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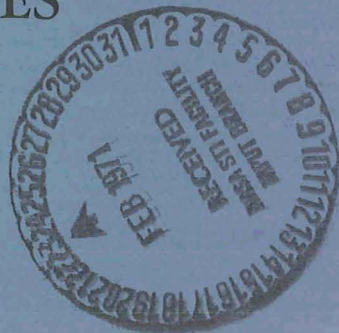
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BURNING OF TEFLON-INSULATED
WIRES IN SUPERCRITICAL OXYGEN
AT NORMAL AND ZERO GRAVITIES

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16. Abstract An experimental program was conducted to investigate the burning characteristics of Teflon-insulated nickel wires in supercritical oxygen in normal and zero gravities. The zero-gravity environment was obtained in a drop tower which made available 5 seconds of test time. The results indicate that the Teflon burned in both normal and zero gravities. However, the flame propagation rate in zero gravity was smaller than in normal gravity.			
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BURNING OF TEFLON-INSULATED WIRES IN SUPERCRITICAL OXYGEN AT NORMAL AND ZERO GRAVITIES

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SUMMARY

An experimental program was conducted to investigate the burning characteristics of Teflon-insulated nickel wires in supercritical oxygen in normal and zero gravities. The zero-gravity environment was obtained in a drop tower which made available 5 seconds of test time. The results indicate that the Teflon burned in both normal and zero gravities. However, the flame propagation rate in zero gravity was smaller than in normal gravity.

INTRODUCTION

To date, the various processes incorporated under the general heading of burning have not been adequately understood. The applicability of these processes in modern day uses, however, has generated significant effort to further the state of the art. In particular, burning in a low-gravity environment, as could occur aboard a spacecraft, has received the attention of an increasing number of investigators.

The majority of the work that has been done on low-gravity combustion has been concerned with the burning of liquids and solids. These processes have been considered to be diffusion limited and, accordingly, are termed diffusion flames. Early experimental work was done by Kumagai and Isoda (ref. 1), who observed liquid droplets burning in reduced gravity. They concluded that gravity induced convection had a definite effect on the combustion process. Hall (ref. 2) experimented with a candle burning in a zero-gravity environment and determined that, although the geometry of the flame was different in zero gravity as compared to normal gravity, burning was sustained during the entire test. Kimzey, Downs, Eldred, and Norris (ref. 3) conducted tests with paraffin and other combustibles and found that for some fuels the flames went out in

zero gravity. A recent theoretical study (ref. 4) calculated the extinguishment time for a laminar diffusion flame in zero gravity and obtained satisfactory agreement with the data of reference 3. In further zero-gravity experimentation, Andracchio and Aydelott (ref. 5) burned different solids in an oxygen-rich atmosphere. The primary conclusion of this work was that the flame spreading rate in zero gravity was smaller than in normal gravity. A recent Russian publication by Abduragimov (ref. 6) has reported the results of burning butyl alcohol in a channel in zero gravity. The results suggest that open diffusion flames cannot exist in weightlessness.

Another type of diffusion process which has received attention is the gas jet diffusion flame. Cochran and Masica (refs. 7 and 8) have investigated the gravity dependence of this process with methanol burning in air at atmospheric conditions. Their results indicate that for small flow rates laminar jet flames extinguished, while for high flow rates a steady-state zero-gravity flame was established.

The purpose of this report is to present the results of work conducted in the NASA Lewis Research Center's 5-Second Zero Gravity Facility on the effects of gravity on the burning of Teflon-insulated wire in supercritical oxygen. This problem has application to the difficulties encountered during the aborted Apollo 13 flight (ref. 9). The initial test conditions, pressure of 920 ± 20 psia (63.4 ± 1.4 N/m²) and temperature of -180 ± 10 ° F (-117.8 ± 5.6 ° C), ignition procedures, and test samples were specified by the NASA Manned Spacecraft Center, which was investigating the explosion on board the Apollo 13 vehicle. Color motion pictures were taken of various configurations of the Teflon-insulated wire burning in normal and zero gravities.

EXPERIMENTAL COMBUSTION APPARATUS

The facility and experiment vehicle employed in the study and the test procedures used are described in the appendix.

An overall view of the drop vehicle and experiment section is presented in figure 1. Figure 2 shows a detailed view of the experimental apparatus. The basic components from left to right are a high-speed motion-picture camera, a combustion chamber with a 1-inch (2.54-cm) diameter sapphire window to permit high-speed photography and an expansion tank. Also shown are the liquid-nitrogen cooling coils and the pneumatic system components used for filling, venting, and pressure relief. The combustion chamber was a 76-cubic-inch (1245.6-cm³) stainless-steel high-pressure cylinder. The expansion tank, which had a volume of 400 cubic inches (6556 cm³), was separated from the combustion chamber by a burst disk. This vessel was used for safety purposes to allow collection of vented gases from the pressure relief system in the event of excessive pressure rise. The camera, which was equipped with a 25-millimeter

lens, ran at a nominal speed of 400 frames per second. Ektachrome MS 2256 (Estar base) film and standard film processing were used. Instrumentation was provided to monitor chamber pressures, temperatures, and ignition conditions during the tests.

