SAND2007-3218C

A Conservative Representative Abnormal Thermal Fire Scenario for the B-61

Alex Brown, Kevin Dowding, and Roy Hogan

Tri-Labs Meeting

May 10, 2007

Objectives

- Pursuant to the safety theme of the B61 system, we are interested in fire scenarios.
- Would like to examine scenarios that are both conservative and representative.
  - Proceeding under the assumption that the maximum flux from the fire will produce the most conservative scenario.
- Met with system team and speculated that a fire with the system half-buried in the snow might give a conservative and representative scenario.
- Employ the Fuego ASC tool because the fire predictions can couple to Calore for thermal response and statistical analysis.
- Stress the ASC tools as part of the Advanced Deployment concept.

Methods

- Constructed a system exterior geometry for meshing in Cubit.
- Performed preliminary scoping to place the system in the most thermally severe part of the fire.
  - Scaled the size of the liquid pool (3.24 m x 8.68 m).
  - Examined the effect of various blockages on the fire.
  - Built a wind inlet boundary condition for modeling the air flow.
- Selected five parameters to optimize.
- Employed Dakota to generate a calculation matrix.
- Employed new capability:
  - Wind-like boundary conditions (Developed for this application)
  - Cantera for thermodynamic properties
  - Responsive fuel evaporation model (Brown and Vembe, 2006)
  - Porous media for blocking object

Wind Boundary Condition

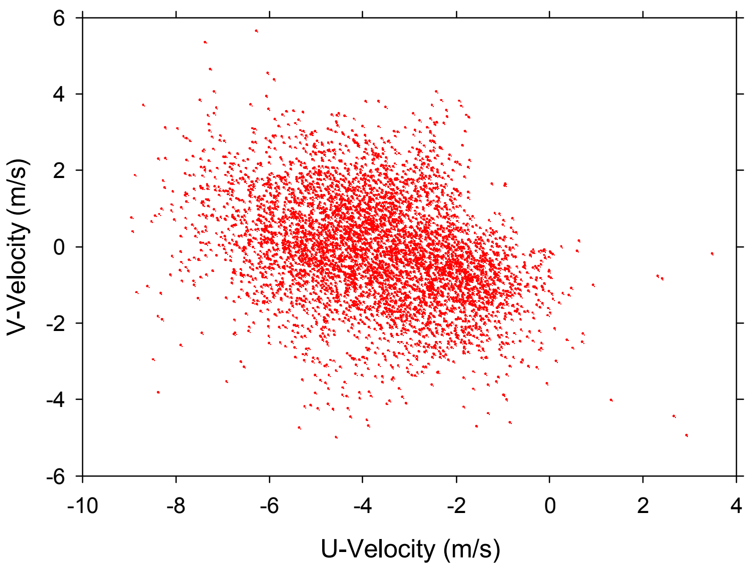
$$U = U_0 + A_1 \sin\left(\frac{2\pi t}{P_1} + \frac{(y+z)}{C_1}\right) + A_1 \sin\left(\frac{2\pi t}{P_1} + \frac{(y-z)}{C_2}\right) + A_2 \sin\left(\frac{2\pi t}{P_2} + \frac{\left[(y-y_c)^2 + (z-z_c)^2\right]^{1/2}}{C_3}\right)$$

$$V = \frac{C_4 A_1}{C_1}\cos\left(\frac{2\pi t}{P_1} + \frac{(y+z)}{C_1}\right) + \frac{C_4 A_1}{C_2}\cos\left(\frac{2\pi t}{P_1} + \frac{(y-z)}{C_2}\right) + \frac{C_4 A_2}{C_3}\frac{[y-y_c]}{\left[(y-y_c)^2 + (z-z_c)^2\right]^{1/2}}\cos\left(\frac{2\pi t}{P_2} + \frac{\left[(y-y_c)^2 + (z-z_c)^2\right]^{1/2}}{C_3}\right)$$

