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LOX-CONTAINER-RUPTURE FIRE HAZARDS

by

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FINAL REPORT

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FOREWORD

This report was prepared at Southwest Research Institute under NASA Contract NASA 9-7510. The work was administered by the Structures and Mechanic Division, NASA Manned Spacecraft Center, Houston, Texas 77058, with Dr. W. R. Downs serving as Technical Monitor.

This report covers work performed in the period from August 29, 1967 through October 16, 1967.

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ABSTRACT

The results of these impingement experiments revealed no combustion initiation for any of the specimens tested. These included the Kapton-covered Mylar superinsulation blanket, the Mylar superinsulation with the Kapton cover removed, and the Kapton cover alone, and the Velcro strip alone. These experiments involved: (1) the rapid ejection of cryogenic oxygen through an orifice by 900 and 1200 psi helium with target specimens located in ambient air 2 - 3/4 inches from the orifice, and (2) the rapid release of 1500 psi oxygen gas through a rupture disc fitting with target specimens located in ambient air 2 - 1/4 inches from the throat of the fitting.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS AND TABLES

I. INTRODUCTION

The purpose of this experimental study has been to explore experimentally the fire hazard situation which could arise upon accidental rupture of a pressurized container of liquid or gaseous oxygen. Specifically, the objectives were to determine experimentally the effect of impingement of 1500 psia compressed oxygen gas and of 900 psia cryogenic supercritical oxygen against Mylar superinsulation in air at 15 psia. If combustion were initiated by such impingement, supplementary objectives were to include impingement in a 6 psia air environment and determination of the threshold air environment pressure for combustion initiation by such impingement.

It is the purpose of this report to present the results of this study.

II. EXPERIMENTAL PROGRAM

A. Materials

The specimen materials used in this experimental study were obtained from a Kapton encapsulated blanket of aluminized Mylar superinsulation provided by NASA. Blanket specimens were cut to a size of about 3 by 4 -1/2 inches, and the Velcro strip (pile) was used as is (2 by 6 inches) after removing edge stitches. All specimens were used as received without cleaning, and no special precautions were taken to avoid contamination due to handling. Hence, these specimens may be considered to be in a dirty (most flammable) condition.

The oxygen used in these impingement tests was obtained commercially in high-pressure gas cylinders at a purity of 99.5%. As discussed subsequently, the cyrogenic oxygen was attained by condensation of this gaseous oxygen by cooling the oxygen reservoir with liquid nitrogen.

B. Apparatus and Procedures

An apparatus was assembled which could rigidly support specimen materials (at various distances) perpendicular to the trajectory of an impinging stream of liquid or gaseous oxygen. Different fluid delivery systems were used for the cryogenic and noncryogenic fluids, as illustrated in Figures 1 and 2, and these are described as follows.

Gaseous Impingement

Initially, an orifice plate was provided in the rupture disc fitting (downstream of the rupture disc). A series of preliminary experiments was conducted using this arrangement to explore gaseous-impingement pressure effects. These experiments utilized a quartz piezoelectric transducer, located 2 inches from the orifice plate in lieu of a target specimen. Three orifice sizes, 0.020, 0.040, and 0.060 inches, were used with nickel rupture discs having a 1500 psi rupture pressure. The results indicated a shock-wave pressure rise followed by very low equilibrium overpressures which were so small that they were obscured by background noise.

