



JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

AIR AND MISSILE DEFENSE SECTOR

Please refer to:
TL-14-092
FGX95

U.S. Department of Energy
Idaho Operations Office
1955 Fremont Avenue
Idaho Falls, ID 83404-1221

Attention: Mr. C. D. Friesen

Subject: DE-NE0000466, Solid Rocket Propellant Fire Characterization, Final Scientific/
Technical Report

Enclosures: Quarterly Management Progress Reports: First Quarter of Fiscal Year 2012 to Third
Quarter of Fiscal Year 2014 (11 reports)

Dear Mr. Friesen:

Per your direction, a program summary and 11 Enclosures are submitted for your review and retention in accordance with the subject award, and represent the Final Scientific/Technical Report. The award end date was 30 June 2014.

This document was electronically submitted on 1 July 2014.

Sincerely,

Y. Chang
Program Manager

M. E. White
Mission Area Executive
Air and Missile Defense

MEW:YC:lmf

Required Electronic Distribution:

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- B. DOE Project Manager: Carl D. Friesen, friesecd@id.doe.gov
- C. DOE Headquarters Program Manager:
- cc: Headquarters' Technical Monitor: Mr. R. Bechtel, Ryan.Becht@nuclear.energy.gov

Award No. DE-NE0000466
Solid Rocket Propellant Fire Characterization
Final Scientific/Technical Report for
15 September 2011 through 30 June 2014

The Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, Maryland 20723-6099

Approved by:



Y. Chang
Program Manager

30 June 2014

SUMMARY

Some accomplishments from the Solid Propellant Fire Characterization Program are as follows, in no particular order:

- Measured propellant linear burn rate for top- and bottom-burning blocks; comparable to burn rates measured by APL in 2001.
- Performed two-dimensional (2D) pyrometry: temperature vs. time.
- Performed three-dimensional (3D) pyrometry: temperature vs. time, with multiple microbolometers.
 - 2014 Society of Photo-optical Instrumentation Engineers (SPIE) paper – 3D Temperature Estimation of a Fire Plume
- Derived tri-modal particle size distributions:
 - Verified particle size distributions with scanning electron microscopy.
- Conducted first propellant fire test on FlexFram.
- Conducted first propellant fire test on Kennedy Space Center concrete.
- Developed and delivered block size, time, distance, and substrate heat flux and temperature specifications.
- Measured mass of alumina particles in plume with micro-pulse lidar.
- Derived mass of ceria and yttria (plutonia surrogates) on alumina particles.
- Measured in-situ amount of ceria and yttria remaining on substrate.
- Measured mass balance, fractions of ceria and yttria.
- Measured flow velocity of plume particles by Doppler lidar.
- Validated spallation of concrete by test and theory.
- Participated in the Department of Defense (DoD) test program at Sandia National Laboratories (SNL) at 6340-ft elevation.
 - Measured 200 to 400 K lower temperatures for top-burning Star 48 blocks vs. sea level.
 - Measured 41% lower burn rate vs. sea level for Star 48.
- Developed and delivered thermochemical model giving simultaneous temperatures and heat fluxes, with variables gap size, degree of reaction, and block size.
- Videotaped plume rise behavior.

- Estimated plume emissivity.
- Measured plume transmissivity.
- Hosted several meetings:
 - Pre-ship Review
 - Test Readiness Review (TRR)
 - Delta TRR
 - Test Data Review
 - Technical Interchange Meeting (TIM) I
 - TIM II
- Identified possibility of different solid propellant fire behaviors and environments at higher elevations than at sea level (atmospheric and climatic) including:
 - Atmospheric pressure effects: theory, analysis, and measurements
 - Some substrates may be moisture and humidity sensitive
 - Some solid propellants are moisture and humidity sensitive
- Participated in DOE Safety Team meetings and teleconferences.
- Participated in DOE/NASA Mars 2020 Draft Environmental Impact Statement (DEIS) meeting.
- Reviewed and provided comments for SNL's Nuclear Risk Assessment and Technical Support Document for NASA's Mars 2020 DEIS.
- Reviewed and provided comments for NASA's Mars 2020 DEIS.
- Reviewed and provided comments for SNL's topical reports.
- Delivered JHU/APL Memorandum A1C-12-U-3-014, "Solid Rocket Propellant Fire Specifications, Version 11," by H. N. Oğuz and L. W. Hunter, March 2012, and its accompanying CD (A1C-12-U-3-016).
- Delivered "Solid Rocket Propellant Fire Characterization Test Reports, Volumes I and II," June 2013, and the accompanying DVD (A1C-13-U-0-039), with contents:
 - Optics Tests and Thermochemistry Reports
 - Particle Image Velocimetry Report

- Interim Test Reports
- Appendices
- Delivered “Transmittal of Memoranda on a Novel Solution to Thermal Environments of Solid Propellant Fires,” JHU/APL Letter TL-14-091, June 2014, with Enclosures:
 - JHU/APL Memorandum REDD-2014-007 rev 4, “The Thermal Environment Created By Burning Aluminized Propellant,” L.W. Hunter,” 27 February 2014
 - JHU/APL Memorandum REDD-2013-383 rev 3, “Boundary Conditions for Heat Transfer from a Burning Propellant,” L.W. Hunter,” 17 November 2013

QUARTERLY MANAGEMENT PROGRESS REPORTS

These reports covering the period of performance from 15 September 2011 to 30 June 2014 are provided as Enclosures. The first report covers the first quarter of fiscal year 2012, and the last report covers the third quarter of fiscal year 2014, for a total of 11 reports.