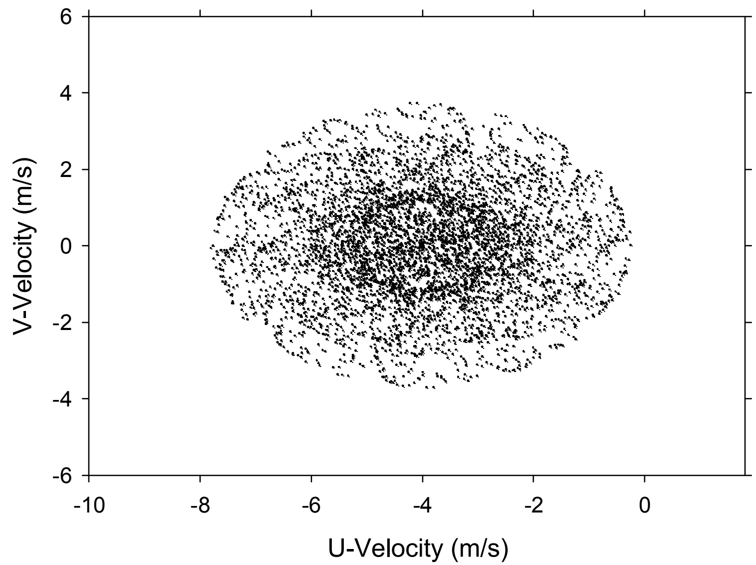
$$W = \frac{C_4 A_1}{C_1}\cos\left(\frac{2\pi t}{P_1} + \frac{(y+z)}{C_1}\right) - \frac{C_4 A_1}{C_2}\cos\left(\frac{2\pi t}{P_1} + \frac{(y-z)}{C_2}\right) + \frac{C_4 A_2}{C_3}\frac{[z-z_c]}{\left[(y-y_c)^2 + (z-z_c)^2\right]^{1/2}}\cos\left(\frac{2\pi t}{P_2} + \frac{\left[(y-y_c)^2 + (z-z_c)^2\right]^{1/2}}{C_3}\right)$$

- **Used a simple continuous function to describe the wind boundary.**
- **Capable of reasonable approximation to data distributions.**

Data



Model



Pool Model Theory

Thermal loading and material properties are taken as input:

$$q''_{total,pool} = \alpha q''_{incident} - \alpha\sigma T^4_{pool} + q''_{conv}$$

$f_{sensible}$, the fraction of absorbed energy used to heat the liquid, is calculated using an empirical assumption:

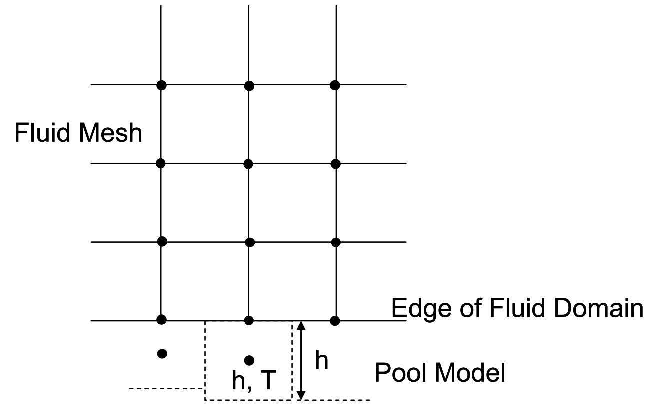
$$f_{sensible} = \max(\min((T_{boil} - T_{pool}) / \Delta T_{b,f}, f_{\max}), 0.0)$$

Pool response may then be calculated:

$$\frac{dT_{pool}}{dt} = \frac{q''_{total,pool} f_{sensible}}{h\rho C_p}$$

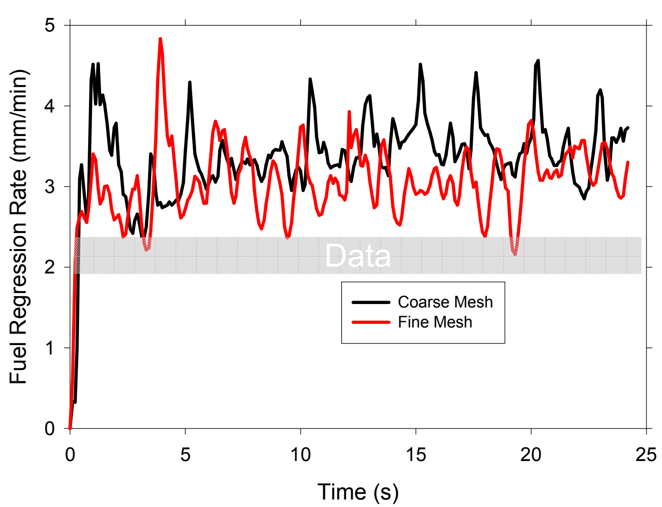
$$\frac{dh}{dt} = \frac{q''_{total,pool}(1 - f_{sensible})}{H_{evap}\rho}$$