The test specimen section consisted of the holder, the test sample, and the ignition source. The holder was a perforated stainless-steel circular ring 1 inch (2.54 cm) wide which could be removed from the chamber to facilitate attachment of test samples. The ignition source was a 1.75-inch (4.45-cm) length of 26 gage Nichrome wire wrapped around the test specimen. Ignition, which occurred just after entering zero gravity, was effected by passing approximately 5 amperes of current through the wire for 2 seconds followed by approximately 10 amperes for 1 second. Three test specimens, as shown in figure 3, were used. The first configuration, figure 3(a), consisted of four 4-inch- (10.2-cm-) long 26-gage nickel wires with 10-mil- (25.4×10^{-3} -cm-) thick Teflon insulation. The wire specifications are MIL-W-16878 type E. The four wires were held in a bundle by a heat-shrinkable white Teflon sleeve 12 mils (30.48×10^{-3} cm) thick. The second configuration, as shown in figure 3(b), was identical to the first with the exception that the four wires were encased in a heat-shrinkable clear Teflon sleeve 12 mils (30.48×10^{-3} cm) thick. Specifications for the heat-shrinkable Teflon are MIL-I-23053 B. The ignition point was at the center of the test specimens for the first and second configurations. The third configuration is shown in figure 3(c). This test specimen consisted of a two-piece aluminum-block assembly, four test wires (identical to those of configurations 1 and 2), a Teflon grommet, and the ignition wire assembly. The Teflon grommet was placed around the wires and installed in a hole in the aluminum blocks. The ignition wire, which was again located at the center of the test specimen wire, was 0.25 inch (0.64 cm) from the blocks.

DATA REDUCTION

The data recorded on film were viewed on a motion analyzer. In addition to generally observing the phenomena, measurements of flame propagation along the specimens as a function of time were made. The pressures and temperatures were recorded on an oscillograph.

RESULTS AND DISCUSSION

Test Conditions

A summary of the test conditions for the different runs is presented in table I. The initial pressures of 915 ± 15 psia ($63.1 \pm 1 \times 10^5$ N/m²) and initial temperatures of

$-182^{\circ} \pm 6^{\circ}$ F ($-119.2^{\circ} \pm 3.3^{\circ}$ C) were within the specified initial conditions. Thermodynamic data, as presented in reference 10, show that, under the test conditions, the state of the oxygen was supercritical.

General Observations

A photograph of the specimen made up of four wires with clear sleeving and burning in a normal-gravity environment is shown in figure 4(a). In general, the flames rose up above the specimen, as would be expected, and billowing smoke was visible. The flames also seemed to propagate along the specimen in an irregular stop and go fashion. In contrast, the zero-gravity burning of this type of specimen, as shown in figure 4(b), was more symmetric about the fuel. Apparently, the absence of gravity-induced convection resulted in the flames seeking an unpreferred orientation. The propagation of the flames, as in the normal-gravity case, appeared to pulsate along the specimen. These results are also typical for the tests conducted with the four wires encased in white sleeving.

Burning of the aluminum-block assembly with four wires in a normal-gravity environment is shown in figure 5. As can be seen in the photograph, the flame penetrated through the hole in the aluminum block and consumed material on the other side. Examination of the specimen after the test revealed that the only damage done to the block was blackening of it. No success was achieved in obtaining clear photographs of this specimen burning in zero gravity. However, although burning did occur, again, no damage was inflicted on the aluminum block.

Flame Propagation Data

Flame propagation rates were obtained from measurements of the displacement of the leading edge of the flame as a function of time. A plot for a typical test is shown in figure 6. No data were obtained during some portions of the tests, usually the early parts, because the intensity of light from the flame was too bright. The propagation rate was obtained by fairing curves through the displacement points and computing an average from the right and left sides.

A compilation of the propagation rates for all the tests is made in table II. All of the normal-gravity tests resulted in a propagation rate of approximately 1.4 centimeters per second. Comparison of the normal- and zero-gravity tests indicates that, although some scatter was evident, the zero-gravity rates were consistently lower than the normal-gravity rates.

SUMMARY OF RESULTS

An experimental program was conducted to investigate the burning characteristics of Teflon-insulated (nickel) wires in supercritical oxygen in normal and zero gravities. The zero-gravity environment was obtained in a drop tower which made available 5 seconds of test time. The tests were conducted with three different configurations of the wire: A bundle of four wires encased in white heat-shrinkable Teflon sleeving; a bundle of four wires encased in clear heat-shrinkable Teflon sleeving; and a bundle of four wires inserted through a Teflon grommet which, in turn, was contained in an aluminum block.

The following results were obtained for the wires encased in the two types of sleeving:

1. The specimens burned and were consumed in both normal and zero gravities.
2. Measurements of the flame front as a function of time indicated that the burning progressed along the specimens in a pulsating fashion.
3. The average flame propagation rate in zero gravity was smaller than in normal gravity.

Tests conducted with the aluminum-block assembly indicated the following:

1. Under normal-gravity conditions, the burning penetrated the Teflon grommet so that material was being consumed on both sides of the aluminum-block support.
2. The aluminum-block support was not damaged by the burning in either normal or zero gravity.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 5, 1970,
124-08.

APPENDIX - APPARATUS AND PROCEDURE

Test Facility

The experimental data for this study were obtained in the Lewis Research Center's 5- to 10-Second Zero Gravity Facility. A schematic diagram of this facility is shown in figure 7. The facility consists of a concrete-lined 28-foot- (8.5-m-) diameter shaft that extends 510 feet (155 m) below ground level. A steel vacuum chamber, 20 feet (6.1 m) in diameter and 470 feet (143 m) high, is contained within the concrete shaft. The pressure in this vacuum chamber is reduced to 1.3×10^{-4} atmosphere (13.3 N/m^2) by utilizing the Center's wind-tunnel exhaust system and an exhaustor system located in the facility.

