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Advanced Emergency Openings for Commercial Aircraft

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SUMMARY

Passenger survivability in large commercial aircraft can be enhanced by the application of explosively actuated emergency openings for passenger egress, fuselage venting, and fuel dump. These openings are created by embedding a tiny, highly stable explosive cord in a composite panel. This panel, bolted to the primary structure, becomes a lightweight, crashworthy, load-carrying member; thus the need for high-strength framework is reduced. With this approach, more egress openings could be created, a row of panels on the top of the fuselage would allow crew members to vent the fuselage over the source of smoke, and panels in the fuel cells would allow rapid fuel dump prior to a crash.

This paper treats the concerns with the use of explosive systems, considers the problems in adding safety improvements, describes the advantages of the proposed concept, shows the latest experimental results, and recommends an approach to gain acceptance of this concept through the development of an emergency egress system.

INTRODUCTION

In-flight and postcrash survivability of passengers within commercial aircraft can be significantly enhanced through the addition of explosively actuated emergency openings for passenger egress, smoke venting, and fuel dump. However, these concepts will not be accepted unless explosive safety concerns are eliminated and economic advantages are clearly indicated.

The need for rapid opening of an adequate number of emergency exits has long been recognized as an important consideration in aircraft safety, but the issues of smoke evacuation and fuel dump are more controversial. As pointed out in reference 1, "Although the probability of a fatal accident per hour of flight in commercial aircraft continues to decline, the percentage involving deaths from fire has remained constant." The authors go on to state that the greatest number of deaths is caused by smoke inhalation produced during the combustion of numerous synthetic materials used in cabin furnishings and linings. Venting of the smoke at a point over the fire could prevent some or all these deaths. In the event of a survivable landing, fire caused by the rupture of fuel tanks is a major cause of fatalities. Although a great deal of effort has been focused by the FAA on fuel antimisting additives, culminating in the crash test of a full-scale Boeing 720 aircraft in 1984, little consideration has been given to an alternate approach, fuel dump.

The use of explosive systems aboard aircraft invokes immediate anathema to the crew, passengers, and everyone else in the commercial industry, because of the perception of the hazardous, unstable nature of explosives. Those responsible for emergency escape from military aircraft easily overcame the understandable reluctance to use explosives because of the tremendous gains accrued in accomplishing large amounts of work with small, lightweight devices. A good example is the F-111 crew module in which some 300 explosive components are needed to separate the cockpit module from the aircraft (ref. 2). The system, first used in 1967, has been proven to be completely safe and is currently installed in approximately 700 aircraft. Recent studies by NASA (ref. 3) on explosive transfer lines, used to control escape system initiation and sequencing on military aircraft, have shown that hexanitrostilbene

(HNS) and dipicramide (DIPAM) explosive materials are unaffected by age or service. The service life of these explosive transfer lines has been extended from an initial specification of 3 years to 15 years, currently, with a possibility of remaining installed for the projected 25-year life of most military aircraft. Furthermore, these explosive materials have survived 50-hour, $350^{\circ}F$ exposures and are insensitive to handling, impact, gunfire, and lightning. They will burn in a fire but will not function in their designed mode to sever the panel.

This paper describes a concept of improving aircraft safety through the use of explosively severed panels integrated into the airframe and used for emergency egress, fuselage venting, and fuel dump. This concept, which is different from past explosive applications, can meet all safety requirements, permit long-term continuous use, and will be less costly to build and operate than many existing systems. Described are past efforts on explosively actuated emergency systems, proposed emergency systems with the benefits to be accrued, results of preliminary developmental efforts on explosively severed panels, and recommendations on system integration studies and testing required to achieve acceptance.

PAST EMERGENCY EGRESS SYSTEM

A number of aircraft emergency escape systems have been developed and qualified, with flexible linear-shaped charge (FLSC) to sever primary structure. Three examples are provided: F-111, Emergency Life-Saving Instant Exit (ELSIE), and an opening for a NASA general aviation research aircraft.

Flexible linear-shaped charge (FLSC) is an explosive-filled lead, silver, or aluminum tube that is shaped into a chevron cross section, as shown in the left-hand sketch in figure 1. On initiation, a pressure wave of several million psi is focused in the "V" of the chevron to produce cuts in metal that have the same appearance as cuts produced by an acetylene torch. The explosive combustion propagates at a velocity of over 20 000 feet per second to allow peripheral severance of a 3- by 5-foot panel in less than 1 millisecond. Very small quantities of explosive are required. For example, this same 3- by 5-foot opening could be created in an overlapped 0.040-inch-thick aircraft skin lay-up with a total of less than 0.5 ounce of explosive.

F-111 Crew Module

The F-111 crew module severance system is shown in figure 1 (ref. 2). The entire system, initiated by either of two squeeze-and-pull handles, is fully automatic. The cockpit module is completely severed from the fuselage, a rocket motor is ignited to thrust the module from the fuselage, parachutes are deployed, and bags inflated for impact and flotation. The crew module is attached to the aircraft structure by means of splice plates, which are cut by the FLSC. The FLSC is installed in a fiberglass holder, contained in an aluminum cover plate, which is attached to the aircraft structure.

Emergency Life-Saving Instant Exit

The Emergency Life-Saving Instant Exit escape system is shown in figures 2 and 3 and is described in reference 4. This system is designed to sever the metal panel inside an existing door. A considerable effort was expended in this study to demonstrate that the explosive output of the FLSC did not ignite jet fuel or fuel vapor.

Figure 3 shows the initiation schematic. An electrical safe/arm mechanism, controlled by the flight commander, locks the system. Once armed, either handle (exterior or interior) can be pulled through a long stroke (to assure action is not inadvertent) to actuate the system.

