NASA TECHNICAL MEMORANDUM

Report No. 53853

DEVELOPMENT OF SPACE STATION WINDOW ASSEMBLIES

By C. N. Irvine
Manufacturing Engineering Laboratory

July 18, 1969

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC - Form 3190 (September 1968)

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. TM X-53853	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DEVELOPMENT OF SPACE STATION WINDOW ASSEMBLIES		5. Report Date July 18, 1969
		6. Performing Organization Code
7. Author(s) C. N. Irvine		8. Performing Organization Report No.
9. Performing Organization Name and Address George C. Marchall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by the Manufacturing Engineering Laboratory
Science and Engineering Directorate

16. Abstract The primary purpose of this effort is to provide a capability to convert the spent S-IVB stage, in its space environment, to a habitable working and living area. This publication presents the results of an MSFC effort to develop the preliminary technology for installing windows into space structures in earth orbit and includes the proposed "Window Cutting Experiment," which has been classified by the MSFC Experiment Review Board as a Flight Technology Item. Design definition, fabrication, and testing of the first prototype window assembly using the explosive cutting techniques are described.

17. Key Words	18. Distribution Statement Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	$3.00

ACKNOWLEDGMENT

Appreciation is extended to Mr. Ed Coleman and his associates of Hayes International Corporation who conducted the test work and to the Army's Explosive Service Division who supported the test firing.

Recognition of the author's associates is also extended to Messrs. Dick Beck, Bennie Wells and Willie Prasthofer of MSFC's Astronautics Laboratory, who have prime responsibility for design and engineering test requirements. Additional appreciation is expressed to Messrs. Chuck Biggerstaff, Will Simpson, Charles Stocks, John Schell, Art Ousley, and Bill Wilson of MSFC's Manufacturing Engineering Laboratory.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM X-53853

DEVELOPMENT OF SPACE STATION WINDOW ASSEMBLIES

SUMMARY

This publication presents the results of Marshall Space Flight Center's efforts in developing the preliminary technology for installing windows in space structures while in an earth orbital environment. The hardware and techniques for installation are directly applicable to the S-IVB spent stage.

Test work to-date has been promising. It was determined that a "stand-off" detonator ignition is necessary for quality acceptable cuts. The window material, Lexan, has withstood all tests. Problem areas still remain to be resolved in the use of fasteners or techniques for withstanding the force of the explosive charge and the use of detonators. Further design definition and testing of the developed hardware should resolve these problems.

INTRODUCTION

General

In September 1967, proposed experiment No. 33, (Window Cutting) was presented to the MSFC Experiments Review Board (ERB). A concept of the window assembly is shown in Figure 1. Objectives of the experiment were essentially:

1. To develop the preliminary technology for installing windows in a spent stage (S-IVB Orbital Workshop) while in earth orbit.

2. To design, fabricate, and test a ground demonstration model.

3. To resolve potential problem areas and document practical hardware.

In December 1967, the Window Cutting Experiment was changed from Flight Experiment status to a Flight Technology Item. MSFC ERB suggested the establishment of an operational capability for installing windows in a spent stage rather than develop an experiment in space.

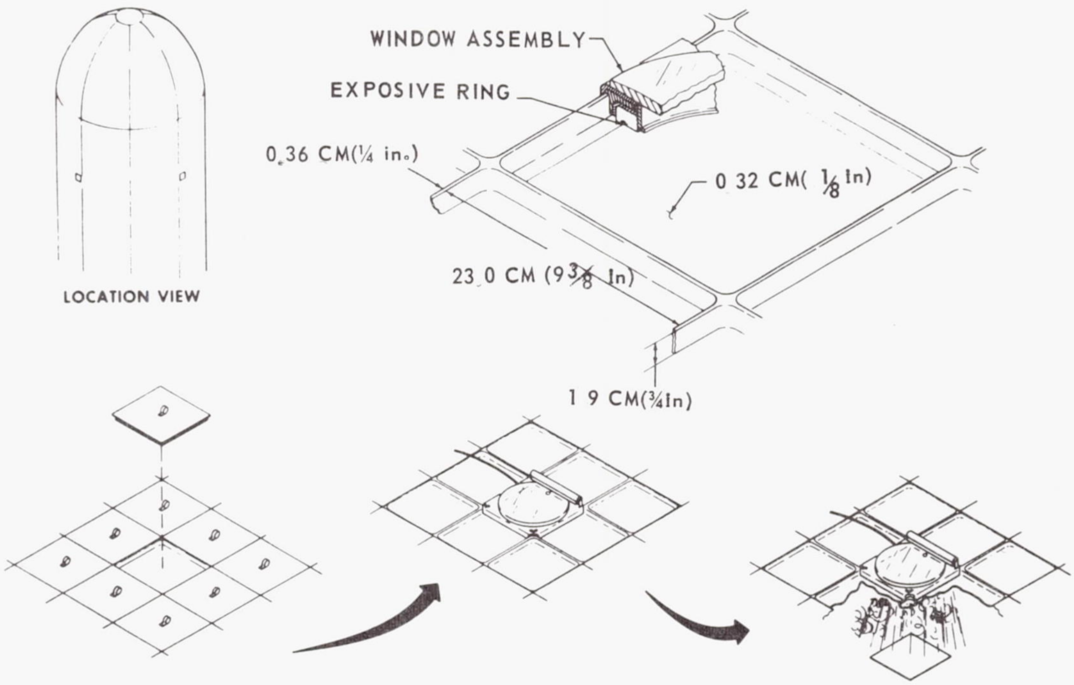


Figure 1. Artist concept — window assembly.

As is known, it is planned to convert empty space vehicle fuel tankage (S-IVB fuel tank) in its space environment to a usable area for a space workshop. Present plans specify windows for the Multiple Docking Adapter (MDA) but not for the Orbital Workshop (OWS). However, a means of accomplishing this for the OWS can be provided by a window assembly kit capable of simultaneously cutting a port hole in the skin of the tank and providing a window sealed to the skin. With this in mind, a preliminary window assembly unit was designed, fabricated, and used in evaluating the various parameters involved; such as, explosive charges, sealing attachment, and window material (Figs. 2 and 3).

Background Information

The installation of window assemblies in space structures will require materials that withstand the environmental conditions encountered in space. Techniques that are reliable, safe, and capable of being conducted by astronauts must be employed. The windows can be designed to be part of the

