SECTION FILE

Report No. FAA-DS-70-8

FEASIBILITY STUDY AND INITIATING SYSTEM DEVELOPMENT OF THE EXPLOSIVE EXIT CONCEPT FOR CIVIL TRANSPORT AIRCRAFT

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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

APRIL 1970

FINAL REPORT

Prepared for

FEDERAL AVIATION ADMINISTRATION

Aircraft Development Service

Washington D. C., 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-DS-70-8	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
FEASIBILITY STUDY AND INITIATING SYSTEM DEVELOPMENT OF THE EXPLOSIVE EXIT CONCEPT FOR CIVIL TRANSPORT AIRCRAFT

5. Report Date
April 1970

6. Performing Organization Code

7. Author(s)
JOSEPH J. JAGLOWSKI, JR.

8. Performing Organization Report No.
FAA-NA-70-20

9. Performing Organization Name and Address
DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

10. Work Unit No.
ADS Project Schedule I

11. Contract or Grant No.
510-002-08X

12. Sponsoring Agency Name and Address
DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Aircraft Development Service
Washington, D. C. 20590

13. Type of Report and Period Covered
Final Report
June 1965 - October 1968

14. Sponsoring Agency Code

15. Supplementary Notes
NONE

16. Abstract
This feasibility study and system development demonstrated the use of liquid explosives to provide emergency exits in commercial transport aircraft. During the course of the study, linear-shaped tubing systems of various designs and materials were fabricated and tested in an attempt to obtain the best cutting efficiency with a minimum of explosive charge. Energy-absorbent shields molded from laminated fiberglas-reinforced plastics were fabricated and evaluated. The purpose of the shield was to provide protection against overpressures and fragments produced as the result of the detonation of the linear-shaped charge. A system to automatically mix the two components while simultaneously pumping them into the linear-shaped tube loop and to initiate the charge was designed, fabricated, and tested.

17. Key Words
Escape Hatches
Abandonment
Explosive Initiators
Civil Aircraft

18. Distribution Statement
General Distribution

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	50	$3.00*

Form DOT F 1700.7 (8-69) *For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151

FOREWORD

The work reported herein was conducted under an interagency agreement with the Department of the Army. The feasibility study and tests were accomplished at the Army's Picatinny Arsenal under the management of Messrs. Michael E. Walsh and William J. Buckley, Jr. The system development was accomplished at the Army's Frankford Arsenal under the management of Mr. Lloyd Insetta. All phases of the work were administered under the direction of Mr. Joseph J. Jaglowski, Jr., who prepared the report and served as Project Engineer for the Structures Section, Aircraft Branch, Test and Evaluation Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey. Further development of the system and the results of evaluation tests of the system will be reported in Report No. FAA-DS-70-9, "Development and Test of the Explosive Exit Concept for Civil Transport Aircraft."

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INTRODUCTION

Purpose

The purpose of this project was to determine the feasibility of using a liquid-filled, linear-shaped charge for providing additional emergency exits for civil transport aircraft and to develop these concepts into a workable system.

Background

Several branches of the military service have successfully utilized the linear-shaped, explosive charge concept for providing emergency escape systems for aircraft occupants. As a result of this success, the Aircraft Development Service (ADS) requested a study of the feasibility of applying this concept to provide additional emergency exits for civil transport aircraft. This request was implemented through the assignment of Project 510-002-08X, titled "Feasibility Study of Explosive Techniques for Providing Emergency Exits," to the National Aviation Facilities Experimental Center (NAFEC).

The initial work in the study was contracted through Interagency Agreement FA66NF-AP-8 with the Army's Picatinny Arsenal to investigate the feasibility of the shaped charge concept to provide exits in typical civil transport fuselage structure and to investigate methods of protecting passengers from any harmful blast effects. Subsequently, under the same project, Interagency Agreement FA67NF-AP-19 was effected with the Army's Picatinny Arsenal in cooperation with the Frankford Arsenal to design a system for filling and activating a liquid, linear-shaped charge emergency exit system.

Description of Concept: The initial investigative study was based on the concept of using a liquid compound comprised of two commercially available liquid components classed as nonhazardous materials. This classification permits shipment of these materials when stored separately by any type of common carrier including scheduled passenger-carrying aircraft. The component materials selected for the application were nitromethane and a sensitizer. Should an emergency arise requiring additional exits for passenger emergency egress, the system would first be armed. The exit could then be actuated, starting an automatic sequence which could mix the separately stored liquids, pump the explosive mixture into the vee-grooved linear tube outlining the preconceived exit, and detonate the linear charge, thus cutting and removing that section of the aircraft fuselage to provide an opening.

Test Program: During the course of the feasibility study, various linear-shaped tubing configurations, materials, and sizes were designed and tested to determine the best cutting efficiency with a minimum of explosive charge. These tests, in most cases, involved the use of sections of jet aircraft fuselage structure.

Concurrent with the explosive tests, laminated fiberglas-reinforced shields were developed and tested to determine the requirements and adequacy of such shields to protect passengers from blast overpressures and fragmentation of the shaped charge material.

Upon establishment of the linear-shaped tubing configuration and size, a system consisting of a mixing pump, initiators and detonator housing was designed, fabricated, and tested by the Frankford Arsenal. The system was designed to contain, mix and fill the shaped tube line with a mixture of 94 percent nitromethane and 6 percent sensitizer by volume. System actuation was provided by a detonator. A number of such systems were tested to perfect the system operational aspects. For these tests a system operation time of three seconds was selected.

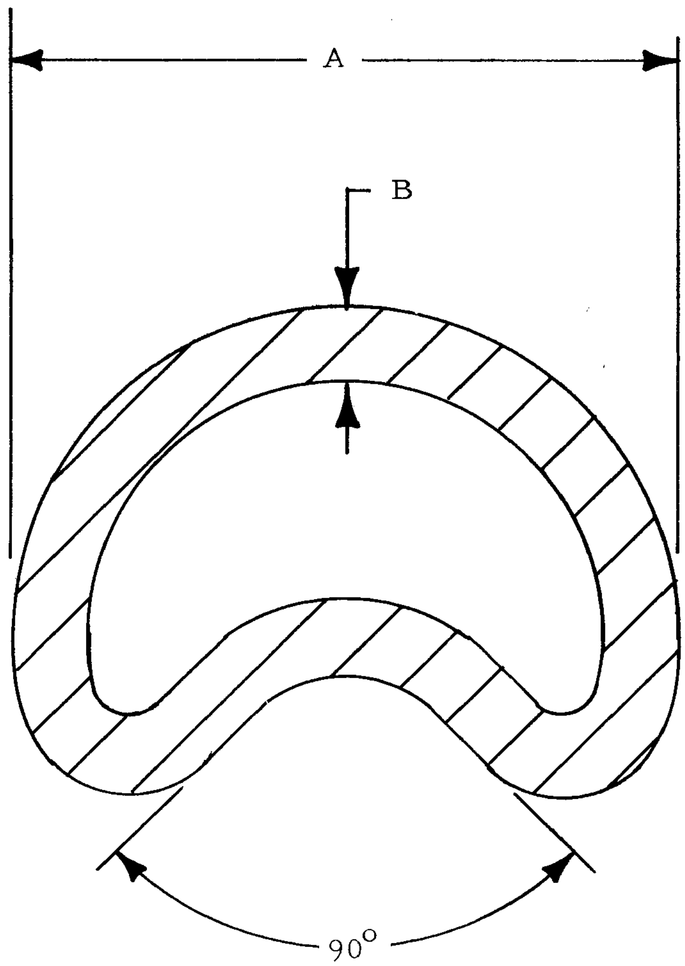
DISCUSSION AND RESULTS

Objectives Of The Study

Through a series of experimental and development tests, the practicability of using a linear-shaped charge concept to cut emergency exits for passenger egress was explored. All the evolutionary phases of the system were demonstrated by tests which included storage of the fluid, mixing to form the explosive, filling the tube, initiation of the liquid charge, and the cutting of typical aircraft fuselage skin stringer networks and other structural members. The major activities of the study completed in the Army program follow.

Feasibility Testing - Linear-Shaped Charge

Linear-Shaped Tubing Materials and Sizing - There are many choices of tubing material for this application. This is because the liquid explosive is in contact with the tubing for only a few seconds, thus eliminating corrosive or other degenerative reactions. For the application being explored, aluminum tubing was selected because of its lightweight and ductility. The tubing size first tested was 5/16-inch outside diameter (OD) with a wall thickness of 0.028 inch. The tubing was shaped cross sectionally as shown in Figure 1. The volumes of these tubes and core loads in grains per foot of liquid explosive are shown in Table I. This range of core loads was considered to be more than adequate for the proposed application.



A	B
1/4	.028
5/16	.028

FIG. 1 CROSS SECTION OF LINEAR-SHAPED CHARGE

Initiation - It was found in previous work conducted at the Picatinny Arsenal that the liquid explosive proposed for the exit concept could be initiated by a J-2 blasting cap which was used throughout the study conducted by Picatinny personnel.

TABLE I

VOLUMES AND CORE LOADS OF LINEAR-SHAPED CHARGES

Tubing (OD)-inch	Volume ml/foot	Weight of Liquid Explosive grains/foot
3/16	1.5	20.0
1/4	3.0	52.5
5/16	6.0	105.0

Cutting Capability - The optimum depth of penetration of the 5/16-inch-diameter, linear-shaped charge tube was determined by the typical test setup shown in Figure 2. The linear-shaped charge tube was arranged so that the vee-grooved tubing lay on the face of the target plate at Point A and angled upward to a standoff from the plate at Point B (refer to Figure 2). Depths of penetration were measured at 1/2-inch intervals from A to B, and the optimum standoff was determined as the point where the penetration depth was greater than 0.1 inch. At this point, the standoff distance was three times the depth of the vee-groove. This distance is that measured from the apex of the vee-groove of the tubing to the target plate.

Cutting tests were made using the 5/16-inch-diameter tubing containing an energy core loading of 105 grains per foot of liquid explosive. In these tests, simulated aircraft structural members, as shown in Figure 3, were fabricated and subjected to the shaped charge cutting action. Results of these tests indicated that a core loading of 105 grains per lineal foot was excessive and that 50 to 75 grains per foot would be an adequate charge. One problem observed with the shaped charge tubing was that the vee-groove skewed during bending even though a bending tool was used. This skewing caused reduced penetration, but was overcome by designing a bending tool with the same contour as the tubing.

Also, cutting tests of typical aircraft fuselage structure, as shown in Figure 4, were conducted with 5/16-inch-diameter tubing. Post test inspection showed that the lighter structural members were severed, but the heavy structural members were only partially cut (see Figures 5 and 6). Because of this, the skin beneath the heavy structure was not cut, but it was judged that these small areas would tear readily if the heavy structured members had been severed. The problem in cutting the heavy structure appeared to be caused by the failure of the vee-groove portion of the tubing

