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Service through Science

Quarterly Technical Summary Report No. 7
June 1, 1967 to August 31, 1967

RESEARCH ON THE DEFLAGRATION
OF HIGH-ENERGY SOLID OXIDIZERS

Contract No. AF 49(638)-1645

To

Air Force Office of Scientific Research
Washington, D. C.

September 15, 1967

ATLANTIC  RESEARCH

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ATLANTIC RESEARCH CORPORATION
ALEXANDRIA, VIRGINIA

Quarterly Technical Summary Report No. 7
June 1, 1967 to August 31, 1967

RESEARCH ON THE DEFLAGRATION
OF HIGH-ENERGY SOLID OXIDIZERS

Contract No. AF 49(638)-1645

To:

Air Force Office of Scientific Research
Washington, D.C.

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September 15, 1967

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I. ABSTRACT AND INTRODUCTION

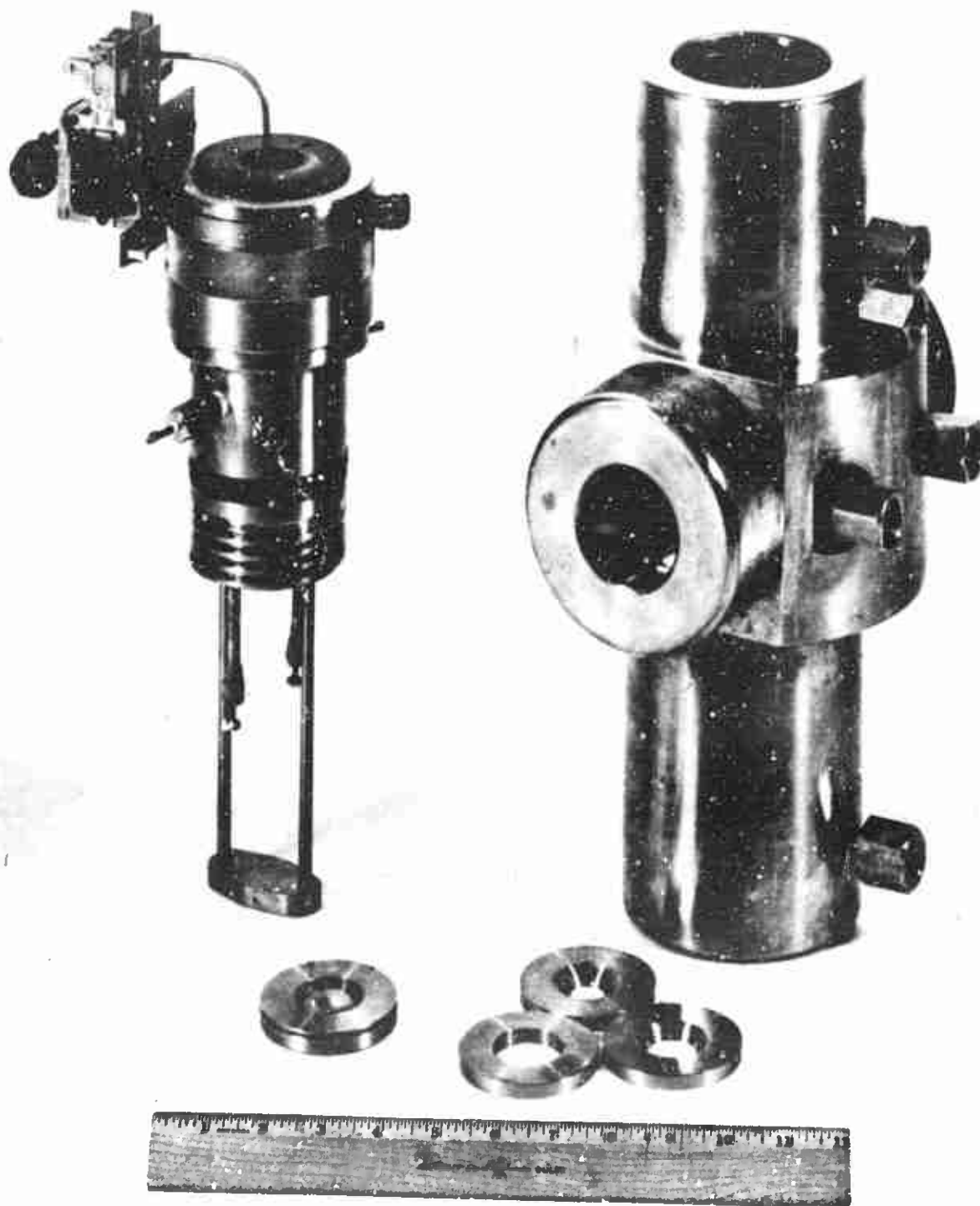
A new phase of the program, the study of solid propellant and oxidizer extinguishment by rapid depressurization, began during this quarter. In this report we describe the apparatus used for this work and the results obtained on the first propellant tested.