The ground-level service building has, as its major elements, a shop area, a control room, and a clean room. Assembly, servicing, and balancing of the experiment vehicle are accomplished in the shop area. Tests are conducted from the control room (see fig. 8), which contains the exhaustor control system, the experiment vehicle pre-drop checkout and control system, and the data retrieval system.

Mode of operation. - The Zero Gravity Facility has two modes of operation. One is to allow the experiment vehicle to free fall from the top of the vacuum chamber, which results in nominally 5 seconds of free fall time. The second mode is to project the experiment vehicle upwards from the bottom of the vacuum chamber by a high-pressure pneumatic accelerator located on the vertical axis of the chamber. The total up-and-down trajectory of the experiment vehicle results in nominally 10 seconds of free-fall time. The 5-second mode of operation was used for this experimental study.

In either mode of operation, the experiment vehicle falls freely. That is, there are no connections to it, such as guide wires or electrical lines. Therefore, the only force (aside from gravity) acting on the freely falling experiment vehicle is due to residual-air drag. This results in an equivalent gravitational acceleration acting on the experiment which is estimated to be a maximum of 10^{-5} g.

Recovery system. - After the experiment vehicle has traversed the total length of the vacuum chamber, it is decelerated in a 4.5-foot- (1.37-m-) diameter, 20-foot- (6.1-m-) deep container which is located on the vertical axis of the chamber and filled with small pellets of expanded polystyrene. The deceleration rate (averaging 32 g's) is controlled by the flow of pellets through the area between the experiment vehicle and the wall of the deceleration chamber. This deceleration container is mounted on a cart which can be retracted prior to utilizing the 10-second mode of operation. In this mode of operation, the cart is deployed after the experiment vehicle is projected upward by the pneumatic accelerator. The deceleration container mounted on the cart is shown in the photograph of figure 9.

Experiment Vehicle

The experiment vehicle used to obtain the data for this study is shown in figure 10. The overall vehicle height (exclusive of support shaft) is 9.85 feet (3.0 m), and the largest diameter is 3.5 feet (1.06 m).

The vehicle consists of a telemetry system section, contained in the aft fairing, and the experiment section and associated electrical, electronic, and mechanical support systems, which are housed in the cylindrical section.

Telemetry system. - The on-board telemetry system is a standard interrange instrumentation group (IRIG) FM/FM 2200-megahertz system with 11 continuous channels. It is used during a test to continuously record combustion-chamber pressure and temperature, expansion tank pressure, ignition parameters, and other data pertinent to the operation of the experiment vehicle. The telemetered data are recorded on a high-response oscillograph located in the control room.

Experiment. - The experiment section is described in the Apparatus and Procedure section.

Test Procedure

Before data were obtained, the combustion chamber was thoroughly cleaned using a degreasing solvent. The test specimen was assembled, cleaned in a trichlorotrifluoroethane solution, and then installed in the combustion chamber.

The combustion chamber was first purged with gaseous oxygen and then pressurized to the desired test conditions. The latter was accomplished by charging the chamber with gaseous oxygen at a set pressure while cooling the experiment apparatus to nominally -200°F (-128.9°C) by flowing liquid nitrogen through the cooling coils. The combustion chamber was then allowed to heat up to the desired test temperature. At this point, the chamber pressure was checked and, if too high, was decreased to the desired value by venting. (The pressure and temperatures were monitored in the control room on digital voltmeters.)

Upon establishing the desired combustion-chamber test conditions, the chamber was cooled to about -290°F (-178.9°C). The experiment vehicle was then positioned at the top of the vacuum chamber as shown in figure 11. It was suspended by the support shaft on a hinged-plate release mechanism. During vacuum-chamber pumpdown and prior to release, monitoring of experiment vehicle systems and combustion-chamber instrumentation was accomplished through an umbilical cable attached to the top of the support shaft. Electrical power was supplied from ground equipment. The system was then switched to internal power a few minutes before release. During vacuum-chamber

pumpdown, the temperature of the combustion chamber gradually increased. When the desired test conditions were reached, the experiment vehicle release sequence was initiated. The umbilical cable was remotely pulled from the support shaft 1.0 second prior to release. The vehicle was released by pneumatically shearing a bolt that was holding the hinged plate in the closed position. No measurable disturbances were imparted to the experiment vehicle by this release procedure. The total free-fall test time obtained in this mode of operation was 5.16 seconds. During the test drop, the trajectory and deceleration of the vehicle were monitored on closed-circuit television.

Following the test drop, the vacuum chamber was vented to the atmosphere. After on-board instrumentation was monitored to determine the status of combustion-chamber conditions, the experiment vehicle was returned to ground level (see fig. 12).

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8. Cochran, Thomas H.; and Masica, William J.: Effects of Gravity on Laminar Gas Jet Diffusion Flames. NASA TN D-5872, 1970.
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10. Anon.: Fluid Properties Handbook. Propulsion Rep. A-364, Missile and Space Systems Div., Douglas Aircraft Co., Inc.