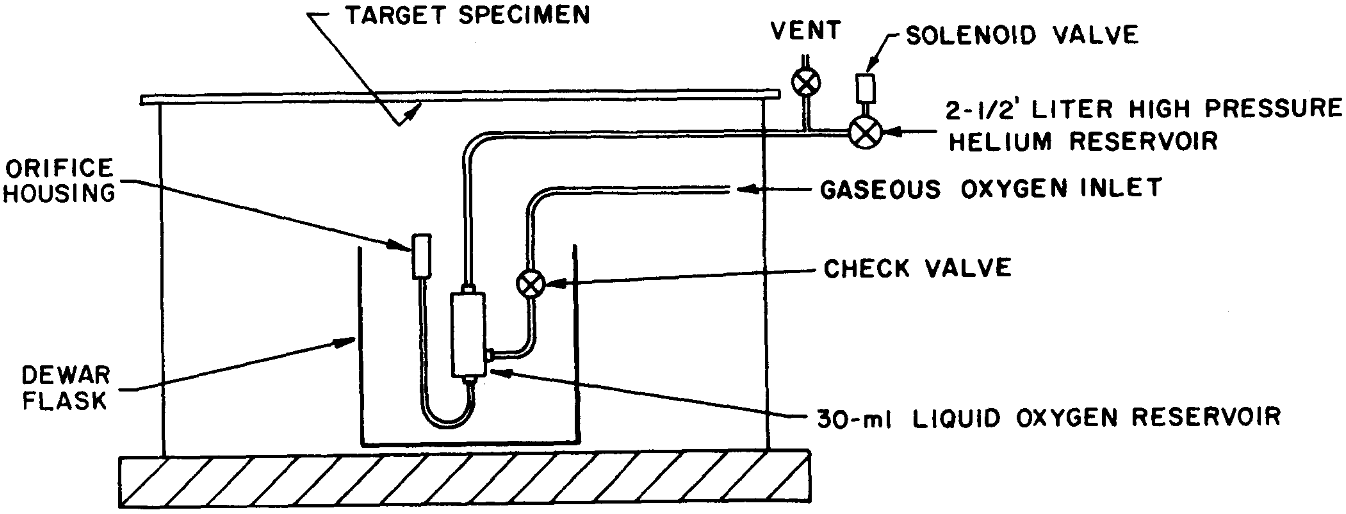

FIGURE 1.
GASEOUS OXYGEN IMPINGEMENT APPARATUS

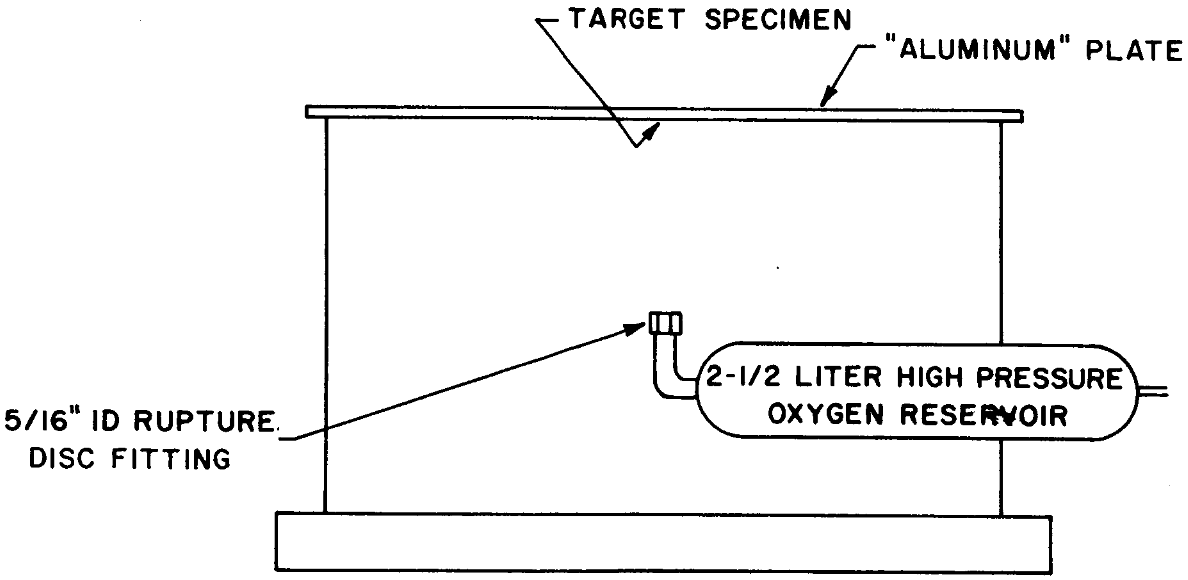

FIGURE 2.
LIQUID OXYGEN IMPINGEMENT APPARATUS

In view of these indications, the following approximate theoretical relations were employed for establishing an appropriate orifice size.

For critical flow of a gas, the mass rate of discharge is given by

$$W = CA_oP_1 \ (g\gamma M/RT_1)(2/[\gamma + 1])^{(\gamma+1)/(\gamma-1)}$$

where

W = mass flow rate

C = orifice discharge coefficient

A_o = throat area of orifice

P = upstream absolute pressure

T = upstream absolute temperature

M = molecular weight of gas

γ = specific heat ratio of gas

R = gas constant

g = force-mass conversion constant

Now, when a jet impinges on a flat surface (normal to the jet axis), the maximum force which could be exerted on an impingement surface area, A, by momentum exchange is:

$$F = WV/2g = W^2/2g\rho A$$

where

F = maximum force which could be exerted by jet impingement

A = impingement area normal to jet axis

V = hypothetical velocity of jet at impingement area (without momentum exchange)

ρ = hypothetical density of expanded gas at impingement area (without momentum exchange)

For adiabatic expansion of jet without entrainment of surrounding air,

$$T = T_1(P/P_1)^{(\gamma - 1)/\gamma}$$

where T and P represent the hypothetical absolute temperature and pressure of the expanded gas at the impingement surface (without momentum exchange). Therefore,

$$\rho = P/RT = MP^{1/\gamma}P_1^{(\gamma - 1)/\gamma}/RT_1$$

By combining the foregoing relations, assuming unit orifice discharge coefficient, the following relation is obtained as an estimate of the maximum possible impingement force (without entrainment of surrounding air), assuming that the entire jet impinges on the area, A.

