NAVSEA WARFARE CENTERS DAHLGREN

Gun and Electric Weapon Systems (E)

Radiant Chambers for Fast Cook-Off Testing and Simulation

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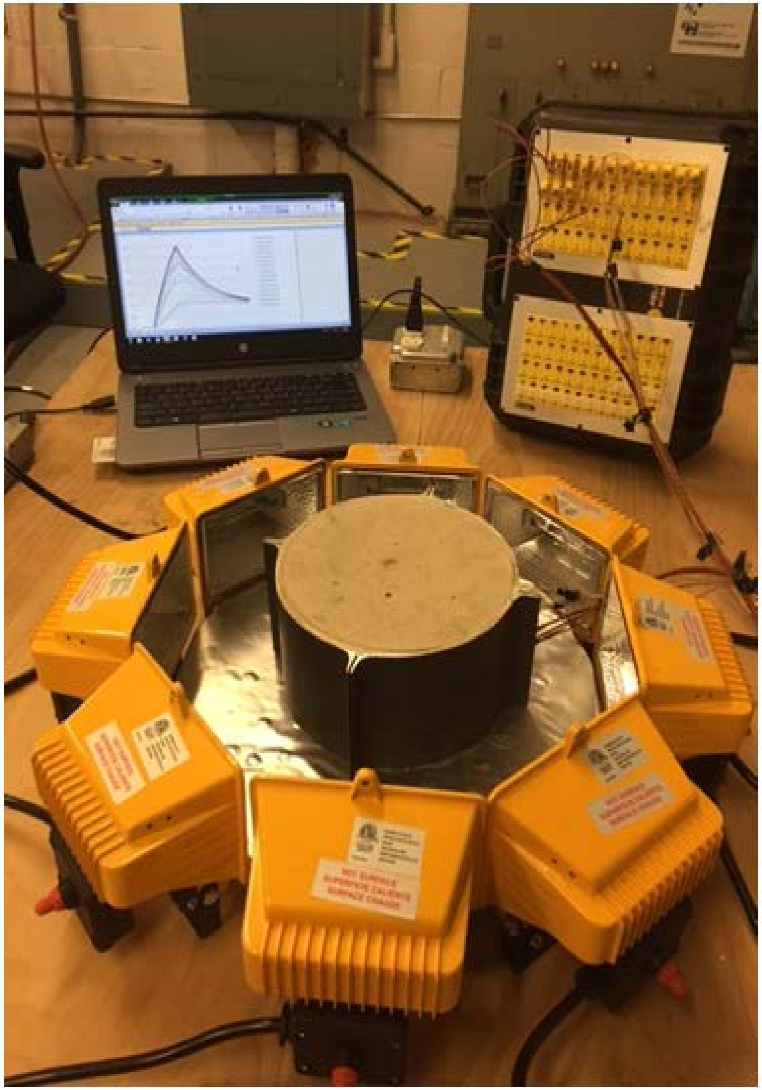
Paper No. 20262

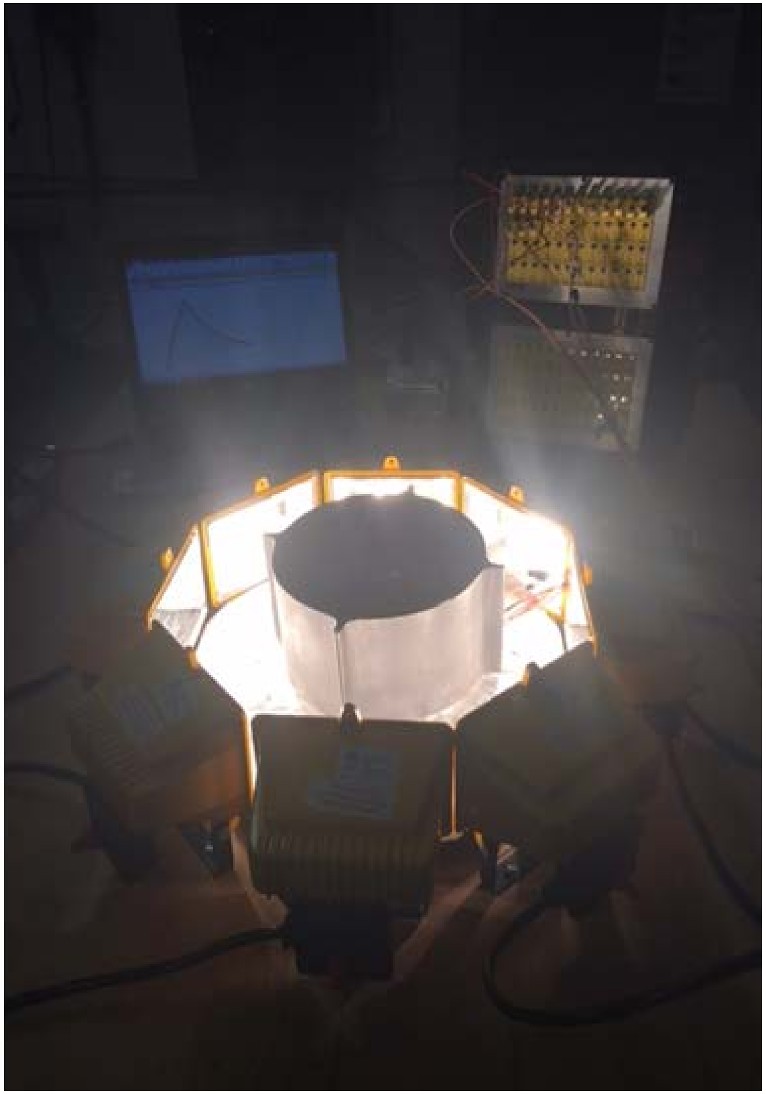
2018 Insensitive Munitions and Energetic Materials Technology Symposium