NASA General Aviation Egress Opening

The NASA General Aviation Egress system (ref. 5) was created to provide an emergency opening within an existing aircraft without modifying primary structure. The results of the final system demonstration test are shown in figure 4. FLSC was installed around the window, across a central stringer, and down to a stringer just above the interior deck. The major technical challenge was to provide complete internal containment of the explosive products. The solution, shown in figure 5, was to cover the FLSC with a metal compartment with sufficient free volume to attenuate the explosive pressure in air. Closed-cell foam, driven ahead of the pressure wave, sealed gaps between the plates. Once severed, the panel to the right of the FLSC slid out of the containment structure and was jettisoned at a velocity of 30 miles per hour. No explosive products were detected inboard.

General Comments on Past Emergency Egress Systems

All three escape systems performed well, but in each design, the aircraft system complexity increased with a significant weight penalty. None contributed to improvements in manufacturing efficiency of the basic airframe.

PROPOSED EMERGENCY SYSTEM CONCEPTS

Advanced emergency systems for egress, fuselage venting, and fuel dump can be accomplished through the application of an explosively severed panel, with only the size changed to accommodate the intended function. This section describes this panel and the three applications, citing the advantages of the proposed systems over existing systems.

The proposed explosively severed panel would be fabricated from composite materials, such as fiberglass, graphite/epoxy, or combinations of lightweight, high-strength materials. This panel would be bolted directly into the airframe to become a load-carrying member. Ribs and stringers molded within the panel would accommodate loads over large areas. A tiny explosive detonating cord with a cylindrical-type cross section (see sketch on right in fig. 6) would be embedded in a low-profile configuration around the periphery of the panel. The ELSIE FLSC configuration is shown on the left for comparison. The composite fibers would be smoothly faired over the cord with all cavities filled with resin. On initiation, the explosive output efficiently fractures the surrounding structure to release the panel. Considerably less explosive quantity is required to fracture high-strength composite panels than is required to sever the aluminum panels they replace. Other advantages (compared with FLSC severance) are the reduction of structure to contain explosive products and the complete protection of the embedded explosive cord against improper handling. The crashworthiness of this panel, compared with aluminum, is superior because of the inherent stiffness of composite structure. Furthermore, this panel would have to be severely fractured to break the explosive cord in at least two places to defeat the intended severance of the panel. Once actuated, the panel could easily be removed and replaced with another panel. Once installed in a new aircraft, test results described in reference 3 indicate that it need not be replaced for the life of the aircraft.

Emergency Egress

Egress systems currently used in commercial aircraft can be improved through the application of the proposed egress panels. Existing doors are heavy and difficult to open by untrained passengers, particularly under panic conditions. Some aircraft require onboard power (which might fail in a crash) to open these doors. Complicated heavy frames are required to carry structural loads. These doors have a history of jamming when the airframe is distorted, particularly in a crash. Furthermore, these doors have a high-maintenance seal. The proposed panel could immediately replace doors used only for escape in existing aircraft. Future aircraft designs could take advantage of the panel's load-carrying capacity and reduce opening framework, which could allow the use of more openings without a weight penalty. The new system could utilize existing actuation handles; passive differential-pressure or forward-motion mechanisms could "safe" the system to prevent actuation in flight. For example, the Boeing 727 uses an external flap that actuates with forward motion to lock the access to the rear stairs.

Fuselage Venting

Since toxic smoke in the fuselage, following a survivable crash, is the greatest killer, an effort should be made toward its reduction. Fuselage venting could reduce the exposure to passengers, provided the venting does not contribute to the fire hazard, as is pointed out in reference 1. A number of small explosively severed panels placed along the top of the fuselage would allow the panel closest to the source of the fire to be opened. The air motion within the fuselage would carry the smoke immediately outboard instead of distributing it through the fuselage. Although the combustion might be enhanced, flame and smoke spreading could be minimized.

Fuel Dump

Dumping the onboard fuel, prior to impact, would minimize the primary source of postcrash fire. Sufficient time (less than 10 seconds) for fuel dump usually exists before impact, even during takeoff. Existing fuel off-loading systems use small plumbing, which results in long time periods (1 hour) to empty full tanks. Dumping the fuel, particularly at takeoff, would significantly reduce aircraft crash loads. The use of explosively severed panels in fuel cells would allow quick gravity dump of the fuel. The fuel cells could be automatically purged with inert gas to prevent explosive conditions of a fuel vapor and oxygen mixture. A small (10-minute) reserve supply of fuel would be carried in a tank positioned for protection from the crash.

PRELIMINARY PANEL SEVERANCE TEST RESULTS

The explosive severability of two different composite panels, fiberglass and graphite/epoxy, has been evaluated. Figure 7 shows a fiberglass (industrially called NEMA G-10), 10- by 14- by 0.063-inch panel in which a 7.5 grain per foot (1.6 grams per meter) charge yielded reliable severance. The explosive cord was bonded immediately below the outer skin panel and supported by backup frames of 0.090-inch fiberglass and 0.063-inch aluminum. The photograph on the lower left is the severed portion of the panel. The blackened areas in the lower right photograph are deposits of unreacted carbon from the explosive, not burning of any of the surrounding structure. The severed 0.084-inch-thick graphite/epoxy panel, shown in figure 8, was fractured by using only 5 grains per foot (1.1 grams per meter). A tough, fracture-resistant 0.063-inch fiberglass sheet provided a backup frame. These panels followed a number of fracture tests made on strips to evaluate the effects of fasteners, adhesives, and backup structure.

RECOMMENDED FOLLOW-ON EFFORT

To gain acceptance of this explosively severed composite panel, participation is needed from industry, FAA, and NASA. The best first application is the area of emergency egress. To support this development, work is needed in the following areas: system integration analysis, egress panel development, actuation system development, and system-level crashworthiness demonstration.