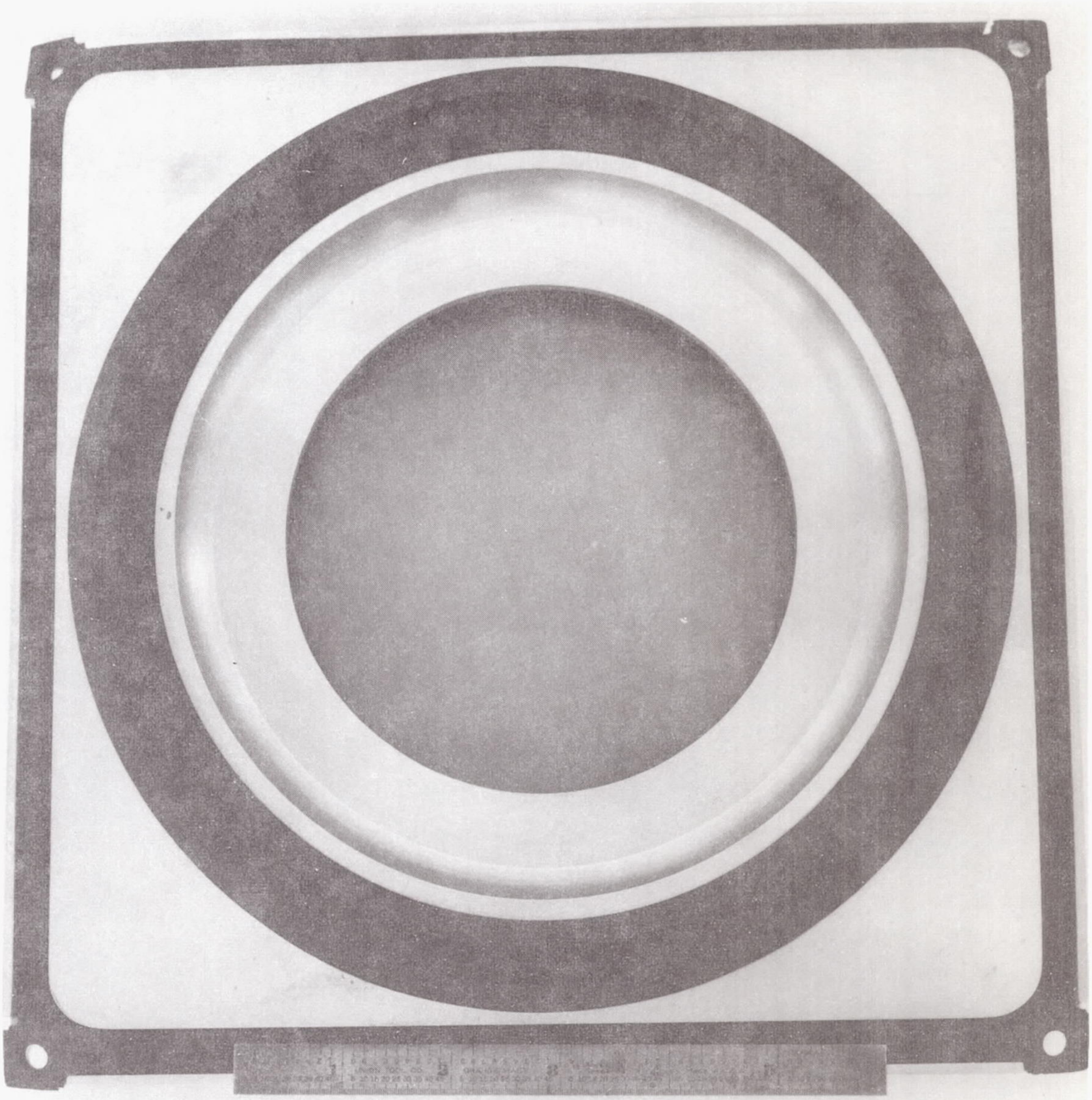


Figure 2. Bottom view of window assembly.

space structure, as are installed in the Apollo Command Module, or as a built-in prepackaged kit. The former would have to withstand the launch loads (impulse, shock, etc.), whereas the latter could be installed by an astronaut.

If a self-contained package were employed, the kit could be stored in the MDA. The astronaut could remove the insulation blocks at a recognizable

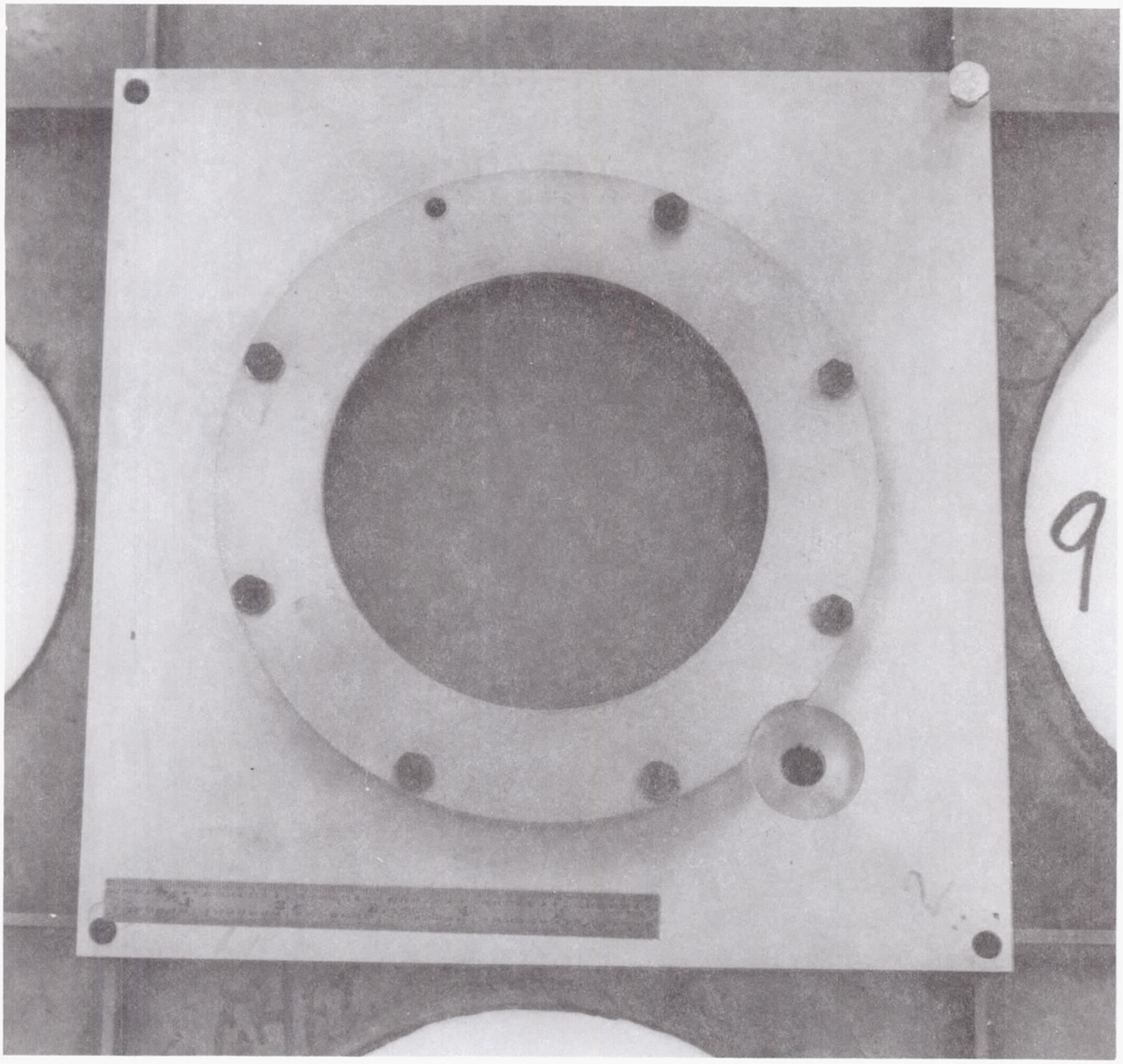


Figure 3. Window unit on test panel.

location of the spent S-IVB cylindrical skin section, place and lock-in a built-in prepackaged kit, and ignite the electrical cutting device. When ignited, the cut-out section will be safely blown into space without damaging the window or sealants. Also, it is impossible to accidentally set off the flexible linear shape charge (FLSC) and detonators. For example, the FLSC can be hit with a hammer, cut with scissors, and literally stomped without ignition.