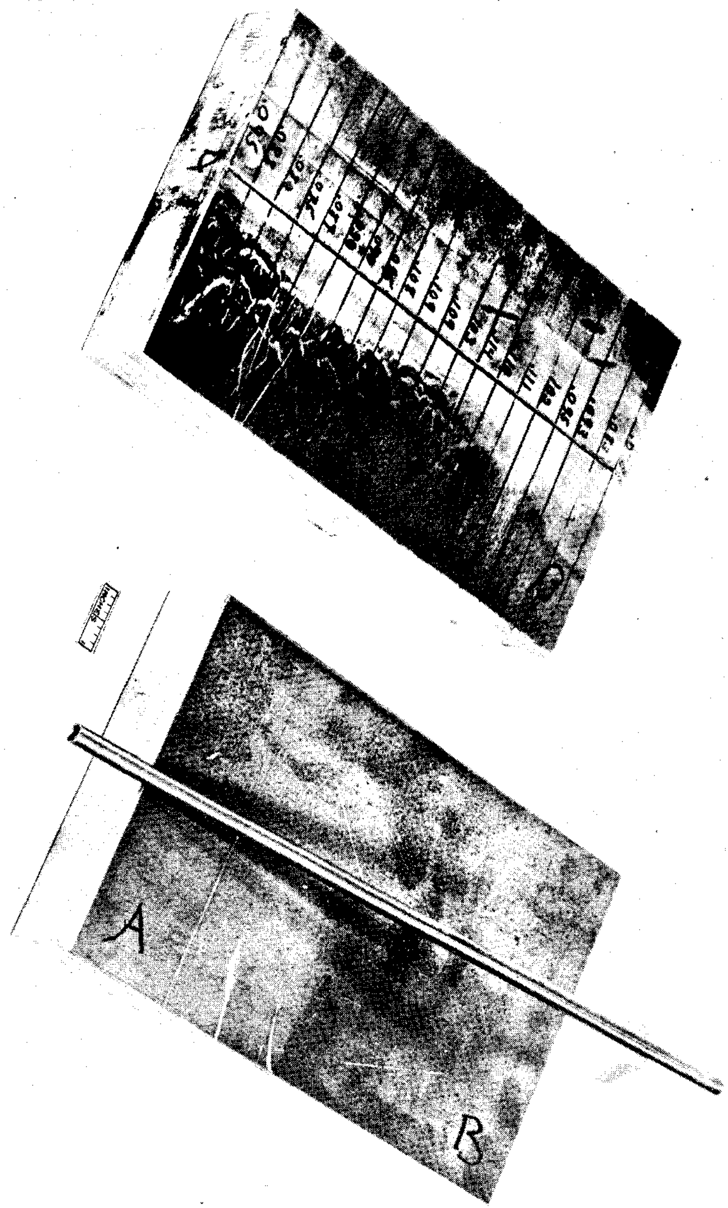


FIG. 2 OPTIMUM STANDOFF-PENETRATION TEST SETUP

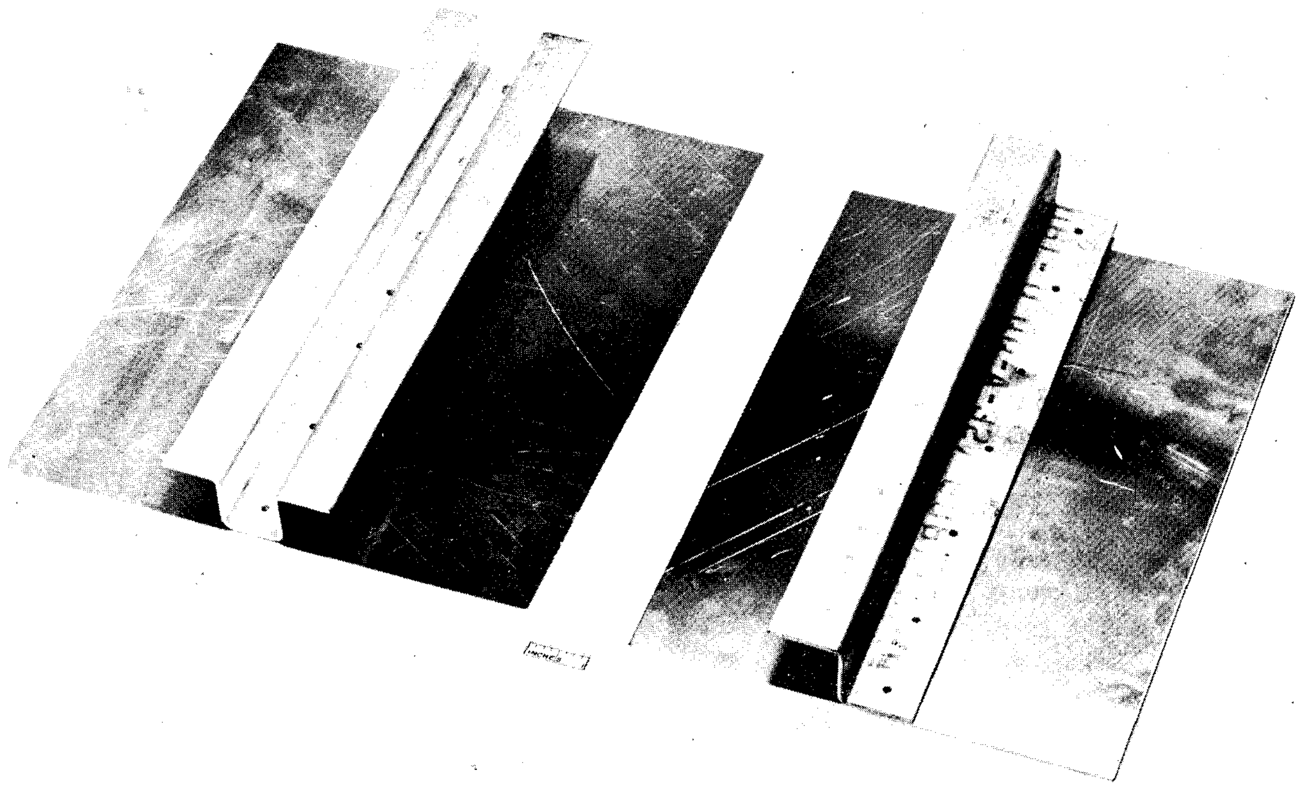


FIG. 3 TEST PANELS OF SIMULATED AIRCRAFT STRUCTURAL MEMBERS

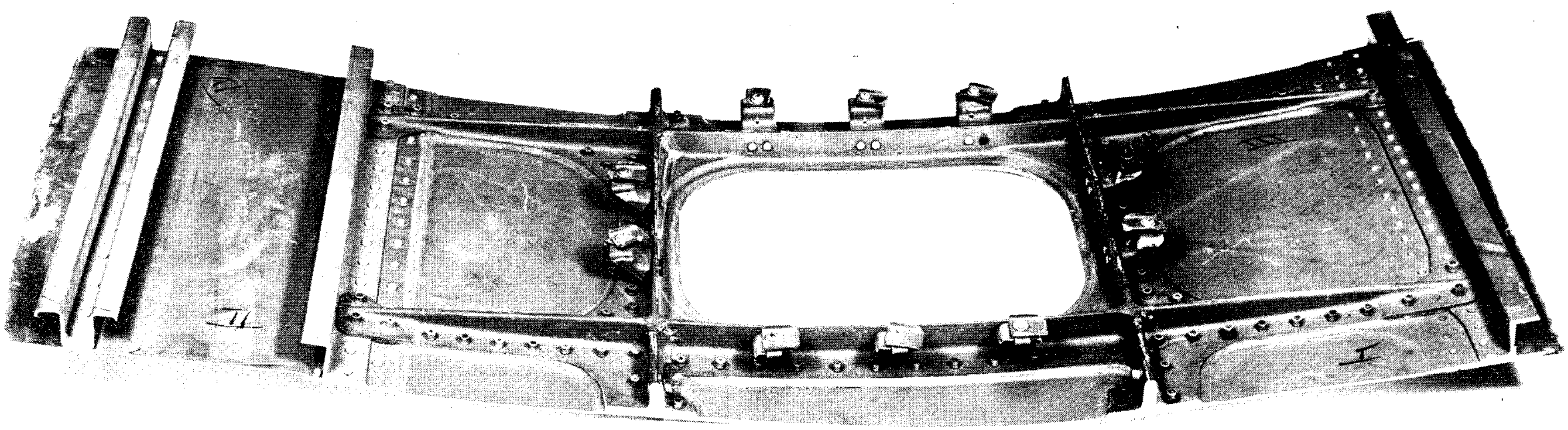


FIG. 4   TYPICAL AIRCRAFT STRUCTURE TEST SECTION

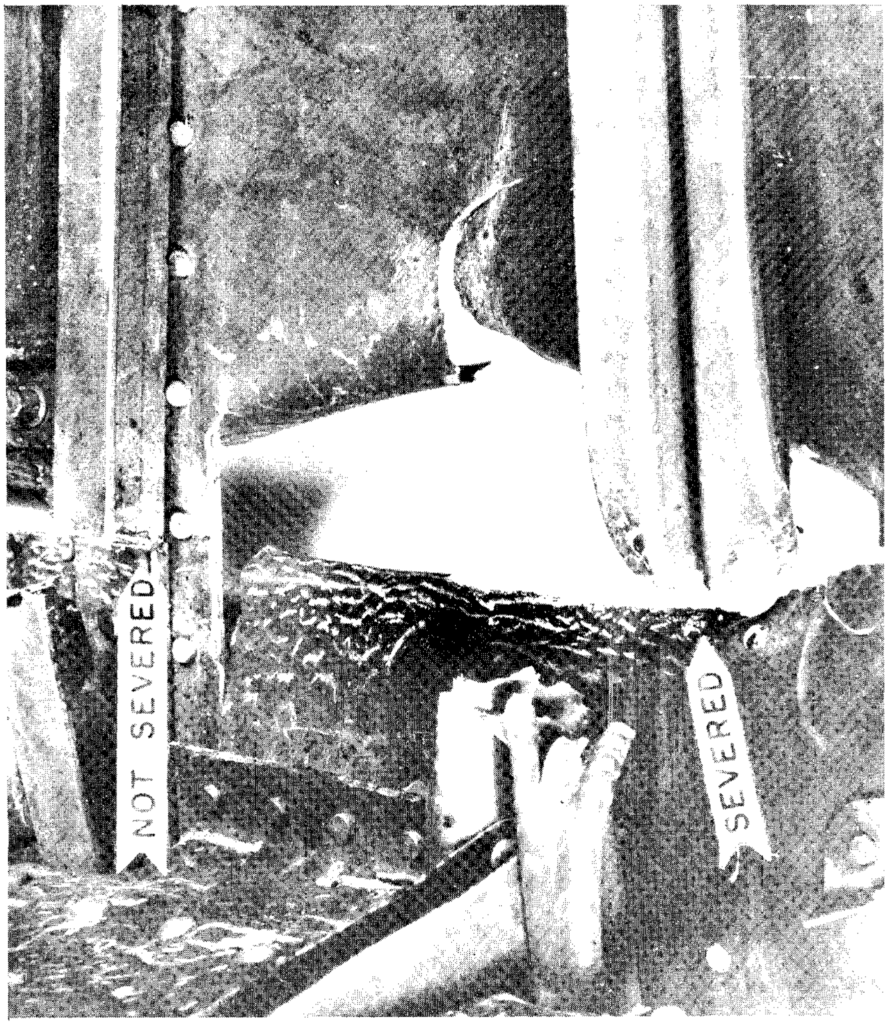


FIG. 5 CLOSEUP OF SEVERED STRUCTURAL MEMBERS

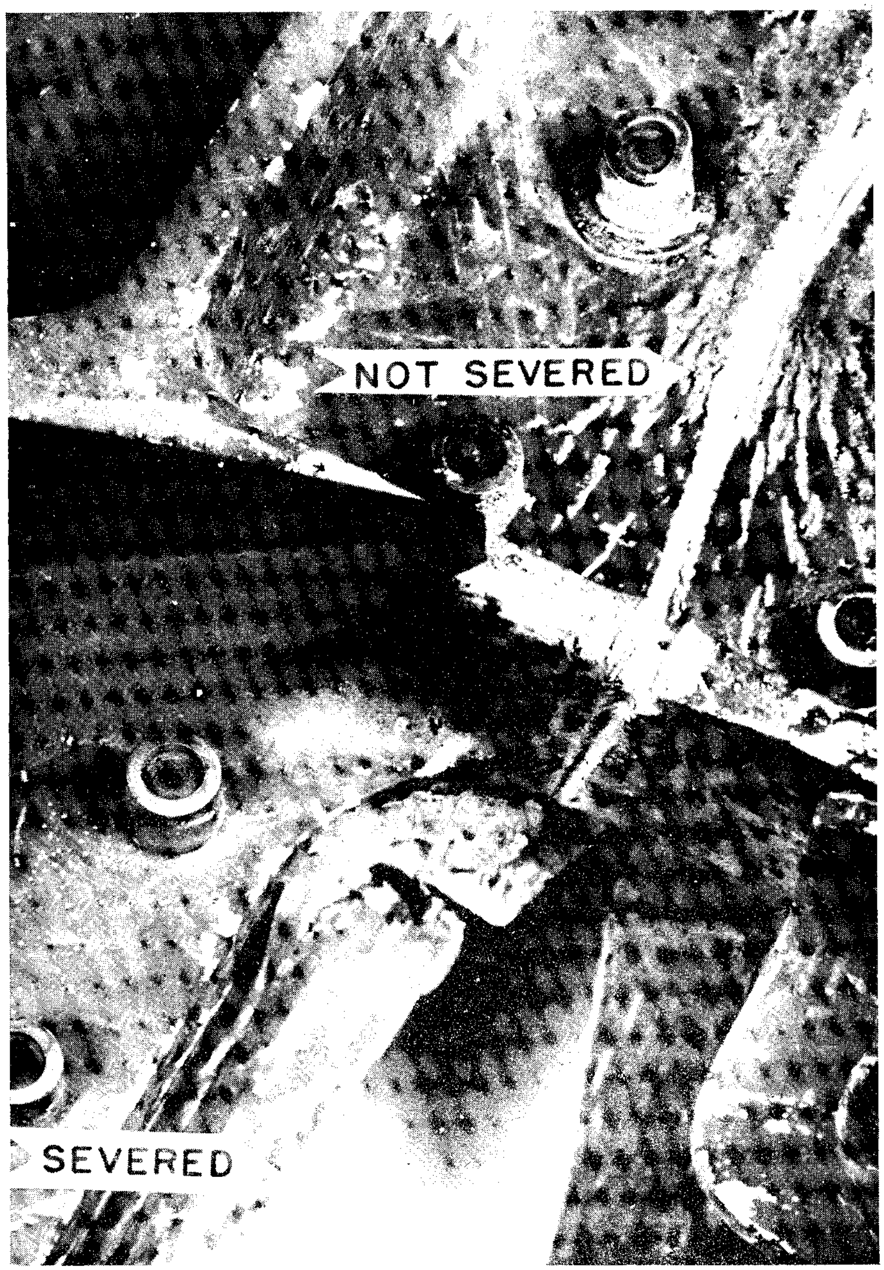


FIG. 6 CLOSEUP OF UNSEVERED WINDOW STRUCTURE

to be properly directed wherever small radius bends occurred. This problem could be overcome by preforming the tubing to the contour of the structural member to be cut by brazing or casting technique.