The apparatus is an optical strand burner modified to allow rapid depressurization by venting. At pressures of 2000 psi, pressure decay rates of 5×10^5 psi/sec can be achieved. Experiments were carried out on a polyvinylchloride-ammonium perchlorate composite propellant, over a range of initial pressures of 68 to 430 psia with decay rates as high as 10^5 psi/sec. The experimental extinguishment results are compared with theory.

II. DESCRIPTION OF APPARATUS FOR EXTINGUISHMENT

An optical strand burner was modified for use as a laboratory-scale apparatus to study extinguishment by rapid depressurization. The advantages of this type of apparatus are that studies can be conveniently carried out on small strand-size samples of propellant and high-speed motion pictures can be taken of the extinguishment event. A photograph of the disassembled equipment is shown in Figure 1. On the right is the bomb body which has an internal volume of about 300cc and contains inlet and outlet connections for gas pressurizing and purging. Fused silica windows are provided for taking motion pictures and for monitoring the propellant flame luminosity with a phototube. A #6365 Dumont Multiplier Phototube is used which has an S-11 spectral response. Also mounted in the body in a plane with the propellant surface is a Kistler pressure transducer.

On the left of the photo is shown the bomb head which has a 1-1/4" hole drilled straight through the top. This vent is sealed with a stainless steel frangible diaphragm which, together with an orifice plate to control the depressurization rate, is inserted under the screw cap on top. A diaphragm in a set of retaining rings and three orifice inserts are shown at the bottom of the photo. The head also contains ignition leads and posts to support the



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Figure 1. Photograph of Modified Optical Bomb for Study of Extinguishment of Solid-Propellant Strands by Rapid Depressurization. (Discussed in text.)

stage on which strands are mounted. Attached to the top of the head is a solenoid-driven plunger for rupturing the diaphragm.

A run is carried out by pressurizing the bomb and igniting a strand (leached to prevent side burning). After steady combustion is attained, the electrically-timed puncture of the diaphragm is effected and simultaneously a dual-trace oscilloscope is triggered. The outputs of the phototube and pressure transducer are fed into the scope which records the luminosity and pressure decay with time. A Polaroid photo of a typical oscilloscope display is shown in Figure 2.

The oscilloscope display photos are analyzed by measuring tangents to the pressure-time curve at a number of points along the line using an optically flat piece of half-silvered glass. The instantaneous $(-dP/dt)$ -values are then computed and from a plot of these versus pressure the critical extinction $(-dP/dt - P)$ -point (luminosity zero) is determined. The apparatus can be used at pressures as high as at least 2000 psi with corresponding pressure decay rates of 5×10^5 psi/sec. At present there are only provisions for venting to ambient pressure.

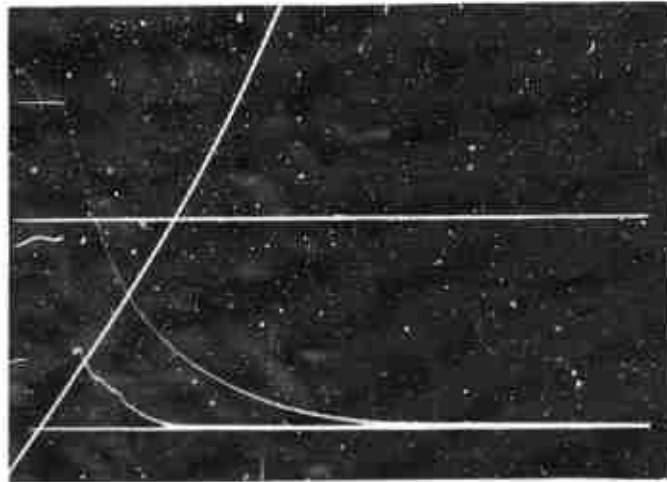
III. INITIAL RESULTS AND COMPARISON TO THEORY

An extinguishment study was made on one candidate propellant of the Arcite series. This was a non-aluminized, polyvinylchloride-based composite containing 10 percent dioctyl adipate plasticizer and approximately 80 percent bimodal ammonium perchlorate. There was a trace of carbon black but no burning rate catalyst. Burning rates were measured over the pressure range of the extinguishment study and are given by the equation:

$$r_o = b P^n = .0128 P^{.567}, \quad (1)$$

where r_o is the steady-state burning rate in in/sec when P is in psia.