$$F = (A_o^2/A)\gamma[2/(\gamma + 1)]^{(\gamma + 1)/(\gamma - 1)}P_1^{(\gamma + 1)/\gamma}/2P^{1/\gamma}$$

In order to render this estimate more realistic, the above relation is modified by correcting the expanded jet velocity at the impingement surface to that which would be observed* in a turbulent free jet expanding from an orifice of diameter, D_o (with entrainment of surrounding air), through the impingement target distance, L, giving

$$F = (A_o^2/A)\gamma[2/(\gamma + 1)]^{(\gamma + 1)/(\gamma - 1)}P_1^{(\gamma + 1)/\gamma}(3.1)(D_o/L)/P^{1/\gamma}$$

The cross sectional area, A, of a free turbulent jet at a distance, L, from an orifice of area, A, may be estimated* as

$$A = (A_o^{1/2} + L/3.2)^2$$

The average impingement overpressure within the impingement area, A, of the target surface can then be estimated as

$$P_i = F/A$$

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* Perry, J. H., ed. "Chemical Engineers' Handbook", fourth ed., McGraw-Hill Book Co., Inc., New York, 1963, p. 5-18.

Therefore

$$P_i = 3.5A_o^{5.2}\gamma[2/(\gamma+1)]^{(\gamma+1)/(\gamma-1)}P_1^{(\gamma-1)/\gamma}/P^{1/\gamma}L(A_o^{1/2}+L/3.2)^4$$

This latter relation estimates the average impingement overpressure exerted by a turbulent free jet of gas against a flat surface normal to the jet axis and located a distance L, from the jet orifice. This estimated overpressure is believed to be conservative (i. e., larger than actual) because of the steps involved in its derivation. In actual cases the impingement area, A, would be greater than that estimated for a free jet. Such area enlargement, which could result as the actual jet impinges and is deflected by the target surface, would lead to a smaller impingement overpressure.

Using these relations, the estimated equilibrium overpressures at a 2 - inch target distance for the previously discussed experimental series of orifices are less than 0.1 psi for 1500 psi upstream of the orifice, which agrees with the small overpressures observed. On the basis of these results, the gaseous impingement device was revised to allow operation with a 5/16 inch I. D. rupture disc fitting (without a downstream orifice plate) attached directly to a 2 - 1/2 liter high-pressure gas reservoir as illustrated in Figure 1. The estimated overpressure is 100 psi at a target distance of two inches for this device with a 1500 psi gas supply pressure.

Liquid Impingement

Cryogenic oxygen impingement tests were conducted using the apparatus illustrated in Figure 2. Rather than attempting to fill the reservoir with liquid oxygen, the device was immersed in liquid nitrogen, and the reservoir (and associated tubing) was filled by allowing pure oxygen to condense. During this condensing - filling operation, the orifice fitting was temporarily closed with a rubber stopper to avoid condensation of air or moisture within the system. Once the system was full of liquid oxygen and all bubbling in the liquid nitrogen bath had ceased, the rubber stopper was removed from the orifice fitting, and helium pressure was suddenly applied to the liquid oxygen reservoir by means of a solenoid valve located at the outlet of a 2-1/2 liter high-pressure helium reservoir.

C. Experimental Tests

Gaseous Oxygen

A series of gaseous impingement tests was conducted using 1500 psi nickel rupture discs for achieving rapid release of the compressed oxygen. These experiments employed the following target specimens, respectively: Kapton covered Mylar blanket, Mylar blanket with Kapton cover removed, Kapton cover alone, single sheet of Mylar superinsulation, and the white Velcro strip(pile) alone. Except for the Velcro strip, the blast effect of the impinging oxygen stream tore the specimens into small pieces (in the case of the multilayer specimens, only the first few layers were thus "shredded") without evidence of combustion. In the case of the Velcro strip, there was no evidence of any effect of the impingement. The target specimens used in this series of experiments are summarized in Table 1.

Several torn pieces of Kapton and aluminized Mylar were examined microscopically, and for the most part, the edges of the fragments appeared as clean fractures. In a few instances, localized regions were observed where the plastic appeared to have experienced plastic flow in the fracture region. In such regions, the torn edge appeared to have softened, and fiber-like strands of "drawn" substance were visible at irregular intervals along the edge. In view of these observations (with both Kapton and Mylar) an additional experiment was conducted using a Kapton-covered Mylar blanket specimen, but the high-pressure gaseous oxygen was replaced with nitrogen. Again, the same type of drawn fibers were visible in some locations along the fracture edges. Therefore, the occurrence of these fibers cannot necessarily be traced to thermal effects stemming from the impingement of pure oxygen.

