SKYLAB EXPERIMENT M479
ZERO GRAVITY FLAMMABILITY

By

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SUMMARY

Flammability under conditions of weightlessness was investigated in Skylab 4. Thirty-seven tests using six materials were successfully carried out to learn more about how a flame acts in the absence of confection. Specific objectives were to note the extent of surface flame propagation and flash-over to adjacent materials, rates of surface and bulk flame propagation, self-extinguishment, and extinguishment by both vacuum and water spray. Data were returned in the form of crew comments on voice tapes and sixteen millimeter motion pictures taken at 24 frames per second. All tests were performed and all hardware functioned properly, although an operational oversight caused the water in the supply tank to be less than the minimum required pressure. Burning rates were significantly reduced as anticipated from earlier aircraft tests. Some reduction of total burning was also noted. The surface burn was not followed by continued inward burning as typically experienced on earth although some one-g tests at extremely low pressures have partially reproduced this condition. Ignition and extinguishment also appear to be similar to one-g. The typical soft blue flame was seen by the crew, but was not detected on the film emulsions used. Smoke patterns were also noted. This can be of value in studying Brownian movement of solids in gases under conditions of weightlessness.

INTRODUCTION

Skylab Experiment M479 was performed February 4, 1974, on Day 81 of the third and last manned mission. This was the latest in a study of flammability as applied to spacecraft.

BACKGROUND

An investigation of flammability under conditions of weightlessness began over 10 years ago. Without convection a flame as a somewhat spherical corona as seen on the right, figure 1. In such a case the fuel is surrounded by a corona which isolates the material from the surrounding atmosphere rather than extending above the fuel as noted on the left. Hardware for these aircraft tests was very basic consisting of a 10-inch diameter chamber in which the fuel was positioned. A motion picture camera recorded ignition and burning (figure 2). Fuels were selected to represent a variety of engineering materials with various melting points and flammability characteristics (figure 3).

AIRCRAFT TESTS

A typical float of the flammability chamber is seen in the motion picture film. Test times varied from 4 to 10 seconds. Burning rates from this series of tests were noted (figure 4) for some materials. Conclusions from these tests are given in figure 5. See also reference 1.

SKYLAB TESTS

Thirty seven tests were performed in Skylab mission 4, (figure 6). The hardware for Experiment M-479 consisted of many items used throughout the Skylab flight in eighteen different experiments. All of the M-479 hardware was designed, built, and tested by the George C. Marshall Space Flight Center. We are grateful for support by the many groups at Huntsville that provided this highly reliable and still functional equipment. The specimens (figure 7) were separately packaged in a designated container. Each one has a piece of test material, a Nichrome heater wire and an electric socket to support the material in the proper orientation.

A number tab served to identify the specimen both for the astronaut operator and for an aid in viewing the film. Once he installed the specimen in the work chamber (figure 8) and closed the cover he observed the test through the hatch window. Another port on the side provided for photographing the test with a motion picture camera. Controls for operating a water spray and a vent are also provided to evaluate these as a means of extinguishment. Tests were conducted in the Skylab atmosphere of 65 percent oxygen at 5.2 psia.

Skylab In-Flight Testing - Operation of the experiment was scheduled for day 81 of SL-4. Commander Gerald Carr performed these tests (figure 9).

Skylab Film Details - A 16 mm motion picture film shows:

1. Commander Carr in SL-4. Test number 2 was video recorded showing the specimen before test and following test as it was compared with specimen number 8 which had identical construction. Focus was poor but the fact that the 1-inch square specimen was not burned was readily apparent.

2. Commander Carr in SL-4. Tests numbered 16 and 17 were video recorded with the camera at the viewport recording the burning of the polyurethane foam specimen and the paper specimen. The test details are narrated as the materials were ignited and burned.

3. Test number 15. Neoprene coated nylon fabric was next ignited and burned using the film exposed in flight. This material exhibited the property of shrinkage on the nylon side and the tendency to curl and quickly roll up disturbing the burning.

4. Test number 16. Polyurethane foam covered in scene 2, above, is next. The flame is seen proceeding along the surface at 0.8 inches per second followed by a venting overboard of the atmosphere. The fire goes

out as the foam melts to a much smaller volume. No estimate of the unburned material is possible. No vent rates are given. Venting is through a 1-inch diameter screened orifice.

5. Test number 17. Paper, also described in the video recording of scene 2, is next. Ignition is noted but the film fails to show the soft blue glow of the flame described by Commander Carr, the same glow barely discernable in part of the video recording as the T.V. lens aperture opened fully. Evidence of the burning could be seen as the metal frame (near the top of the screen) began to glow as it was heated to a dark red heat (650 - 750 °C). The venting caused a significant flare up as burning rates and luminousity increased markedly due to the forced convection.

6. Test number 18. Teflon fabric is next. The igniter caused a flame of the material contacting the fabric. However, the flame did not persist. As the igniter cooled, after about three seconds, the flame went out.