The explosive cutting technique is used in the Saturn program for stage separations and emergency thrust termination. In addition, it is also used for stage separations of most operational missiles. The FLSC of 3.2 g/m (15 gr/ft) has a reliability of 99.99 percent in cutting holes from 0.3-cm (0.125-in.) thick aluminum alloy 2014-T6, which is the same thickness and material as the spent liquid hydrogen tank of the S-IVB stage.

Flexible linear shaped charge is a V-shaped flexible tube containing a high explosive core that provides a sharply defined cutting action when detonated. Excellent results in both atmosphere and vacuum conditions were obtained in the MSFC tests when explosively cutting manholes in simulated Saturn upper stage tanks.[1]

Program Approach

In developing an operational capability to emplace windows, it was recognized that:

1. Windows can be emplaced in space from a self-contained package by the astronauts.

2. Windows can be emplaced from pre-installed assemblies using either insulation or a balsa type of framework. Such assemblies could be fabricated and installed in a terrestrial environment. The astronaut would "push a button" to obtain a window.

Initial priority was to develop a self-contained window assembly unit (SK10-9670), which consists of window seals, housing attachment frame, and window, affixed to an S-IVB aluminum alloy waffle panel section, 24.1 by 24.1 cm (9.5 by 9.5 in.) square, 1.8 cm (0.75 in.) deep, and 0.3 cm (0.125 in.) thick.

In developing the explosive cutting portion of the window cutting assembly, objectives were to resolve principally problems that might exist in:

1. Seals (impact and pressure build-up)

2. Debris (to be defined)

3. Window Material (effect of shock on it).

---

1. Hamilton, L. O.: Explosive Cutting of a Manhole in Simulated Saturn V Upper Stage Fuel Tanks in Space Environments, NASA-TM X-53440, April, 1966.

As test work progressed, it became evident that modifications to the existing design were needed. Originally the 20-cm (8-in.) diameter charge incorporated in the window assembly unit caused fracturing along the stress point where the rib joins the panel of the S-IVB skin. Subsequent testing with a 15-cm (6-in.) diameter charge resulted in a clean cut without damage to basic structures.

The subsequent portions of this report document the design, fabrication, testing, and modifications of the prototype window assembly.

DESIGN

The first prototype window assembly tested included the parts shown in Table 1. These parts, and others, were used in fabrication of components necessary to perform initial feasibility studies of a window experiment in the S-IVB spent stage. Figures 2 and 3 depict views of the assembled unit.

TABLE 1. WINDOW ASSEMBLY PARTS

Nomenclature	Design Drawing No.
FLSC, Ring, Alignment	SK10-9663
Alignment Ring, Seal	SK10-9664
Window	SK10-9665
Window Gasket	SK10-9666
Retainer-Window	SK10-9667
Base Plate-Window	SK10-9668
Seal, Outer	SK10-9671

Other materials were evaluated and may be required for flight hardware; however, for the purpose of conducting the ground testing, relatively inexpensive materials were specified. Aluminum Alloy 2219-T87 was used for frame housing parts, and 15-cm (6-in.) diameter, 1.3-cm (0.50-in.) thick Lexan (polycarbonate) was selected as the window material. Fifty durometer hardness neoprene rubber was used as the gasket material.

The first FLSC used consisted of an RDX15 lead configuration of 6 percent antimonial lead (± 0.5 percent antimony) RDX (explosive per MIL-R-398), 3.2 g/m (15 gr/ft) as furnished by Ensign Bickford, Simsbury, Connecticut. Subsequent tests employed FLSC of 2.1 g/m (10 gr/ft) or 1.5 g/m (7 gr/ft).

The detonator (Fig. 4), originally designed for another purpose, proved too powerful for the window assembly unit. However, by using a detonator stand-off distance of 1.3 cm (0.50 in.), a FLSC of 2.1 g/m (10 gr/ft) and cutting a hole 15 cm (6 in.) in diameter, the detonator performed satisfactorily.

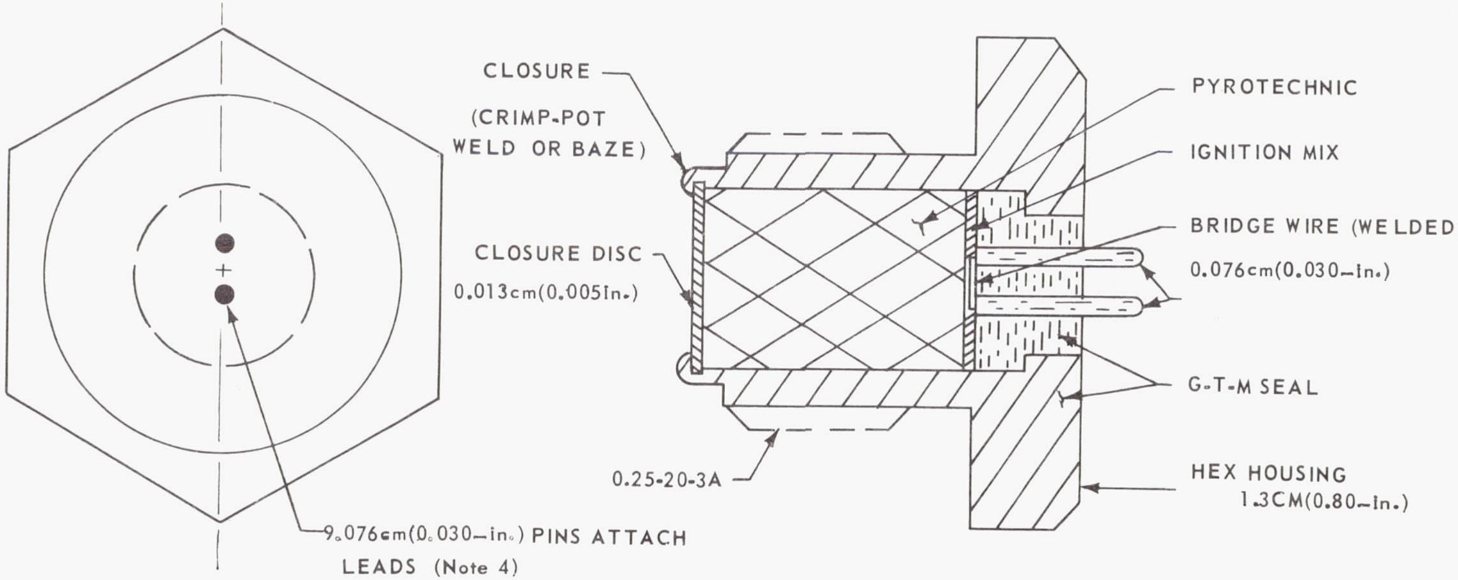
FABRICATION

Sufficient details to assemble five of the units were procured. Allied Engineering, Alameda, California, supplied the base plate and seals. Flexible linear shape charges, fasteners, and detonators were already on hand at MSFC. Redstone Machine and Tool Company, Huntsville, Alabama, supplied the FLSC alignment rings, the windows, and window retainers. The Lexan windows were received with a rough finish condition. One detail was polished in-house and used throughout the subsequent test work described in this report. The 20-cm (8-in.) diameter FLSC alignment rings for a FLSC of 3.2 g/m (15 gr/ft) were modified and eventually changed to a 15-cm (6-in.) diameter.

