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Crash Impact and Escape Study

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Prepared for
Air Force Systems Command, Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio 45433

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13. ABSTRACT

Advanced crash impact and emergency egress concepts, equipment, and techniques which have application to crew and passenger life support and crash safety in Air Force high-wing and low-wing air transport aircraft have been evaluated. An analysis of Air Force C-135 and C-141 aircraft accidents was made. Seventy-four state-of-the-art concepts and systems have been analyzed from a systems engineering viewpoint. A comprehensive evaluation of the airbag inflatable restraint system and smoke-hood concepts was conducted, with additional investigation of developments relating to aisle and evacuation path markers and illumination; passenger warning and public address systems; passive restraint systems; egress including slides, slide/rafts, and telescape systems exit area ablative coatings; emergency inflight egress concepts, and high-energy emergency egress systems. It was concluded that use of present rear-facing seat systems in Air Force transport aircraft offers more reliable impact protection than does the current state of the art of airbag inflatable restraint systems. The use of the Schjeldahl smoke hood with septal neck seal was found to offer the best current protection against smoke, toxic fumes, and fire, reported to be the major cause of military air transport fatalities in survivable accidents. High energy emergency egress systems were considered to represent the most promising advance for improving emergency egress.

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FOREWORD

The work presented in this report was conducted under Contract F33657-71-C-1078 from the Life Support System Program Office-Aeronautical Systems Division/Air Force Systems Command/Wright-Patterson Air Force Base, Ohio. This program was initiated on 28 June, 1971 for a 5 1/2 month term by the Biosciences Division, Highway Safety Research Institute, Institute of Science and Technology, The University of Michigan, Ann Arbor, Michigan.

Major authors and investigators were Professor Richard G. Snyder, Head, Biomedical Department, and Dr. D. Hurley Robbins, Research Engineer, Biomechanics Department, Bioscience Division. Expert technical assistance was provided by Ernest B. McFadden, Chief, Survival Equipment Research, Protection and Survival Laboratories, Civil Aeromedical Institute, Federal Aviation Administration, Department of Transportation, Oklahoma City, particularly with regard to the smoke-hood concept and emergency lighting sources.

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This technical report has been reviewed and is approved.

Albert P. Lovelady, Colonel, USAF
Systems Program Director
Life Support System Program Office
Deputy for Subsystems

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INTRODUCTION

STUDY OBJECTIVE

The objective of this study was to investigate new crash impact, escape and survival equipment, and techniques which have application to crew and passenger life support crash safety in Air Force transport aircraft, with particular attention to two types of current aircraft: the C-141 (typical high-wing type aircraft) and the C-135 (typical low-wing type aircraft). Consideration was given to current and advanced state-of-the-art developments including, but not limited to, the following concepts:

a. Inflatable airbag passive restraint systems.
b. Schjeldahl smoke hood and other protective mask devices.
c. Aisle and evacuation markers.
d. Passenger warning and public address systems.
e. Other available or currently anticipated system developments and technology which could enhance crash impact, escape, and survival in USAF aircraft.

BACKGROUND

During the past few years there has been an increased emphasis on studies relating to crash impact protection, emergency egress, and survival, resulting in developments which have greatly advanced the state of the art. Some of these advances have resulted in spin-offs from aerospace technology, others have been spurred by identification of specific deficiencies through analysis of current accident experience, and many have resulted from efforts of the Department of Transportation to improve occupant protection in ground vehicle accidents. However, no single document has previously attempted to bring together and evaluate systematically those developments in the state of the art which might have especial application to crew and passenger crash safety in Air Force transport aircraft.

Major research and development of passive restraint systems have been conducted within the past three years, due to efforts to design and manufacture automotive vehicles which must comply to proposed Federal Standards requiring the inclusion of such devices by 15 August, 1974, for 1975 vehicles. "Passive" restraint applies to any system which does not require occupant action for initiation. The most common of these devices are inflatable ("air bag") restraint systems. Examples of other methods of achieving this objective include deployable net restraint, "blanket," and head restraints. The requirement for a passive system has resulted from findings that too few automotive occupants wear present protective restraint systems and is based on a decision that a more automatic system is necessary to solve this problem. Although developed for automotive impact, which involves quite different crash profiles in respect to magnitude, vector directions, and time duration, than in typical aircraft accidents, there has been interest in application to aircraft. Early tests of a pre-inflated airbag device in the FAA crash test of a DC-7 transport in 1964, and in a series of ten decelerations at impact velocities up to 87 mph in 1965 indicated considerable protective capabilities, but it was also evident that a cabin full of airbags post-impact could create major evacuation problems. Since then such systems have been greatly refined, and a new analysis at this time seems justified.