7. Test number 1. The aluminized mylar is seen next. This material burned at 3.8 inches per second, with a bright light, indicating that the aluminum was burning and contributing significantly to the heat. This same material in one-g burns the same way irrespective of orientation as convection cannot overcome inertia as quickly as the flame moves.

8. Test number 2. Nylon of scene number 1 is next. Three ignition attempts are seen.

9. Test number 26. Nylon in this test has a different geometry but an identical igniter. The first attempt did not produce a flame. The second, however, did. The film shows two flame zones that start in a subtle, gentle glow that pulses as the material melts and liberates flammable gases. As time passes the agitation increases. The material burns for 10 minutes 43 seconds at which time the atmosphere was dumped to cause extinguishment. The effects of venting include intensified burning as seen earlier with polyurethane foam and paper in tests number 16 and 17.

In addition to video tape and motion pictures we have two still photographs. The first (figure 10) shows the burning of polyurethane foam in test number 10. Note the spherical shape of the flame. The diameter is estimated at more than 6 centimeters. This means that this material has a flame in zero-gravity (at this atmosphere) extending over 3 centimeters. Another picture immediately after the fire went out shows the smoke pattern (figure 11). It reportedly persisted for a long period of time.

SKYLAB SPECIMENS RETURNED

Two specimens were brought back, as requested (figures 12 and 13). These are the nylon from tests numbered 2 and 8. Neither ignited. This being the case, Col. Carr included the residue from test number 26 (figures 14, 15, and 16). After burning for nearly 11 minutes, this fire was deliberately extinguished by dumping the atmosphere. We still have over 10 percent of the material unburned in this specimen.

Another returned specimen was a piece of residue from test number 17 (figure 17). Paper burned with a very soft blue flame not visible to the camera. Carr reported that the residue "has remarkable strength." An estimation, based on area and weight, showed it was consumed between 74 and 79 percent. Similar paper ignited in one-g (in air) was consumed by 91 percent.

CONCLUSIONS

Several conclusions can be made regarding fire in zero-gravity (figure 18). These include ignition, burning rates, extinguishment by vacuum dump, water spray and self-extinguishment and the validity of one-g tests.

RECOMMENDATIONS

The M-479 experiment was an engineering study designed to assist in future manned space programs. The need for additional zero-gravity testing is obvious. Areas of concern are as follows (figure 19):

1. Fire detection - Document the light emission from various materials. Note specifically the wavelength and intensity for paper.

2. Ignition - Ignition energies should be quantitatively measured.

3. Propagation rates - Various fuel compositions, thicknesses and geometry.

4. Critical gap distances - Determine critical spacing for various materials.

5. Other fuels - Flammable liquids, flammable gases and metals could have unique mechanisms of burning in zero gravity. Metals do not have gaseous products of combustion therefore they probably burn in zero-gravity as vigorously as in one-g.

6. Extinguishment - The suitability of water as an extinguishment should be verified as well as the use of solids (bicarbonates) and gases (CO_2 and Halons such as 1301 bromotrifluoromethane).

REFERENCES

[1] Kimzey, J. H., "Zero Gravity Flammability," included in "Space Processing and Manufacturing" symposium held October 21, 1969, at the George C. Marshall Space Flight Center, Huntsville, Alabama. ME-69-1. N-70-14669, N71-11719, N70-20535.