TABLE I. - TEST CONDITIONS

Specimen	Gravity level	Initial pressure		Initial temperature	
		psia	N/m ²	°F	°C
Four wires with white sleeving	Normal	900	62.1×10 ⁵	-187.4	-121.8
Four wires with clear sleeving	Normal	927	63.9	-185.7	-120.8
Four wires with clear sleeving	Zero	912	62.9	-181.6	-118.5
Aluminum-block assembly with four wires	Zero	930	64.1	-181.4	-118.4
Four wires with white sleeving	Zero	922	63.6	-177.4	-116.2
Four wires with white sleeving	Normal	909	62.7	-180.8	-118.1
Four wires with clear sleeving	Zero	909	62.7	-181.4	-118.4
Aluminum-block assembly with four wires	Normal	920	63.4	-185	-120.4

TABLE II. - FLAME PROPAGATION RATES

Specimen	Gravity level	Propagation rate, cm/sec		
		Right edge	Left edge	Average
Four wires with white sleeving	Normal	1.4	1.4	1.4
Four wires with clear sleeving	Normal	1.3	1.5	1.4
Four wires with clear sleeving	Zero	.5	.3	.4
Four wires with white sleeving	Zero	.3	.2	.3
Four wires with white sleeving	Normal	1.5	1.3	1.4
Four wires with clear sleeving	Zero	.9	.7	.8

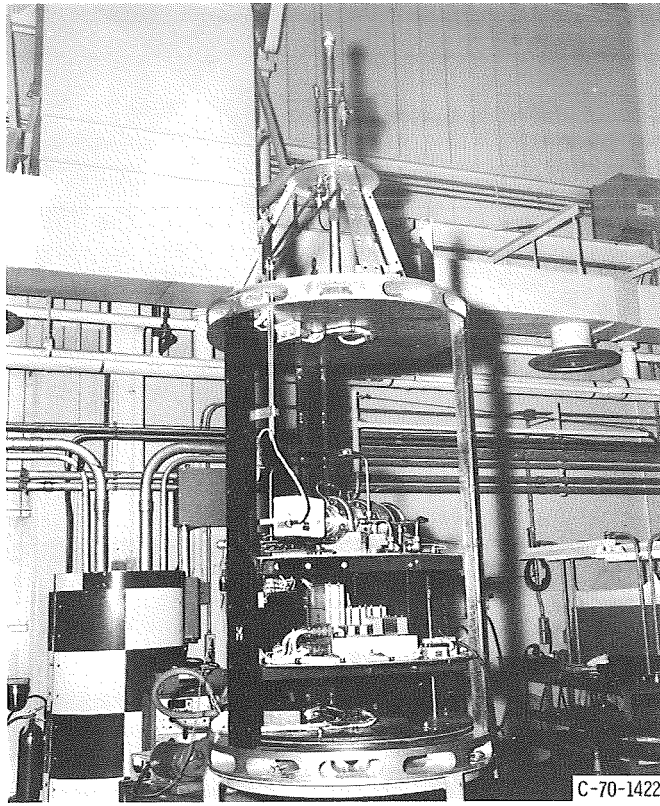


Figure 1. - Experiment section details.

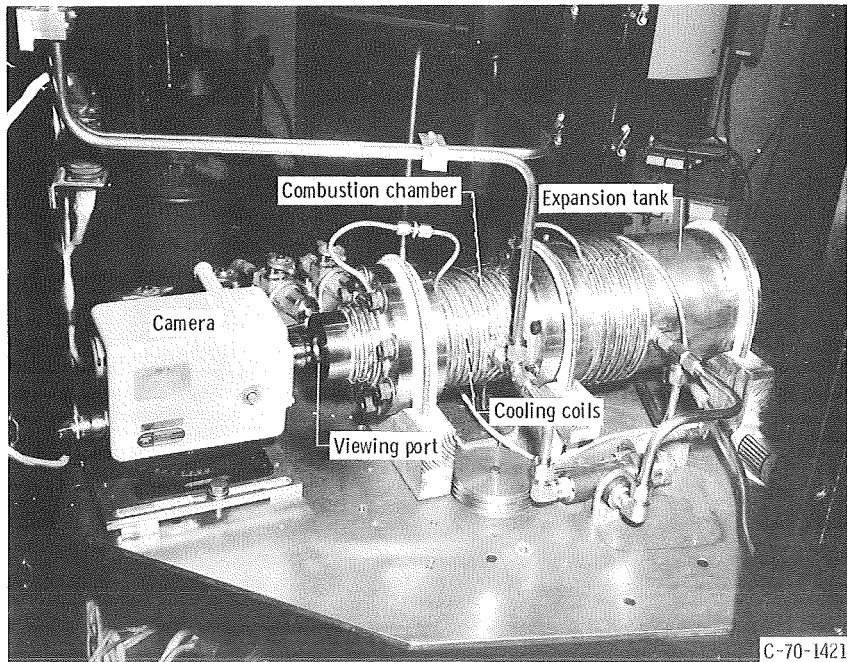
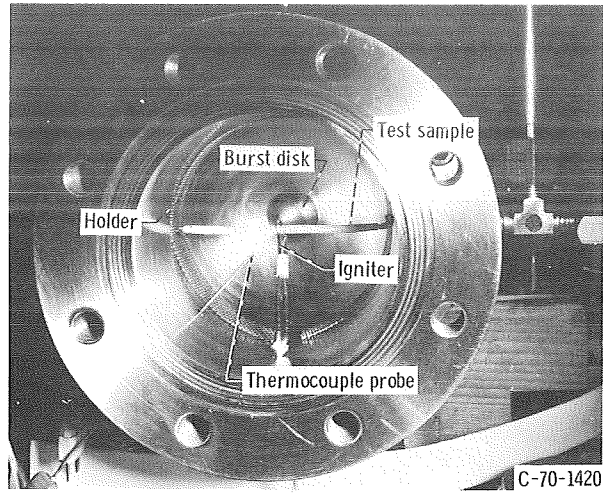
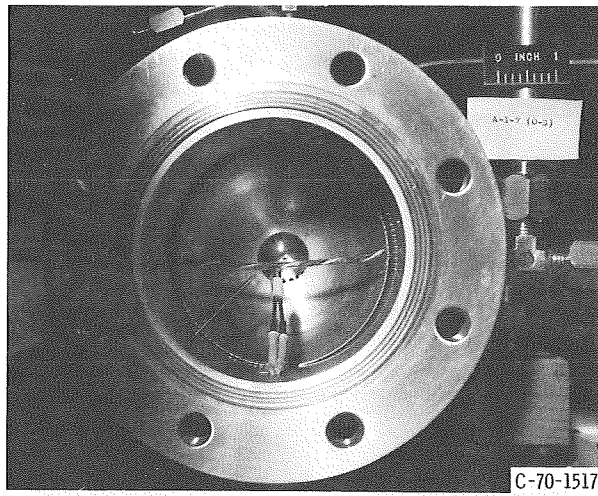