Back Pressures - To obtain some quantitative data concerning the blast pressures to be expected from linear-shaped charges, calculations were made using the method of Hoffman and Mills[1]. This method assumed that the linear-shaped charge was comprised of a 1/4-inch-diameter sphere, and that the pressures realized would be produced by one-half of each of these spheres. A 10-foot length of polyethelene tubing 3/16 inch in diameter was fixed to a blast plate. Several paper blastmeters capable of measuring pressure from 1 to 20 psi were placed adjacent to one another in the same plane and at a distance of 2 feet from the plane of the tubing as shown in Figure 7. Polyethelene tubing was used to reduce the possibility of fragments from any type of metal tubing from tearing the blastmeters. After the first test, it was noted that plastic fragments were embedded in the wooden frame of the blastmeter. Consequently, a modified test setup using piezoelectric pressure gauges was used for the remainder of the tests (see Figure 8). These results are summarized in Table II. The quantity of liquid explosive used in these tests was approximately identical to the quantity used in the 1/4-inch-diameter, vee-grooved shaped tubing.

Retention of Back Pressures - Panels as shown in Figure 9 were fabricated and tested to gain insight regarding the required massiveness of a protective shield for the attenuation of back pressures and the retention of fragments produced by detonation of the linear-shaped charge tubing. Initially, it was believed that the pressures developed could be deflected and vented through the cutout by a lightweight shield. Results of the tests conducted showed the need for developing a high-strength shield capable of containing the immediate pressures produced by the detonation until outside venting occurred.

Development and Testing - Linear-Shaped Charge

Tubing Development Special Shapes and Materials - Linear-shaped tube systems of various designs and materials were fabricated and tested in an attempt to obtain the best cutting efficiency with a minimum of liquid explosive. The initial designs tested were special shaped sections (see Figures 10 and 11) having the contour of the structural members to be cut (refer to Figure 4). This particular length of tubing was fabricated from stainless steel material with a vee-groove having a 90° included angle and a volume equivalent to a 1/2-inch-diameter tube.

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[1] Hoffman and Mills, "Air Blast Measurements about Explosive Charges at Side-On and Normal Incidence," July 1956, Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland.

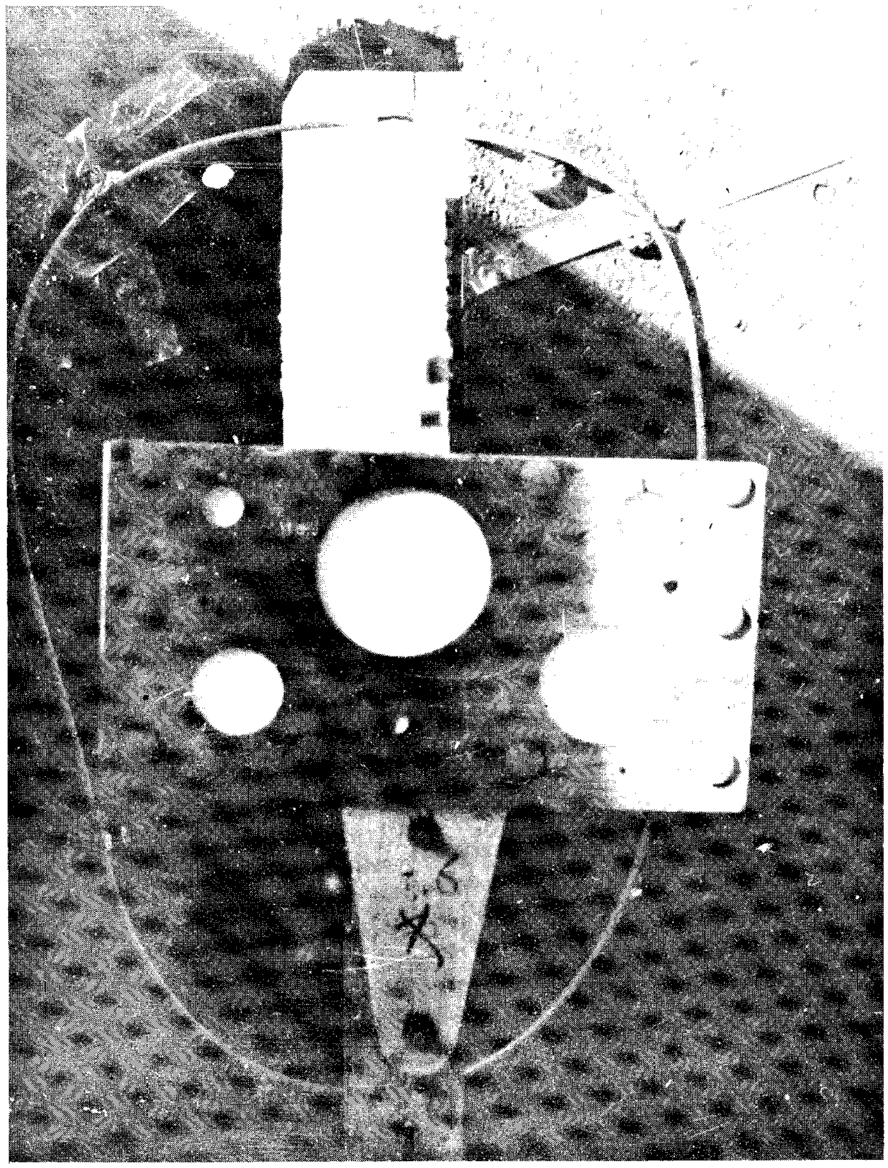


FIG. 7 INITIAL PRESSURE MEASUREMENT TEST SETUP

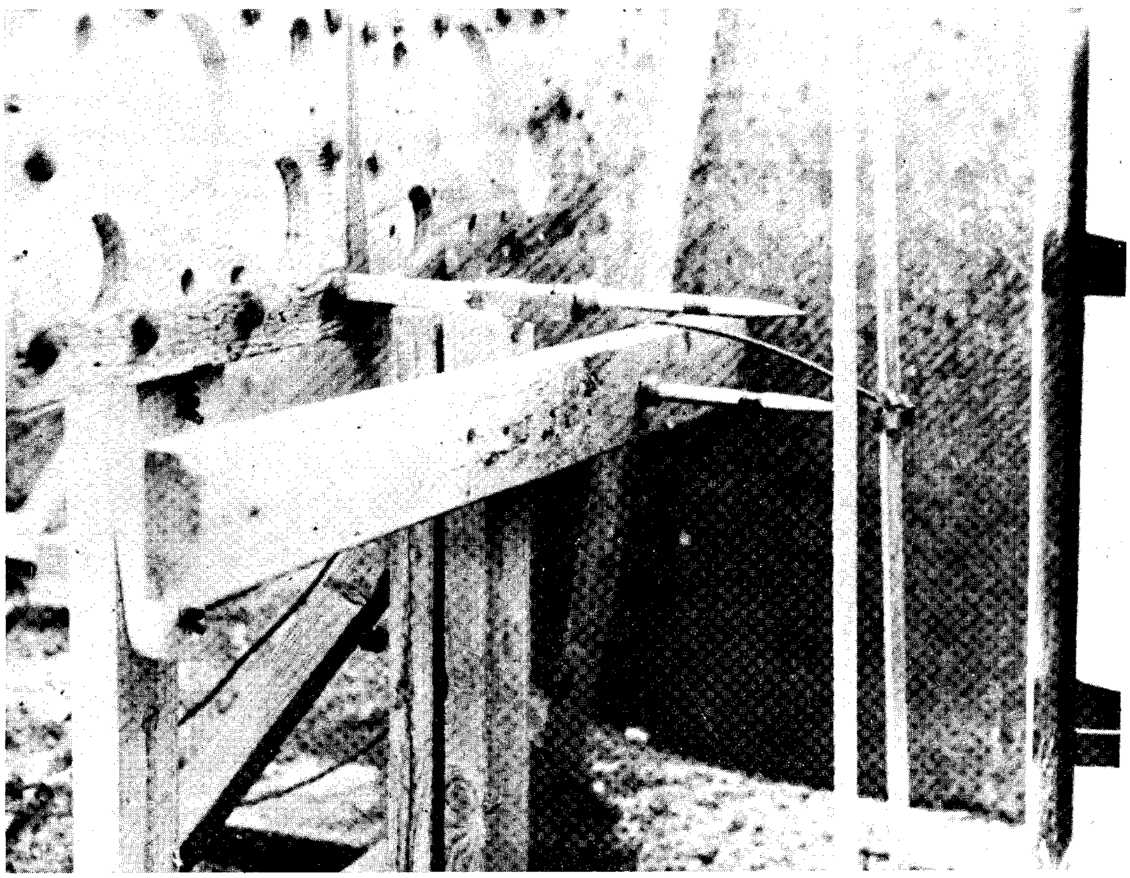


FIG. 8 MODIFIED PRESSURE MEASUREMENT TEST SETUP

TABLE II

SUMMARY OF PRESSURE MEASUREMENT TESTS

Test	Round Tubing (I.D.-inch)	Grains/foot	Piezoelectric gauge*	Distance from charge (inch)	Pressure (psi)
1	1/4	52.5	A	12	48.0
			B	12	44.0
2	1/4	52.5	A	18	29.5
			B	18	29.0
3	1/4	52.5	A	24	22.0
			B	24	22.5
4	1/4	52.5	A	60	6.5
			B	60	6.0
5	3/16	20.0	A	6	92.0
			B	18	21.0
6	3/16	20.0	A	12	29.0
			B	24	12.5
7	3/16	20.0	A	60	4.2
			B	60	4.7

*Gauges A and B were 12 inches apart and positioned directly opposite the charge.