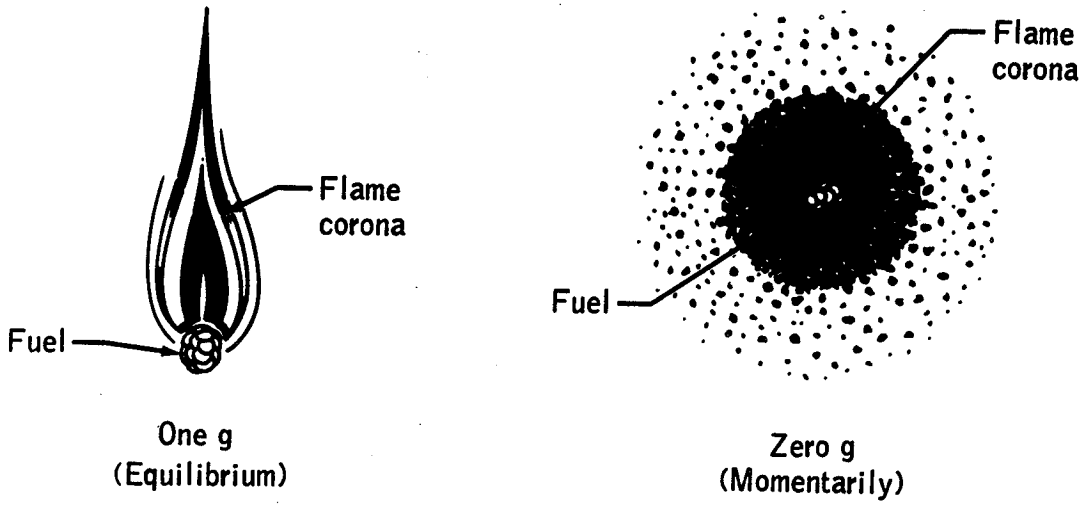

FIGURE 1. COMPARISON OF FUEL BURNING AT ONE-G AND ZERO-G IN OXYGEN ATMOSPHERE

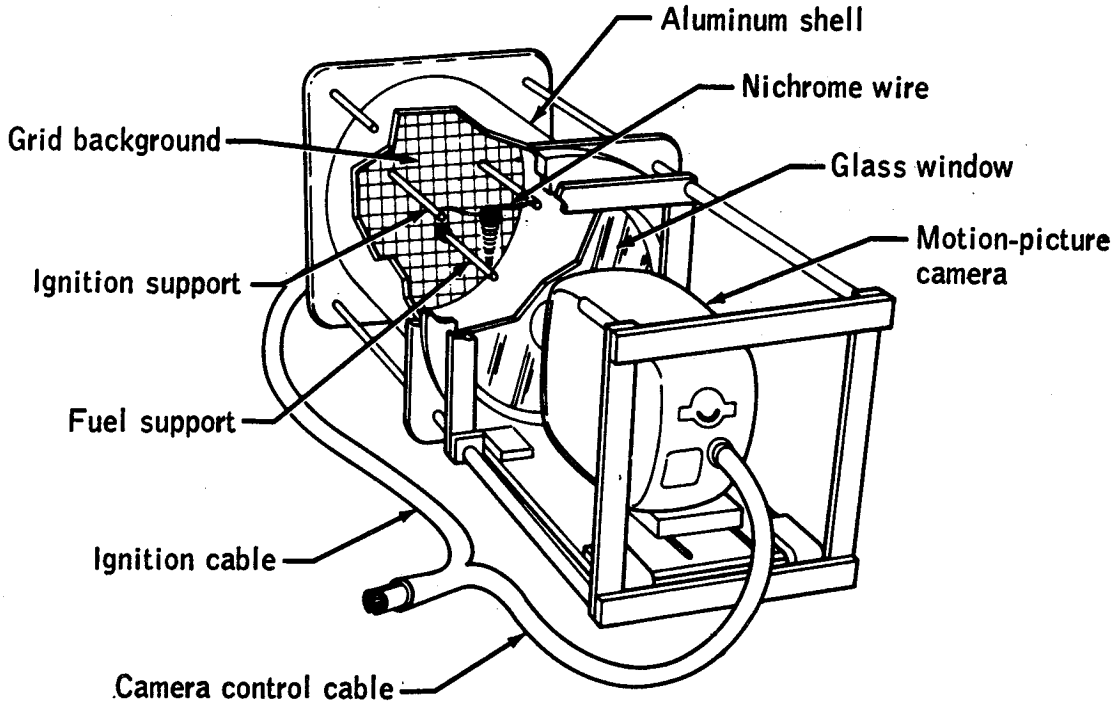

FIGURE 2. ZERO-G FLAMMABILITY CHAMBER

MATERIALS

DACRON THREAD

NEOPRENE RUBBER, FOAMED

NEOPRENE RUBBER TUBING

PARAFFIN

POLYURETHANE RUBBER

SILICONE RUBBER

STYRENE PLASTIC

TEFLON TUBING

FIGURE 3. AIRCRAFT FLAMMABILITY TEST

FUEL [1]	RATE OF BURNING, INCH PER SECOND					
	ONE-g			ZERO-g		
	15 PSIA AIR	5 PSIA O_2	15 PSIA O_2	15 PSIA AIR	5 PSIA O_2	15 PSIA O_2
NEOPRENE	0.0	0.2	0.4		0.10	
SILICONE	0.04	0.5	1.1	0.0	0.08	
TEFLON	0.0				0.00	
POLYURETHANE		0.6	0.7	0.0	0.08	0.15
DACRON [2]		0.6	0.7		0.08	0.15

NOTE:

1. FUEL IS TUBULAR (NO.10 AWG I D) AND THREADED OVER A STEEL OR CERAMIC MANDREL
2. DACRON THREAD IS WRAPPED AROUND POLYURETHANE
3. IGNITION IS PROVIDED BY ELECTRIC RESISTANCE COIL
4. TEMPERATURE OF ATMOSPHERE IS 65 ± 5°F

FIGURE 4. BURNING RATES IN ONE-G AND ZERO-G

CONCLUSIONS

IGNITION - NO DIFFERENT THAN ONE-G

BURNING RATES - SLOWER THAN ONE-G

- o FIRE WILL PROPAGATE ALONG A SURFACE

SELF EXTINGUISHMENT - HIGHLY PROBABLE

- o FIRE WILL NOT BURN INWARD AS GASEOUS PRODUCTS OF COMBUSTION WILL IMPEDE OXYGEN FLOW

CONVECTION - INTRODUCING CONVECTION PROMPTLY INCREASES FLAME SIZE AND INTENSITY.