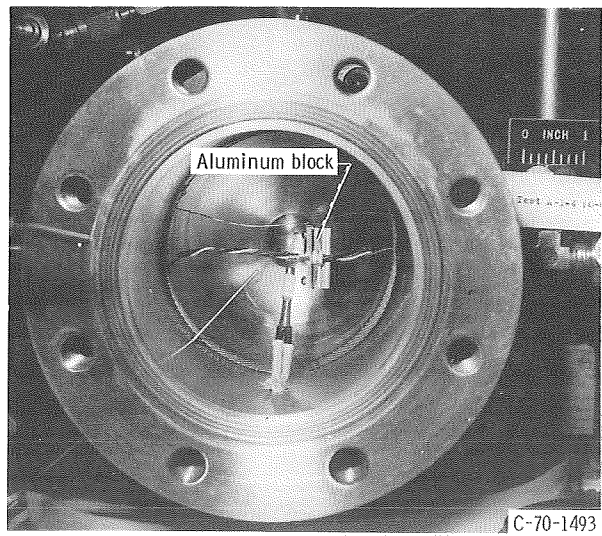
Figure 2. - Experimental apparatus.



(a) Four wires with white sleeving.

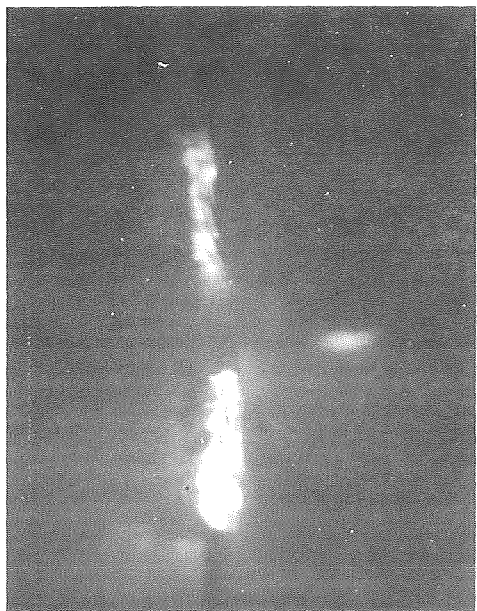


(b) Four wires with clear sleeving.

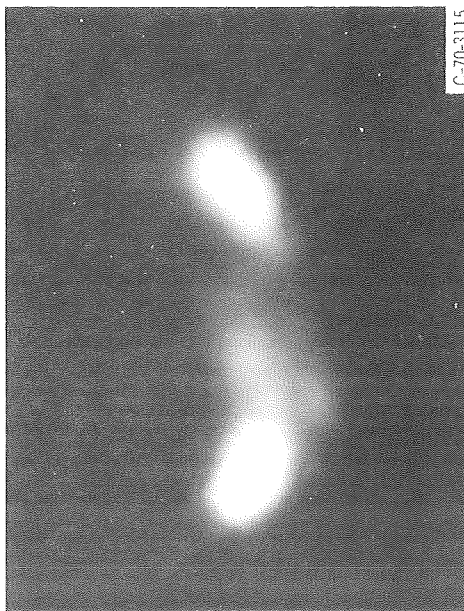


(c) Aluminum block assembly with four wires.

Figure 3. - Test specimens.



(a) Normal gravity.



(b) Zero gravity.

Figure 4. - Burning of four wires with clear sleeving in normal and zero gravities.