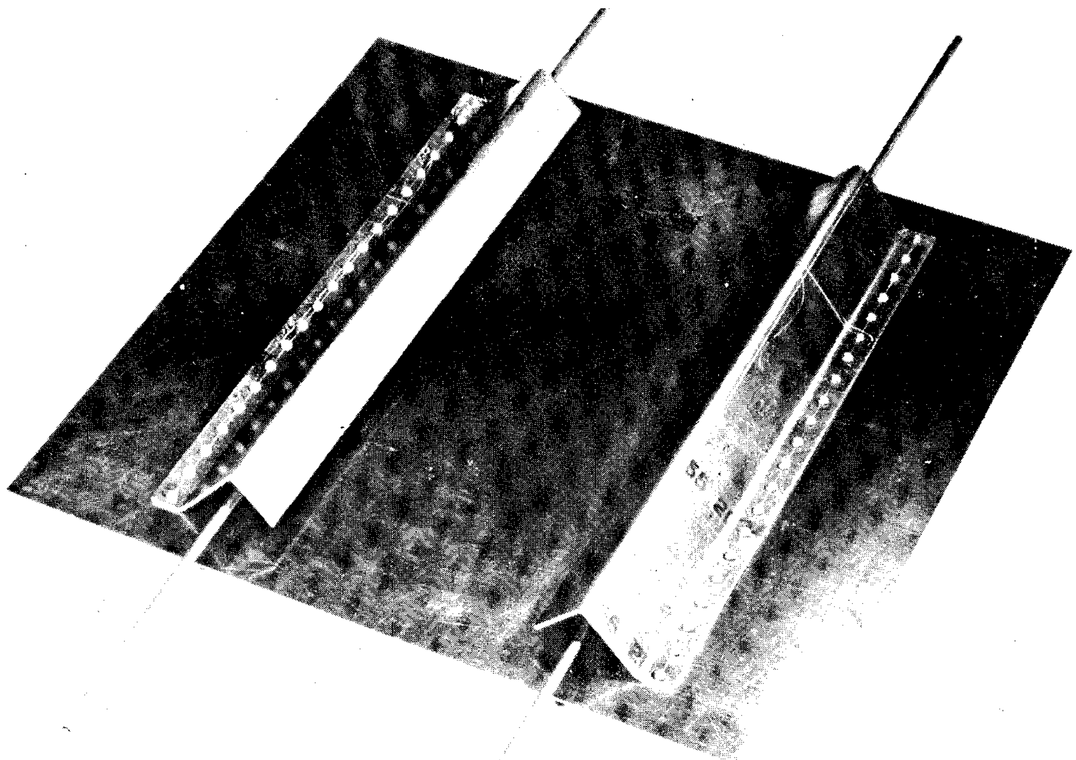


FIG. 9 INITIAL PRESSURE RETENTION TEST PANEL

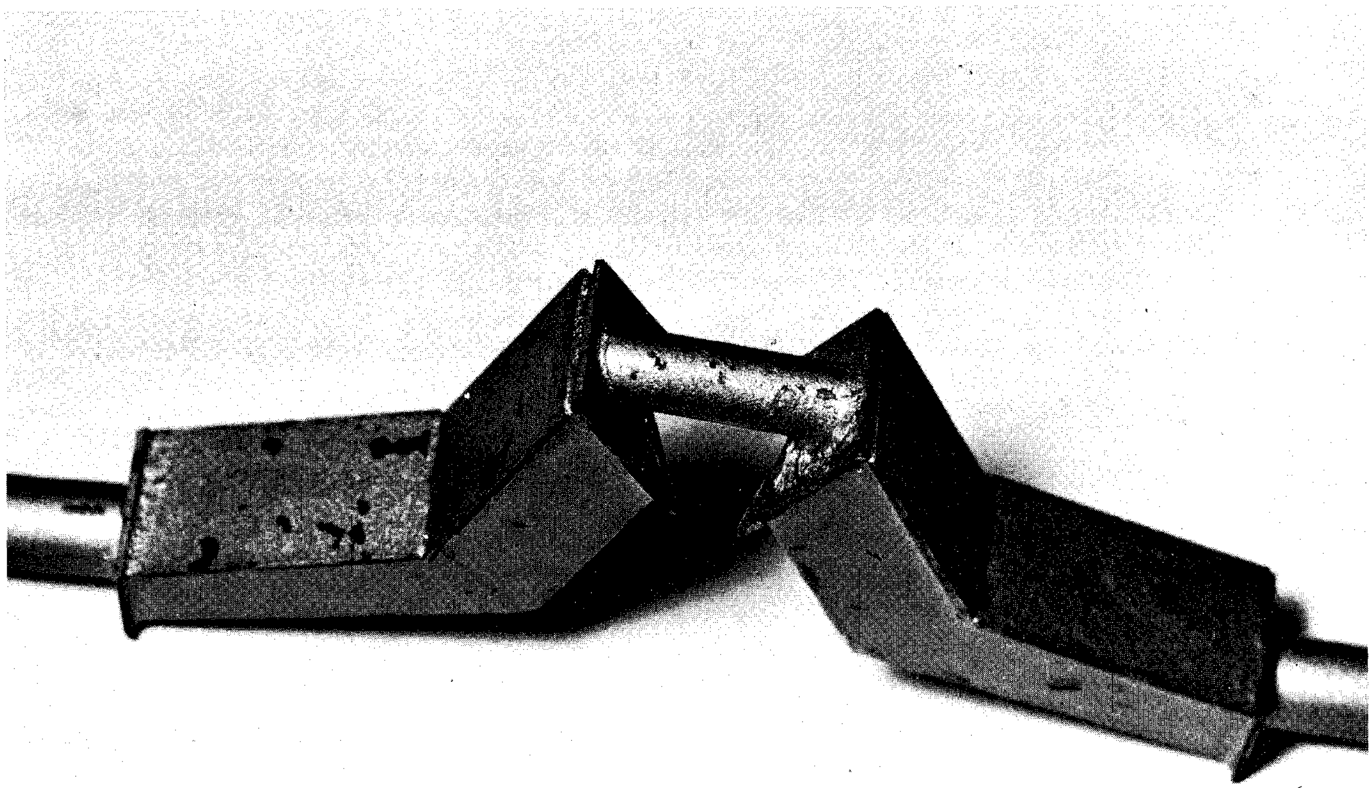


FIG. 10 PREFORMED DESIGN - TOP VIEW

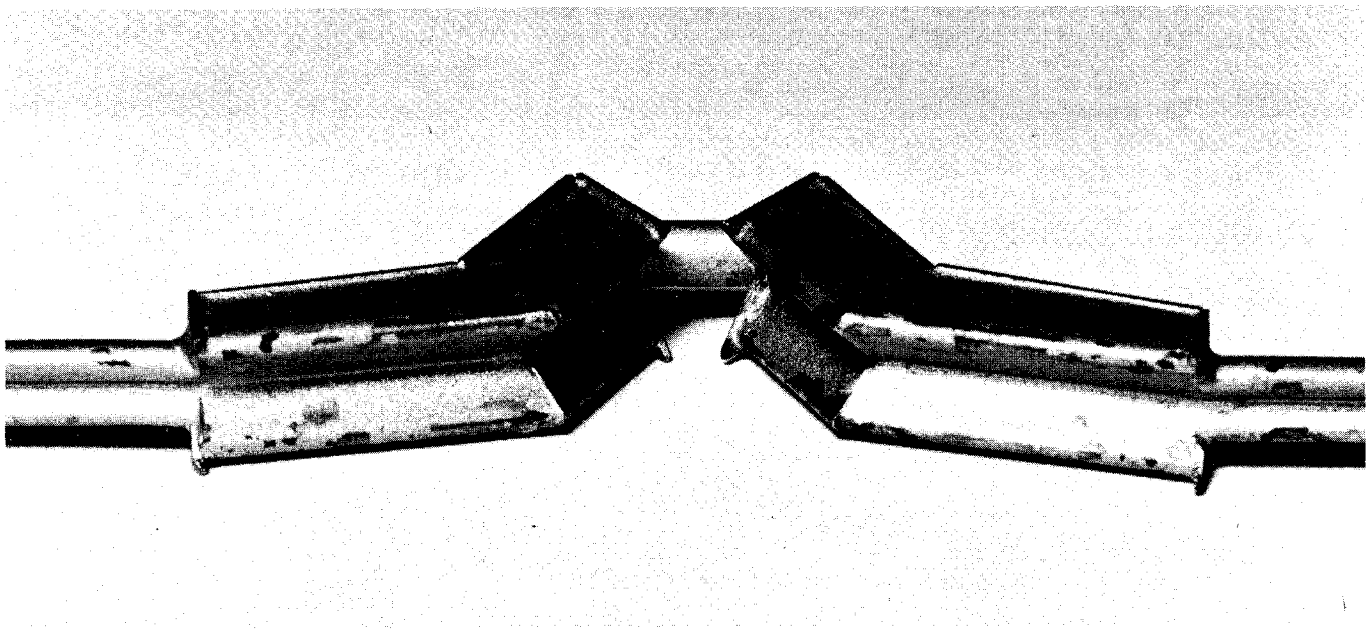


FIG. 11 PREFORMED DESIGN - BOTTOM VIEW

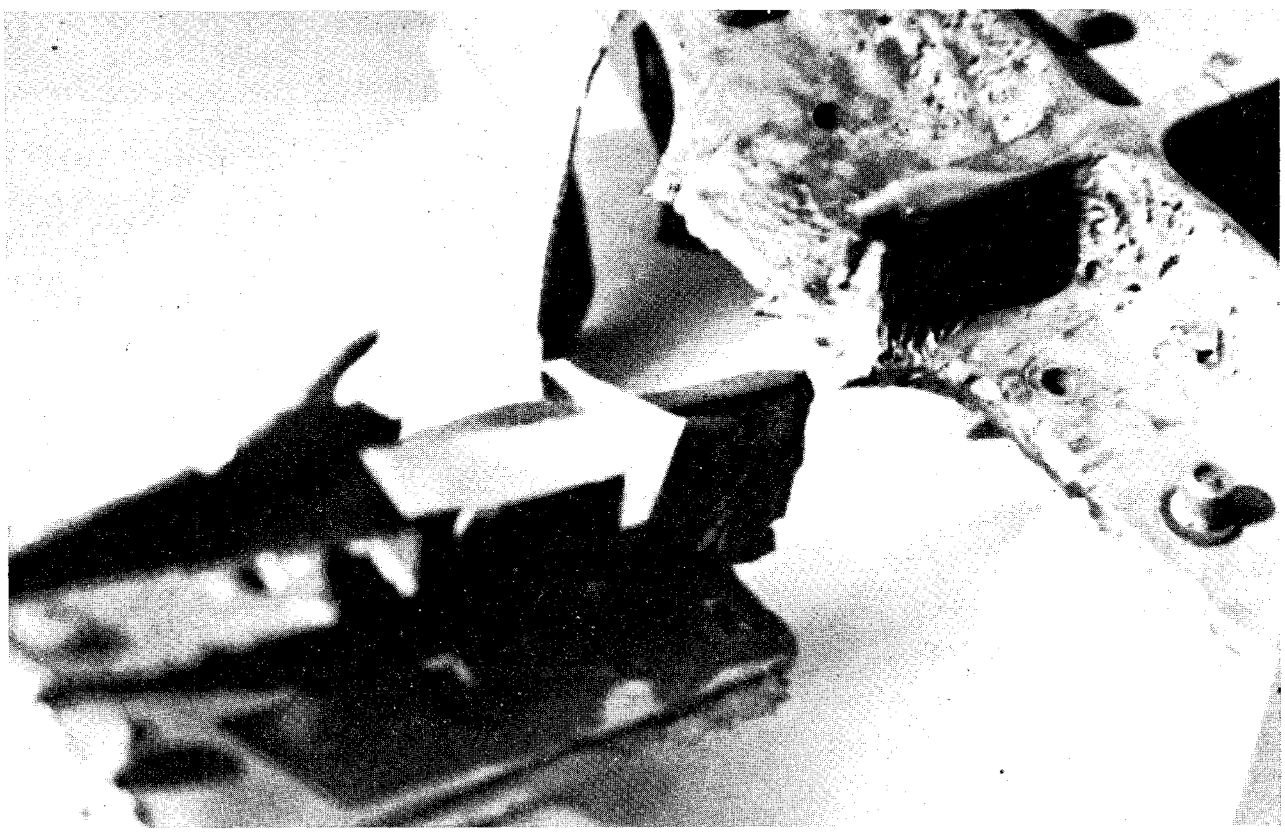


FIG. 12 CLOSEUP OF SEVERED HEAVY STRUCTURAL MEMBER

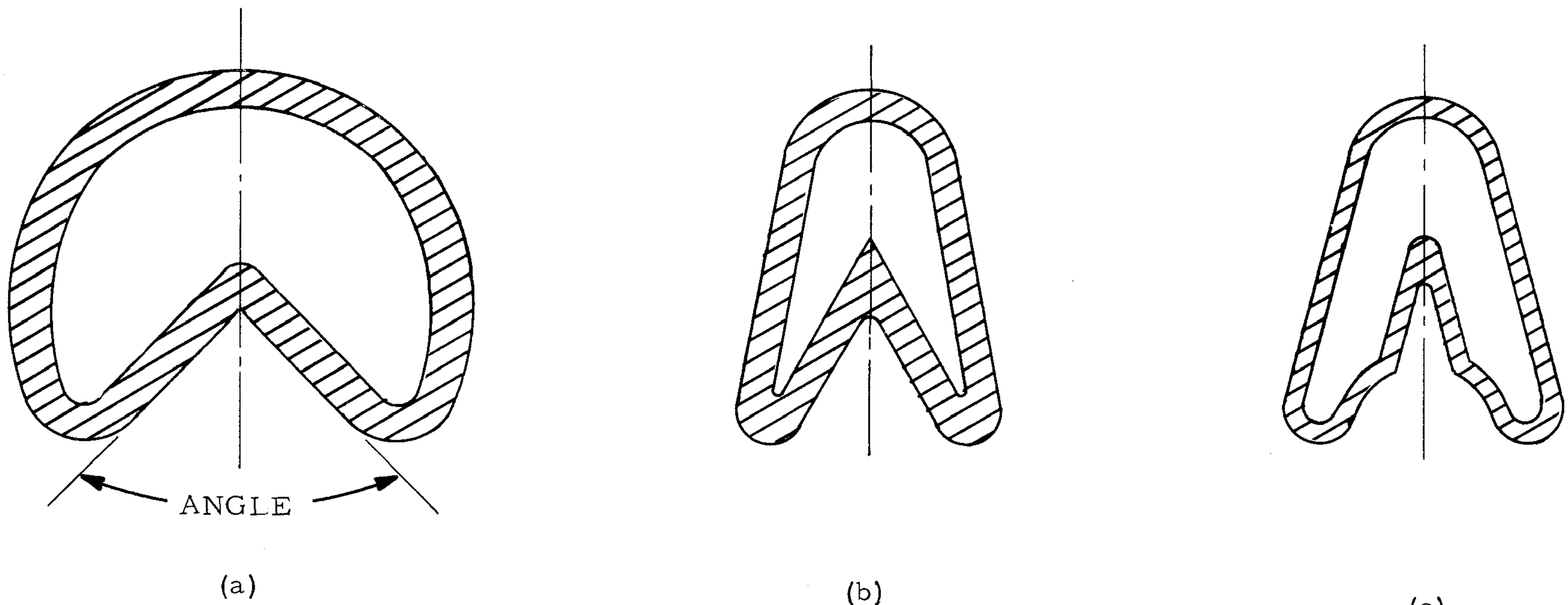


FIG. 13 LINEAR-SHAPED TUBING DESIGNS

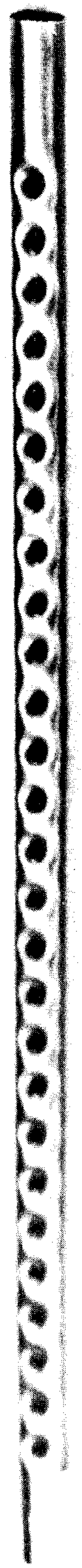


FIG. 14 CONICAL-SHAPED TUBING DESIGN

Test results (see Figure 12) showed that heavy structural members can be cut providing the shaped charge tubing is properly designed and fabricated. However, as a result of the tests, it was found that cutting such heavy structural members was impractical because of the problem of containing the fragmentation and high overpressures resulting from detonation of the large charge required. Therefore, no further testing of the specially sized, shaped sections was conducted. To be more realistic, it was decided that the quantity of explosive must be reduced significantly.