TABLE 1. IMPINGEMENT EXPERIMENTS WITH KAPTON-COVERED MYLAR SUPERINSULATION

Conditions: Gas - 1500 psig
Temp - Room (rupture-disc-actuated release at 2-1/4 inch target distance)

Experiment No.	Target Material	Impingement Gas
1	Mylar Superinsulation Only	Oxygen
2	Kapton Cover	Oxygen
3	Single Sheet of Mylar Superinsulation	Oxygen
4	Velcro Strip Only	Oxygen
5	Velcro Strip Only	Oxygen
6	Kapton-covered Mylar Superinsulation	Oxygen
7	Kapton-covered Mylar Superinsulation	Nitrogen

Cryogenic Supercritical Oxygen

A series of experiments was conducted in which supercritical oxygen was impinged against specimens which were initially at room temperature in ambient air. In these tests, the contents of the LOX reservoir (> 30 ml) were discharged through the orifice by the sudden application of high-pressure helium to the liquid-filled reservoir by means of a solenoid valve. In each case, a stream of liquid oxygen was clearly visible until the reservoir (and associated tubing) was empty. Two experiments were conducted using 900 psig helium and a 0.005 inch discharge orifice. The target specimen comprised a section of the Kapton-covered superinsulation blanket (not cleaned) in two of these tests, and a section of the aluminized Mylar blanket with the Kapton removed in the third experiment. No evidence of combustion was detected in these experiments. The third experiment was repeated, using a 0.020 inch discharge orifice, and again, no combustion was detected. A final series of three experiments was then conducted using the 0.020 inch orifice with a helium driving pressure of 1200 psig. The target specimen for the first test in this series was the white Velcro strip removed from the back of the Kapton-covered blanket. The last two tests used the Mylar superinsulation blanket, with and without the Kapton cover, as a target specimen. In no case, was there any evidence of combustion. The target specimens used for this series of experiments are summarized in Table 2.

TABLE 2. IMPINGEMENT EXPERIMENTS WITH KAPTON-COVERED MYLAR SUPERINSULATION USING CRYOGENIC SUPERCRITICAL OXYGEN (SOLENOID-ACTUATED RELEASE)

Experiment No.	Target Distance, in.	Driving Pressure, psig	Target Material
1	4	900	Kapton Cover Only
2	2-3/4	900	Kapton Cover Only
3	2-3/4	900	Mylar Superinsulation Only
4	2-3/4	900	Mylar Superinsulation Only
5	2-3/4	1200	Velcro Strip Only
6	2-3/4	1200	Mylar Superinsulation Only
7	2-3/4	1200	Kapton-Covered Mylar Superinsulation

III. CONCLUSIONS

The results of these experiments did not reveal combustion initiation by impinging oxygen in liquid or gaseous form. In the case of a rupturing oxygen container, it is possible that solid fragments of the container wall (or insulation) could be present as flying shrapnel. For such cases, the high-velocity debris particles would represent a direct physical hazard to equipment and personnel and also could subject materials to impact heating in the presence of oxygen. Simulation of such situations was beyond the scope of this study. However, it is understood that Mylar film has been successfully subjected to extensive liquid oxygen service applications which possibly include mechanical-shock environments. Both Mylar and Kapton films have been subjected to liquid oxygen impact tests in a program sponsored by the United States Air Force,[1] with only a low-level reaction intensity being observed. This reaction intensity is somewhat greater than the (background) intensity measured for Teflon, and it is significantly less than that observed with acetate and phenolic films.[2] It has been suggested[1] that the successful use of Mylar with liquid oxygen in mechanical-shock environments indicates that service conditions are not severe enough to cause reaction, or else that reactions occur without sufficient intensity to be self sustaining. In either event, these experiences suggest a low probability that Mylar or Kapton combustion would be initiated by flying shrapnel. On the other hand, because the nature of the shrapnel

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[1] Blackstone, W. R., Baber, B.B., and Ku, P. M., "Development of New Test Techniques for Determining the Compatibility of Materials with Liquid Oxygen under Impact", AFAPL-TR-67-41, Southwest Research Institute, February, 1967.

[2] It should be noted that the impact test referred to is different from the standard NASA and Air Force test methods. The referenced method is sufficiently severe to cause reaction for most materials except solid Teflon, and the intensity (overpressure) of the resulting blast wave is quantitatively measured. Background maximum intensities of 0.1-0.4 psi are typical for Teflon; 0.2-3.0 psi, for Mylar and Kapton; and 6-40 psi, for acetate and phenolics.

that may result from rupture of a pressurized oxygen container is not known, the possibility of combustion initiation by such shrapnel cannot be ruled out. Evaluation of such shrapnel effects would require experimental testing beyond the scope of the present program.