Portland, Oregon USA

April 2018

Radiant Chamber and Data Acquisition Equipment





Radiant Chamber and Data Acquisition Equipment

- Two radiant chambers built and tested
- Uniform radiation field for testing small items
- Calibrated with thermocouple rakes and calorimeters

✓ Used to test instruments before putting them in large fuel fires

✓ Highly controlled laboratory data for development of computer simulations

✓ Explaining experimental data from equipment being tested during development

Organization of the Paper

Calibrating the chambers

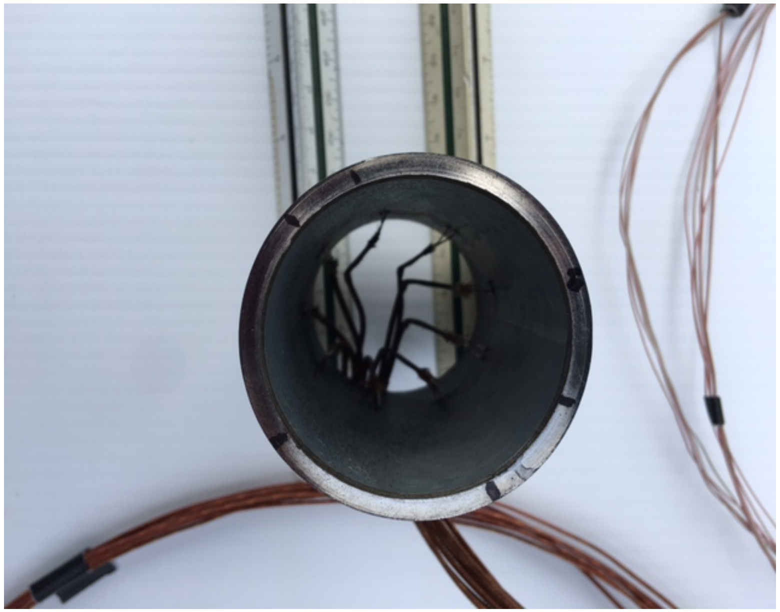
Checking and calibrating instruments

Checking and calibrating for test items

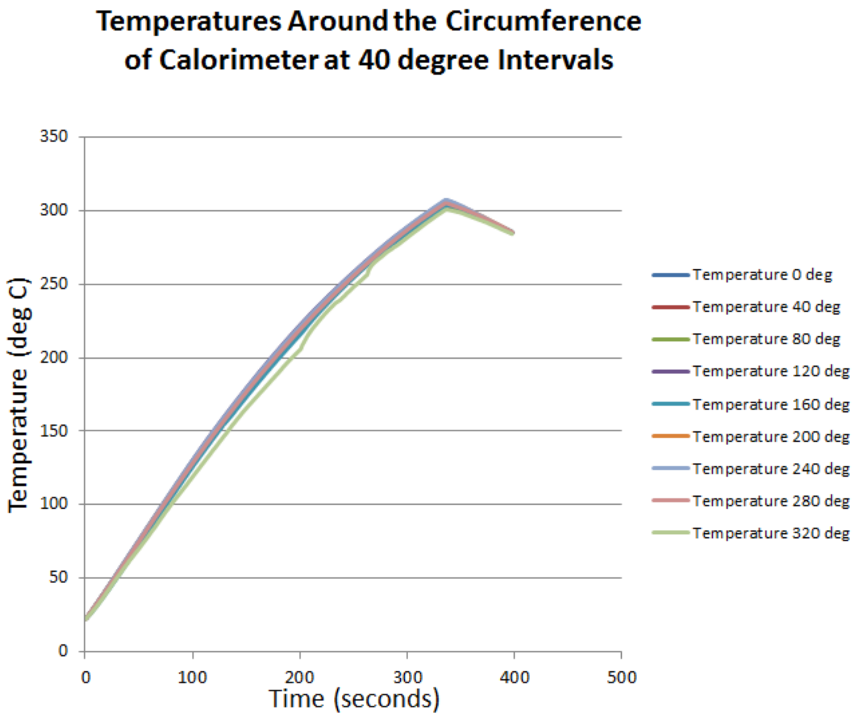
Testing a rocket motor

Temperature and Heat Flux Calibration

Temperature Around Circumference of Calorimeter