Concurrent with the special shape development work, consideration was also given to the use of lighter materials to contain the charge. Consequently, the investigation was directed toward linear-shaped tubing designs that could be easily contoured to the structural members to be severed without requiring special fabrication processes. Figure 13 shows three linear-shaped tubing designs that were fabricated of various metals and tested. Design A was fabricated from aluminum, copper, stainless steel, and lead incorporating vee-grooves of 60° and 120°, respectively. Results of the subsequent explosive tests showed that penetration is not significantly affected by varying these parameters. Two other designs (Figure 13, B and C) fabricated from aluminum were expected to have better penetration characteristics and would require a minimum standoff distance because of the more acute vee-grooves. The results of explosive tests of Designs B and C showed no improvement in penetration over Design A. Another novel linear-shaped tube design (see Figure 14) consisting of a series of conical dimples imprinted along the length of the tubing was fabricated and tested. This design utilized 3/8-inch-diameter copper tubing. Test results showed that penetration was less than the linear-shaped charged tubing conforming to Design A.

Explosive Mixture Tests - Consideration was given to substituting a more powerful liquid explosive for the sensitized nitromethane presently used. Preliminary tests with a hydrazine base explosive showed that better cutting efficiencies could be obtained. However, one of the constituents was a solid, and it was found that mixing could not be accomplished in the desired time of less than 3 seconds.

Protective Shield Development - The approach selected, to retain the overpressures and fragments resulting from the detonation of the charge, was to use a laminated fiberglas-reinforced plastic which functions by absorbing, through deformation and delamination, the compressive and reflected pressure wave energies emitted by the explosive. The shield was fabricated from five plies of fiberglas material impregnated with a starch oil and a polyester resin. Tests were then conducted to evaluate the performance of this design in retaining the fragments and overpressures resulting from detonation of the linear-shaped charged tubing. The evaluation was made by placing a short section of 1/4-inch-diameter, linear-shaped tubing on an aluminum test panel and then placing the protective shield over the tubing as shown in Figure 15. The shield was attached to the panel by a bonding material. In principle, the bond on Side A had a

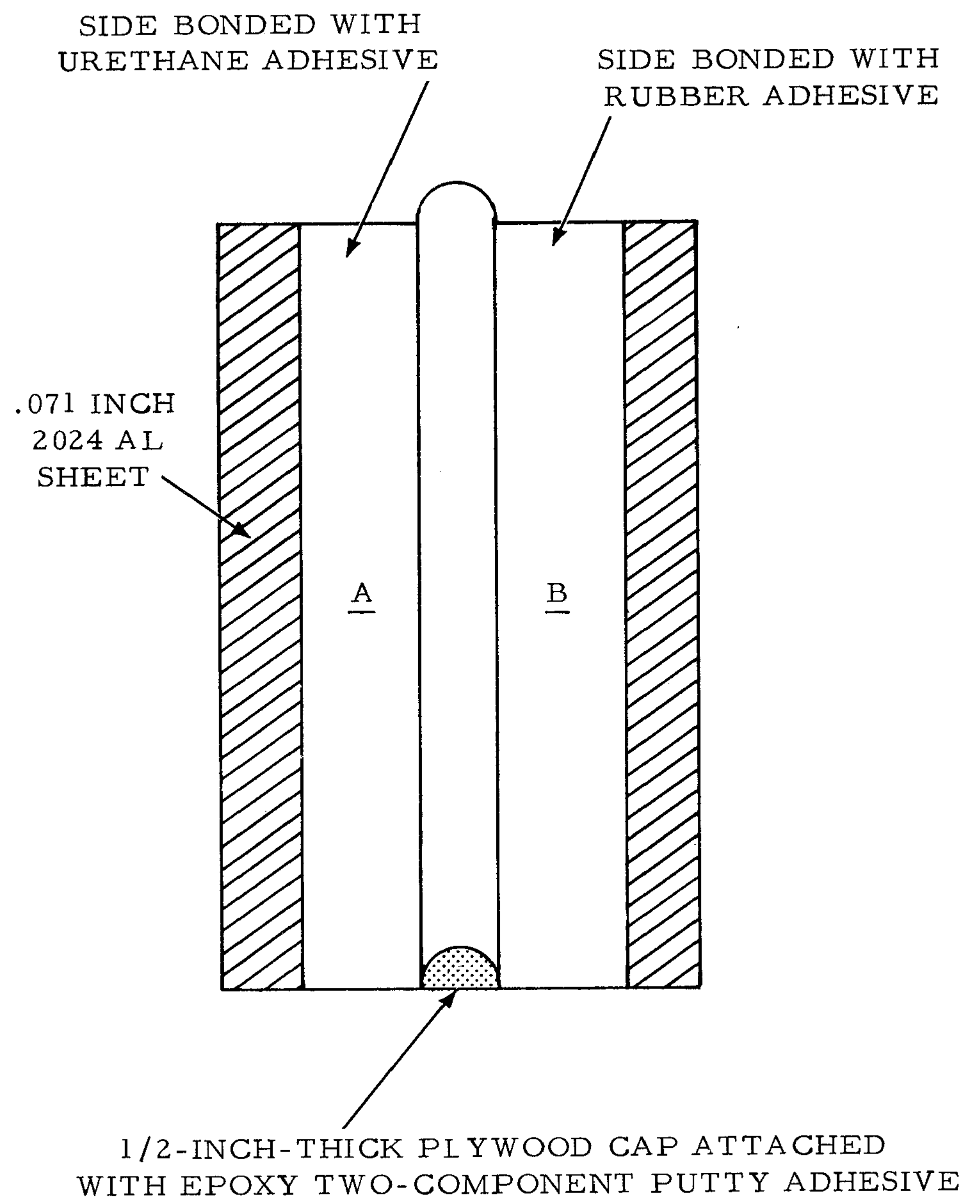


FIG. 15 PROTECTIVE SHIELD TEST PANEL

greater peel strength than that on Side B so that upon detonation of the charge the bond on Side B would fail, and the bond on Side A would hold the shield to the panel (see Figure 15). After the shield was attached to the test panel, the linear-shaped tube was filled with liquid explosive from the opened end and the charge was initiated.

Four tests were conducted using the bond method. In all four cases, the shield was separated from the test panel on both Sides A and B by pressures generated by detonation of the charge. Based on these test results, it was decided that some means of mechanical attachment would be necessary, bolting the test panel on one side and incorporating a frangible bond on the other. Several detonation tests were conducted, and in each the shield remained attached to the test panel. Based on these results, it was decided that the use of a bond in addition to the bolts was not necessary.

For a subsequent test phase, a shield was fabricated for mounting on a typical fuselage structure. The linear-shaped charge and shield outlined two windows of a Convair 880 fuselage which were separated by a frame. The intended cutout was approximately 30 inches high by 39 inches wide. The linear-shaped tubing was installed by forming it to the contour of the fuselage, and it was held in place by clips. The shield was then fastened in place over the tubing. Figure 16 shows this rather crude protective shield installation. The tubing lays underneath the raised portion of the shield with the ends extending out from under the shield as seen at the top left-hand corner of the picture (refer to Figure 16).

The linear-shaped tubing used to cut the opening was 1/4 inch in diameter. The tubing loop was formed in two sections. The length of a section of the tubing was limited to 6 feet, the length available at that time. Therefore, the loop was made up by joining the first length of tubing to a portion of another length utilizing a sleeve made from a 5/16-inch-diameter tube. This joint was sealed with epoxy.

It was noted upon mounting the shield that there were a number of places where the shield did not fit flush against the fuselage. This was caused by the shrinkage and warpage of the shield in the curing process. Where there was considerable space between the shield and airframe, the shield was pulled as tight as possible against the fuselage by using additional bolts in those areas. Even so, there were still some places where gaps between the shield flanges and fuselage remained. Since this was the first installation made on an actual aircraft, it was decided to conduct the test even though the shield fit poorly.

The linear-shaped tubing loop was filled with liquid explosive, and an electric blasting cap was used to initiate detonation. The detonation propagated cutting the opening with the exception of one place (see Figure 17). This is where the two lengths of tubing were joined. It was surmised that the attempt to force the shield flush