- o FORCED AIR FLOW OR VENTING INCREASES BURNING

FIGURE 5. AIRCRAFT FLAMMABILITY TEST

(ZERO GRAVITY FLAMMABILITY)

DATE: FEBRUARY 4 & 5, 1974 - MISSION DAY 81

MISSION: SL-4

ASTRONAUT - OPERATOR: LT. COL. GERALD P. CARR

EQUIPMENT: M-512 FACILITY IN M.D.A.

FIGURE 6. SKYLAB M-479 EXPERIMENT

MATERIAL	DIMENSIONS	TEST NUMBERS
ALUMINIZED MYLAR	2 5/8" x 3 5/8" x .0003	1,7,13,19,25
NYLON SHEET	1" x 1" x .125	2,8,14,20,26
NEOPRENE COATED NYLON FABRIC	2 5/8" x 3 5/8"	3,9,15,21,27
POLYURETHANE FOAM	1/4" x 1/4" x 2"	4,10,16,22,28
BLEACHED CELLULOSE PAPER	2 5/8" x 3 5/8" x .009"	5,11,17,23,29
TEFLON FABRIC	2 5/8" x 3 5/8"	6,12,18,24,30
PAPER, 2 PIECES, MOUNTED IN PARALLEL FACE-TO FACE WITH A GAP OF 1/8, 1/4, 1/2"	2 5/8" x 3 5/8" x .009"	31 THROUGH 37