Space technology has also resulted in many concepts and techniques which might have application to increased air transport crash safety and passenger life support. An example of potential application of space technology to air transport crash-fire protection is illustrated by the Apollo spacecraft development of fire-retardant materials such as polyisocyanurate foam and an intumescent paint which acts on ablative principles to provide additional thermal protection. The concept of providing a means of emergency in-flight egress in air transport aircraft has had very little attention, although several systems have been proposed, including one which would modify present operational techniques of aerial cargo delivery for human passenger and crew usage. In a technology which has expended considerable effort in devising methods of astronaut space rescue, it would seem to be within the state of the art to similarly seriously consider in-flight egress of air transport passengers in the event of presently non-survivable in-flight catastrophic structural failures.

A basis for evaluating the particular areas where increased protection is necessary in air transport crashes can best be determined by analysis of previous accident experience. Unfortunately, these areas often receive little attention until a major air disaster emphasizes the problem and spurs research for a solution. An example is the serious deficiency of emergency warning and communication systems which was evident in the ditching of a DC-9 jet transport near St. Croix, Virgin Islands. In this ditching the main communication system failed and no warning (after a 10-minute warning) was given to either passengers or some crew, resulting in numerous injuries due to unrestrained passengers standing in the aisles still donning life jackets at the time of impact.

An analysis of civil air-transport accidents from 1957 through 1967 resulted in the estimate that 35 to 50 percent of the 794 non-survivors of survivable air carrier crashes could have been saved had adequate egress been available (Caldera, 1970). Some three-fourths of the exits available were not used, due to jamming from fuselage distortion, blockage, fire, or other reasons. Analysis of C-135 and C-141 accident experience has also shown that fatalities have occurred due to inadequate exits, as detailed in Section II of the current report. Similarly, studies of air transport evacuations during major crashes have shown that the primary cause for fatalities has been attributed to inhalation of smoke, toxic fumes, and fire. At present no protection at all is given crew or passengers under fire and smoke egress conditions.

In 1969 the Combat Egress Working Group (Reagin, et al., 1970) investigated passenger cargo aircraft in the USAF inventory to identify equipment and procedural deficiencies. This represents the most current analysis of crew and passenger crash safety, and provides many specific recommendations for areas where improvements are necessary. Earlier Air Force studies by Brown (1969) and Sawyer (1967) had also pointed out many deficiencies based upon accident experience.

In 1967 an overall assessment of the state of the art of crash safety and crew and passenger life support for air transport aircraft was independently conducted by three groups. The USAF-Industry Life Support Conference (1967) at Las Vegas considered a number of recommendations to responsible agencies for the immediate and long-range solution of many of the most pressing problems and requirements in the life support system. Within the industry, a Joint Crashworthiness Development Program was conducted by the Aerospace Industries Association of America, Inc. (1968). This one-year study resulted in an industry evaluation of the state of the art at that time of interior materials, fire suppression, smoke and fume protection, emergency lighting and exit awareness, and evacuation systems. Also in 1967 (Roebuck, 1968) North American Rockwell Corporation conducted an analysis of new concepts for emergency evacuation of air transport aircraft for the Aircraft Development Service of the Federal Aviation Administration.

SCOPE OF THIS REPORT

The following report attempts to evaluate the state of the art of crew and passenger and crash safety life support systems. To our knowledge this work represents the first major effort in this direction in approximately five years.

The work is presented in five parts. The first of these consists of an analysis of the magnitude of the crash safety and escape problem based on available accident data (Section II). Both military and civil experience is included. The second consists of a brief discussion of observations made during visits to operational C-141 and C-135 aircraft (Section III). The third aspect of the work which is presented is a detailed state-of-the-art explanation of passive restraint systems (Section IV), smoke protective devices (Section V), aisle and path markers (Section VI), emergency warning and public address systems (Section VII), and other technology (Section VIII). The fourth part (Section IX), a systems analysis of the impact protection and escape problem, is related to the subject systems. The report ends with conclusions and recommendations (Section X).