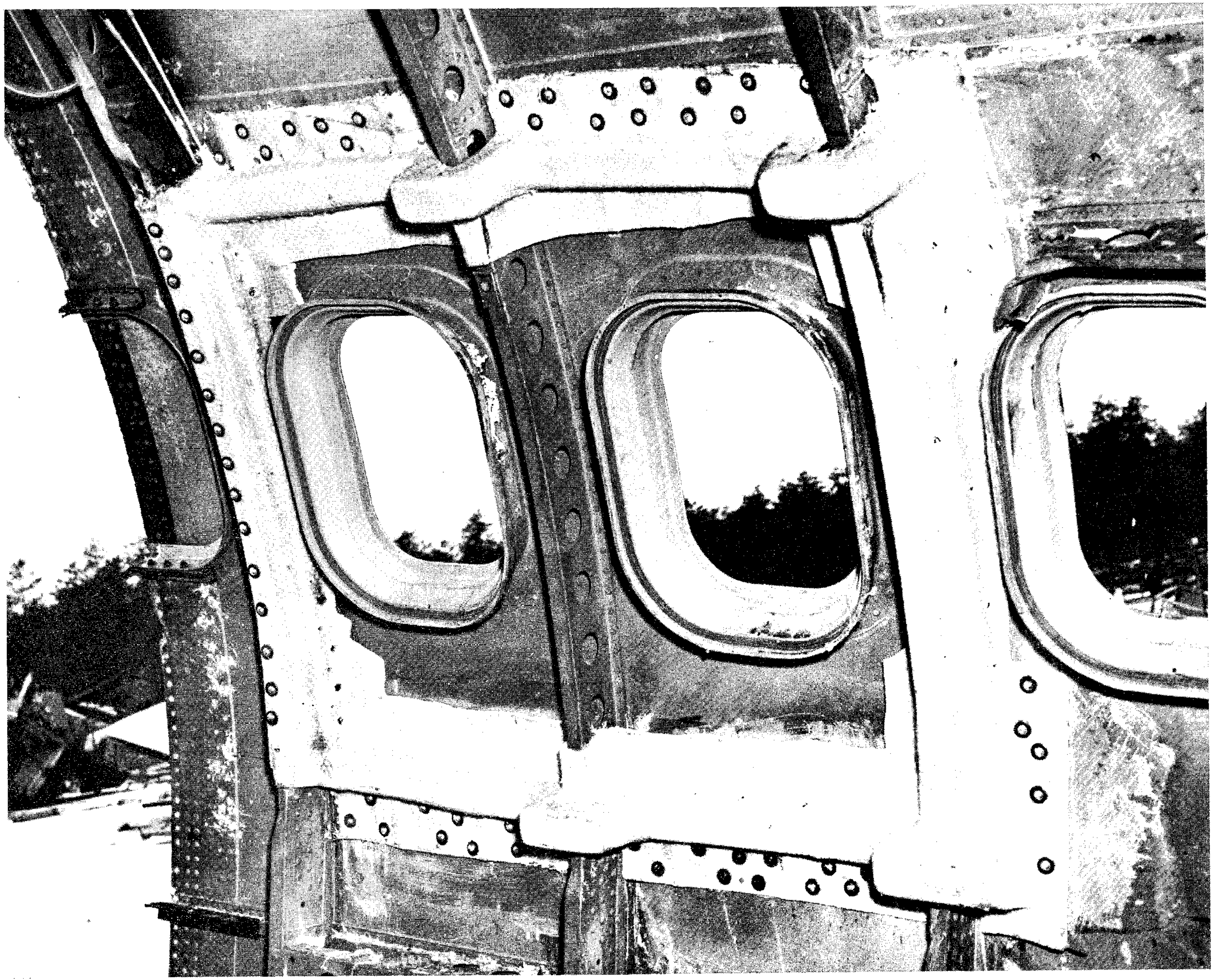


FIG. 16 SHIELD MOUNTED ON THE FUSELAGE

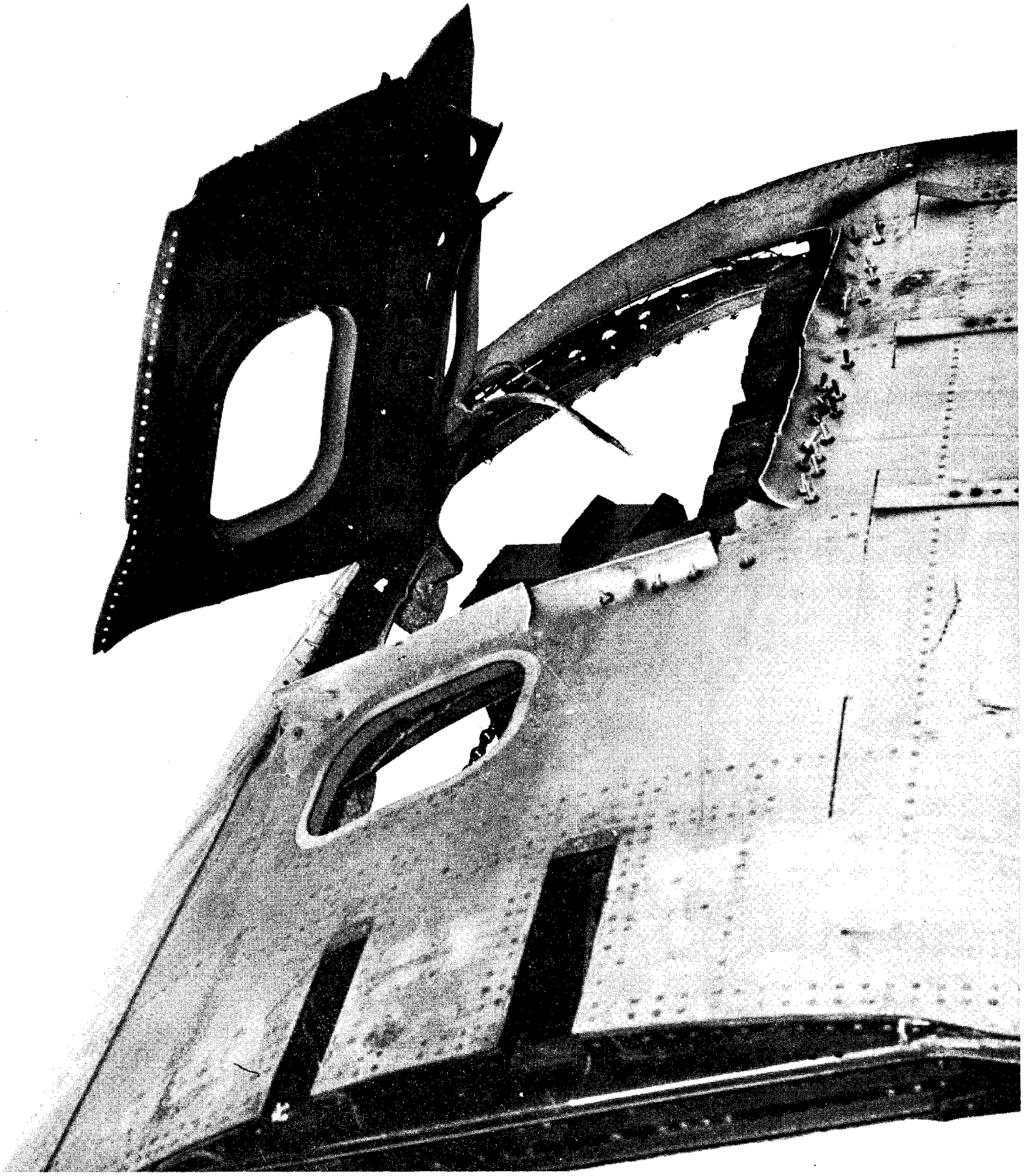


FIG. 17 OUTSIDE VIEW AFTER TEST

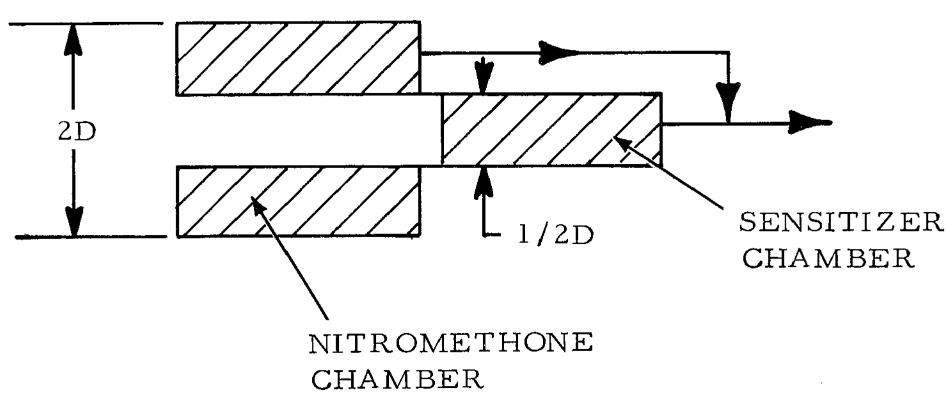
against the fuselage broke the seal, thus causing a leak and terminating the propagation of the explosion at that point. Another test was conducted with a new shield and shaped loop formed and installed as in the previous test. The same problems occurred in this installation as with the previous shield. Because of the installation problems encountered, it appears that the fiberglas, laminate-type of protective shield may be impractical for the application considered.

<u>Design of a Fluid-Mixing, Distribution and Detonation System</u>: In this phase of the project, the design, fabrication, and testing of a system which would utilize a liquid, linear-shaped charge to explosively cut and remove an emergency exit in the aircraft structure was accomplished. The system was designed to contain, mix, expel, and detonate two fluid components which when combined become an explosive as previously described. System operation time to fill a loop of linear-shaped tubing without voids and initiate detonation was specified to be 3 seconds or less.

<u>Mixing Pump Design</u> - The pump was designed to store both fluids in two chambers so arranged that pumping could be accomplished by a double piston to assure the correct mixing ratio (see Figure 18). Two mixing pumps were fabricated with the proper dimensions to fill a 3/16-inch-diameter, linear-shaped tube with a capacity of 51 cm^3 of the explosive fluid. The pump was designed with a 2-inch-diameter piston for the nitromethane and a 1/2-inch-diameter piston for the sensitizer, which produced a pumping ratio of 15 to 1 for a mixture of 93.4 percent nitromethane to 6.6 percent sensitizer.

<u>Design Calculations</u> - The design calculations for the pump are as follows:

A. Piston Area Requirements



2" dia. area = 3.141 $in.^2$

1/2" dia. area = 0.196 $in.^2$ sensitizer piston area

3.141—0.196 = 2.945 $in.^2$ nitromethane piston area

Ratio = 2.945 to 0.196 or 15 to 1

i.e. 93.4 percent nitromethane to 6.6 percent sensitizer

B. Pump Chamber Design Pressure

Material - 7075 - T6 aluminum

Yield Strength = 60,000 psi

Wall (W) OD/ID = 2.240/2.00 = 1.120

C. Design Internal Pressure

$$P = \frac{SY}{1.73} \times \left(1 - \frac{1}{W^2}\right)$$

$$P = \frac{60,000}{1.73} \times \left(1 - \frac{1}{1.25}\right)$$

$$P = 34,700 \times .2$$

$$P = 6,940 \text{ psi}$$

The maximum pressure measured during testing was 1,475 psi. Therefore, the safety factor is 6,940/1,475 = 4.7.

Preliminary Tests - A system was constructed using the mixing pump containing colored water and plastic tubing. For this series of tests, the orifice plate located in front of the piston (reference Figure 18) was not used. Compressed air was used to operate the system at first to determine the pressure requirements of the mixing pump and to check the pump's capability of purging air from the system. Results of these tests indicated that the system could be operated with 100-psi air pressure and that the pump was effective in removing air from the system.

Tests were conducted with the system in both the horizontal and vertical positions to determine the effects of pump orientation on system performance. Inspection of the system after test indicated similar performance in either position.

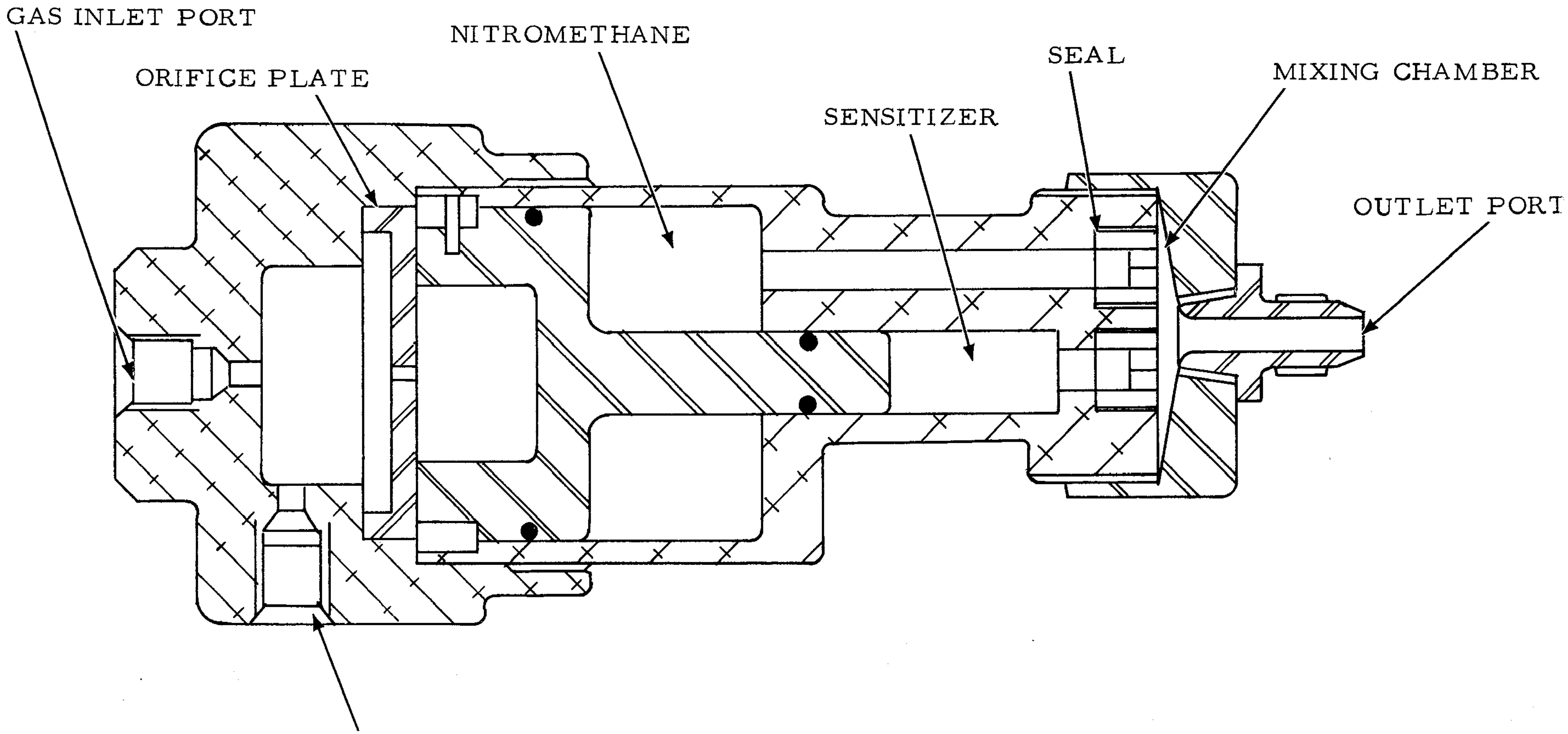


FIG. 18 MIXING PUMP ASSEMBLY

These preliminary tests also included the use of a chamber which was placed at the end of the tubing to provide a closed system condition for comparing performance with the open system. Test results showed that air bubbles, which could potentially interrupt propagation of the detonation, formed more readily with a closed system. Therefore, it was decided at this time to conduct all live testing with a vented system thus minimizing the possibility of air entrapment. Tests were then commenced with the simulated system using colored water and a gas-producing initiator to operate the mixing pump and simultaneously produce sufficient pressure to fire two delay initiators. The mixing pump initiator consists of a standard, mechanically operated miniature initiator similar to those used in aircraft ejection seat systems. These initial tests were conducted with an XM169 cartridge which contains 1.35 grams of M10 propellant.

Tests with the XM169 cartridge indicated that the pump operation was too rapid and caused the liquid to overrun the air in the tubing, thus forming untenable air bubbles in the tube circuit. To slow down the pumping action, an orifice plate was located in front of the piston to meter the gas flow to the piston (see Figure 18), and to provide high-pressure gas for operating the two delay initiators. These initiators will be described under "System Tests." Additional tests were conducted using cartridges containing charges of boron potassium nitrate pellate as the propellant. These tests were not satisfactory since the gases were hot enough to melt the bottom of the cartridge case, thus causing the orifice plate to clog. Cartridges were then assembled using charges of M5 propellant (0.5 gram). These produced satisfactory operation of the system. During the pumping tests, time for the pump to operate was measured and high-speed, colored movies were used to observe the flow of the colored water through the system. Data from these tests are listed in Table III.

<u>System Development</u> - The following components were tested during successive stages of system development.

A. <u>M47 Detonator</u> - Initially, the M47 stab detonator was selected and tested in housing assemblies containing a premixed explosive fluid which was pressure injected into lengths of 3/16-inch-diameter aluminum tubing secured to the detonator housings. These tests were unsuccessful since the M47 detonator either along or with a booster would not detonate the liquid explosive. It was believed that, since the fluid could contact the detonator in the assembly, the cylotrimethylene trinitramine cyclonite (RDX) charge was neutralized in the unsealed detonator. New assemblies were made in which a 1/32-inch wall was provided in the housing between the liquid explosive and the detonator. Four tests were then conducted in which successful detonation of the liquid explosive was attained.

System tests conducted with this detonator resulted in only one test in four being successful.

TABLE III

LIQUID-SHAPED CHARGE PRESSURIZATION SYSTEM DEVELOPMENT TEST DATA

Test	Initiator Charge Wt. (grams)	Initiator Propellant	Initiator Pressure (psi)	Pumping Time (second)	Orifice Size (inches diam.)	Remarks
1	1.35	M-10	2270	--	NA	Several large bubbles in system.
2	1.35	M-10	2250	--	1/32	Tube came off pump.
3	1.35	M-10	2005	.270	1/32	Few tiny bubbles. Fast operation time.
4	.70	boron	270	--	1/32	Pressure too low. Delay initiator did not function.
5	2.10	boron	1475	.305	1/32	Used cartridge case with bottom removed - good test.
6	1.40	boron	855	.565	1/32	Good test.
7	1.40	boron	625	.985	1/32	Small and large bubbles. Slow pumping time.
8	1.40	boron	710	--	1/32	Small bubbles. Slow pumping time.
9	1.40	boron	905	.485	--	Small bubbles.
10	1.70	boron	705	.765	--	Small bubbles. Used full cartridge case. Orifice clogged. Pump did not stroke out.