Because the S-IVB skin target has a double contour, careful machining of the interface parts was required to meet the FLSC standoff tolerance of 0.005 cm (0.002 in.).

TESTING

The subsequent series of tests were conducted on the prototype S-IVB Window Emplacement Assembly (SK10-9670). The purpose of the tests, generally, was to evaluate the feasibility of emplacing windows on the cylindrical skin of the S-IVB stage using flexible linear shape charges to explosively cut the port holes while simultaneously sealing the interior of the S-IVB stage against the external environment. The window emplacement assembly was originally designed to accept a 3.2 g/m (15 gr/ft) FLSC. Therefore tests were initiated utilizing this configuration.



SPECIFICATIONS

1 - ALL FIRE - 3.5 AMPS - 28 VOLT SOURCE

2 - TIME - 4 - 4.5 AMPS

3 - NO FIRE - 1 AMP - 1 WATT- 5 MIN

4 - LEADS - TYPE 1: 15CM(6in.) FLEXIBLE
TYPE 2: 30CM(12in.) WITH CONNECTOR

5 - OUTPUT - RELIABLY DRIVE STUD 172 O.D.
THROUGH AL TARGET (2014-T6, 0.3-CM THICK)

6 - CLOSURE - OPTIONAL

Figure 4. Pressure cartridge, MR&T-SK-1284.

TWENTY-CENTIMETER (8-in.) DIAMETER HOLE – 3.2 g/m (15 gr/ft)

The first test was made using a charge of 3.2 g/m (15 gr/ft) with the FLSC's Teflon cover removed. The window assembly was attached to the S-IVB skin section by four high strength 0.64-cm (0.25-in.) bolts located at the four corners of the unit (Fig. 2). At detonation, the window assembly was blown away from the panel, stripping the threads out of the tapped holes in the panel. Also, two of the corner bolt holes in the window unit were torn. Although a 20-cm (8-in.) diameter hole was cut, the target panel was badly fractured (Fig. 5). The Lexan window was in good condition and was used in all subsequent testing without failure. In general, a shaped charge of 3.2 g/m (15 gr/ft) was too powerful and destroyed the retention mechanism.

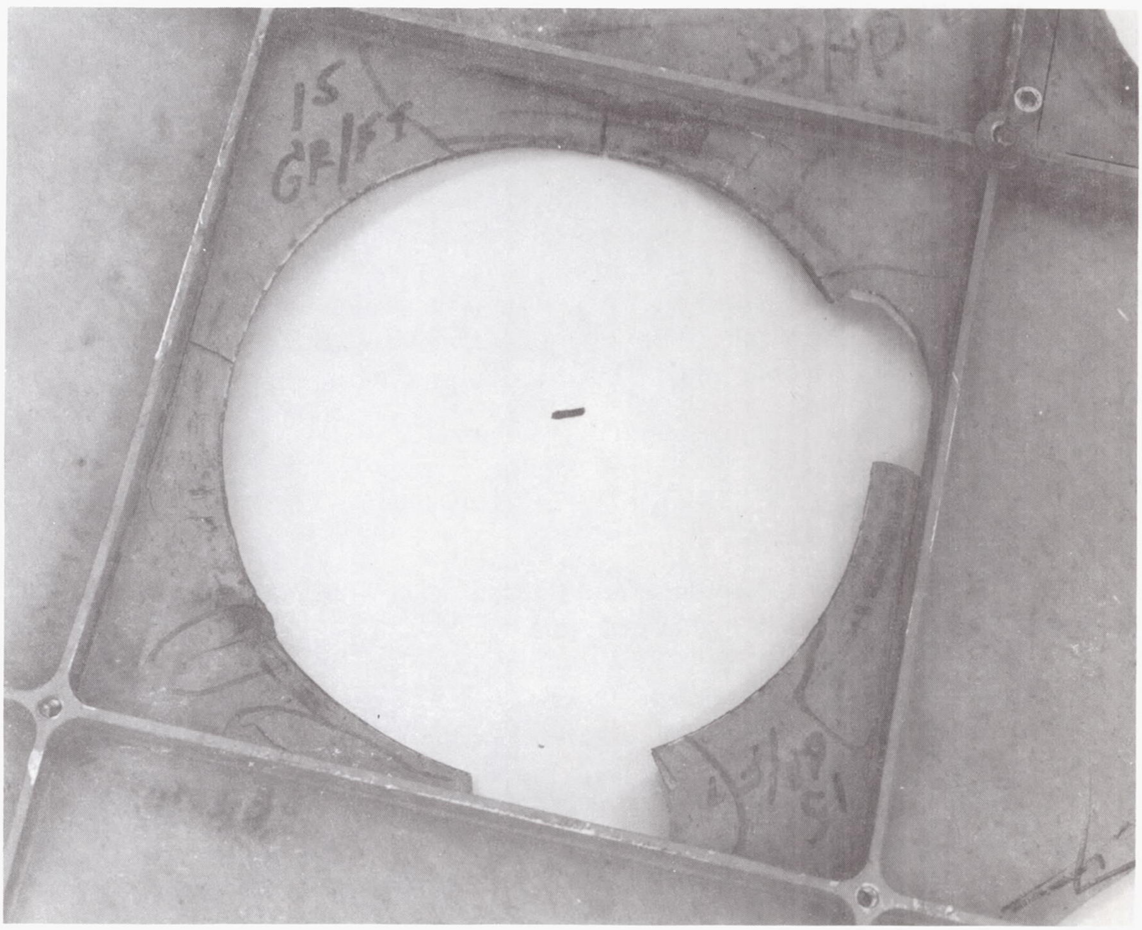


Figure 5. Test panel cut with 3.2 g/m (15 gr/ft) "FLSC".

TWENTY-CENTIMETERS (8-in.) DIAMETER HOLE – 2.1 g/m (10 gr/ft)

The second test was made with a new assembly except for the Lexan window. The unit had been modified by reworking the charge holder to accept a 2.1 g/m (10 gr/ft) charge encased in Teflon. This test resulted in a misfire when the detonator failed to ignite the charge. There was no damage to the unit except for the threaded hole which contained the detonator. After firing, it was impossible to remove (unthread) the spent detonator because the threads had expanded into the body of the window housing.

A new detonator hole was drilled and tapped in order to make the same window assembly available for test three. The 2.1 g/m (10 gr/ft) shot FLSC cut a fairly clean 20-cm (8-in.) diameter hole, but again the panel was fractured. Two slight cracks occurred around the edge of the 20-cm (8-in.) opening as shown in Figure 6. The window assembly remained on the panel although one bolt was sheared off and a second bolt stripped the threads from the panel.

Test four was similar to test three except four "C" clamps were added to augment the four bolts holding the kit to the panel. When fired, the window assembly did not loosen and a clean hole was cut with one fracture extending from the hole to one rib. There was also fracturing at two of the clamp positions (Fig. 7).