A complete systems approach was required to accomplish this project, with consideration given to the effects on both the aircraft and crew memebers in accordance with MIL-STD-1472A. A preliminary analysis in accordance with MIL-STD-785A was conducted on all concepts included in the study to determine which systems indicate the highest reliability. System components must be designed for minimum routine maintenance and servicing by technicians assigned to the using unit and field maintenance activities, and for major repairs by depot level maintenance, in accordance with MIL-STD-470. In addition, a preliminary Hazard Analysis prepared in accordance with MIL-STD-882 to evaluate system safety is included. In this respect overall systems analysis has been initiated with emphasis on the event-oriented nature of the problem of survival and escape from a crashed aircraft. A time-scaled flow chart of the crash and escape event has been developed to form a framework for the performance evaluation of each concept studied. This is supplemented by a detailed discussion of factors included in the analysis of system safety, reliability, maintainability, human engineering aspects, and technological feasibility.

Major emphasis has been placed on evaluation of inflatable (passive) restraint systems and smoke-hood devices. We believe that this study represents the most comprehensive analysis of inflatable (passive) restraint systems and smoke mask/hood devices which has been made to date, and represents the only known systems analysis of the airbag restraint system. Work was also conducted within the time and funding limitations of this contract on aisle and evacuation path markers and emergency illumination systems, passenger warning and public address systems, and a number of other devices and concepts relating to emergency egress, including slide and slide/raft devices, ablative coating, telescape, emergency in-flight egress, and high-energy egress systems.

SECTION II

AIR TRANSPORT ACCIDENT EXPERIENCE

MILITARY C-135 AND C-141 ACCIDENT BACKGROUND

The state of the art of protection and survival technology is constantly changing as new materials, techniques, innovations, and requirements are developed. Nevertheless, the most valid basis for both determining future requirements and projecting most effective concepts in crash impact and emergency egress are largely dependent upon past and current field performance. Accident investigation often results in finding egress problems, human factors considerations, and pointing out potential areas of future concern. Emergency equipment and escape device performance under actual crash-fire conditions involving aircraft occupants in panic may differ considerably from predictions developed in non-stress laboratory environments. Similarly, concepts which appear feasible in theory may not be in fact.

Current air transport crash impact and egress problems, as typified by the high-wing Lockheed C-141 and the low wing Boeing C-135, were determined from reports of field investigation of accidents. In addition to review of these military air transport accidents, human factors reports of comparable types of civil air transports provided additional valuable background to more validly determine future needs, and thus more realistically assess concepts. A summary of these findings follows, and will be referred to in subsequent portions of this study as particularly appropriate to restraint, aisle or emergency exit, smoke, or other impact and egress considerations.

Air Force air transport accident experience for the C-135 and C-141 aircraft was studied at the Directorate of Aerospace Safety, Norton Air Force Base. Accidents were identified by three computer runs, made on 3 August, 31 August, and 8 November, 1971 by the Life Sciences Division. Readouts allowed selection of individual reports for intensive review which were survivable and could contribute impact or egress information.

A total of 14 C-141 accidents have been reported to 8 November 1971, and these are summarized in Table 1. Only two of these accidents, however, appeared to involve an actual emergency egress situation, and one of these, which crashed into the sea on takeoff and was destroyed, provided little useful information. This case is summarized in a subsequent section on ditchings.

TABLE 1. SUMMARY OF USAF C-141 ACCIDENTS (JAN. 1966-NOV. 1971)

Day/Night	Total Occupants	Survivability	Injuries			Circumstances and Egress Comments
			Pilot	Crew	Passengers	
Day	7	No crash	2 none	5 none		ldg and go-around damage.
Day	7	No crash	2 none	5 none		minor damage.
Day	7	No crash	2 none	5 none		inflight explosive decompression.
Day	7	No crash	2 none	5 none		inflight hail damage.
Day	5	No crash	2 none	1 major 2 none		inflight evasion to avoid midair collision--engineer unrestrained.
Day	68	No crash	2 none	11 none	1 major 1 minor 53 none	air evacuation. inflight turbulence. 2 nurses unrestrained.
Dusk	32	No crash	2 none	5 none	1 fatal	Nigh drop, paratrooper fatality.
Day	8	No crash	2 none	6 none		inflight hail damage.
Night	9	Non-survivable (?)	1 fatal	6 fatal		T.O. crash in sea, two survivors.
Night	5	Non-survivable	2 fatal	3 fatal		aircraft destroyed in runway collision.
Day	8	No crash	2 none	6 none		precautionary ldg.
Night	8	No crash	2 none	1 major 5 none		inflight explosive decompression.
Day	7	No crash	3 none	4 none		inflight explosive decompression.
Day	29	Survivable	2 none	9 none	18 none	inflight rapid decompression and hydraulic failure, loss of communication system; use of aft and crew entrance exits; hand fire extinguisher on flight deck.