TABLE III (Continued)

LIQUID-SHAPED CHARGE PRESSURIZATION SYSTEM DEVELOPMENT TEST DATA

11	1.40	boron	530	--	--	Same as Test #10
12	1.40	boron	725	--	1/32	Same as Test #1
13	1.40	boron	705	--	3/64	Increased orifice size.
14	1.10	M-5	1595	.336	1/32	Tiny bubbles.
15	.90	M-5	1292	.375	1/32	Tiny bubbles after pump.
16	.80	M-5	1005	.435	1/32	Tiny bubbles after pump.
17	.60	M-5	865	.520	1/32	No bubbles.
18	.33	M-5	1310	.577	1/32	No bubbles. New Orifice ass'y used.
19	.33	M-5	1175	.576	1/32	Inverted system. Bubbles in runoff.
20	.33	M-5	900	.683	1/32	Inverted system. Bubble in runoff.
21	.50	M-5	1350	.541	1/32	Small bubble in line from pump.
22	.33	M-5	820	.700	1/32	Vertical system. No bubbles.
23	.33	M-5	815	.583	1/32	Vertical system. No bubbles.

TABLE III (Continued)

LIQUID-SHAPED CHARGE PRESSURIZATION SYSTEM DEVELOPMENT TEST DATA

24	.33	M-5	755	--	1/32	Inverted system. Small bubbles.
25	.33	M-5	860	.671	1/32	Inverted system. Bubble in runoff.
26	.50	M-5	1230	.533	1/32	Inverted system. Bubble in runoff.

NOTE: All tests conducted at 70° F.

B. M17 Detonator - The M17 detonator is a flash detonator requiring heat for initiation. It contains a base charge of 80 mg tetryl, whereas the base charge of the M47 detonator is 41 mg of RDX.

A test of the detonator alone was conducted successfully, thus indicating that the heat from the 3-second-delay initiator was sufficient to initiate the M17 detonator. A second test was then conducted in which the explosive fluid was premixed and tested with the detonator. This test was unsuccessful as the liquid explosive failed to detonate. No further tests were conducted with the M17 detonator.

C. M46 Detonator - This detonator is also a stab detonator with a base charge of 145 mg of RDX. It was tested in assemblies where the fluid was premixed. Five of the six tests conducted were successful. Examination after the one failure revealed that in this case the detonator had been assembled incorrectly.

Six tests were conducted using the automatic mixing system together with the M46 detonator. Only two of these tests resulted in successful detonation of the liquid explosive. No definite reason could be given as to why the detonator worked when the fluid was hand mixed and would not propagate in the system when the fluid was mixed and pumped automatically.

D. M50 Detonator - This unit is also a stab detonator with a base charge of 495 mg of RDX. Initially, three tests were conducted and the charge propagated successfully each time. Ultimately, this unit was selected for use in all subsequent development tests. Figure 19 illustrates the M50 detonator and housing assembly.

System Tests - The initial system used in the explosive tests was similar to the system using colored water except that nitromethane and the sensitizer were used and 3/16-inch-diameter, linear-shaped aluminum tubing was employed instead of plastic tubing (see Figure 20). The objective was to check the automatic pumping, mixing, and detonation phases of the system. The test was partially successful as all phases of the system functioned properly with the exception of the check valve, which allowed the detonation to propagate back into the mixing pump causing considerable damage.

To prevent a like occurrence in future tests, it was decided to isolate the pump from the system after the pump had functioned. This was accomplished by introducing a stripper mechanism on the end of the mixing nozzle. In operation, the gas generated by a 1-second-delay initiator removed the stripper mechanism after the pump had functioned, thus isolating the pump from the system (see Figure 21).

Two tests were conducted with the tube stripping mechanism and 3/16-inch-diameter, shaped tubing assembled on an aluminum plate. On both occasions, the detonator failed to propagate at sufficiently high

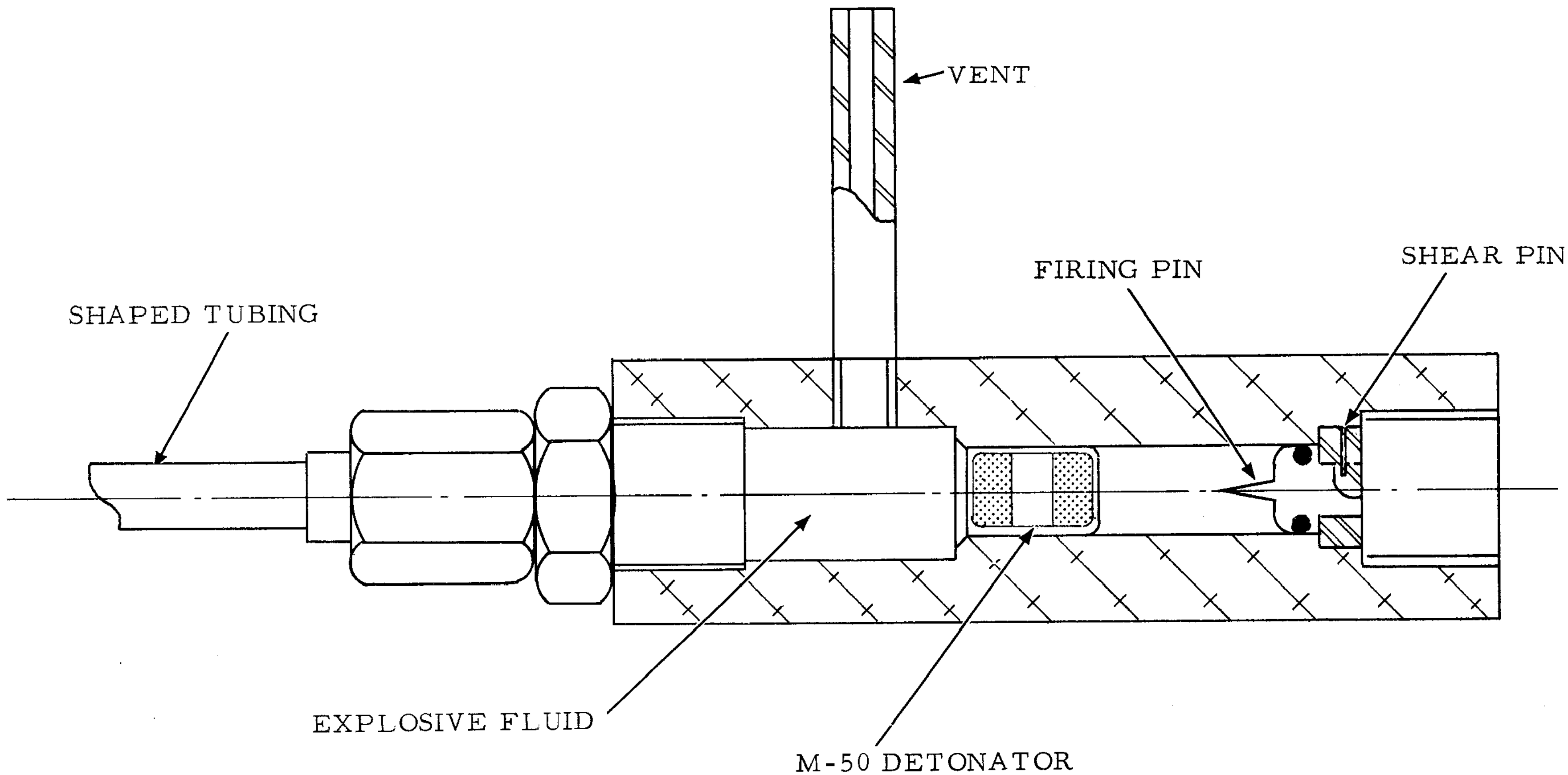


FIG. 19 DETONATOR HOUSING ASSEMBLY

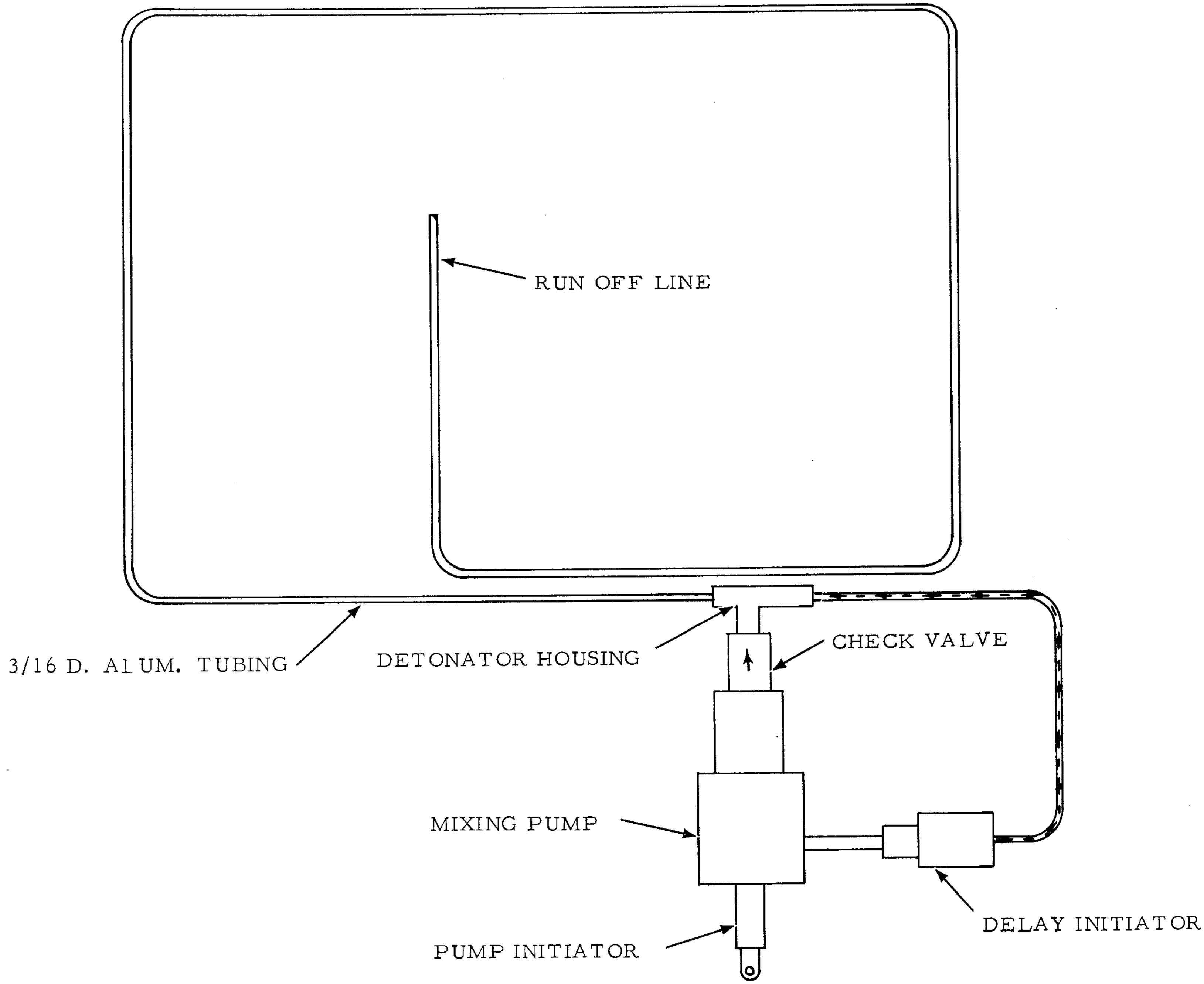


FIG. 20 SYSTEM TEST SETUP

order to detonate the liquid explosive. In the first test, the tubing was connected directly to the detonator housing. In the second test, a straight piece of standard 3/16-inch-diameter aluminum tubing, 3 inches long, was placed between the detonator housing and the shaped tubing in an attempt to increase detonation potential. When this also failed, it was theorized that gas from the delay initiator, which operated the stripper mechanism, was getting into the system thereby creating voids or bubbles in the system which prevented propagation of the detonation. Since this method of isolating the mixing pump from the system presented functional problems, it was discarded.

Another method used incorporated an M3 cable cutter which cut the plastic tubing and isolated the pump from the system. A check valve was installed to prevent possible leakage of the liquid explosive from the system during the time period between cutting and detonation.

In all tests in which the liquid explosive failed to detonate, it was believed that all the air was not being purged from the check valve and was entering the detonator housing prior to detonation.

Another method which proved to be the most successful in isolating the mixing pump from the system was a tube-closer device which also operated from the gas pressure furnished by a delay initiator. This device protected the pump by flattening and sealing the aluminum-shaped tubing between the pump and the system. It had the additional advantage of maintaining a closed system after operation which results in better confinement of the liquid explosive. This device was used in the final system tests, and is considered the best method for protecting the mixing pump without affecting the operational reliability of the total system. An assembly of the tube-closer is shown in Figure 22.