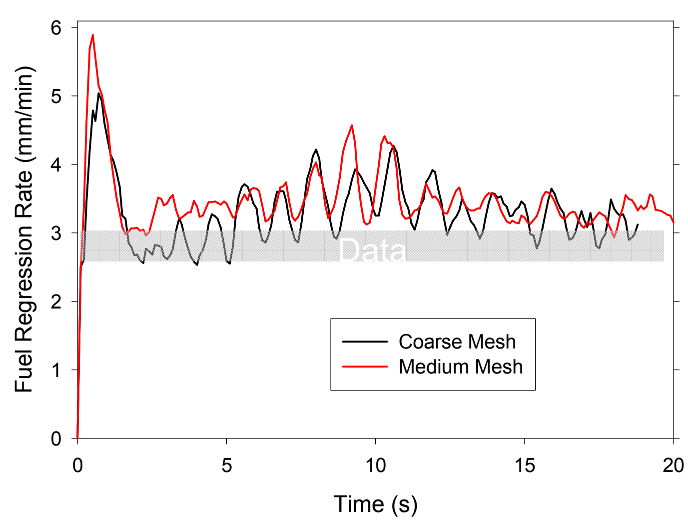
$$\frac{dm}{dt} = \frac{q''_{total,pool} A(1 - f_{sensible})}{H_{evap}}$$



Pool Model Characterization

- **Comparisons made for four practical and large scale cases.**
  - Testing was for a variety of problems in the large-scale test range (1-5 meters characteristic length), multiple fuels, cross-flow configurations.
- **Study Conclusion:**
  - Predicted fuel regression rates are mostly reasonable, with up to 50% errors for the worst case.





Baseline Model

- **Fuego was employed for the fire calculations:**
  - Employed the TFNS turbulence model
  - Syrinx Discrete Ordinates for radiation calculation
  - ~600,000 node mesh for the fluid region
  - Surrogate system model to save the thermal boundary condition
  - Use of the porous media model allowed definition of the object without having to re-mesh
- **Dakota was used to design the tests**
  - Latin Hypercube Sampling (LHS)
  - Automated input file generation to reduce likelihood of mistakes

Sensitivity of Fire Scenario to 5 Parameters Investigated

Table Includes Variable Designations and Ranges considered

x-loc	z-loc	U-ave	U-inten1	U-inten2
(m)	*(m)*	*(m/s)*		
-3.37	**-10.5**	**2.0**	**0**	**0.8**
6.9	**-7**	**8**	**0.3333**	**1.5**

- **Location of an obstruction (x-loc, z-loc)**
- **Inlet velocity**
- **Inlet Fluctuation Intensity Factors**