System Integration Analysis

A system analysis needs to be conducted by a manufacturer of wide-body aircraft to determine crashworthiness goals, reliability goals, material requirements and selection, compatibility with aircraft structure and subsystems, fire stability requirements, recommended system control (pilot, crew, passengers, and/or ground crew), recommended system actuation and interlock methods, replacement time for actuated system, and potential gains in passenger survivability and cost savings in manufacturing, weight, fuel, and maintenance.

Egress Panel Development

Based on the results of this study, a representative aircraft should be selected in which a complete explosively severed panel would be integrated. A design should be created to replace existing doors, followed by a design to incorporate the panel concept into the manufacturing of airframes. Test panels should be designed and developed (functionally and structurally) to meet both requirements. Structural evaluation should include load tests to buckling, followed by functional testing.

Actuation System Development

An actuation system should be developed based on this analysis to prevent actuation on forward movement of the aircraft and at differential pressures between the inside and outside of the aircraft. The design should include interfacing to existing actuation handles to assure passenger confidence. Final system demonstrations should include environmental testing, including fire, crash, and deformation conditions.

System-Level Crashworthiness Demonstration

System tests, such as fuselage or aircraft drop tests, should be conducted. The approach should be to install the panels at several different crash intensity/ deformation sites, conduct the crash test with instrumentation to monitor dynamics, assess the damage to the panels (deformation and residual loads), and actuate the panels, monitoring dynamics and posttest status.

CONCLUDING REMARKS

In-flight and postcrash survivability of passengers within large aircraft can be enhanced through the use of explosively actuated emergency openings for passenger egress, fuselage venting, and fuel dump. A novel explosive severance approach is used to create openings in composite panels to accomplish these emergency functions. A tiny, highly stable explosive cord is embedded into the periphery of a composite lay-up and, on initiation, efficiently fractures the panel. This panel would be bolted into the primary structure to become a lightweight, crashworthy, load-carrying member; thus the need is reduced for high-strength framework, such as is used for current doors.

The immediate anathema against explosive systems can be placated through the realization of military experience and the stability of the explosive materials to be used. Military aircraft, such as the F-111, have extensively applied explosive systems, achieving very high levels of reliability and safety for nearly 20 years. The same explosive materials, used in these past applications and to be used in this proposed system, are insensitive to handling, impact, gunfire, and lightning, are unaffected by 50-hour, $350^{\circ}F$ exposure, are unaffected by age or service, and current projections are for installations to remain for the lifetime of the aircraft (25 years).

Airlines continue to press for reductions in passenger egress openings, maintaining 30-year-old safety standards. Little effort has been made to control smoke within fuselage and little consideration has been given to reducing postcrash fires through the use of fuel dump.

This paper proposes the application of this explosively severed composite panel (which has been experimentally demonstrated) to significantly improve safety for commercial aviation while increasing functional reliability, reducing system cost, weight, and maintenance. More zero-maintenance, jam-proof passenger egress openings could clearly save lives. Installing a series of panels along the top of the fuselage would allow the crew to vent the fuselage over the source of the smoke to reduce the opportunity for both smoke and flame spreading. Placing panels in the fuel cells would allow the fuel to be quickly dumped prior to a potential crash, particularly at takeoff.

To gain acceptance of this concept, the best first application would be an effort to improve passenger egress. A joint Aircraft Industry/Government team would direct a system integration study to define structural and performance requirements, followed by hardware development and demonstration, and culminated by fuselage crashes.

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July 19, 1985

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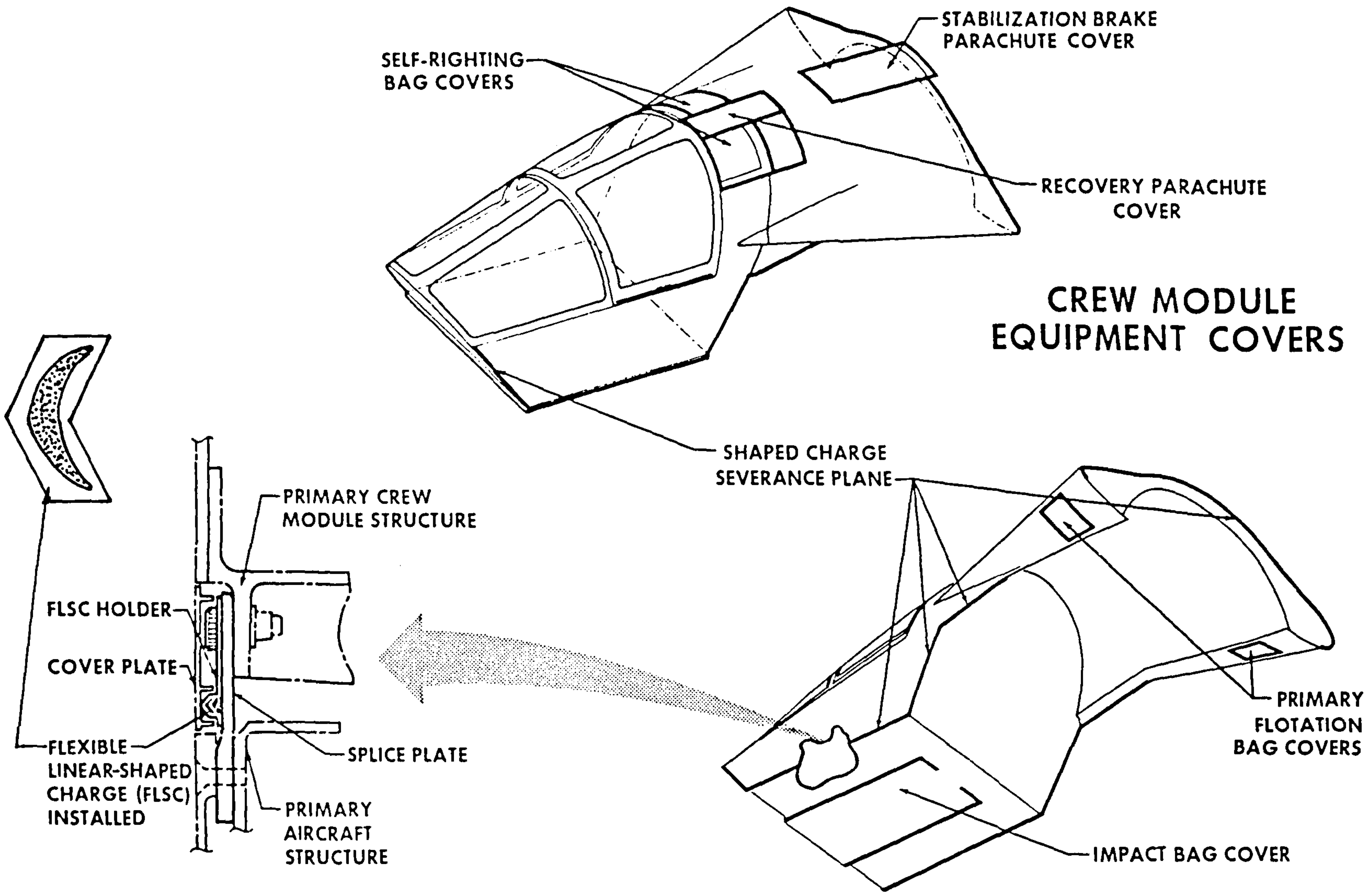