Fourteen runs were made at initial pressures varying from 67.5 to 430 psia. Ten extinguishments were obtained and in four runs the depressurization



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Figure 2. Polaroid Photo of Typical Oscilloscope Display (Run No. 14). Upper Trace is Pressure Decay from Initial Pressure of 129 psia. Lower Trace is Propellant Flame Luminosity Measured with Phototube. Horizontal Lines are Pressure Calibrations of 15 and 73 psig. Sweep Time is 5 msec/division.

rate was too low to cause extinction. A summary of pertinent data is given in Table I. In this table, P_i is the initial pressure; P_e is the pressure at which extinction occurred which was read directly off the oscilloscope records; $-dP/dt$ is the rate of pressure decay at P_e , the instant of extinction; the other quantities are discussed below.

The results must be discussed in relation to theoretical concepts of propellant combustion and extinguishment. Several theories of extinguishment have been presented (1-6), and in this report we shall not review these theories, but only note that there is substantial agreement among those (1,5,6) that yield dimensional transient burning rate expressions. The discussion is limited to a comparison of the experimental results with the predictions of theory 6.

According to reference 6, the linear ablation rate of a solid propellant grain during a pressure transient (decrease) is given by

$$r = b P^n \left(1 + \frac{2\alpha n}{b^2} P^{-(2n+1)} \frac{dP}{dt} \right) \quad (2)$$

where $\alpha = \lambda/\rho C_p$ is the thermal diffusivity of the solid and $b P^n = r_0$ is the steady-state burning rate. Extinction occurs when $r = 0$, so that

$$-\frac{dP}{dt} = \frac{(b P^n)^2}{2\alpha n} P = \frac{r_0^2}{2\alpha n} P \quad (3)$$

A log-log plot of dP/dt vs. P will yield a straight line which defines the theoretical extinction boundary. Equation (3) is plotted in Figure 3 using the measured steady-state burning rates for the propellant of this study and taking $\alpha = .00020 \text{ in}^2/\text{sec}$, which is the approximate average thermal diffusivity for this Arcite. The points are the experimental data of Table I for the ten runs in which the burning was quenched. The dashed line shows the experimental $(dP/dt - P)$ -curve for one typical run (#14). Of the four runs in which extinction did not occur only one (#7) crossed the theoretical boundary line, the others all lying in the non-extinction region of the graph. In run #9 extinction occurred, but after the oscilloscope sweep was completed, so no data point was available.

TABLE I

Experimental Extinguishment Data for Arcite Propellant

Run	P_i (psia)	P_e (psia)	$-\frac{dP}{dt}$ ($\frac{\text{psi}}{\text{sec}}$)	r_{oe} (Theory)	r_o ($\frac{\text{in}}{\text{sec}}$) (Exper.)
1	425				
2	430	81	7.7	.12	.16
3	425	71	6.4	.12	.147
4	102	25	1.55	.12	.08
5	99	31.7	2.88	.14	.095
6	105	34	2.41	.13	.098
7	103				
8	223	35	1.39	.095	.10
9	21?	extinguished off record			
10	214				
11	67.5				
12	71	30.6	2.08	.125	.090
13	76	21	.40	.066	.075
14	129	40.2	3.45	.14	.105