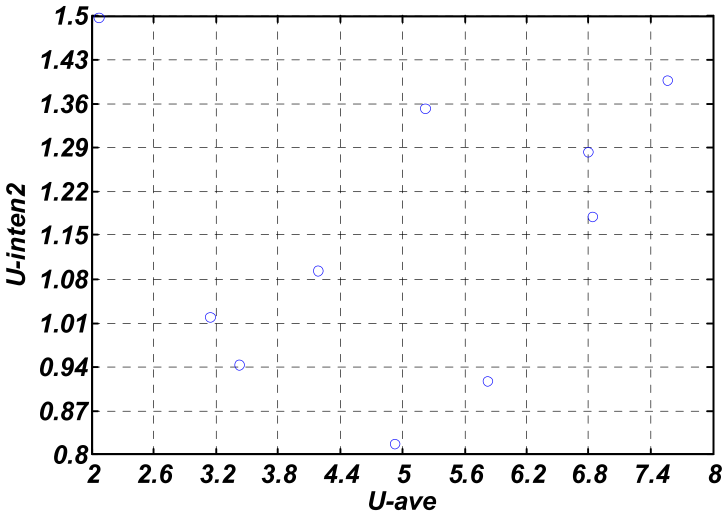
$$A_1 = U - ave \times U - int\,en1$$

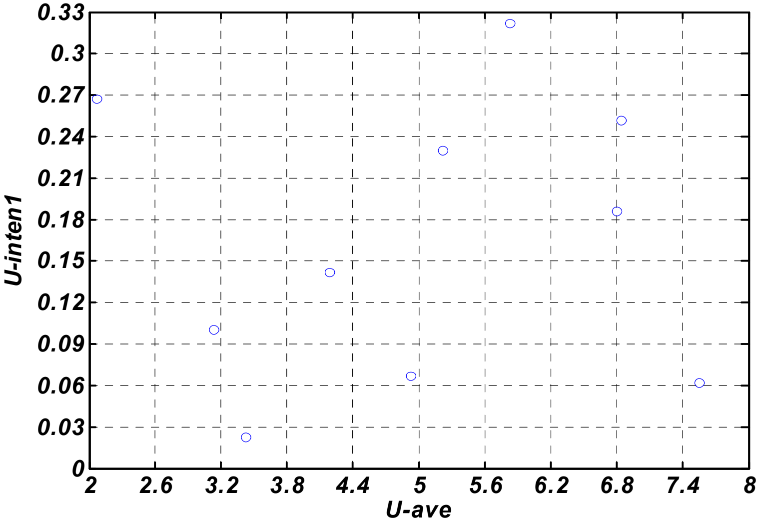
$$A_2 = A_1 \times U - int\,en2$$

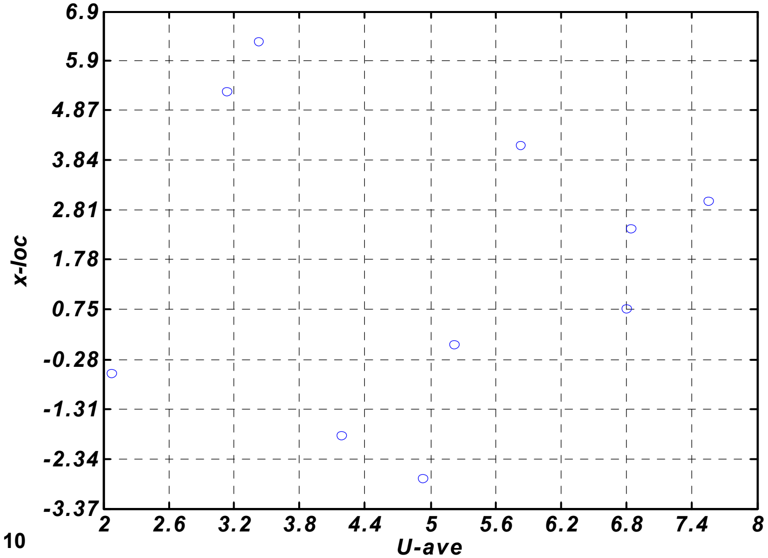
Parameter combinations selected with Latin Hypercube Sampling (10 samples)

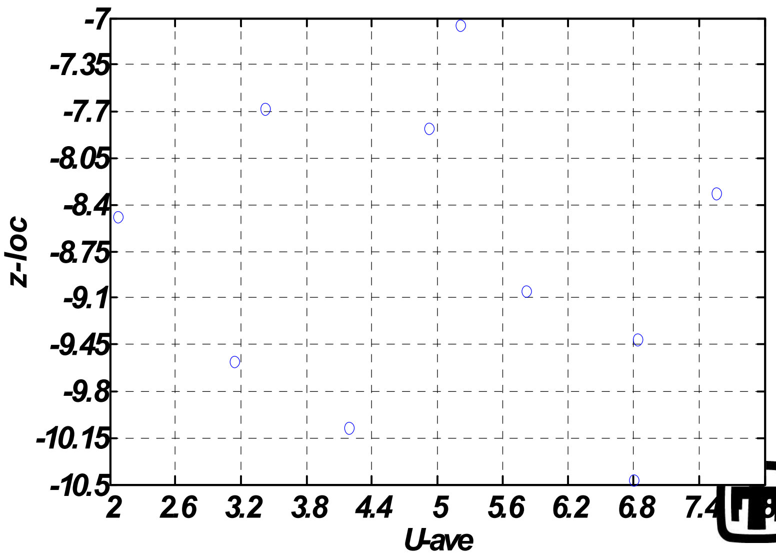
x-loc	z-loc	U-ave	U-inten1	U-inten2
2.9938	-8.3185	7.5560	0.0621	1.3970
4.1333	-9.0510	5.8208	0.3216	0.9189
-0.5792	-8.4939	2.0691	0.2676	1.4968
2.4254	-9.4057	6.8380	0.2517	1.1810
5.2449	-9.5800	3.1379	0.1005	1.0192
-2.7342	-7.8296	4.9268	0.0671	0.8179
0.7674	-10.4612	6.7955	0.1863	1.2835
6.2820	-7.6815	3.4216	0.0225	0.9444
-1.8443	-10.0779	4.1887	0.1420	1.0941
0.0384	-7.0507	5.2162	0.2298	1.3525