Figure 1.- F-111 crew module severance system.

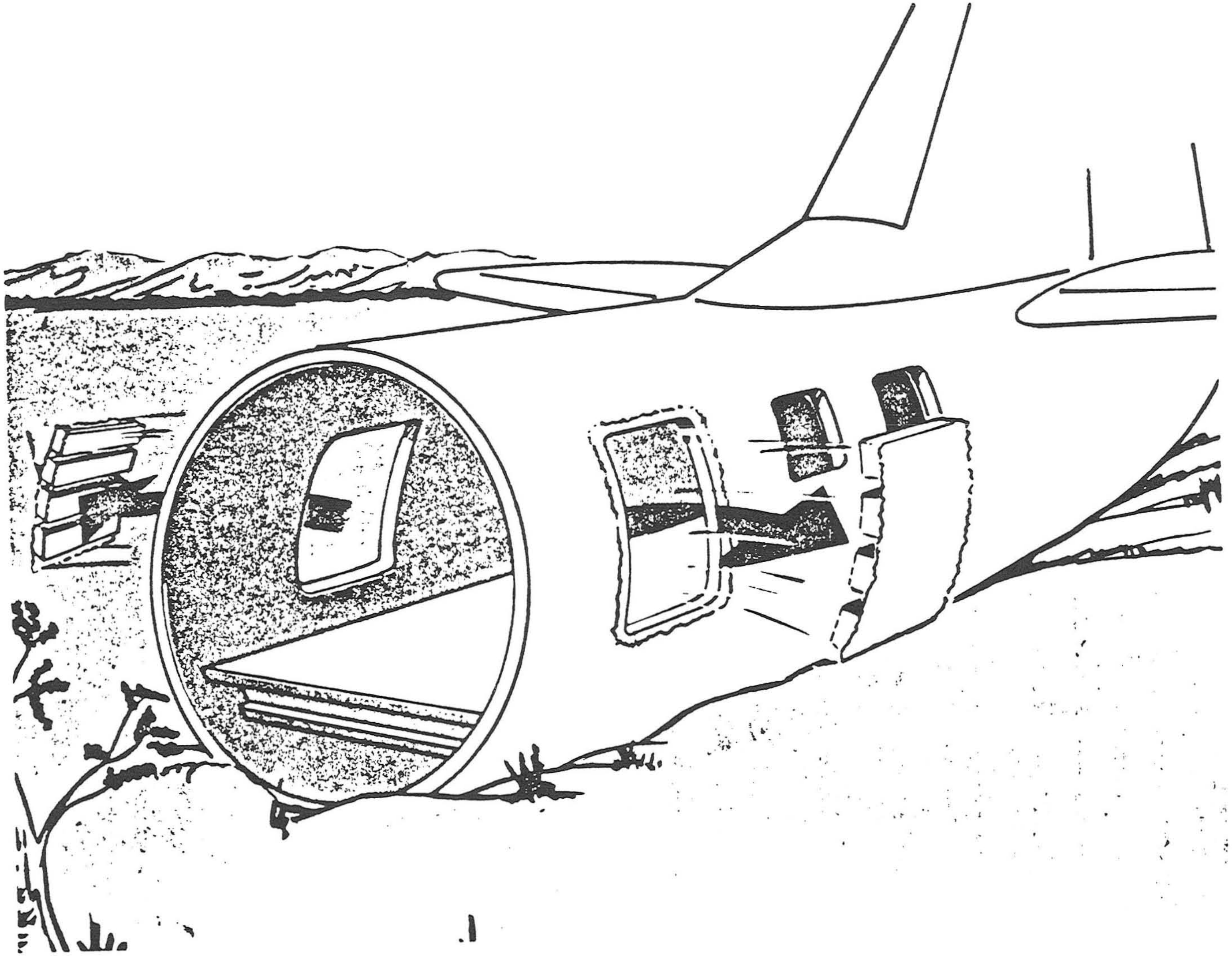

Figure 2.- Emergency life-saving Instant Exit (ELSIE) escape system.