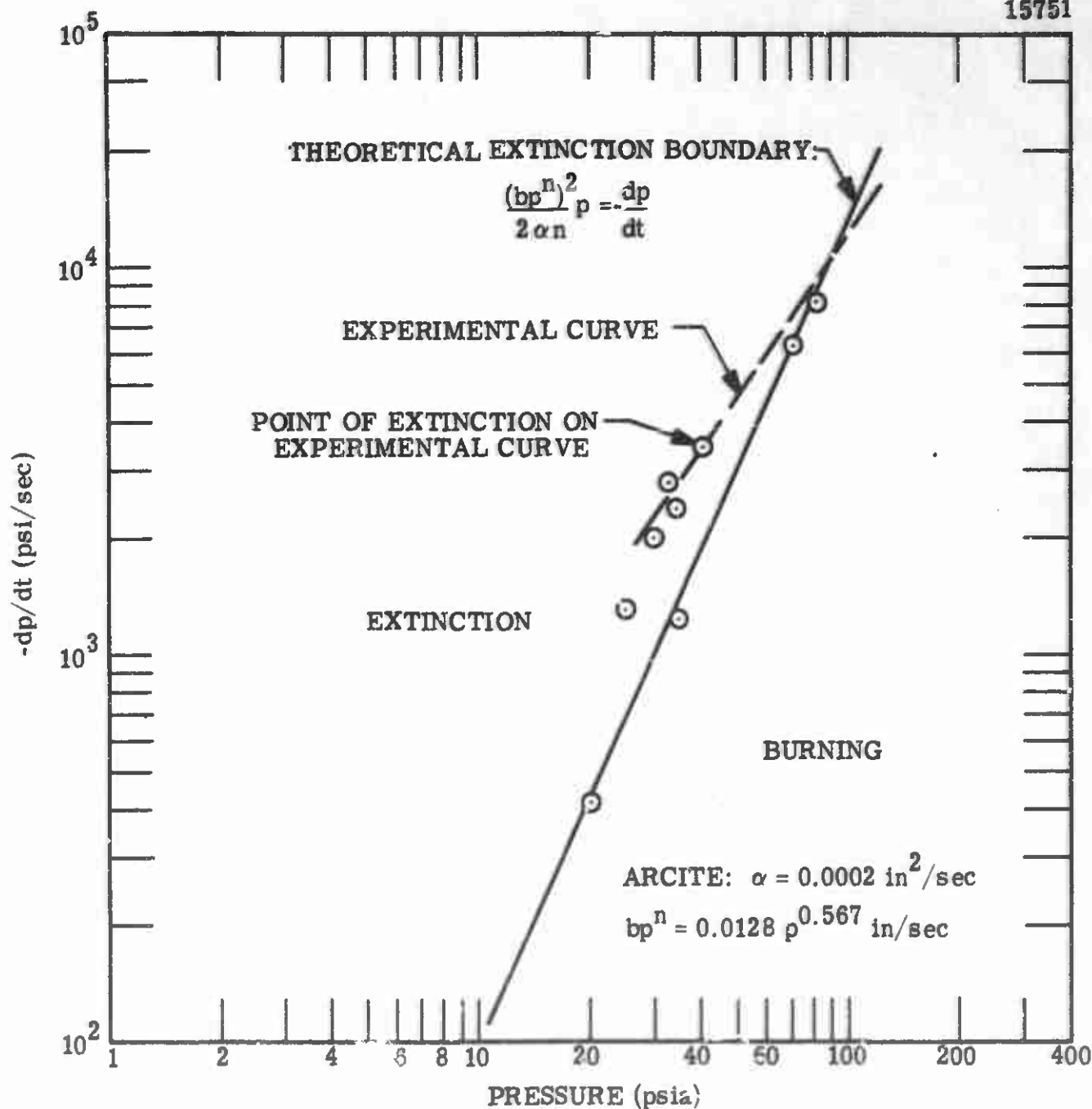


Figure 3. Comparison of Experimental Extinguishment Results for an Arcite Propellant with Theory of Reference 6.

It is apparent that remarkable agreement was obtained between experiment and theory, which we take as mutually supporting evidence for the general validity of both. An equivalent rough check on the approximate correctness of equation (3) can be obtained by computing r_0 from

$$r_0 = \sqrt{2\alpha n \frac{d \ln P}{dt}} \quad (4)$$

and comparing with the measured r_0 . These are shown in the last two columns of Table I, and the agreement is very fine.

We have taken Fastax movies of two extinguishment runs at approximately 3000 frames/sec. In one of these we failed to obtain an oscilloscope record although the movie and run otherwise were normal. The second, run #14, was satisfactory and the movie provided a check on whether the phototube was properly monitoring the extinction event. On Figure 2 it can be seen that the luminosity reaches zero at 8.8 milliseconds after the pressure begins to decay. In the movie, the arrival of the expansion wave at the flame front is very apparent and the light intensity was no longer visible 8.7 ± 0.2 milliseconds later. This still leaves unsettled a more basic question of whether the combustion process has ceased to be self-sustaining at the instant the visible flame luminosity is no longer detectable.

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Solid propellant extinguishment						
Extinguishment of solid propellants						

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