The second case, occurring in 1971, involved a C-141 with a crew of 11 and 18 passengers, two of whom were rated pilots. This aircraft experienced a rapid decompression at FL 330, cabin altitude 5000 feet, with subsequent hydraulic system failure. The aircraft commander experienced difficulty in donning his oxygen mask because of a previously broken plastic C-shaped support strap, and was forced to hold his mask to his face by hand. The interphone became inoperative during the rapid decompression, resulting in difficulty in communicating with crew and passengers. The copilot successfully donned his mask and took control of the aircraft. Three passengers who had become slightly hypoxic due to mask malfunction or improper placement were assisted by a load master, equipped with a walk-around bottle, who alternated his mask with them. Passengers were reported "in state of shock" and overreacted to the emergency in improperly donning oxygen masks.

An emergency landing was initiated and it was found that the decompression event had caused damage to the lower nose section, preventing nose gear lowering. Loose items were secured. A smooth landing was made on the main gear, with the nose gear retracted and subsequent nose-down attitude. Personnel in the cargo compartment exited through the aft troop doors. Those on the flight deck evacuated through the crew entrance door because when the copilot opened the flight-deck overhead escape hatch he noticed fire. The instructor flight engineer used a fire extinguisher briefly before evacuating through the crew entrance door. It was subsequently determined that all of the passengers' MA-1 oxygen masks were unserviceable.

A total of 30 C-135 accidents occurring to date, involving 194 crew members and 214 passengers, were reviewed. Of these, 15 accidents involved no injury to crew or passengers, 11 accidents were non-survivable and fatal to all occupants, 1 accident could probably be classed as non-survivable (fatal to 81 of 83 occupants), and 3 accidents involved minor to major injuries. Table 2 outlines these accidents. Nine C-135 accidents provided crash evacuation performance information of particular pertinence to this study and are summarized as follows.

Case No. 1. KC-135A making 3-engine approach crashed short of runway with 56 crew and passengers aboard. The aircraft was destroyed by post-impact fire. All 11 passenger fatalities were attributed to asphyxiation from smoke inhalation secondary to hypoxia and inhalation of smoke due to their inability to locate or egress through emergency escape exits in the confusion resulting from fire, smoke, and inadequate warning of the emergency landing. Thirty-two passengers received no injury, 3 minor injury, 6 major injury, 1 crew member received major injury, 1 none, and the two pilots minor injuries.

TABLE 2. SUMMARY OF USAF C-135 ACCIDENTS JAN. 1964 - NOV. 1971

Configuration	Night/Day	Total Occupants	Survivability	Injuries Pilot	Injuries Crew	Passengers	Circumstances and Egress Comments
KC-135A	Day	5	Non-survivable	3 fatal	2 fatal		Crash into ground, catastrophic destruction. IFR approach. Material failure.
KC-135A	Night	8	Survivable	3 none	4 none		Overran F4C on night T.O. Emergency exits used by crew. Rope used on left pilot side but unable to use on right side. Alarm bell used.
KC-135Q	Night	5	Survivable	3 none	2 none		Normal ldg and wing damage. No emergency egress.
RC-135S	Night	18	Survivable	2 none	16 none		Ran off icy runway on ldg. Alarm bell used. Pilot & Copilot windows jammed. Change pilot inertia reel locked to rt. side.
KC-135A	Night	6	Survivable	2 none	4 none		Aborted T.O. ran off runway. Normal Exit. No crew briefing. Alarm bell used Only 5 sets survival gear for 6 crew; helmets worn.
KC-135A	Day	6	Survivable	3 none	3 none		Minor accident. 3 engine ldg. Normal exit
KC-135A	Day	4	Survivable	1 none	1 none	2 none	Ldg. go-around. Normal exit.
WC-135B	Day	9	Survivable	2 none	7 none		Ldg. roll off runway. Emergency exits used. Evacuation in 45 secs.
KC-135A	Night	7	Survivable	2 none	2 none	3 none	Blew tires on T.O. Gear collapse on ldg. Alarm bell used. Crew evacuation through crew entry chute using escape rope.
	Night	6	Non-survivable	2 fatal	4 fatal		WX approach into mt. Total destruction.
	Day	4	Non-survivable	2 fatal	2 fatal		Crash on T.O. Total destruction. None of crew wearing restraints fastened nor helmets.
KC-135A	Day	56	Survivable	2 minor	1 major 1 none	11 fatal 6 major 3 minor 32 none	Ldg. short of runway. Aircraft destroyed. Emergency evacuation in 45 secs. All fatalities due to smoke inhalation; poor emergency lighting; 5 crew injuries due to improper lock on shoulder restraint.

Table 2 con't.