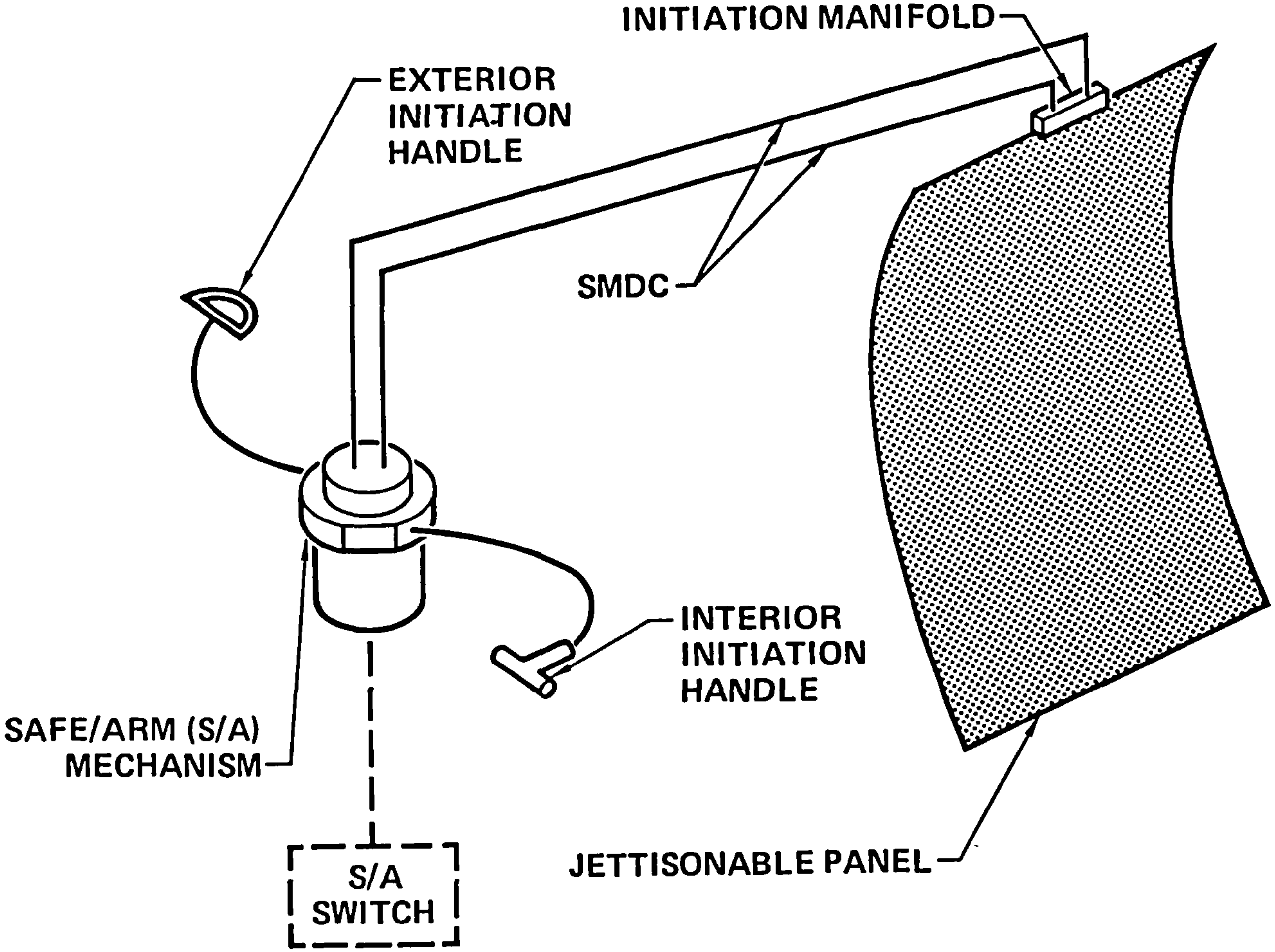

Figure 3.- ELSIE initiation schematic. (SMDC stands for shielded mild detonating cord.)