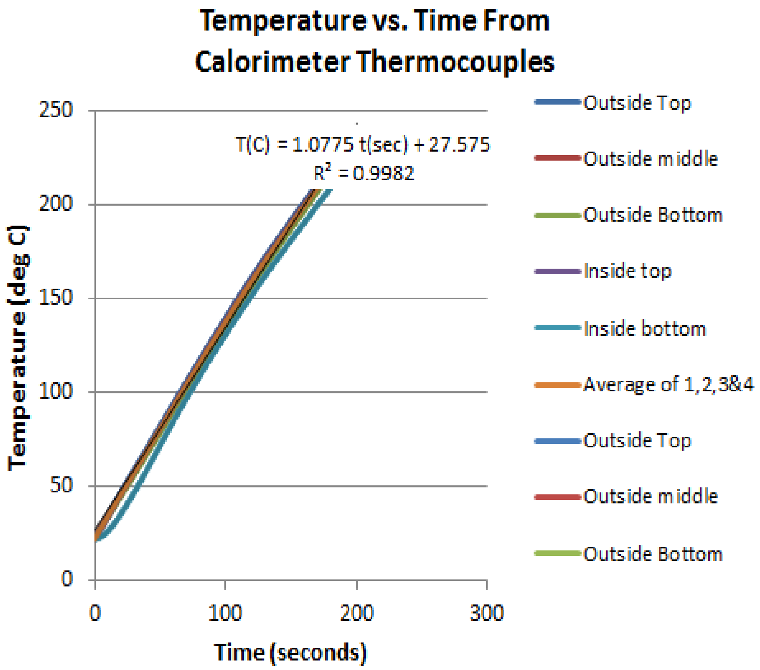
Calorimeter for showing angular uniformity of temperature



Nine locations radiated by eight lamps

Circumferential variation should be detected

Very little variation around the circumference



Temperature at three axial locations

Measurements inside and outside of the calorimeter

The temperature verses time traces on one line

Heat Flux Calibration

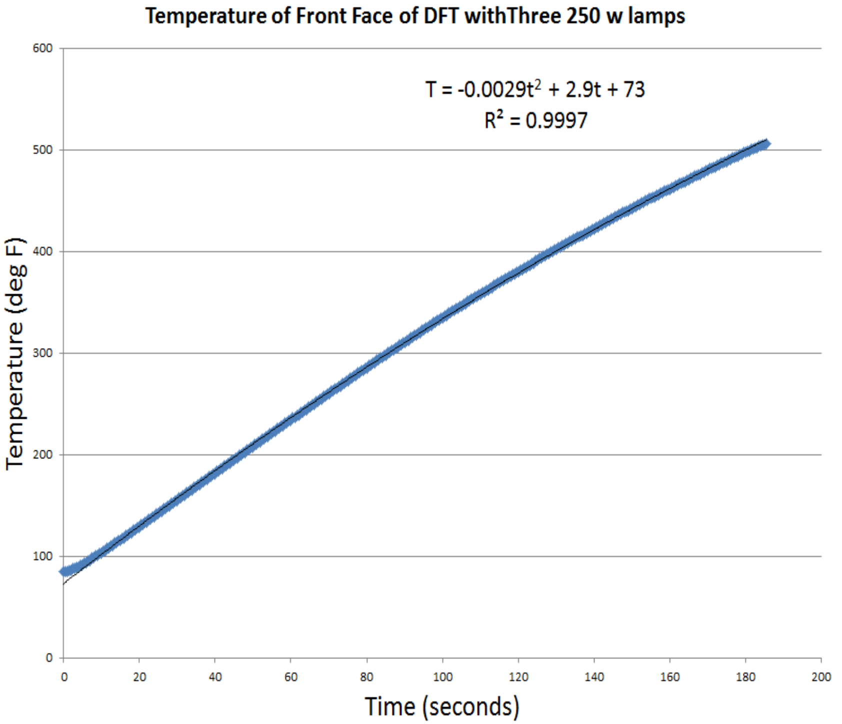
Compute Heat Flux				
dT/dt			1.078	Kelvins/sec
mass			0.517	kg
specific heat			896	j/kgK
C heat cacity			463	j/K
dQ/dt=mcdT/dt			499	J/s watts
			0.499	kw
diameter			2.391	in
			0.0607	m
circumference			0.191	m
length			3.391	in
			0.0861	m
area			0.01642	sq m
absorbed heat flux			30.4	kw/sq m

Absorbed heat flux 30.4 kW/m

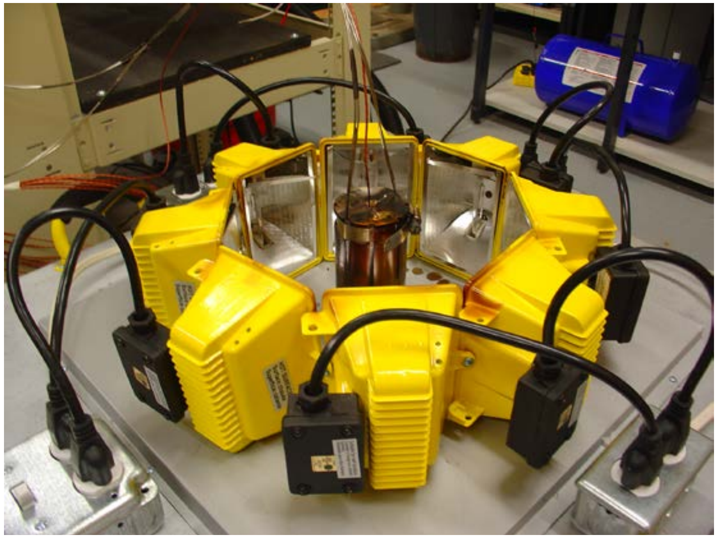
Spans range of the heat flux for encanistered missiles