15-cm (6-in.) DIAMETER HOLE

Test five was completed using a modified window emplacement assembly with an insert which contained a groove for a 15-cm (6-in.) diameter circle of 1.5 g/m (7 gr/ft) FLSC. The bottom interface of the tool kit was covered with 0.3 (0.125-in.) thick double backed adhesive which had been trimmed to fit the inside and outside diameter of the charge. The window assembly was positioned on the panel with the adhesive against the panel face and then clamped with "C" clamps. The charge was initiated by running the 1.5 g/m (7 gr/ft) charge up through a 1.3-cm (0.50-in.) diameter hole in the assembly and detonating it with an E-90 blasting cap. Following detonation, the window assembly remained fastened securely to the panel after the clamps had been removed. An examination of the hole and cut out portion showed the charge had turned slightly in one area. No evaluation of the window sealing was attempted due to the failure of the bolts to securely hold the window assembly to the panel.

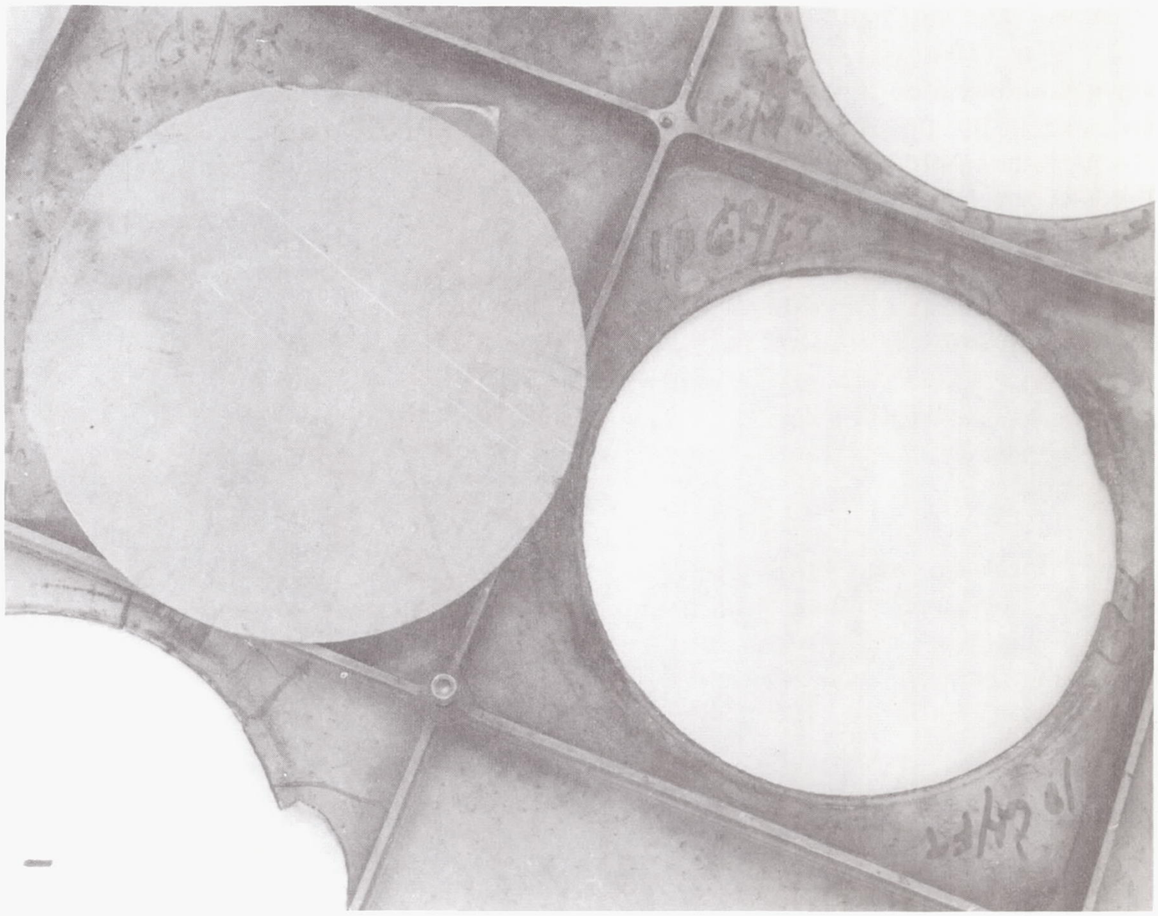


Figure 6. Test panel cut with 2.1 g/m (10 gr/ft) "FLSC".

Test six, which consisted of a series of shots, was conducted in an effort to determine the pressures and acceleration forces acting upon the tool kit at the time of detonation. A pressure transducer (300 000 psi or 20×10^8 N/m^2) and an accelerometer (10 000 gs) were mounted on a 20-cm (8-in.) diameter window assembly which had been modified to take a 1.5 g/m (7 gr/ft) FLSC. On two test shots the transducers and accelerometers were destroyed. The accelerometers indicated a reading of 20 000 gs which is unreliable because this is twice the range of the unit used. The pressure measurements were also inconclusive because the readings were off scale and therefore in excess of the transducer capabilities.

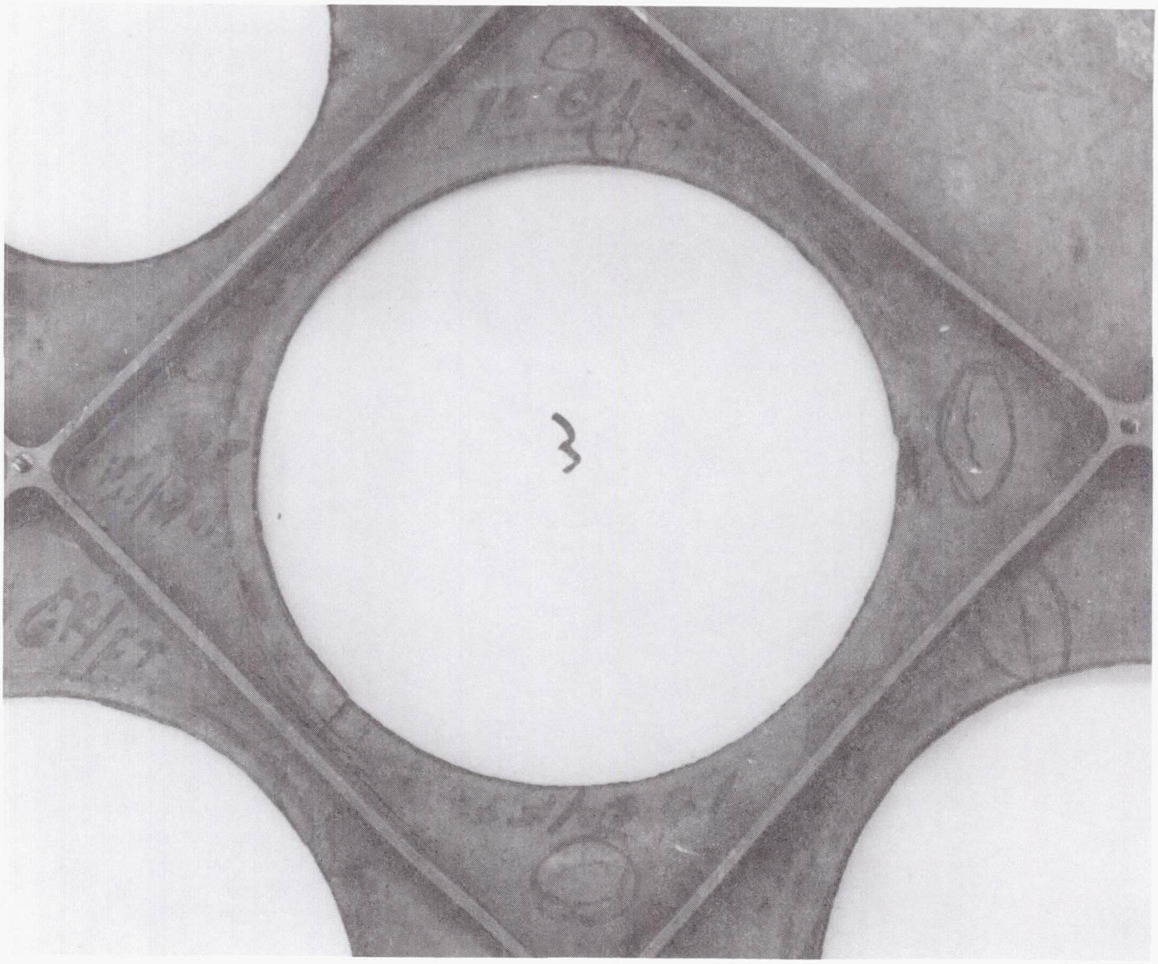


Figure 7. Test panel cut with 2.1 g/m (10 gr/ft) "FLSC" using clamps.