FIGURE 7. SKYLAB EXPERIMENT M-479

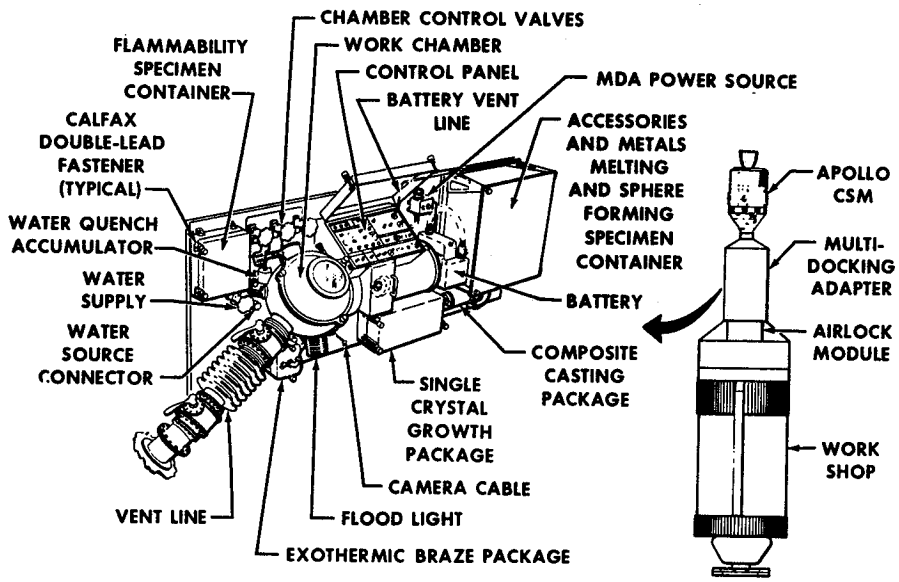

FIGURE 8. SKYLAB EXPERIMENT M-479 ZERO GRAVITY FLAMMABILITY

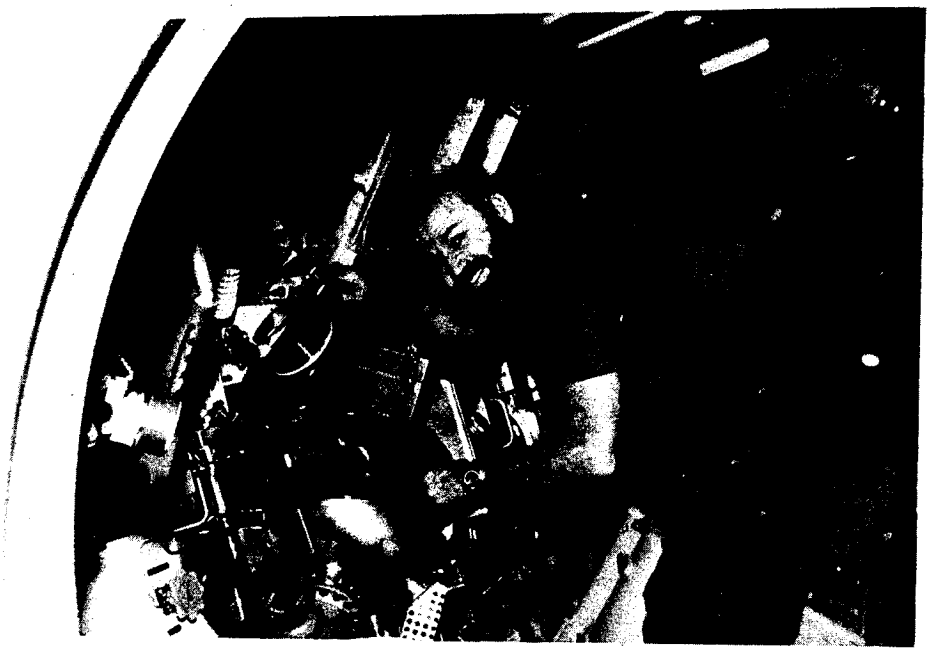

FIGURE 9. SKYLAB IN-FLIGHT TESTING

FIGURE 10. PHOTOGRAPH OF BURNING POLYURETHANE FOAM IN TEST NUMBER 10

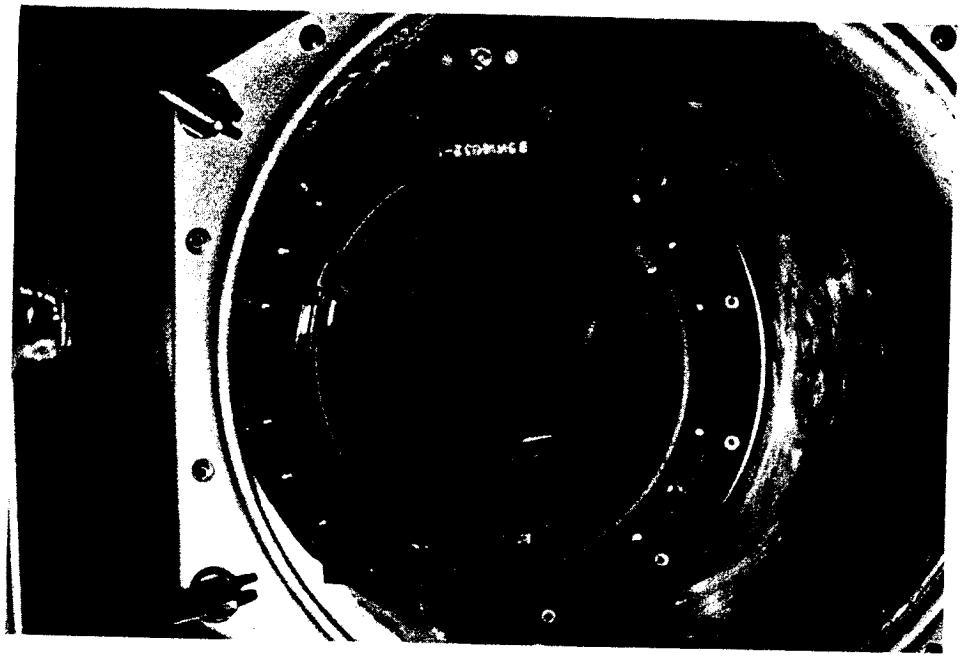

FIGURE 11. PHOTOGRAPH OF SMOKE PATTERN OF BURNING POLYURETHANE FOAM IMMEDIATELY AFTER FIRE WENT OUT