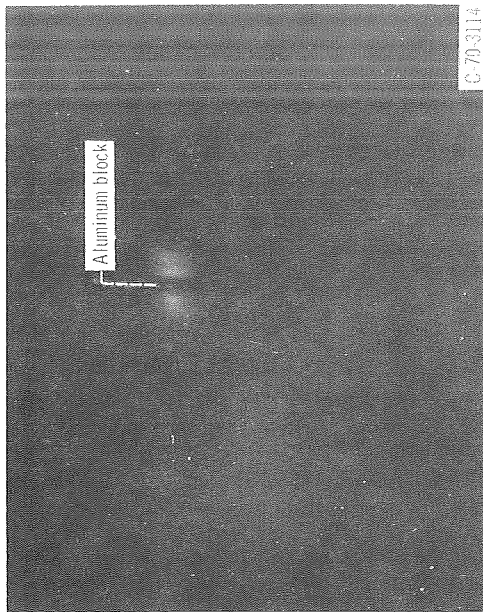
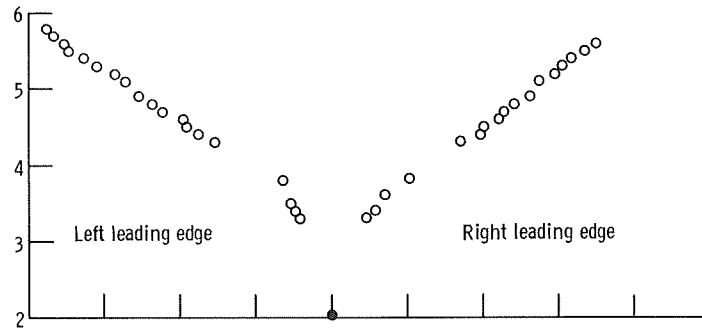
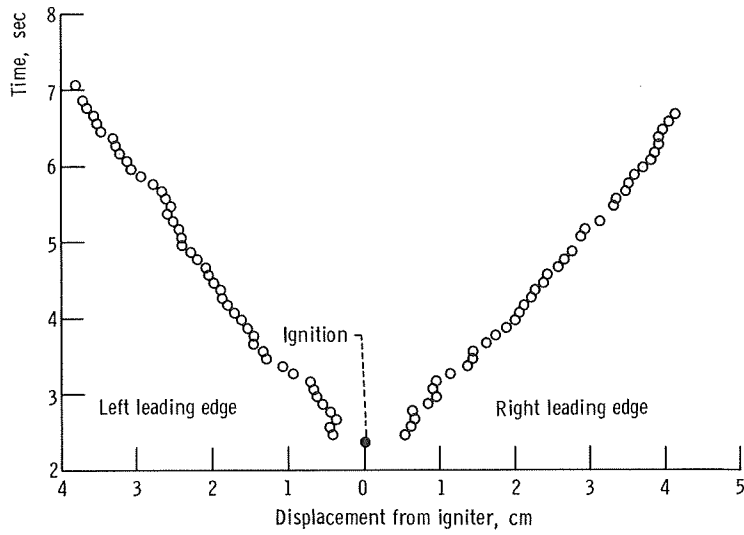


Figure 5. - Burning of aluminum block assembly with four wires in normal gravity.



(a) Normal gravity.



(b) Zero gravity.

Figure 6. - Flame propagation for four wires with clear sleeving in normal and zero gravities.