Parameter Samples









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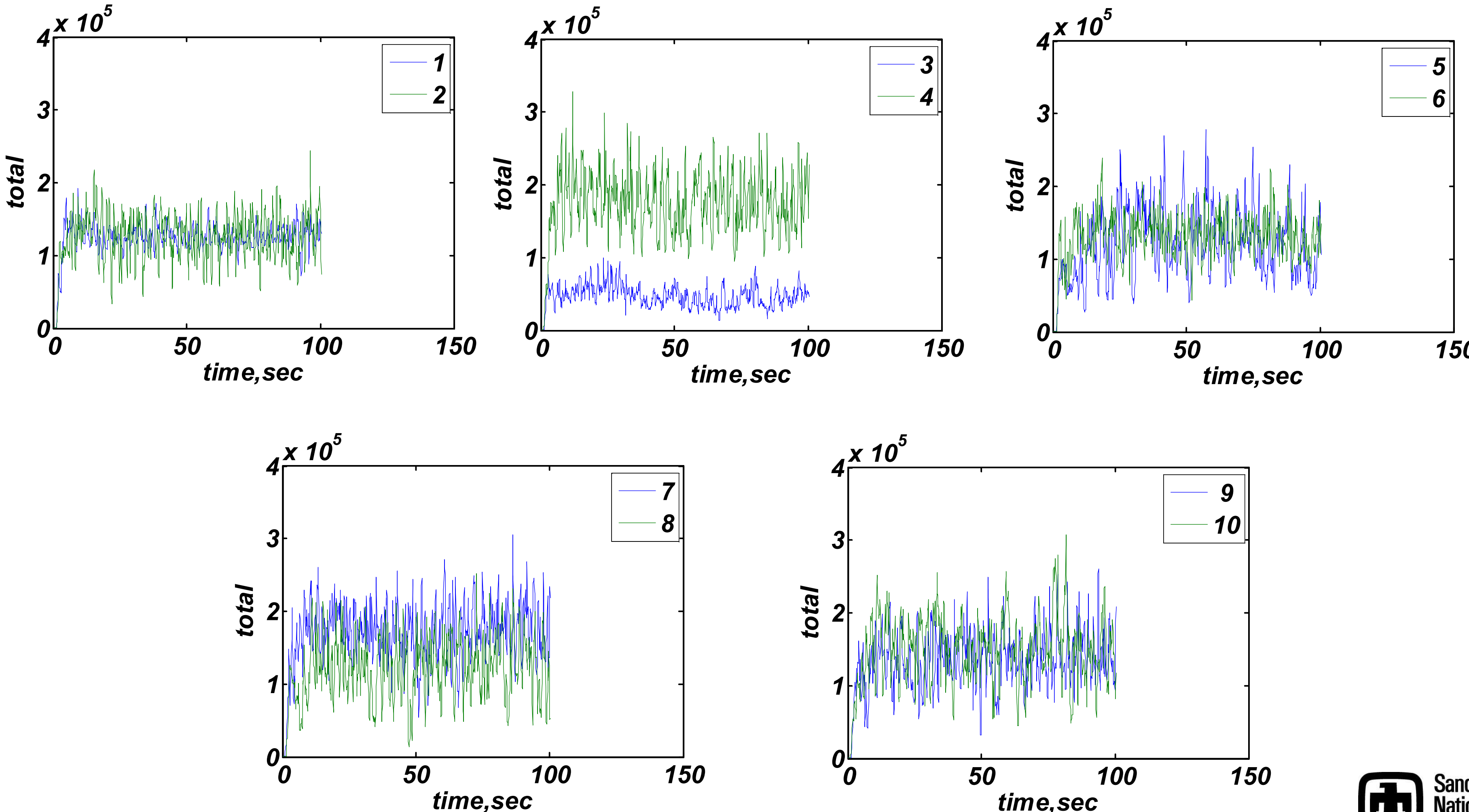
Output of interest is the total energy on a surface of the weapon

- **Heat flux on the surface of the weapon is computed as a function of time**
  - At least 100 second duration fire
- **Total energy is computed by integrating heat flux over the surface and averaging over time region**
  - Steady condition: 15 to 100 seconds
- **Performing analysis on the total incident flux plus the convective flux.**