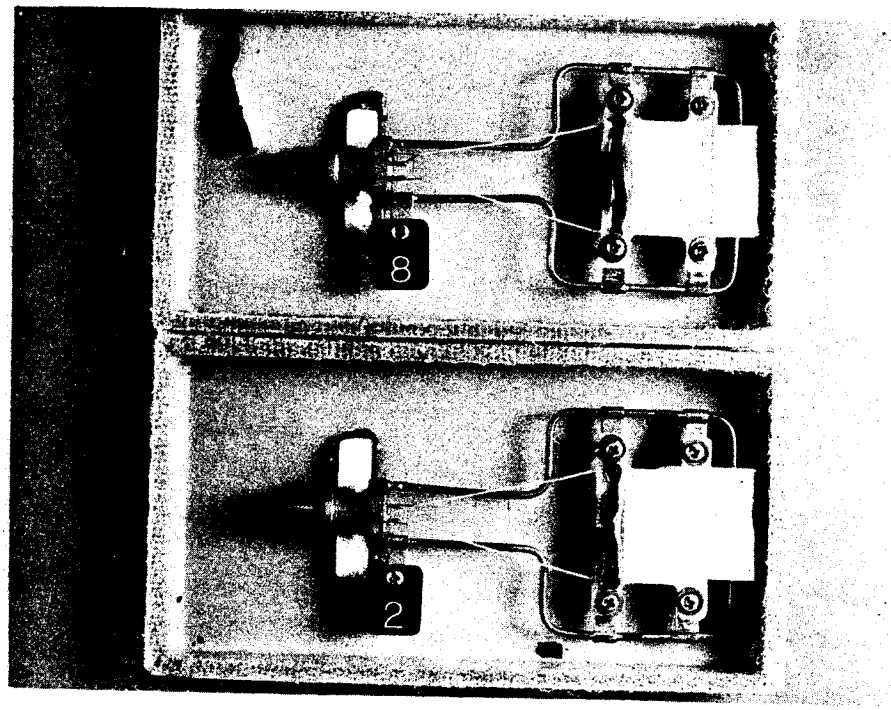

FIGURE 12. PHOTOGRAPH OF SPECIMEN RETURNED FROM TEST NUMBER 2 WHICH DID NOT IGNITE

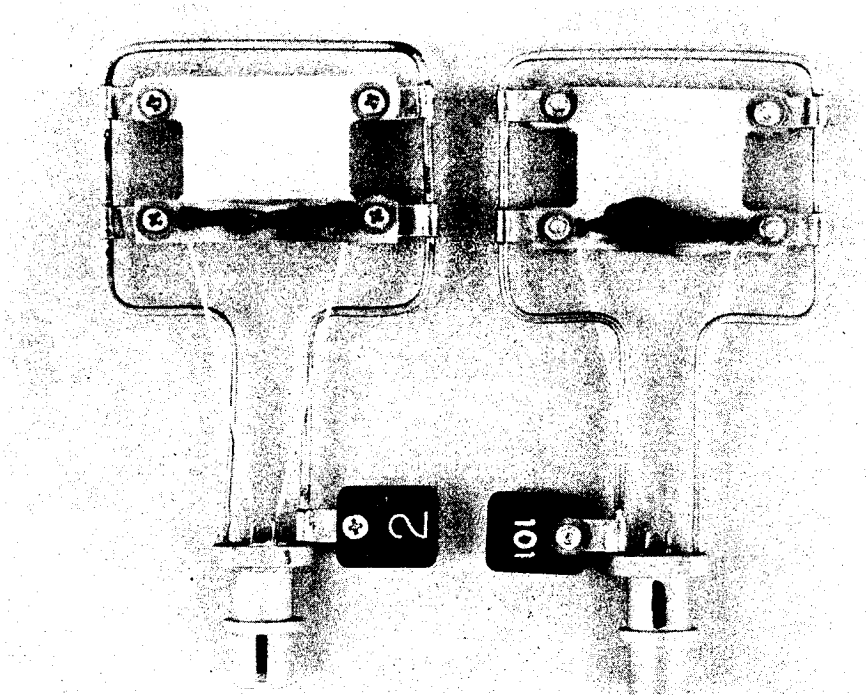

FIGURE 13. PHOTOGRAPH OF SPECIMEN RETURNED FROM TEST NUMBER 8 WHICH DID NOT IGNITE

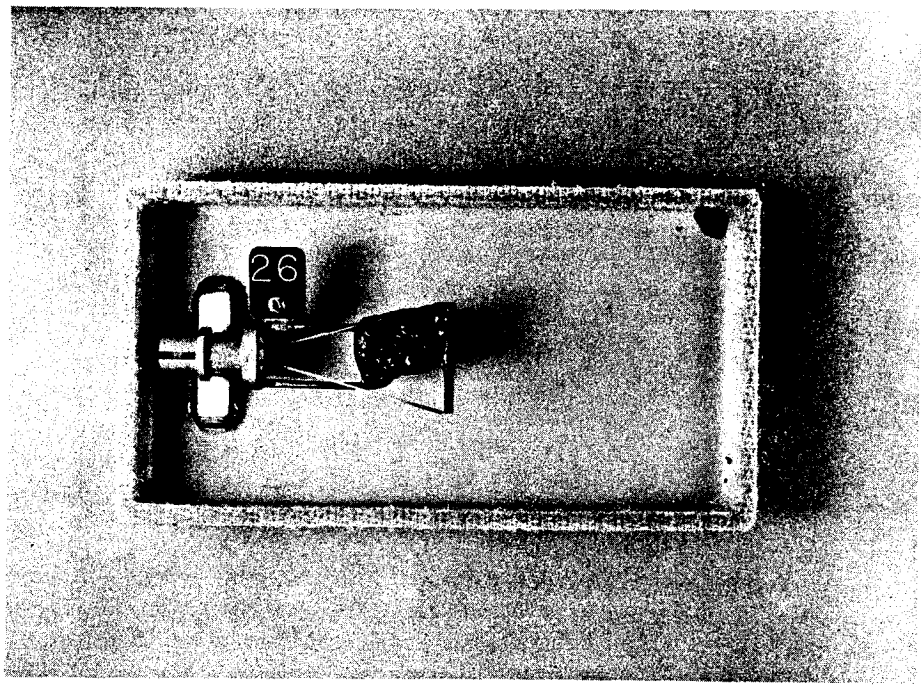

FIGURE 14. PHOTOGRAPH OF RETURNED RESIDUE FROM TEST NUMBER 26 WHICH AFTER BURNING FOR NEARLY 11 MINUTES WAS DELIBERATELY EXTINGUISHED BY DUMPING THE ATMOSPHERE.