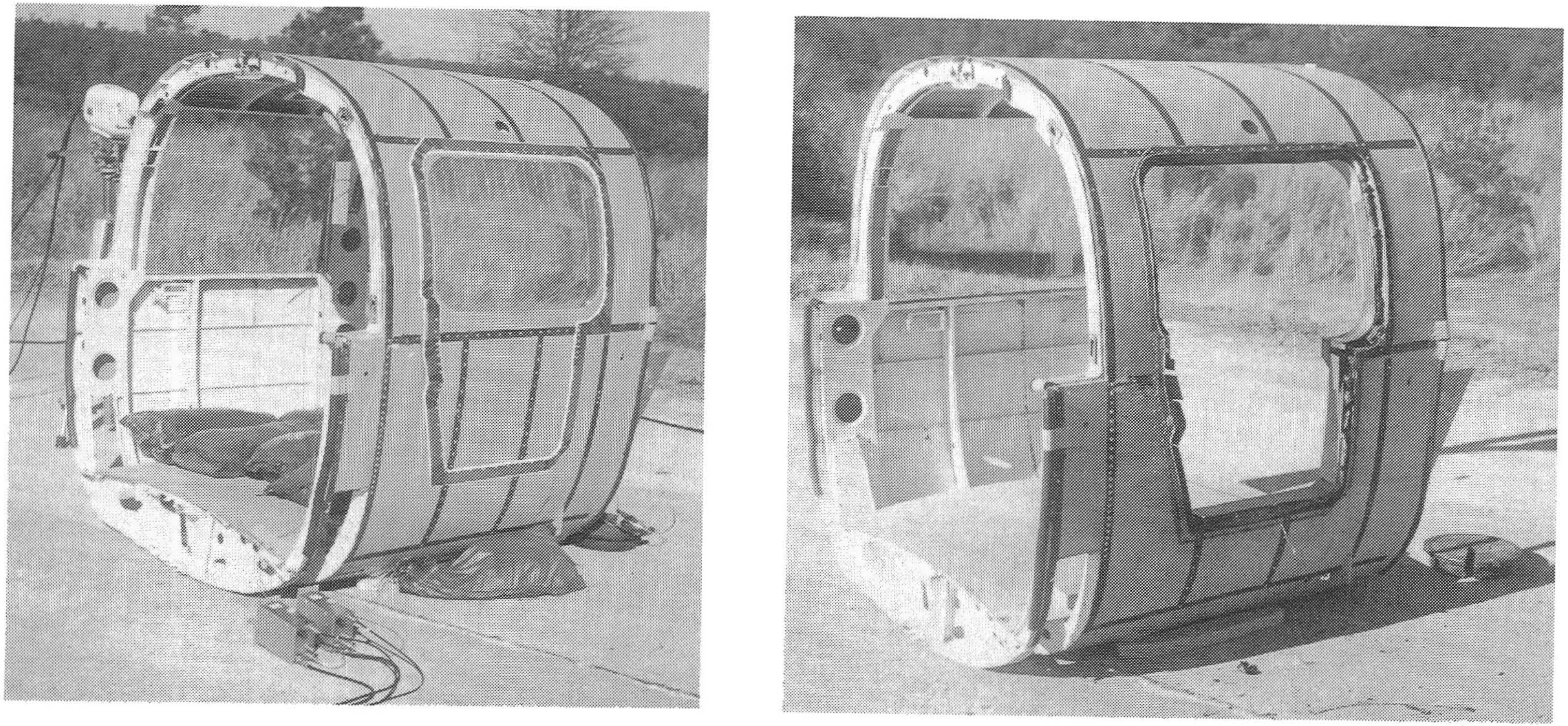

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Figure 4.- NASA general aviation egress system, before and after actuation in final demonstration test.

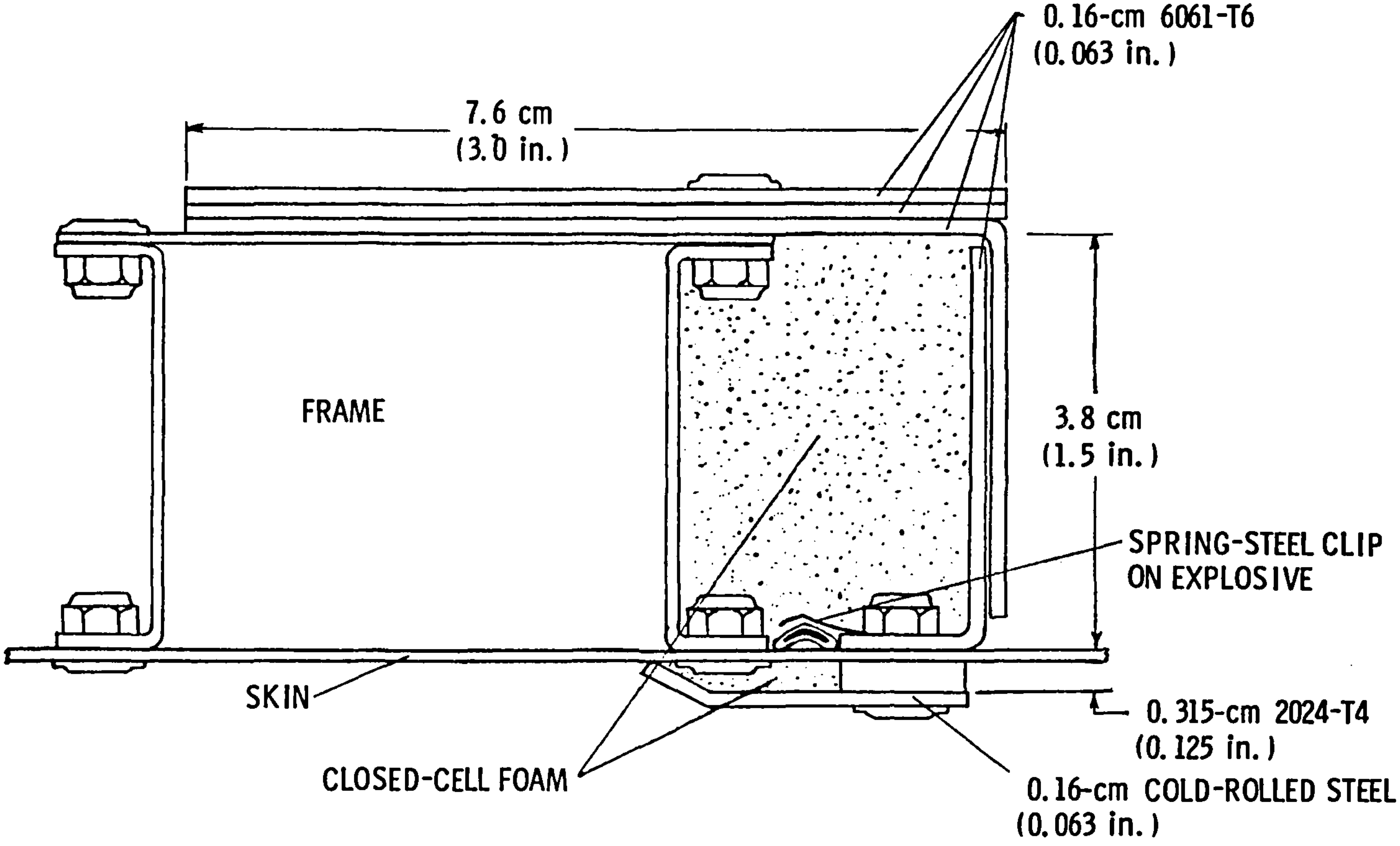

Figure 5.- Cross section of internal explosive containment system for NASA egress system.