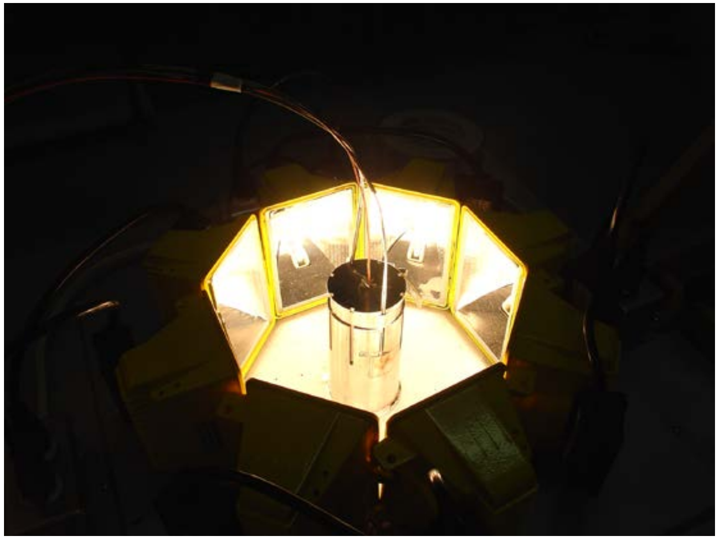
Checking and Calibrating Instruments

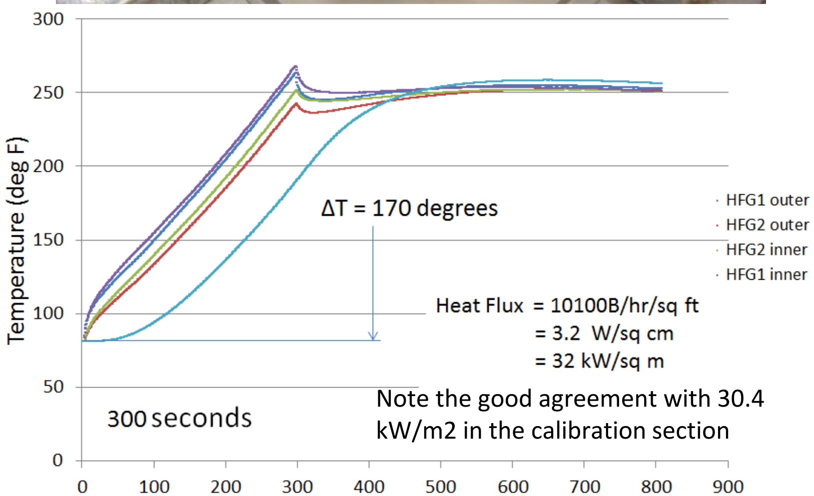
Differential Flame Thermometer Being Checked Out in Radiant Chamber