The final and most successful system tested utilized the M50 detonator placed at the end of the shaped tube farthest from the pump. An assembly of the final test setup is shown in Figure 23. Operation of this system is as follows:

1. Arm the System - Remove safety pin from pump initiator.

2. Actuate the System - Pull lanyard on pump initiator (requires a force of 25 pounds minimum over distance of 3/8 inch).

3. Mixing pump will now automatically mix the nitromethane and sensitizer while simultaneously pumping them into the system. This operation requires 1/2 second.

4. Gas pressure in the mixing pump will concurrently actuate both the 2-second-delay tube-closer initiator and the 3-second-delay detonator initiator.

5. The tube-closer will operate thereby disconnecting the mixing pump from the system 2 seconds after the lanyard on the pump initiator has been actuated.

6. The detonator initiator will operate and fire the detonator which, in turn, propagates a high-order detonation in the liquid explosive contained in the shaped charged tubing 3 seconds after the lanyard has been actuated.

The system was tested three times and all tests were successful. A tube-closer was used on these tests to flatten the shaped charge tube leading from the pump and was actuated after completion of the pumping operation.

The difficulties encountered during system development, specifically in detonating the liquid explosive, were due to the lack of energy supplied by the detonators. Upon introducing the M50 detonator, the problem of providing a sufficient high-order energy transfer was solved.

The 50-cm^3 mixing pump is capable of filling approximately 30 feet of the 3/16-inch-diameter, linear-shaped tubing. Since only a length of 15 feet of the tubing was used in the system, the fluid overflow was over 100 percent including the fluid required to fill the volume of the detonator housing. It is believed that an overflow of 20 percent is sufficient to purge the air and completely fill the system.

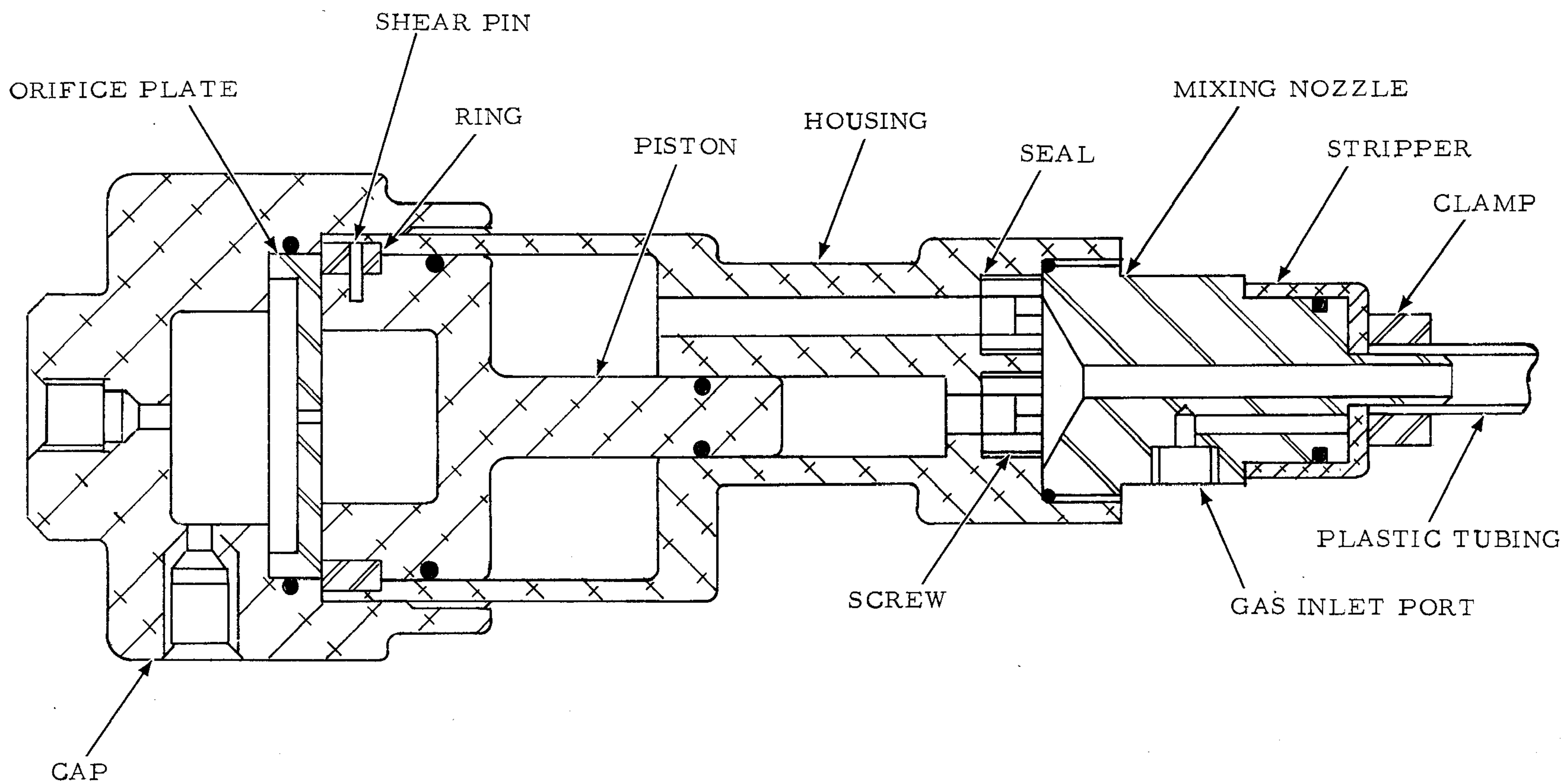


FIG. 21 MIXING PUMP ASSEMBLY WITH TUBE STRIPPER

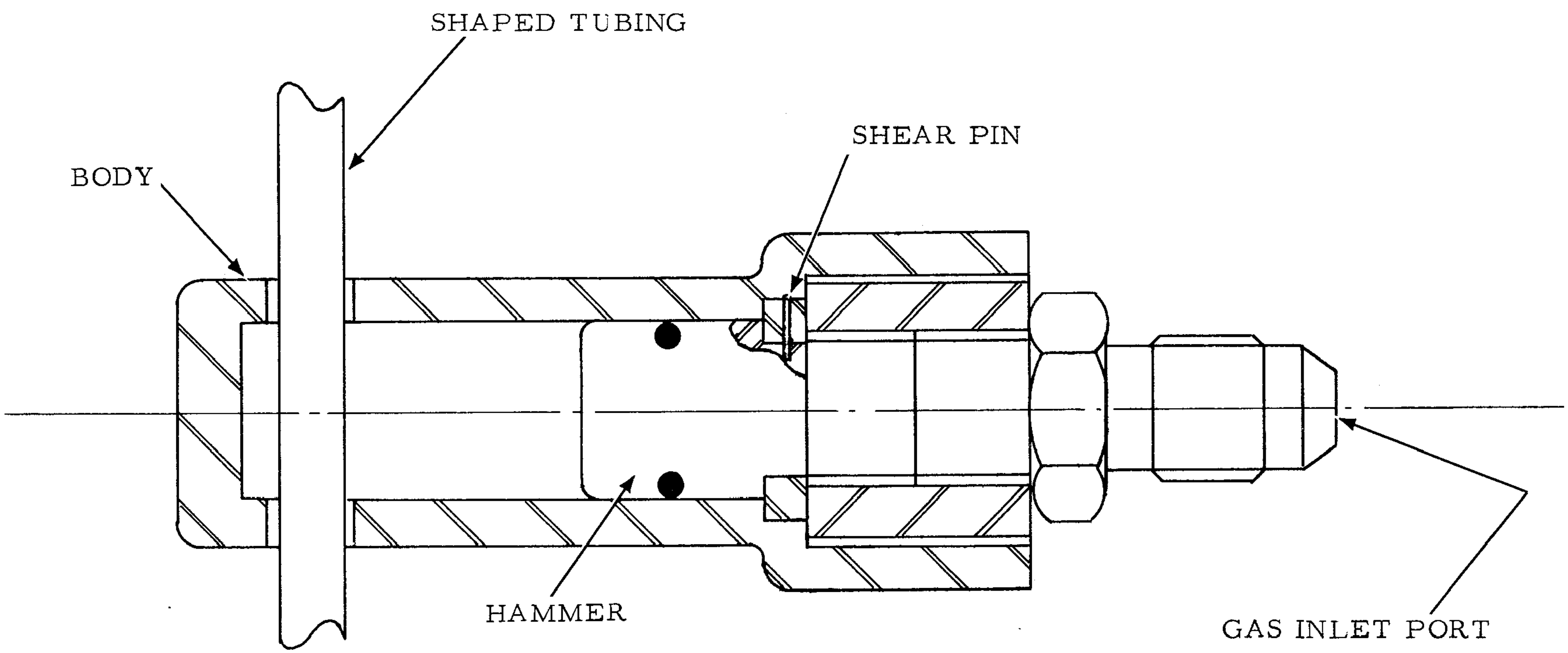


FIG. 22 TUBE-CLOSER ASSEMBLY

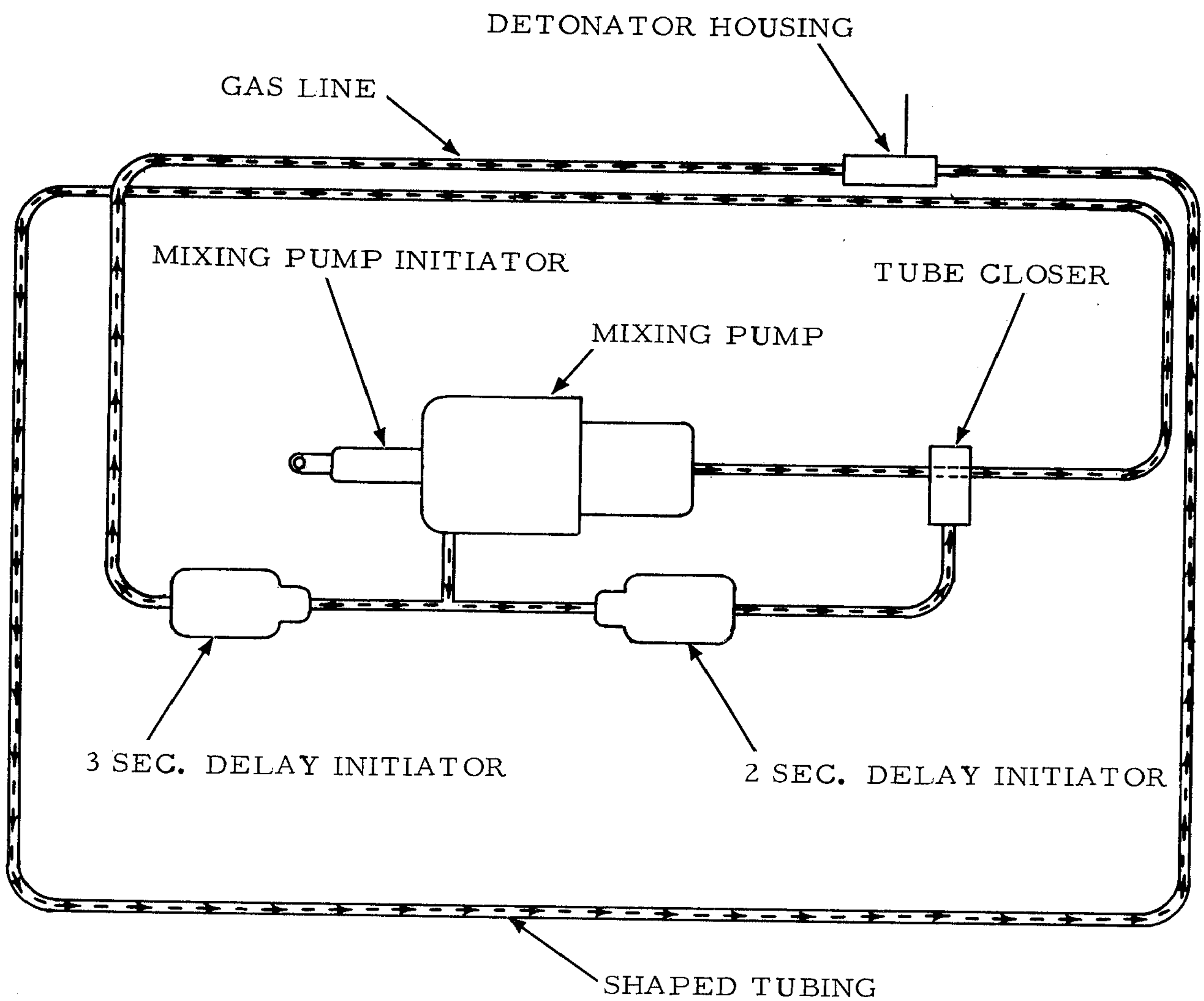


FIG. 23 FINAL TEST SETUP

CONCLUSIONS

Based upon tests performed, it is concluded that:

1. The concept of using a liquid-filled, linear-shaped explosive charge to create additional emergency exits for civil transport aircraft is feasible.

2. The fragmentation produced by the detonation of a linear-shaped charge can be controlled.

3. Overpressures generated by the detonation of a linear-shaped charge can be controlled within safe limits.

4. Exploding the liquid charge requires a high order of energy transfer.