Test seven was conducted to determine if the combination of the double backed adhesive and the four 0.64-cm (0.25-in.) were capable of holding the window assembly to the panel after detonation. A used window assembly was modified to accept a 15-cm (6-in.) diameter by 1.5 g/m (7 gr/ft) FLSC and detonator (Fig. 8). After firing, the bolts were still in place and the threads in the panel were intact, although one bolt needed tightening. After removing the bolts, the adhesive still held the unit to the skin. The panel had a small (thumbnail) size fracture at the point of detonation, thus it appears that a less powerful detonator would be more applicable to this concept.

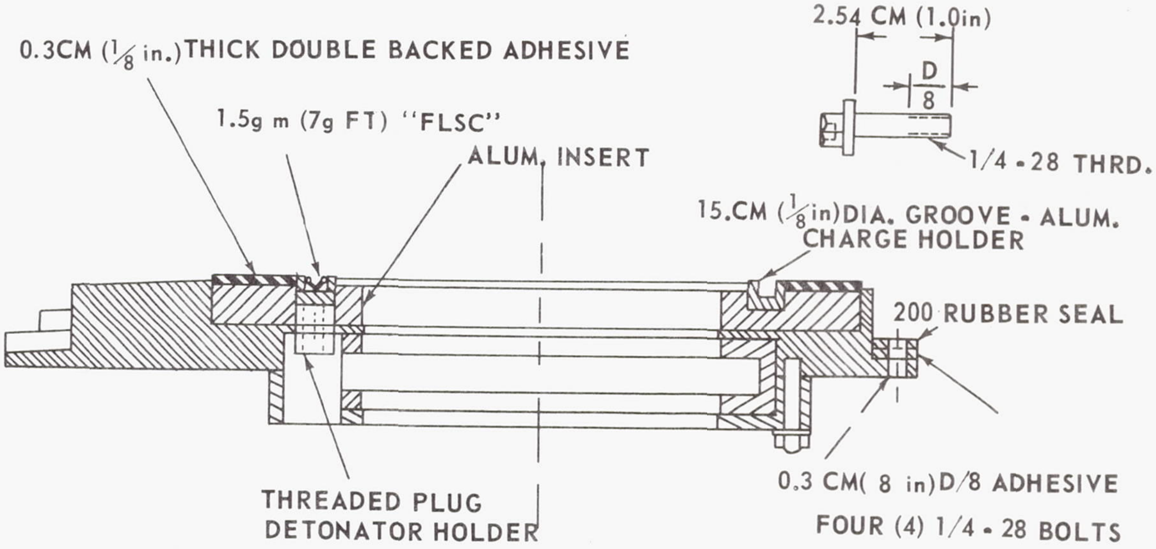


Figure 8. Test set-up using double back adhesive and four 0.64-cm (0.25-in.) bolts.

FIFTEEN-CENTIMETER (6-in.) DIAMETER HOLE-VENT

Test eight was conducted using a window assembly modified to vent the gases formed during detonation (Fig. 9). The reasons for venting the gases were to reduce the pressure acting upon the bolts and alleviate the fracturing of the panel. Examination of the unit after the hole had been cut in the panel showed the window assembly was still held securely to the panel by four bolts. Upon removing the bolts, the unit did not adhere to the panel as it had in previous tests. The double backed adhesive was not bonded to the panel and only lightly bonded to the tool. This condition may have been caused by the assembly being outdoors overnight during which time there was a heavy frost. The panel area under the detonator was fractured as in previous tests. The double backed adhesive surface was unmarred as a result of venting the gases.

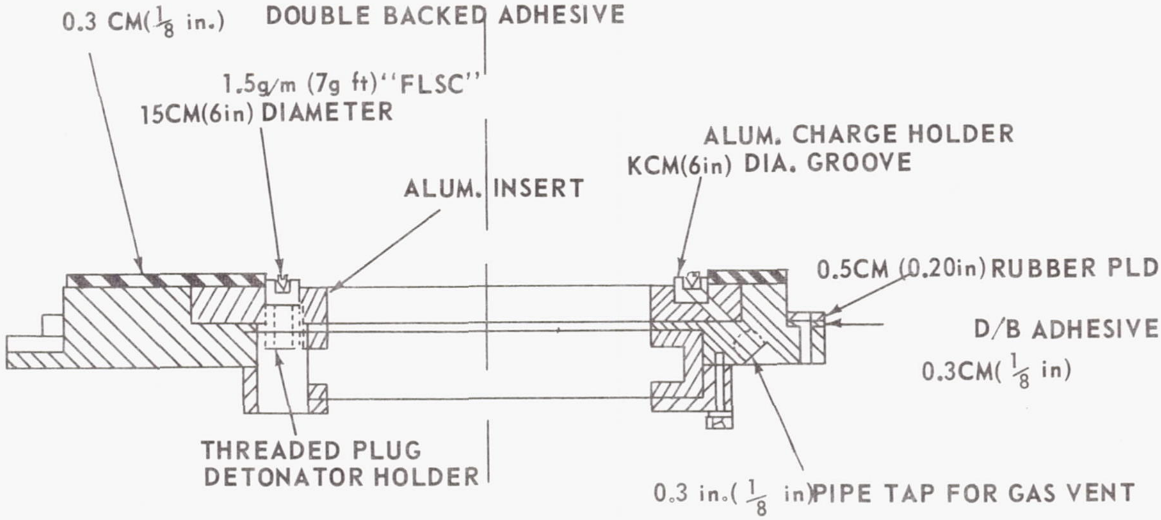


Figure 9. Test tool modification for venting gases.

FIFTEEN-CENTIMETER (6-in.) DIAMETER HOLE-DETONATOR STANDOFF

Test nine was conducted to eliminate the panel fracturing by removing the detonator from the immediate vicinity of the part. This was accomplished by installing a short pipe threaded on the outside diameter to match the tool and threaded on the inside diameter to match the thread on the detonator (Fig. 10). From the tests conducted it was determined that a 1.3 cm (0.50-in.) stand-off between the detonator and the charge was sufficient to ignite the charge without harm to the test panel. Two of the tests made with this set-up using 1.5 g/m (7 gr/ft) FLSC were unsuccessful because the charge detonated but did not cut through the panel. This may have been caused by the condition of the aluminum charge holder which had been used in previous tests and was spread open slightly.