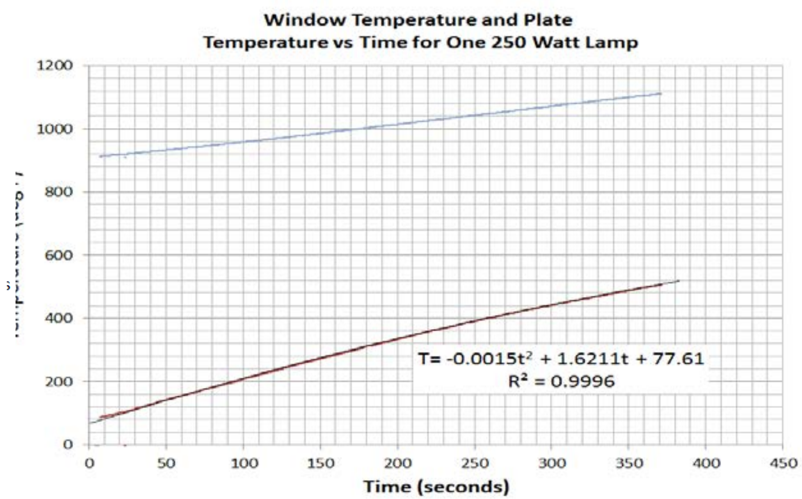


Heat Flux Calibration with a Low-Emissivity Thermopile Calorimeter

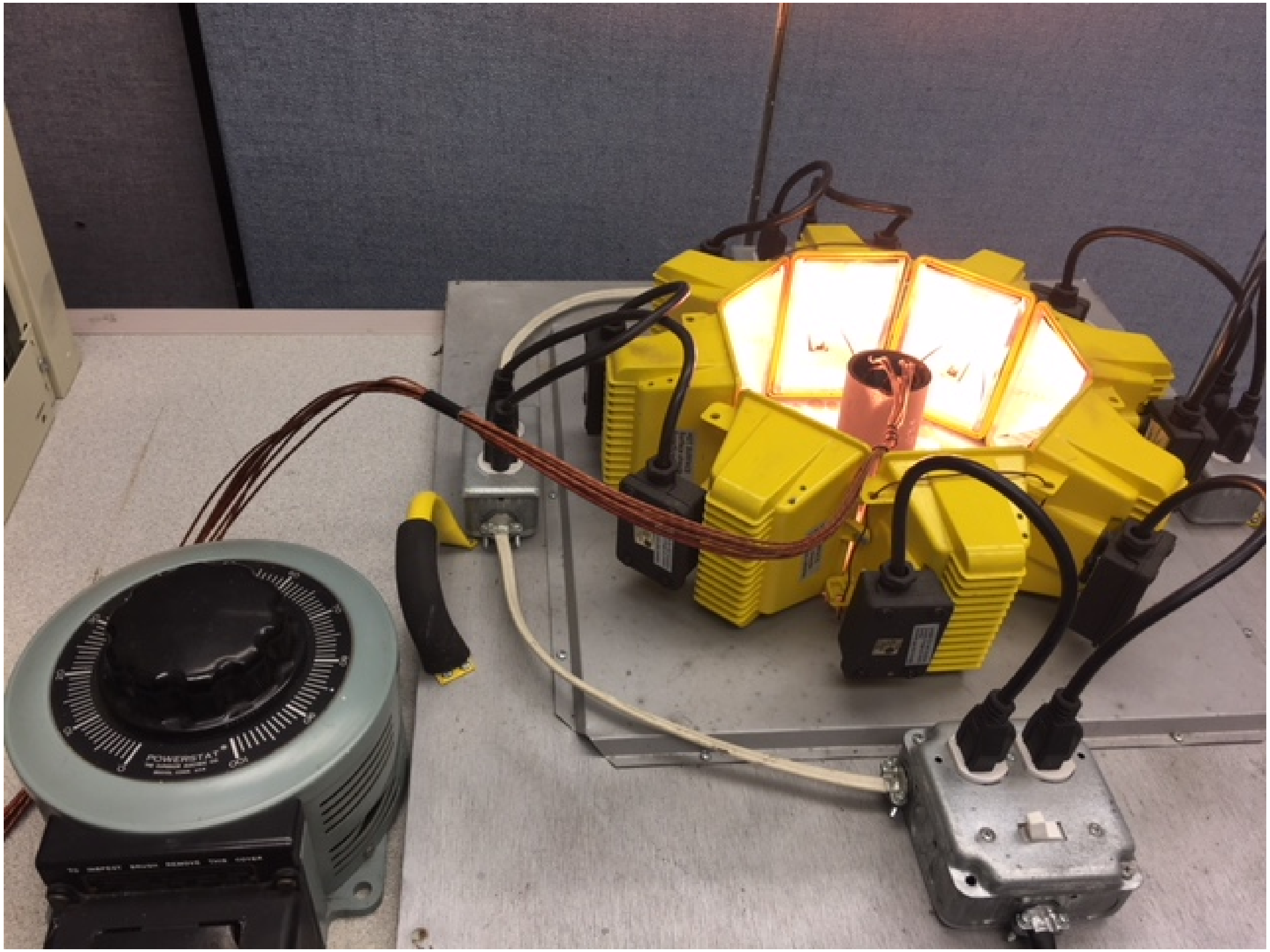








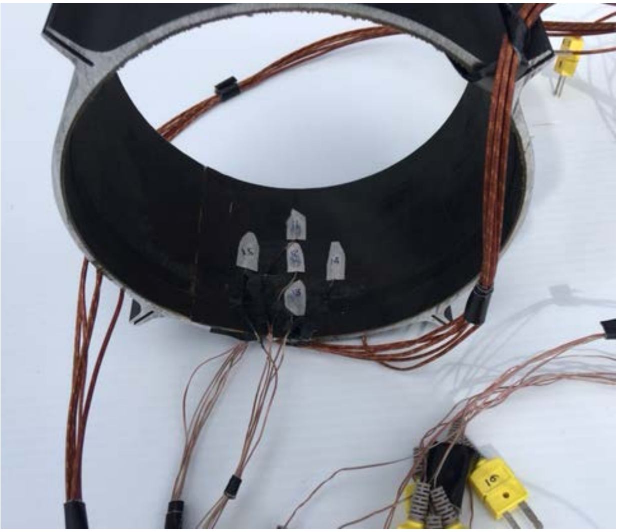
Variable Transformer Allows Adjustment of Heat Flux