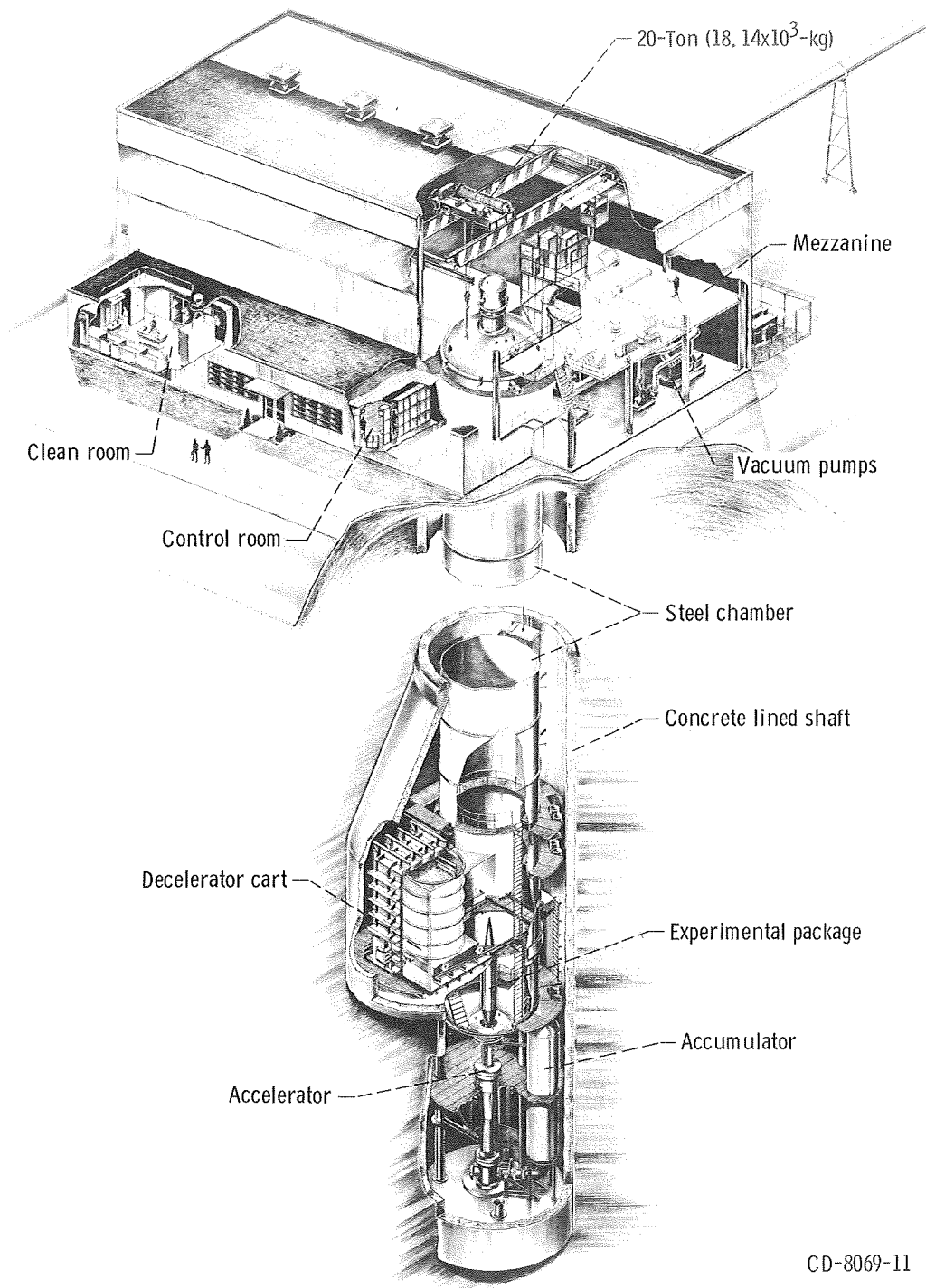


Figure 7. - Schematic diagram of 5 to 10-second Zero-Gravity Facility.

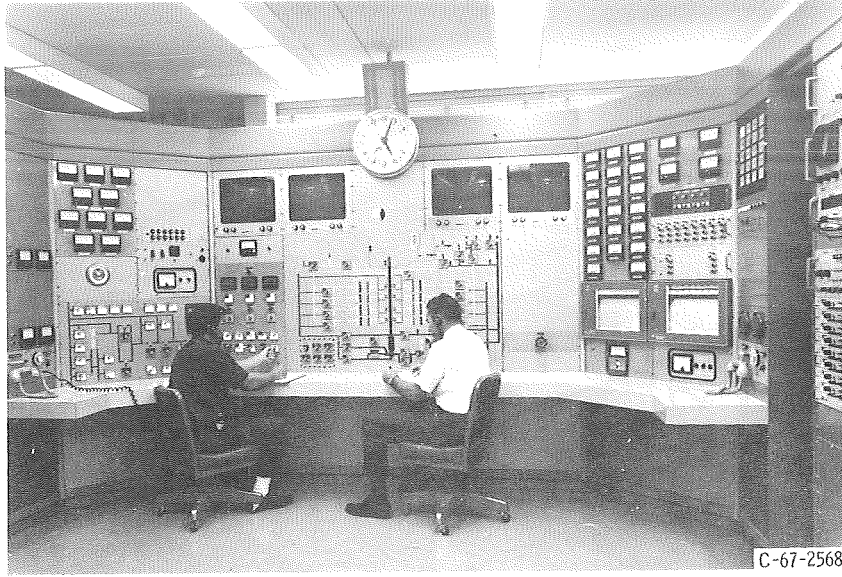


Figure 8. - Control room.