Total Q on the surface of the weapon: Raw Data



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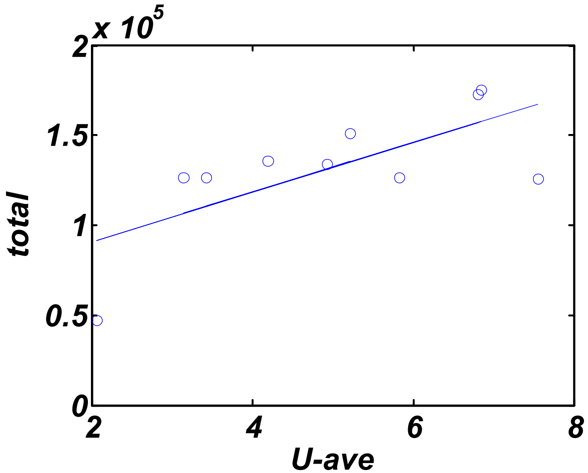
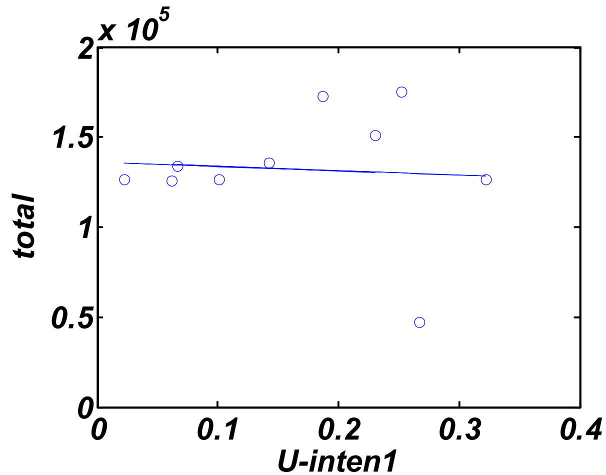
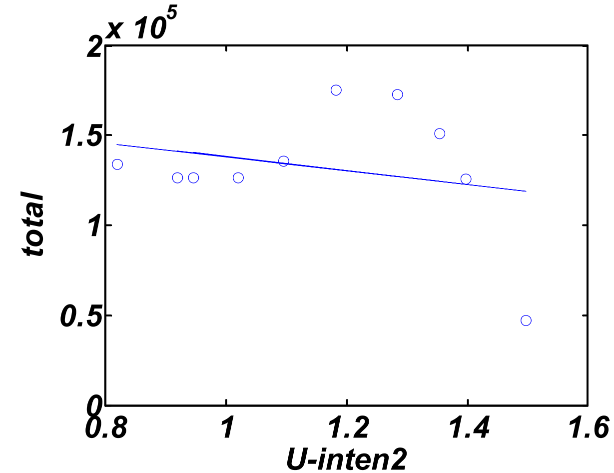
Ranking of parameter sets for maximizing Q

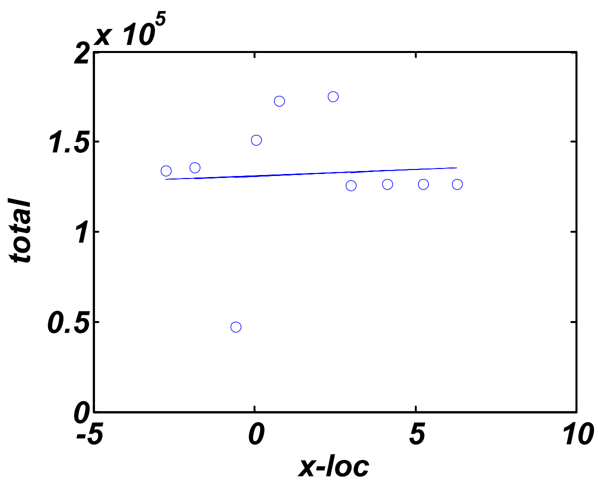
Run	Rank	x-loc [-3.37, 6.9]	z-loc [-10.5, -7]	U-ave [2,8]	U-inten1 [0, 0.33]	U-inten2 [0.8, 1.5]	Q (KW/m^2)
1	9	2.9938	-8.3185	7.5560	0.0621	1.3970	125.8
2	7	4.1333	-9.0510	5.8208	0.3216	0.9189	126.6
3	10	-0.5792	-8.4939	2.0691	0.2676	1.4968	47.2
4	1	2.4254	-9.4057	6.8380	0.2517	1.1810	175.4
5	5	5.2449	-9.5800	3.1379	0.1005	1.0192	126.8
6	6	-2.7342	-7.8296	4.9268	0.0671	0.8179	134.4
7	2	0.7674	-10.4612	6.7955	0.1863	1.2835	172.8
8	7	6.2820	-7.6815	3.4216	0.0225	0.9444	126.4
9	4	-1.8443	-10.0779	4.1887	0.1420	1.0941	136.5
10	3	0.0384	-7.0507	5.2162	0.2298	1.3525	151.2