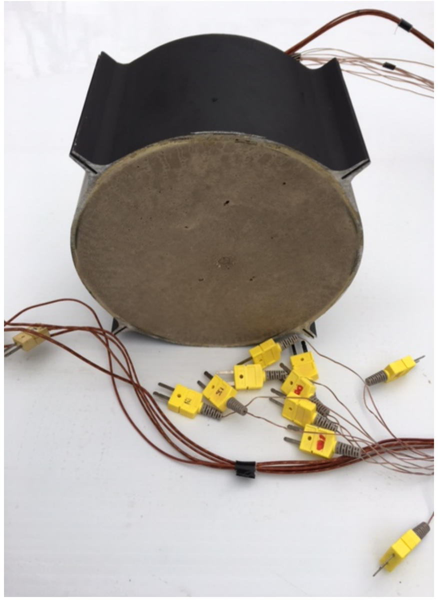
Magazine Safety Test

Buildup for Fast-Heating Test of Rocket Motor

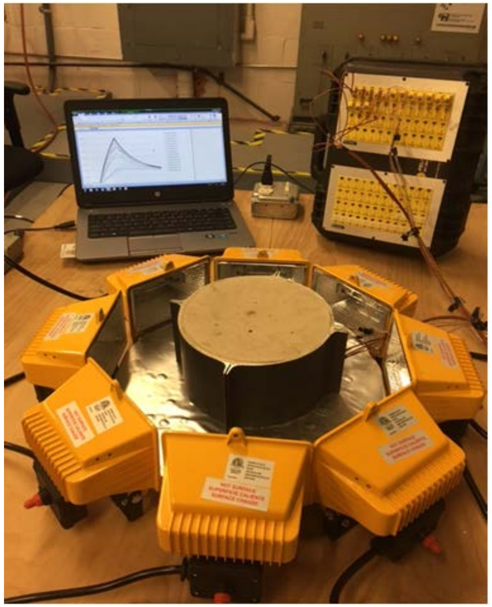
Empty Rocket Motor Casing



Motor Case Filled with Inert Propellant



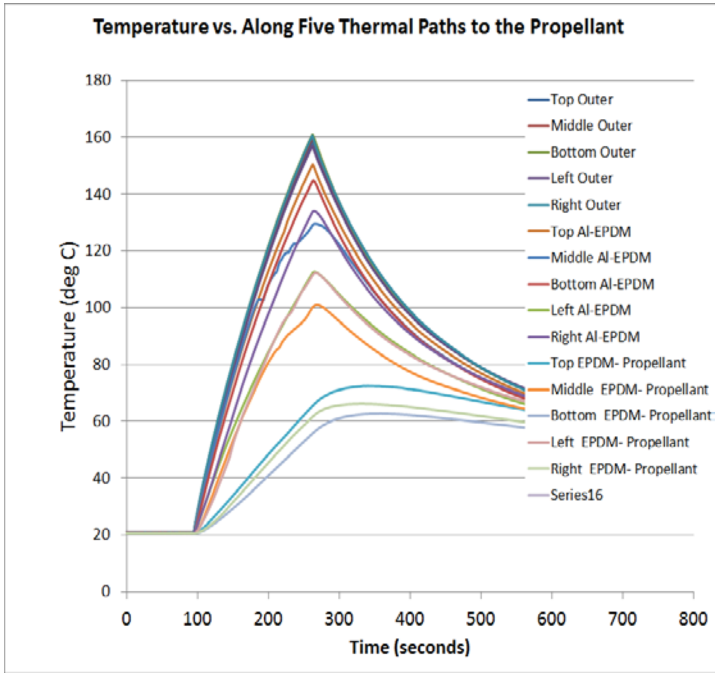
Full Setup with Instrumentation



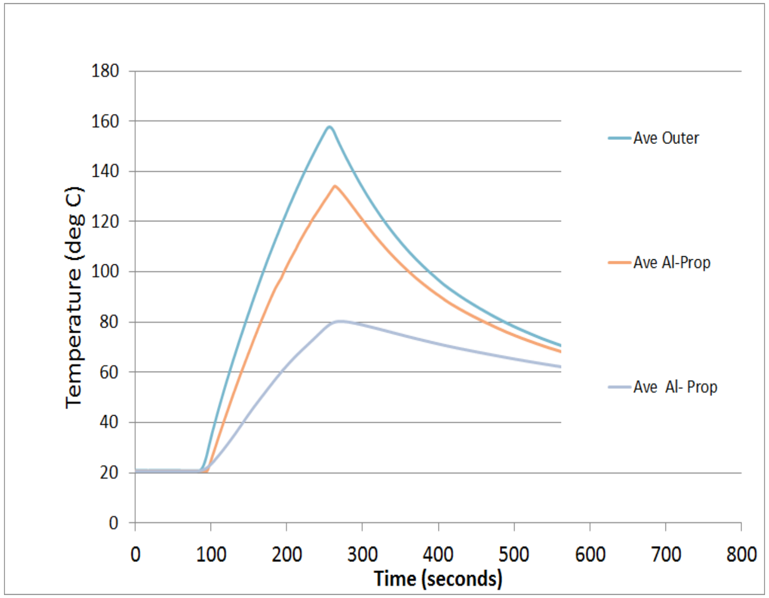
- Section of a real test motor
- Inert propellant simulant
- TCs along five thermal paths to propellant
- TCs on outer casing, between case and insulation, between the insulation and the propellant