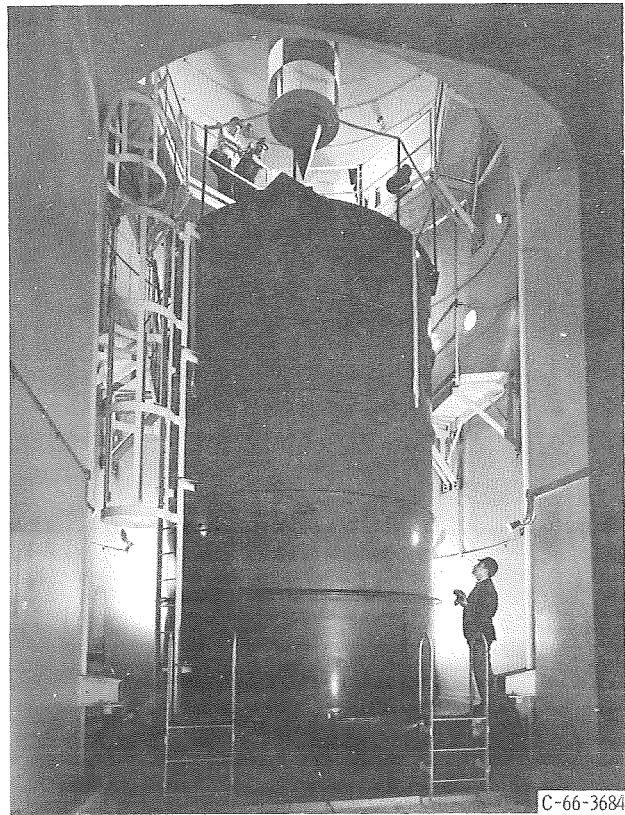
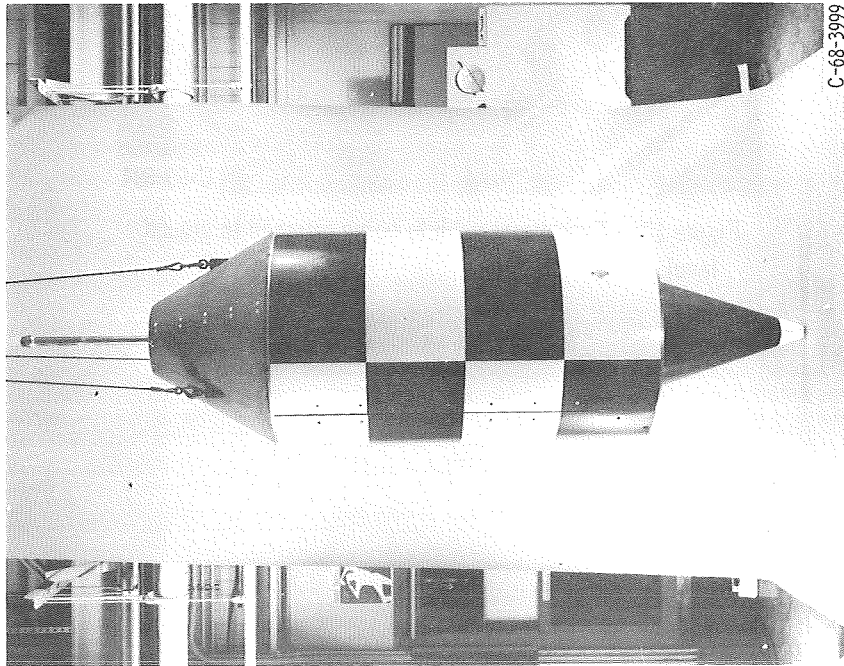
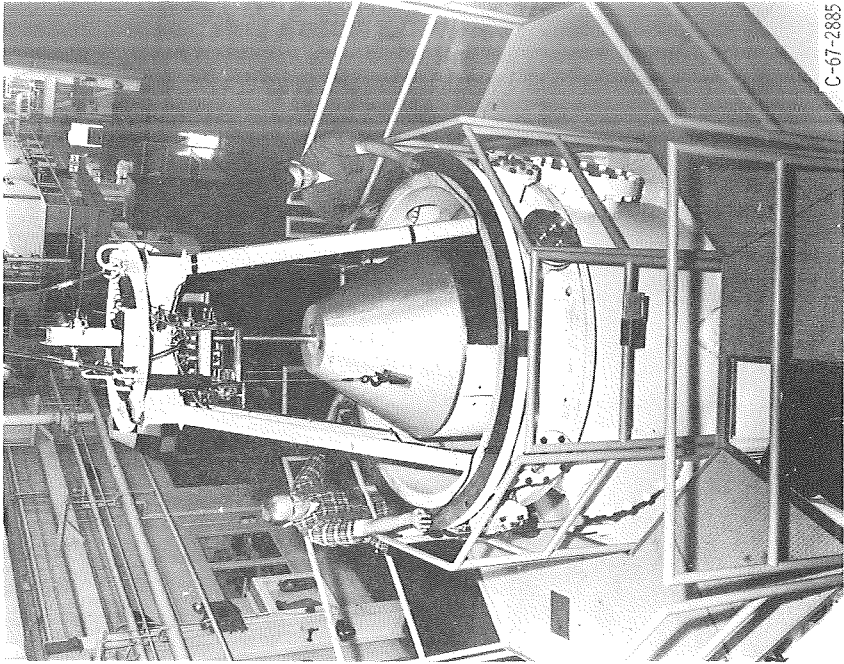


Figure 9. - Deceleration system.



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Figure 10. - Experiment vehicle.



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Figure 11. - Vehicle position prior to release.

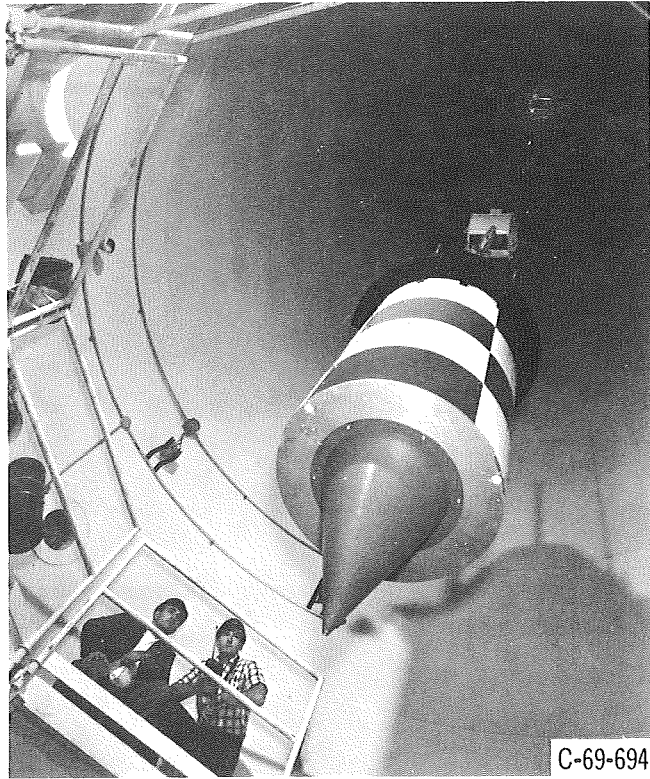


Figure 12. - Experiment vehicle being returned to ground level.



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— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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