The final test was made using 2.1 g/m (10 gr/ft) FLSC in a new charge holder with the detonator at the same 1.3-cm (0.50-in.) stand-off. This test resulted in a clean hole being cut with no damage to the test panel (Figs. 11 through 15).

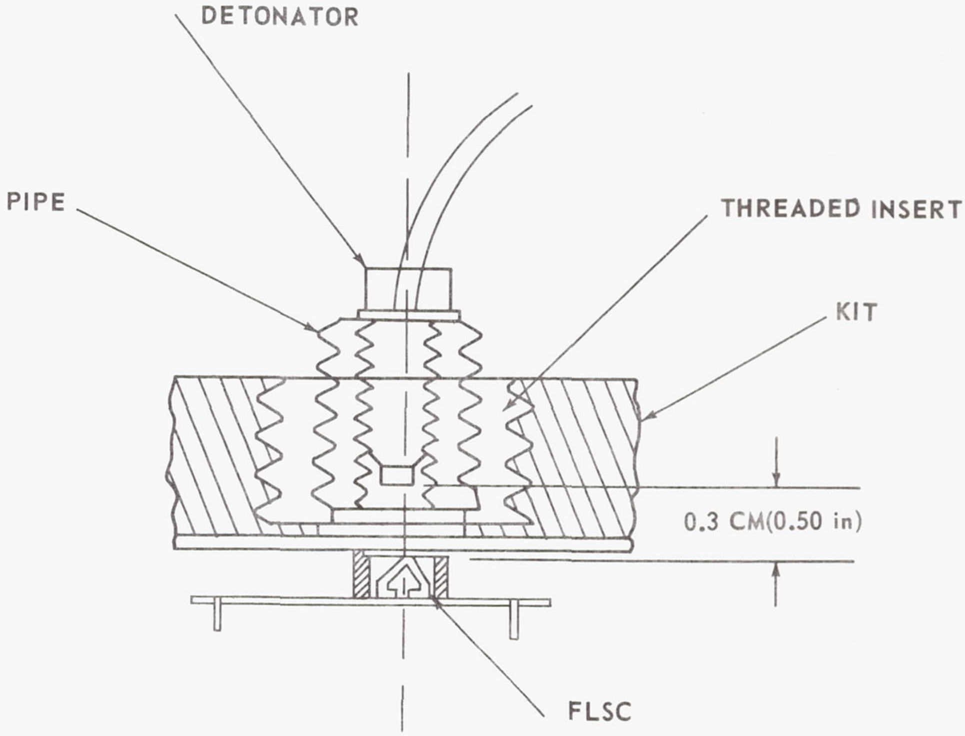


Figure 10. Modification for detonator stand-off.

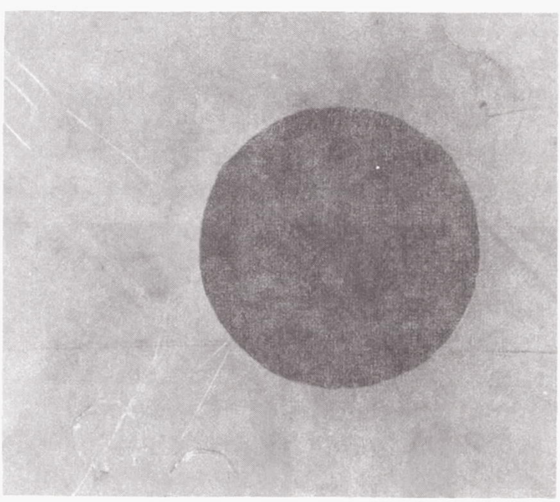


Figure 11. Exterior view of cut-out with 2.1 g/m (10 gr/ft) "FLSC" — 1.3-cm (0.50-in.) detonator stand-off.

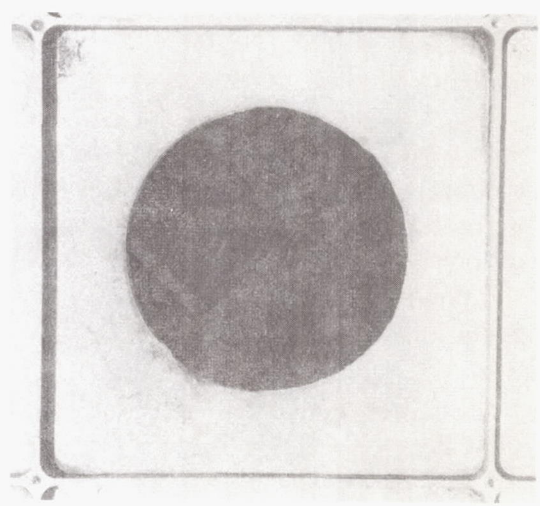


Figure 12. Interior view of cut-off with 2.1 g/m (10/ft) "FLSC" — 1.3-cm (0.50-in.) detonator stand-off.

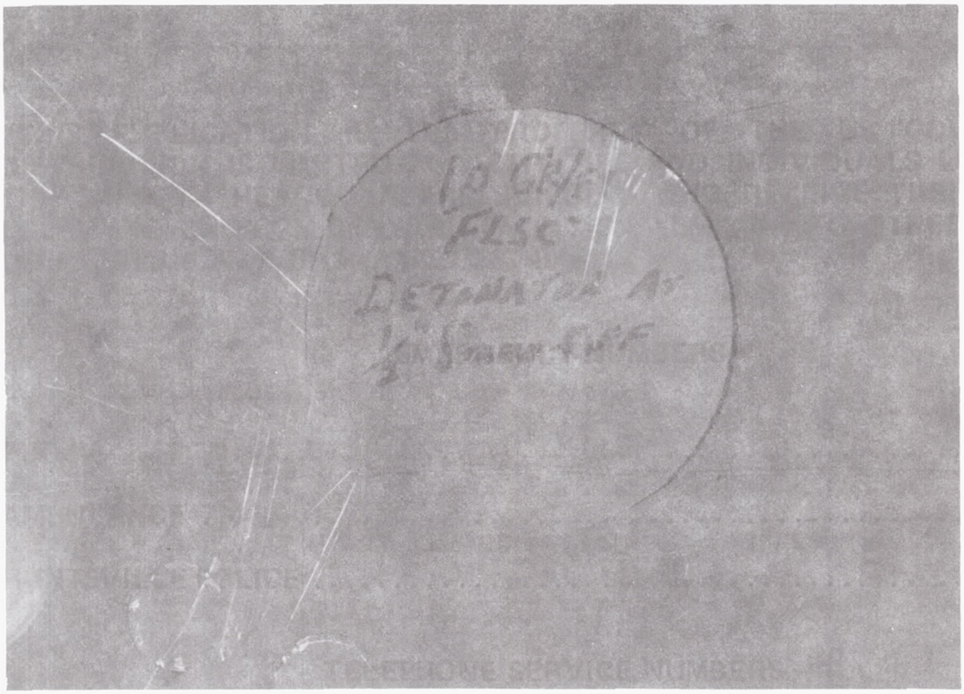


Figure 13. View of cut-off section replaced in hole.