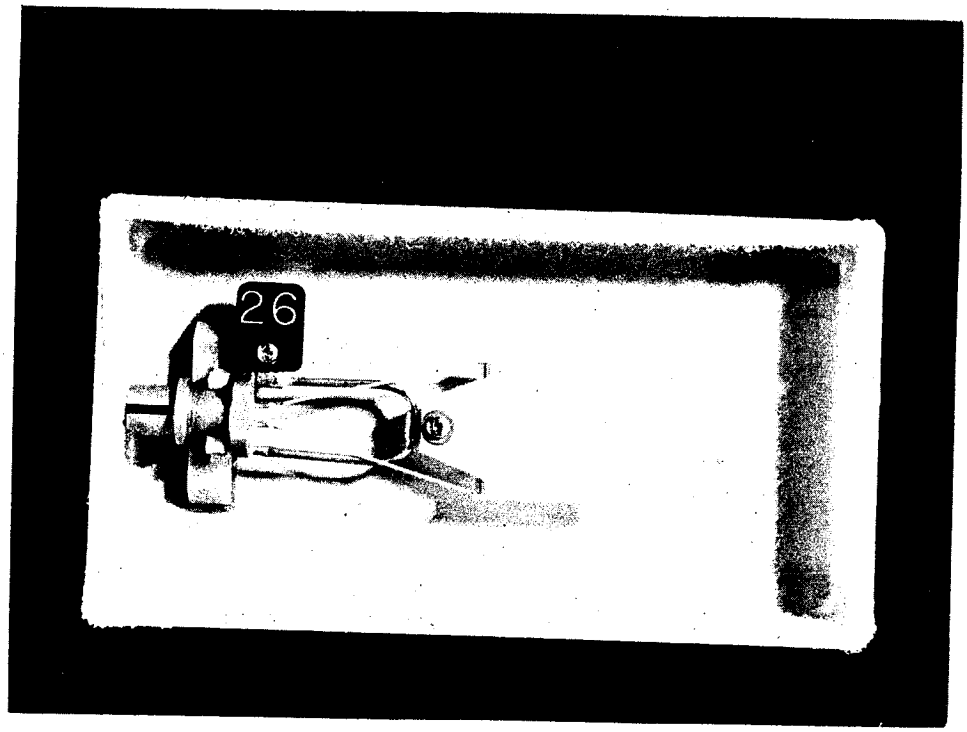

FIGURE 15. PHOTOGRAPH OF RETURNED RESIDUE FROM TEST NUMBER 26 WHICH AFTER BURNING FOR NEARLY 11 MINUTES WAS DELIBERATELY EXTINGUISHED BY DUMPING THE ATMOSPHERE.

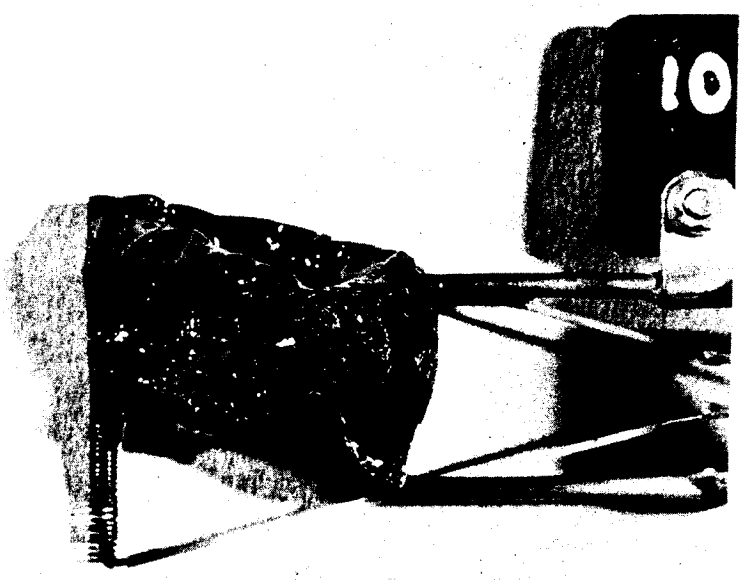

FIGURE 16. PHOTOGRAPH OF RETURNED RESIDUE FROM TEST NUMBER 26 WHICH AFTER BURNING FOR NEARLY 11 MINUTES WAS DELIBERATELY EXTINGUISHED BY DUMPING THE ATMOSPHERE.

