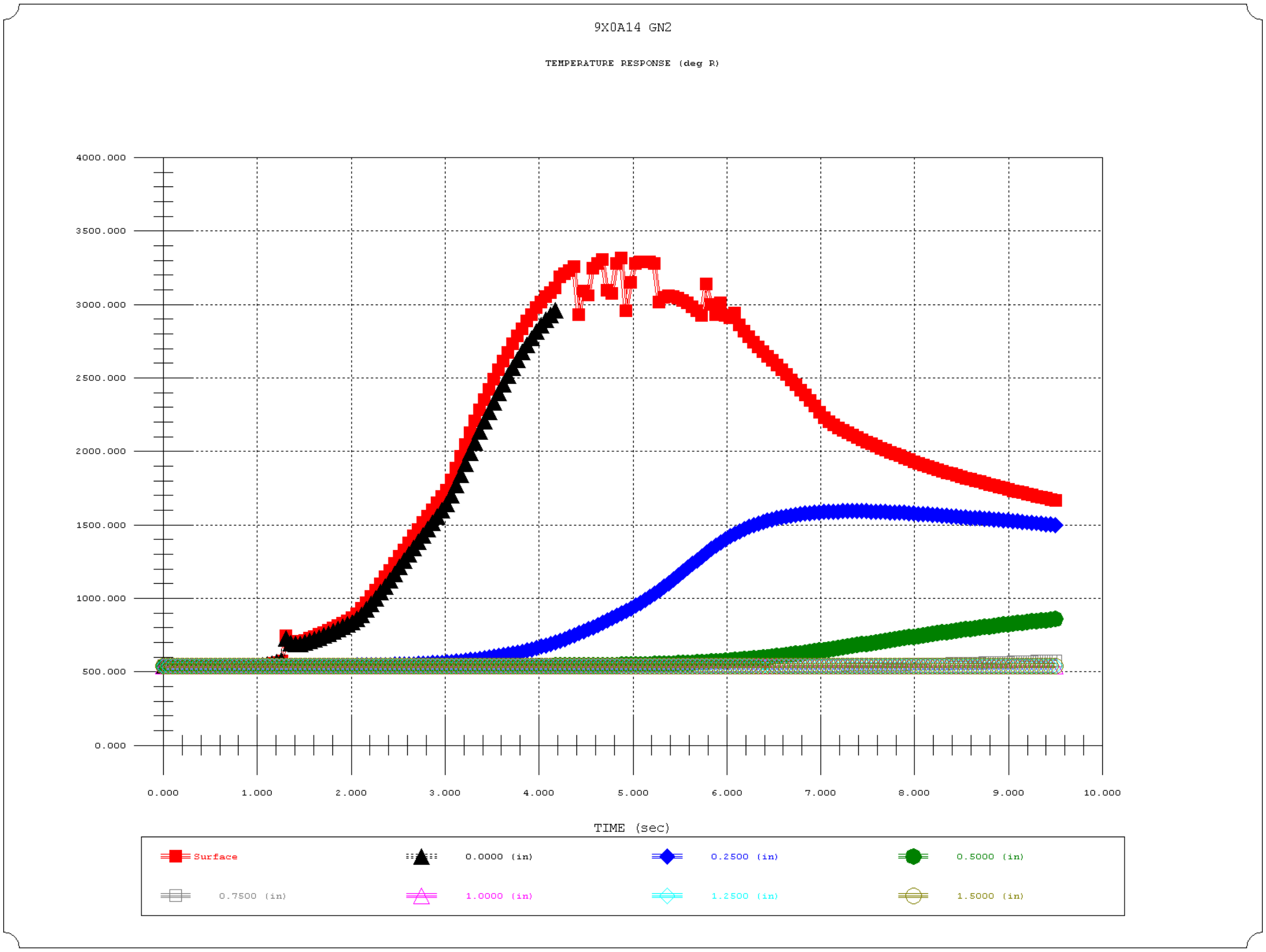


Figure 12. Thermal Responses

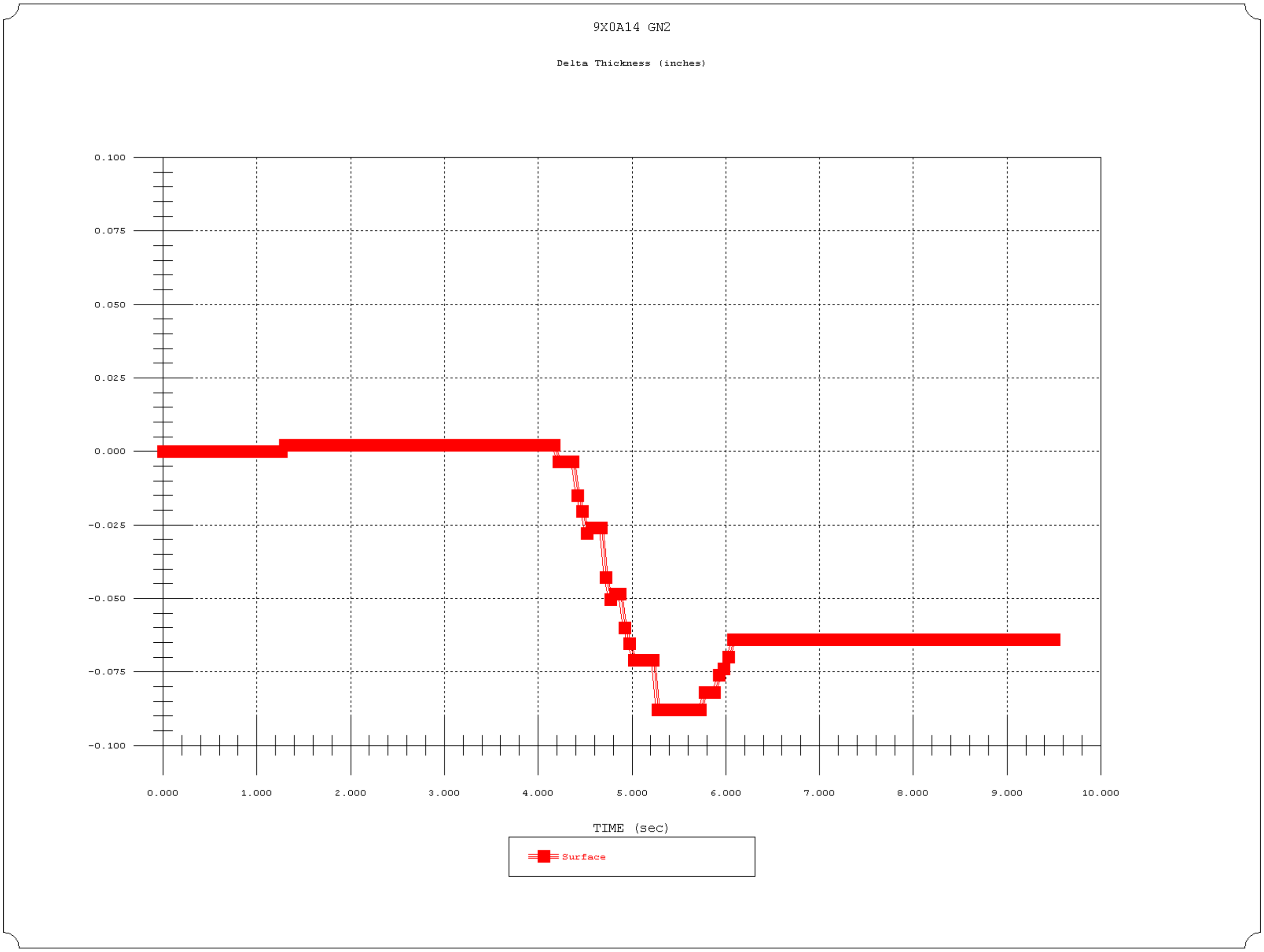


Figure 13. Material Degradation

ACKNOWLEDGEMENTS

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REFERENCES

1. Pond, J.E., "A Small Thermal Analyzer Package with Simplified Input," Lockheed Missiles & Space Company, Huntsville, AL, LMSC/HREC D162533, February 1971.
2. Smith, S., "Unified Test Stand Design and Environmental Impact Model," PT-FR-03-01, Plumetech, Huntsville, AL, Contract No. NAS13-01006, July 16, 2003.