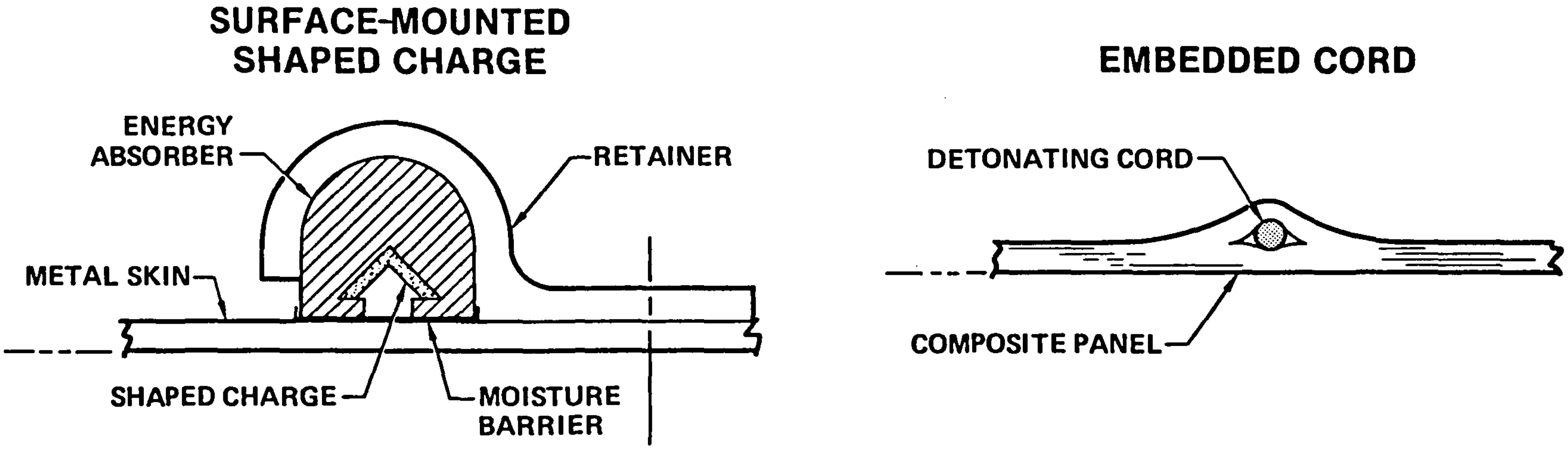

Figure 6.- Proposed composite panel utilizing embedded detonating cord, compared with ELSIE FLSC approach.