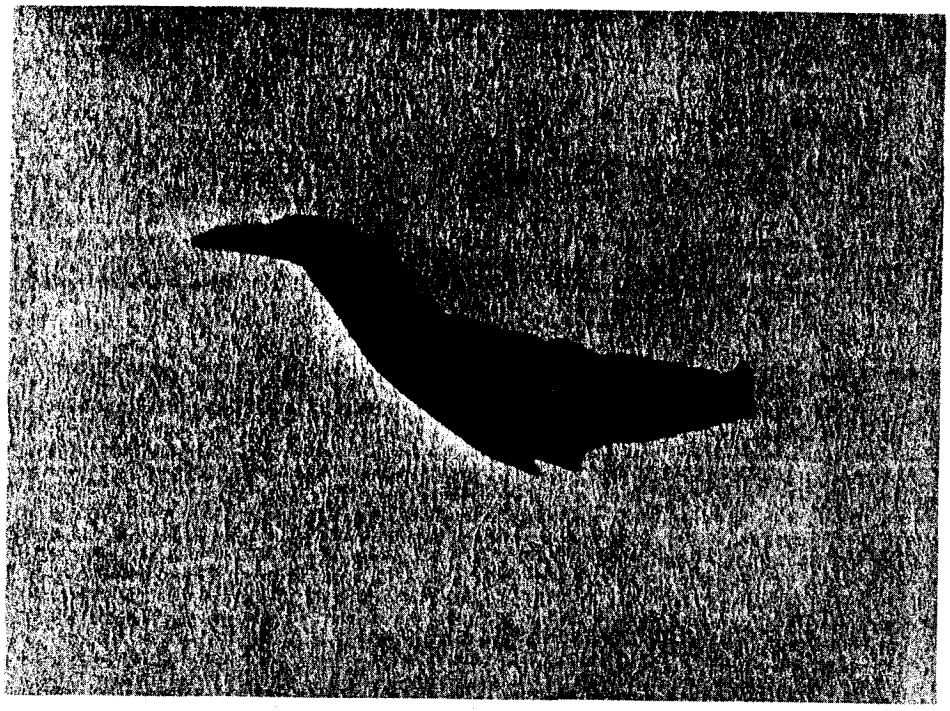

FIGURE 17. PHOTOGRAPH OF RETURNED RESIDUE FROM TEST NUMBER 17. PAPER BURNED WITH A VERY SOFT BLUE FLAME NOT VISIBLE TO THE CAMERA.

(CONCLUSIONS)

IGNITION - NO DIFFERENT THAN ONE-G

BURNING RATES - SLOWER THAN IN ONE-G. NO TENDENCY TO INCREASE WITH TIME AS ONE-G UPWARD BURNING

- o HIGHLY FLAMMABLE, THIN MATERIAL - FAST BURNING IN ONE-G REGARDLESS OF ORIENTATION. SIMILAR FAST BURNING IN ZERO-G.
- o THICKER MATERIAL, NONMELTING - A NEARLY INVISIBLE FLAME PASSES OVER THE SURFACE COMPLETELY SURROUNDING THE FUEL SLOWER THAN ONE-G.
- o PLASTIC MATERIAL, LOW MELTING POINT - SLOWER BURNING THAN ONE-G. NOT SELF EXTINGUISHING. WILL BURN FOR EXTENDED PERIOD OF TIME IN A VERY SMALL, NEARLY INVISIBLE FLAME WHICH IS ERRATIC DUE TO HIGH VISCOSITY DISTURBANCES.

FIGURE 18. SKYLAB EXPERIMENT M-479

- o FOAM MATERIAL, FLAMMABLE - SLOWER BURNING THAN ONE-G

EXTINGUISHMENT BY VACUUM - POSSIBLE BUT ADVERSE EFFECTS FROM EDDY CURRENTS CAUSE INCREASED BURNING

EXTINGUISHMENT BY WATER - POSSIBLE IF APPLICATION IS CONTROLLED

SELF EXTINGUISHMENT

- o YES - NONMELTING MATERIAL (PAPER, CARBON, ETC.) AND MATERIAL REQUIRING HIGH HEAT TO IGNITE (TEFLON)
- o NO - PLASTIC MATERIALS WITH A LARGE TEMPERATURE SPREAD BETWEEN MELTING POINT AND BOILING POINT (NYLON, ETC.) AND METALS - NO GASEOUS PRODUCTS OF COMBUSTION RAPIDLY BURNING MATERIAL (ALUMINIZED MYLAR, ETC.) MATERIALS CONTAINING OXIDIZERS AND MATERIALS TRAPPING OXYGEN (OPEN CELL FOAMED POLYURETHANE)

FLASHOVER TO ADJACENT MATERIAL - BURNING PAPER REQUIRES GAP DISTANCES OF OVER 1/2 INCH TO PREVENT FLASHOVER.

FLAME VISIBILITY - THE FUEL-RICH NATURE OF MANY KINDS OF ZERO-G FLAMES CAUSES A SOFT BLUE FLAME WHICH IS BOTH SMALL AND NEARLY INVISIBLE. FLAMES FROM RAPIDLY BURNING MATERIAL ARE GENERALLY VISIBLE.

MATERIAL TESTING - ONE-G TESTING FOR FLAMMABILITY PROVIDES AN ADEQUATE, SOMEWHAT CONSERVATIVE, TEST FOR FIRE SAFETY.

FIGURE 18. SKYLAB EXPERIMENT M-479 (CONT.)

FUTURE STUDIES OF ZERO-GRAVITY FLAMMABILITY

SHOULD INCLUDE:

- FIRE DETECTION - FLAME SPECTRA
- IGNITION ENERGIES
- PROPAGATION RATES
- OTHER FUELS
  - LIQUIDS
  - GASES
  - METALS
- EXTINGUISHMENT

FIGURE 19. RECOMMENDATIONS