Temperature Data Recorded During Heating in Chamber

Temperature Versus Time for All Fifteen (15) Thermocouples



Average Temperature Versus Time at Three Stations

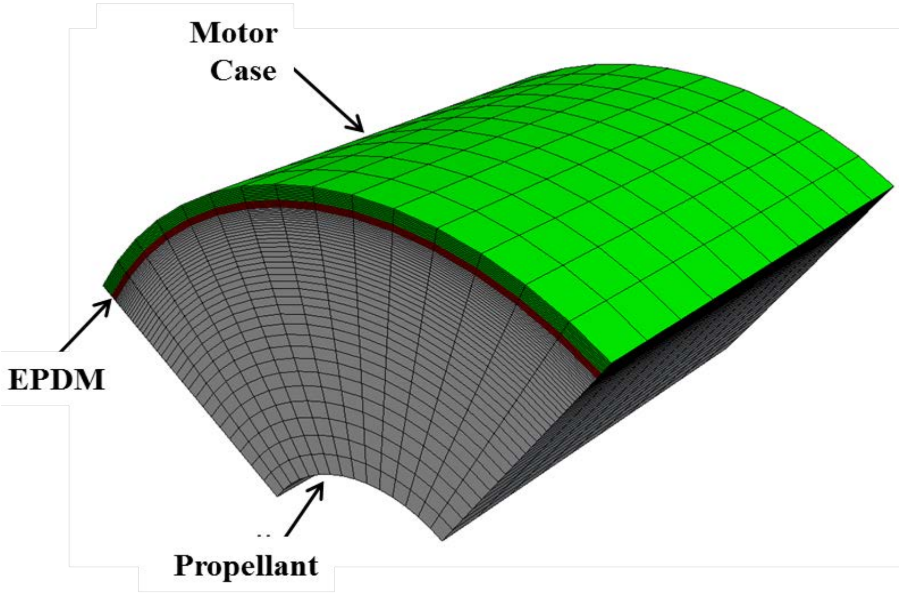


- Data recorded at fifteen (15) thermocouples
- Motor was heated for approximately 160 seconds
- Solved inverse heat transfer problem to determine material thermal properties

Computational Model Development

- Finite volume model of the rocket motor
- Heat transfer problem was solved using Aria
- Constant heat flux applied to outer surface to mimic radiant heat flux from chamber
- Convection was assumed negligible compared to radiation
- Initial material thermal properties assumed from similar materials
- Optimization method used to iteratively improve values for material properties

Rocket Motor Finite Volume Model



Material Property Optimization

Iterative Improvement of Material Property Values

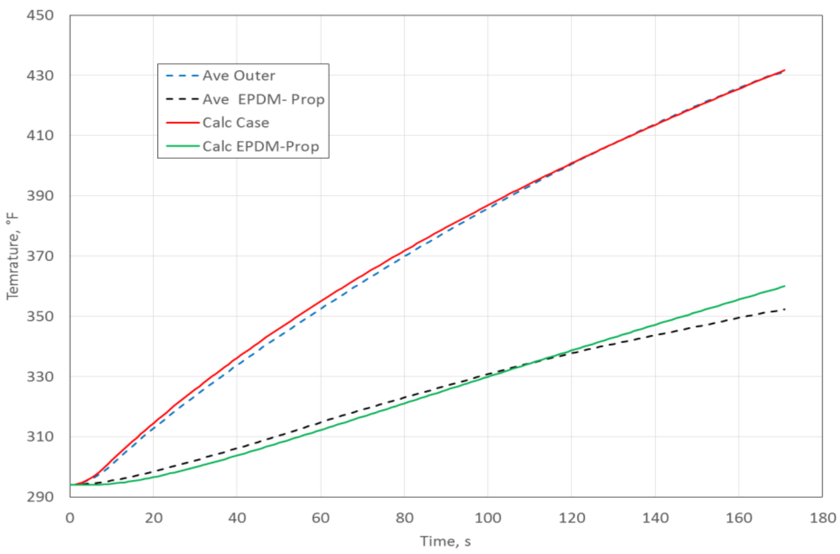
	Variable	Units	Case 1	Case 2	Case 3	…	Case 8
Motor Case	ρ	kg/m^3	2770	2500	2191.8		2191.8
	k	W/m^2K	130	130	130		130
	c_p	J/kgK	1047	1047	1047		1047
Insulation	ρ	kg/m^3	1000	1000	1000		900
	k	W/m^2K	0.13	.013	0.13		0.13
	c_p	J/kgK	2010	2010	2010		1700
Propellant	ρ	kg/m^3	1500	1500	1500		1786
	k	W/m^2K	0.16	0.16	.016		0.16
	c_p	J/kgK	4190	4190	4190		4190
L^2-norm			183.4	119.0	48.33		39.64

- Modified Newton method used for optimizing material properties
  - L2 norm of temperature versus time curves
  - $L^2 = \sqrt{\sum_{i=1}^{n}(\hat{T}_i - T_i)^2}$
- $\hat{T}$ is the test data at each *i* time, *T* is the modeled temperature at time *I*
- Newton method provided predictions for property values from case to case

Optimized Material Properties

- Final results show good agreement between calculated and measured temperatures
- Provides confidence that material properties are correct
- Data from radiant chamber instrumental in development of these values

Calculated and Measured Temperature Data Using Optimized Material Properties



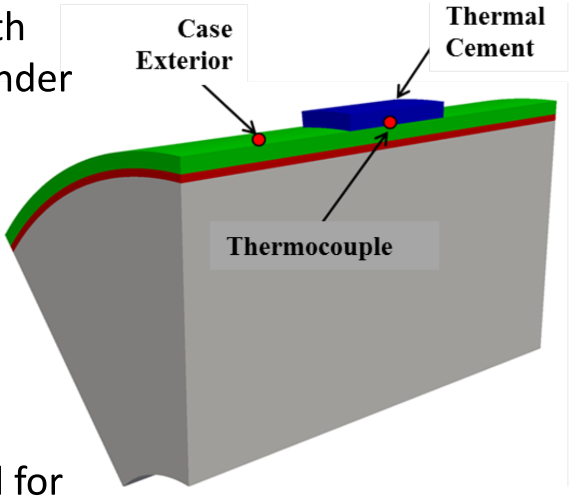
Final Calibrated Material Properties

Property	ρ	k	c_p
Units	kg/m^3	W/m^2K	J/kgK
Motor Case	2192	130	1047
EPDM	900	0.13	1700
Propellant	1786	0.16	4190