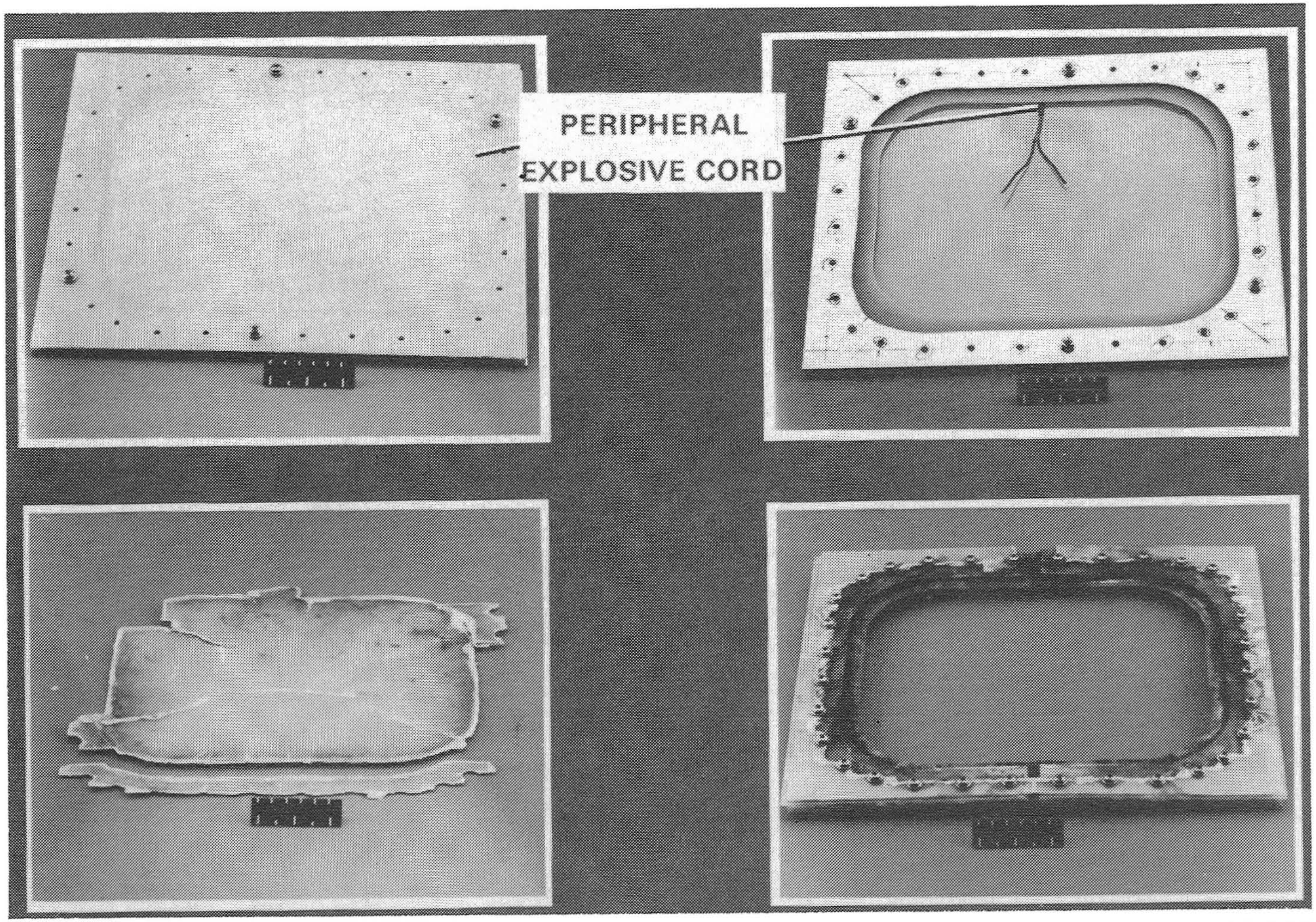

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Figure 7.- Embedded explosive severance of 0.063- by 10- by 14-inch fiberglass panel (MIL-P18177C). The top photographs show the pretest configuration: left, outboard; right, inboard.

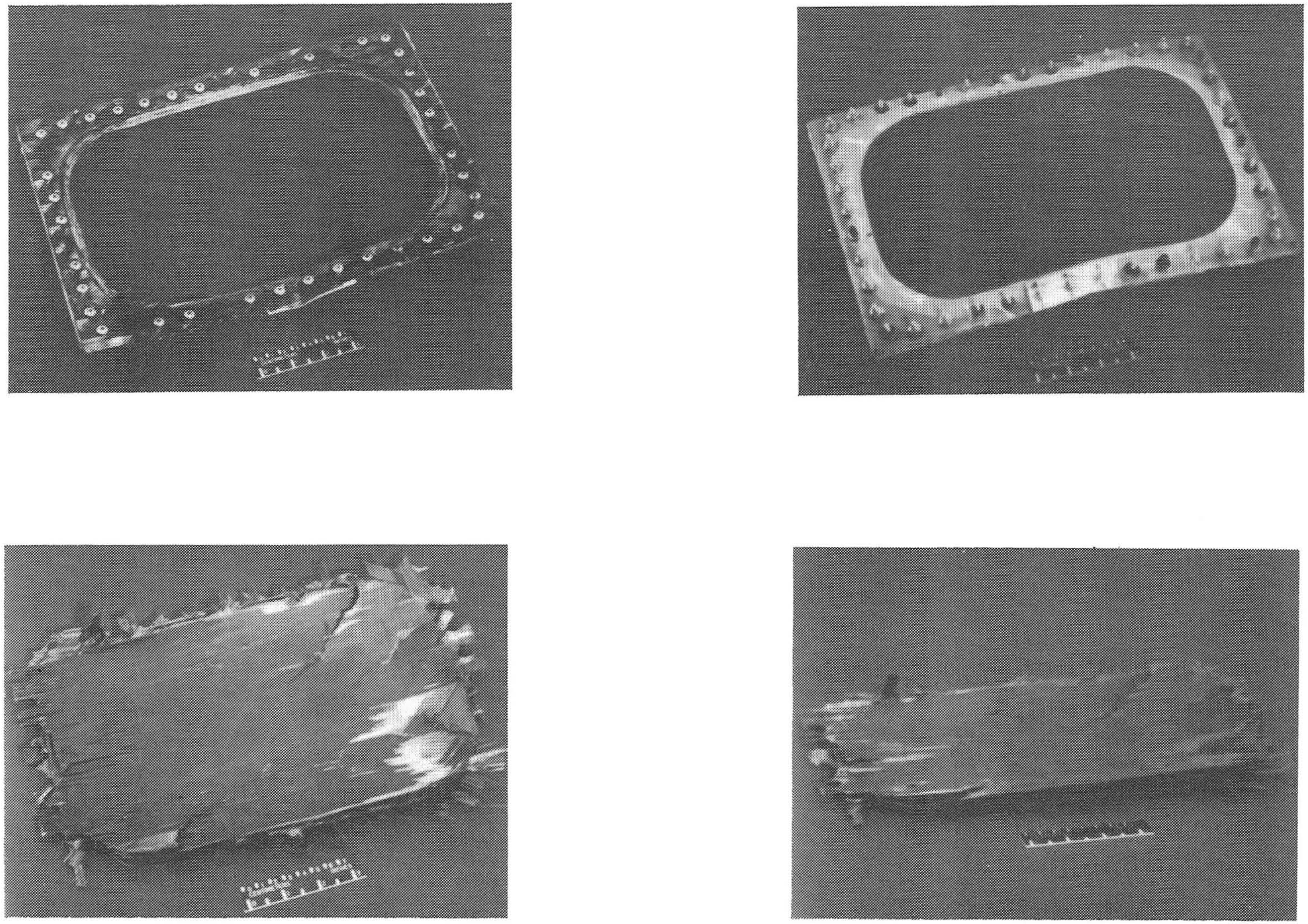

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Figure 8.- Embedded explosive severance of 0.084- by 10- by 14-inch 16-ply T300/5208 graphite/epoxy panel (posttest). $[0/+45/90/-45/0/+45/90/-45]_s$.

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15. Supplementary Notes

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16. Abstract

Explosively actuated openings in composite panels are proposed to enhance passenger survivability within commercial aircraft by providing improvements in emergency openings, fuselage venting, and fuel dump. The concept is to embed a tiny, highly stable explosive cord in the periphery of a load-carrying composite panel; on initiation of the cord, the panel is fractured to create a well-defined opening. The panel would be installed in the sides of the fuselage for passenger egress, in the top of the fuselage for smoke venting, and in the bottoms of the fuel cells for fuel dump. Described are the concerns with the use of explosive systems, safety improvements, advantages, experimental results, and recommended approach to gain acceptance and develop this concept.

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