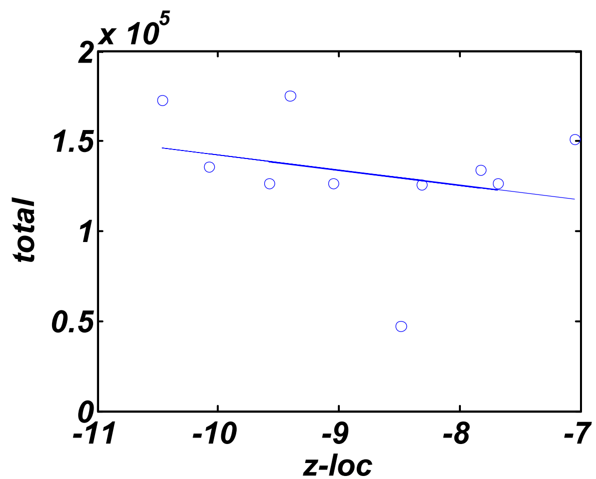
Total Q vs. each parameter for all 10 runs











Var	ρ (CC)	SRC
U-ave	0.70	0.71
U_int1	- 0.07	- 0.07
U-int2	- 0.25	- 0.31
x-loc	0.07	- 0.01
z-loc	- 0.27	- 0.16