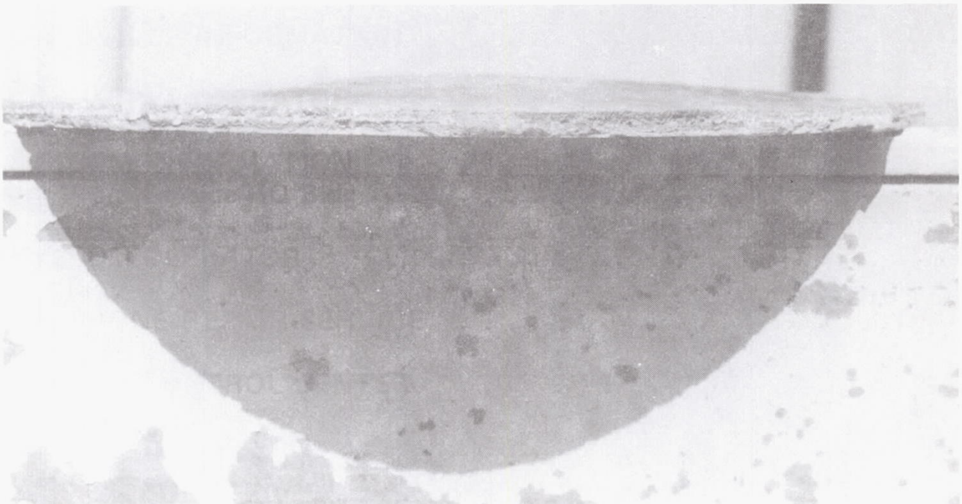


Figure 14. Edge view of cut-out section.

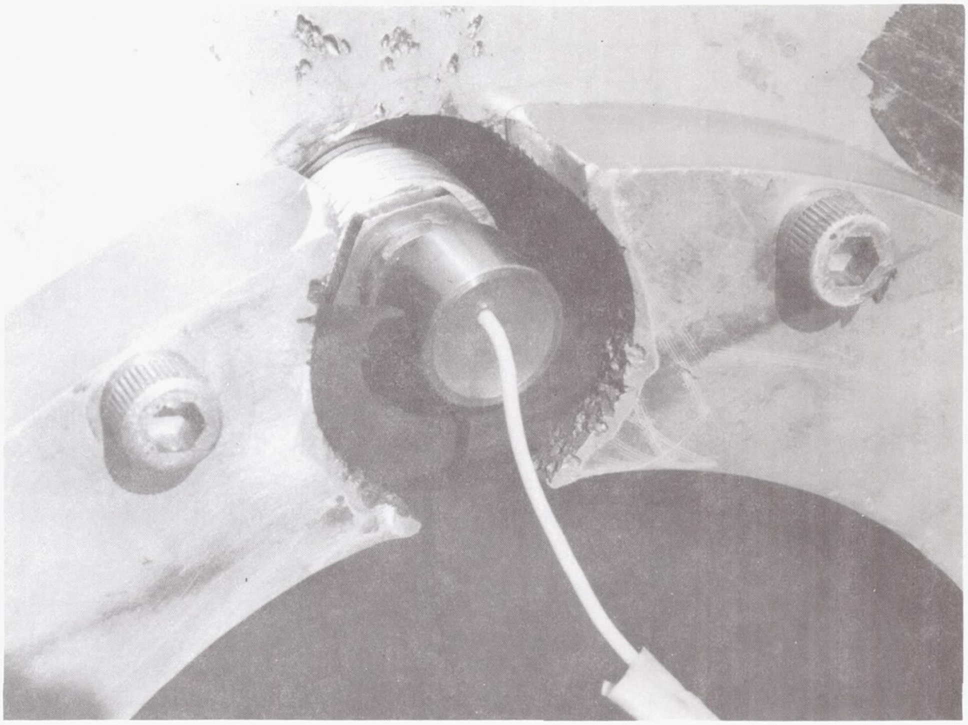


Figure 15. View showing threaded detonator stand-off.

CONCLUSIONS

A 2.1 g/m (10 gr/ft) flexible linear shaped charge is adequate to cut a hole in the S-IVB skin section and the Lexan window material will survive the shock of the cutting charge. The 20-cm (8-in.) diameter charge is not compatible with the rib configuration of the S-IVB skin.

There seems to be insufficient information on the shaped charge pressures involved on the window assembly as a cutting tool. Although pressure and acceleration measurements were attempted, the measurements were inconclusive. Indications were off-scale and therefore in excess of the transducer capabilities. Because adequate pressure transducers are not available, the use of "cut and try" techniques, coupled with strain gage instrumentation on the fasteners, may provide the desired information to determine the forces involved in shearing the four bolts that hold the window assembly in place.

It appears that the major problems that remain to be resolved are in the area of the fasteners or techniques for withstanding the force of the explosive charge, and the use of a less powerful detonator. The latter has already been resolved through the procurement of an on-shelf commercial type detonator. Further design definition and testing of the developed hardware should resolve the fastener problem.

RECOMMENDATIONS

It can be concluded that the work done to date demonstrates the flexible linear shape charge technique is a practical method to explosively cut port holes for emplacing windows on a spent stage such as the S-IVB skin section. If it is desired to emplace windows on the future spent S-IVB stages in space, further effort through design definition, manufacturing, and testing of the developed hardware is required.

A 15-cm (6-in.) diameter cut-out should be used on future designs.

Material thickness at the bolt hole area of the window assembly should be increased in future designs.

A full evaluation of the double backed adhesive should be conducted.

MSFC—RSA, Ala

APPROVAL

TM X-53853

DEVELOPMENT OF SPACE STATION WINDOW ASSEMBLIES

By C. N. Irvine

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

For Edwin L. Brown

W. A. WILSON
Chief, Mechanical and Chemical Development Branch

W. ANGELE
Chief, Manufacturing Research and Technology Division

9/15/69

MATHIAS P. L. SIEBEL
Director, Manufacturing Engineering Laboratory

DISTRIBUTION

INTERNAL

DIR
Dr. von Braun

DEP-T
Dr. Rees

S&E-DIR
Mr. Weidner

S&E-R
Dr. Johnson

S&E-R-F
Mr. Lake
Mr. Capowski
Mr. Ousley

S&E-R-R
Mr. Miles

PD-MP
Mr. Downey

S&E-ASTN-DIR
Mr. Heimburg

S&E-ASTN-M
Mr. Schwinghamer
Mr. Curry
Mr. Schell

S&E-ASTN-V
Mr. Isbell
Mr. Prasthofer
Mr. Beck
Mr. Wells

S&E-ME-DIR
Dr. Siebel
Mr. Wuenscher

S&E-ME-A
Mr. Crumpton
Mr. Nowak

S&E-ME-D
Mr. Eisenhardt

S&E-ME-I
Mr. Swanson

S&E-ME-M
Mr. Angele
Mr. Holland (10)
Mr. Bennight
Mr. Wilson
Mr. Schuerer
Mr. Simpson
Mr. Stocks
Mr. Wood
Mr. Irvine (10)

S&E-ME-T
Mr. Franklin

S&E-QUAL-A (2)

AD-S

A&TS-PAT
Mr. Wofford

A&TS-MS-H
A&TS-MS-IP (2)
A&TS-MS-IL (8)
A&TS-TU (21)
PM-PR-M

EXTERNAL

DASO/EXPLO (2)
Explosive Division
Redstone Arsenal, Alabama 35809

Scientific and Technical Information
Facility (25)
Attn: NASA Representative (S-AK-RKT)
P. O. Box 33
College Park, Maryland 20740

Hayes International Corporation (3)
MEL Operations
P. O. Box 1568
Huntsville, Alabama 35807