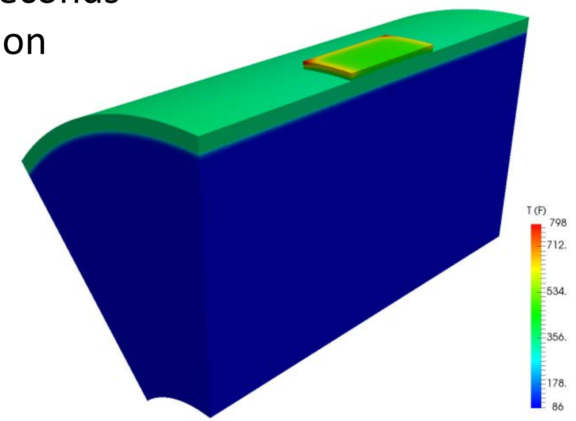
Rocket Motor Restrained Firing Model

- During RF test, TCs were covered with thermal cement with known properties
- Cement included in model with other three layers
- Thermal properties of other materials determined using radiant chamber data
- Thickness of cement was estimated, and multiple cases were run to determine sensitivity of results to cement thickness

Finite Volume Model of Rocket Motor with Thermocouple Under Cement



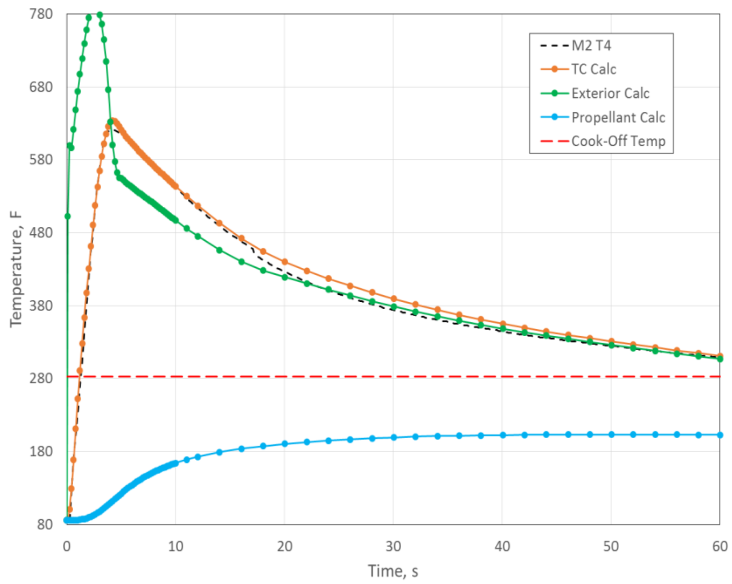
Cut-Away View of Temperature Predicted for One Case at 3.1 Seconds After Motor Ignition



Check for Rocket Motor FCO

- Finite volume model of rocket motor created to duplicate the previous restrained firing test
- Calibrated material properties used in model
- Temperatures measured on rocket motor case used to determine time-varying heat flux from restrained firing
- SCO temperature data used to estimate propellant cook-off temperature
- Plot indicates
  - Good agreement between calculated and measured TC temperature
  - Propellant temperature remains well below cook-off temperature

Temperature versus Time for RF Thermocouple Location and Propellant



- M2T4 is measured data from TC mounted on the rocket motor case
- TC Calc is the calculated temperature of the TC
- Propellant case is the calculated temperature of the motor case
- Propellant Calc is the peak temperature of the modeled propellant
- Cook-Off Temp is the cook-off temperature of the propellant derived from SCO data

Summary and Conclusions

- Radiant chambers have been built to simulate the radiant heating in fast cook-off fires
- The radiant chambers show good axial and circumferential uniformity in temperature
- The chambers provide a broad range of heat fluxes which easily span the range of heat flux into propellant in enclosed systems (20–25 kW/m^2)
- The heat flux is in the range for developing enclosed systems to qualify under STANAG 4240
- The chambers have been used for testing instruments and test items prior to exposure to fires
- The chambers have been used to solve complex problems in fast cook-off and Navy launcher safety testing

Backup

Introduction

Two radiant chambers have been built and tested. They provide a uniform radiation field for testing small items. They have been calibrated with thermocouple rakes and cylindrical steel calorimeters. The radiation fields are unexpectedly uniform and have axial and circumferential uniformity. The chambers use eight 250-Watt cylindrical halogen bulbs. The bulbs are enclosed in inexpensive work light housings readily available at home centers. A variac has been used to control the heat flux. Since fast cook heating of test items is 90% radiative, the chambers provide good tests for many items.

The chambers have been used to test instruments before putting them in large fuel fires. They have also been used to obtain highly controlled laboratory data for development of computer simulations, explaining experimental data from equipment being tested during development, and converging computer simulations when there was uncertainty in material property data.

Calibration data are presented along with results from testing a 7-inch (180 mm) rocket motor chamber with insulation and simulated propellant. Temperature versus time data was recorded by fifteen (15) thermocouples to measure the heat flow along each of five thermal paths from the outer surface of the motor, through the insulation, and into the propellant. The data were used to resolve problems caused by uncertainty in property data for the motor chamber and insulation in a finite element model used to analyze a restrained firing of a missile in a shipboard launcher.

Introduction, continued

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