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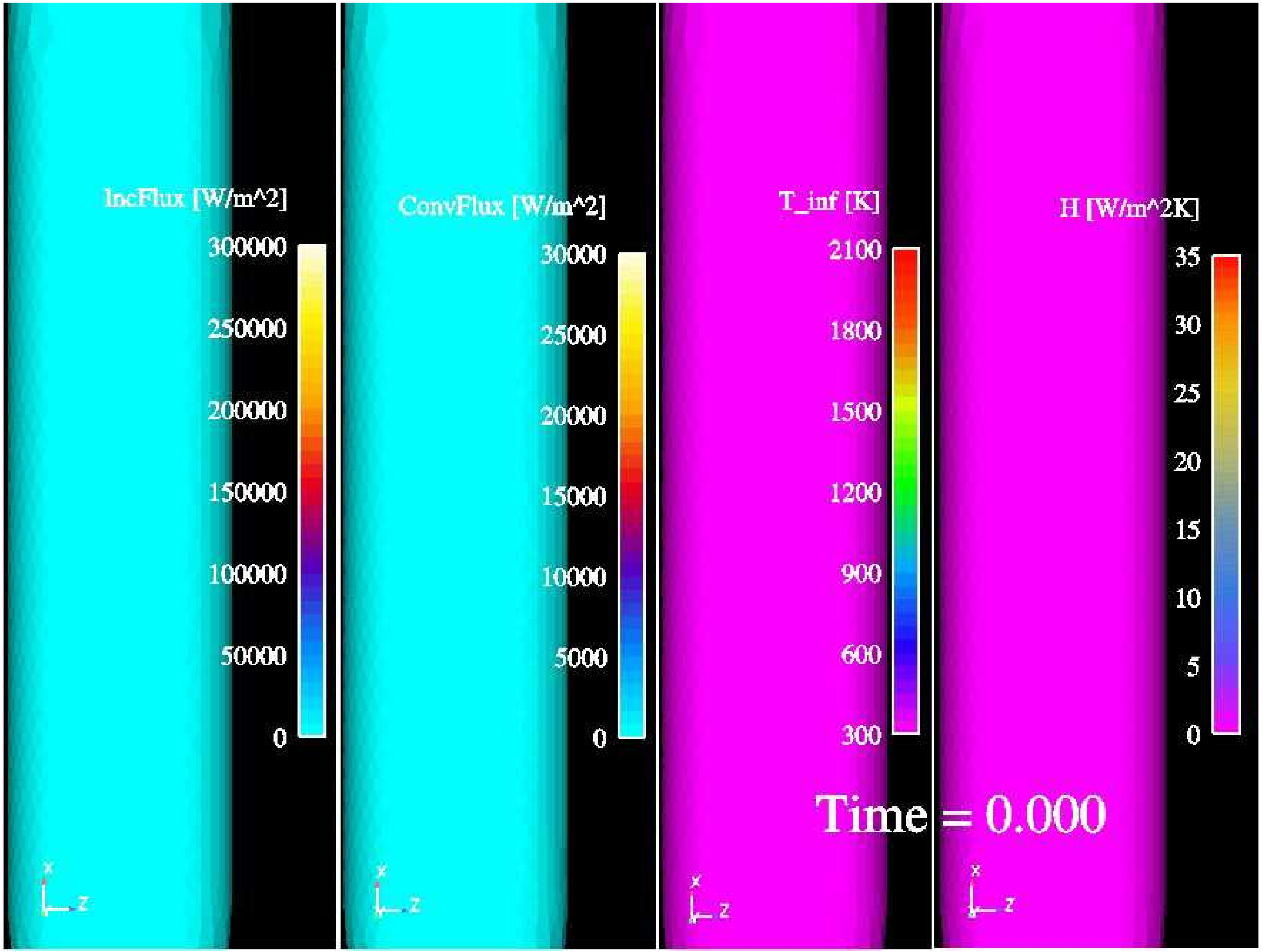
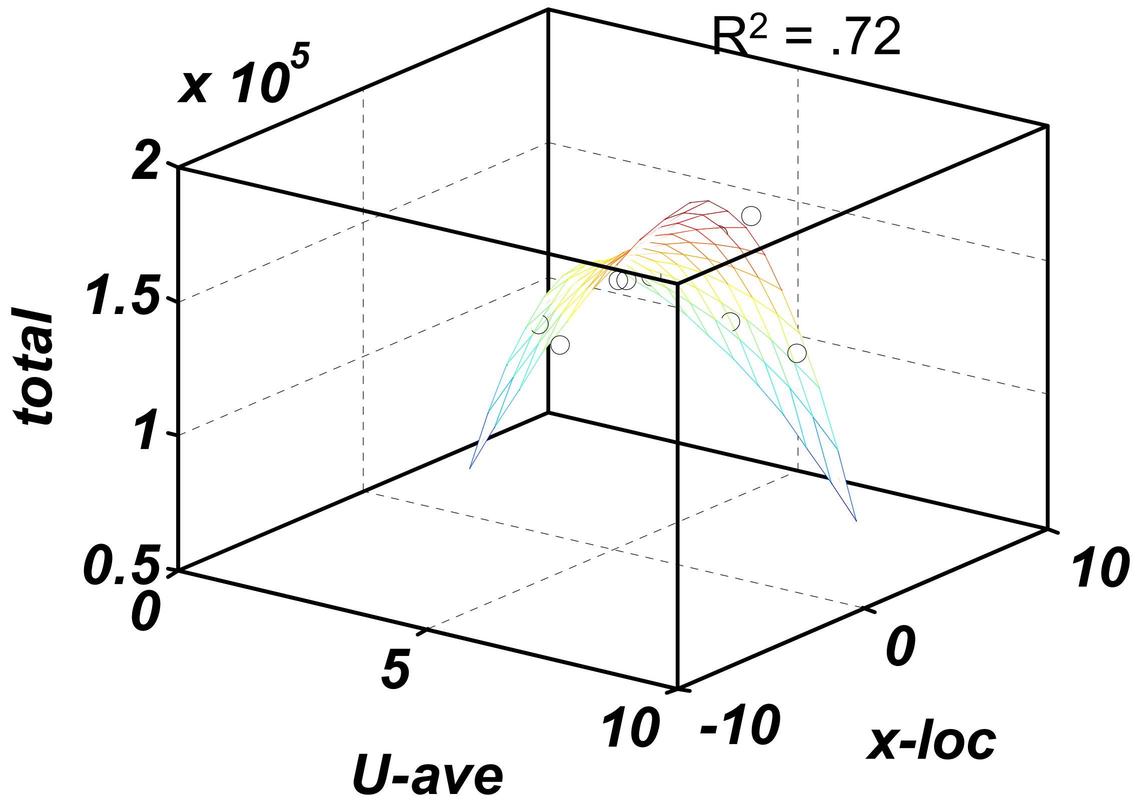
An Example of the Predicted Object Environment (case 4)

Radiative Flux | Convective flux | Gas Temperature | Convective Heat Transfer Coefficient



In Progress: Response Modeling Linear + interaction + 2-quad



This fit assumes dependence on U-ave and x-loc only.

Fit suggests:

- The additional variables may be significant.
- More data might help fit accuracy.

Summary

- **Performed a study used to identify the dependence of the total energy on the weapon to scenario parameters**
- **Sensitivity analysis is not yet capable of identifying dominant parameter(s)**
  - Small sample size (10), nonlinear dependence impacted the study
  - In-progress analysis yields moderate to poor fit
  - Further work expected to improve the fit
- **Regardless of fitting, ten scenarios have been modeled**
  - The most severe of which may be considered 'conservative'
- **Subsequent work involves sensitivity analysis with Calore**