Configuration	Night/Day	Total Occupants	Survivability	Pilot	Injuries Crew	Passengers	Circumstances and Egress Comments
	Day	9	Non-survivable	3 fatal	6 fatal		Inflight accident. Total destruction.
	Day	4	Survivable	1 none	3 none		Air refueling damage in flight.
KC-135A	Day	5	Survivable	3 none	2 none		T.O. crash. Emergency evacuation. Rope used tangled.
	Day	4	Survivable	2 none	2 none		Hail damage inflight.
	Day	6	Survivable	2 none	4 none		Hail damage inflight.
	Day	4	Survivable	2 none	2 none		F4 boom collision inflight.
	Day	13	Non- survivable	8 fatal	5 fatal		T.O. crash, Total destruction.
	Day	3	Survivable	1 none	2 none		Air refuel damage inflight.
KC-135A	Dusk	14	Survivable	2 none	5 none	7 none	T.O. abort. Alarm bell used. Unable to use rear exit.
KC-135R	Day	5	Survivable	3 major	1 fatal 1 major		T.O. crash fire. Aircraft destroyed. Fatality due to not wearing seat belt or helmet.
	Night	9	Non- survivable	4 fatal	5 fatal		IFR ldg. approach. hit mt. aircraft destroyed.
	Day	7	Non- survivable	2 fatal	5 fatal		T.O. crash. Aircraft destroyed.
	Night	5	Non- survivable	2 fatal	1 fatal	1 fatal	Ldg. crash/fire aircraft destroyed.
	Night	84	Non- survivable	3 fatal	8 fatal	73 fatal	1 FR T.O. crash. Aircraft destroyed.
	Night	5	Non- survivable	2 fatal	3 fatal		1 FR ldg. crash. Aircraft destroyed.
	Day	4	Non- survivable	2 fatal	2 fatal		T.O. dutch roll. Aircraft destroyed.
	Night	8	Survivable	3 none	4 none	1 none	Ldg. short of runway.
KC-135B	Night	83	Non- survivable(?)	3 major	3 fatal 2 major	75 fatal	1 FR ldg. Crashed short of runway coming to rest inverted in 3 sections Destroyed in fire and explosions. Copilot's window jammed. Difficulty in locating crash axe.

Passengers were not briefed and the pilot didn't even know how many passengers were aboard. There was no announcement to passengers to prepare for landing. The crash was unexpected by the pilots, and no alarm bell was used prior to crash. Life Preserver Units (LPU) were not worn by the pilot and some crew members, and only 31 life preservers were worn during the egress. Had the crash occurred in ocean, some 1000' from the runway, egress from this aircraft could have resulted in more lives lost. Fire broke out in the aft section and the cargo compartment and flight deck filled with black smoke and apparently ammonia gas, causing panic among some passengers. Surviving passengers escaped through the crew entry door, emergency hatch over the right wing, and emergency hatch over the left wing. It was found that the KC-135 aircraft is not properly configured to perform passenger service with safe emergency egress and emergency escape is impossible under conditions of no emergency lighting, inadequate emergency exits for the number of passengers carried, and lack of briefing. (As a result it was recommended to: limit the number of passengers on KC-135 aircraft to that number that can safely egress under simulated emergency conditions in one minute, using only the three escape hatches in the passenger compartment; modify the loud-speaker system to insure positive communication between crew and passengers; consider additional emergency exits or enlargement of existing escape hatches; and consider installing impact-actuated emergency lighting system for emergency exits.) This accident also illustrates the urgent need for improved emergency egress systems such as might be provided by the ELSIE (Emergency Life Saving Instant Exits) concept, described in Section VIII, pages 146-151. Had such a means of ensuring that the present C-135 exits were immediately open and available in this case, it is probable that far fewer fatalities would have resulted. Serious consideration should be given to installation for an ELSIE type system at all existing emergency exits in C-141 and C-135 aircraft. Further, the ELSIE system should be installed at additional locations to provide larger and more optimal passenger egress. For the C-135 configuration in this accident, recommended locations for additional ELSIE exits have been indicated on Figure 1.

The pilot, copilot, and boom operator received compression vertebral fractures in the impact due to either not having the shoulder harness on or not locking it prior to landing impact. The navigator noted all the equipment in the compartment above his station came down on his head on impact. Egress problems were noted on the flight deck, with both the pilot and copilot getting stuck in their respective window exits, blocking exit for other crew, and not having time to locate or use the escape rope. Evacuation was completed in 45 seconds. The location of exits and fatalities is shown in Figure 1. Note the pile-up of four

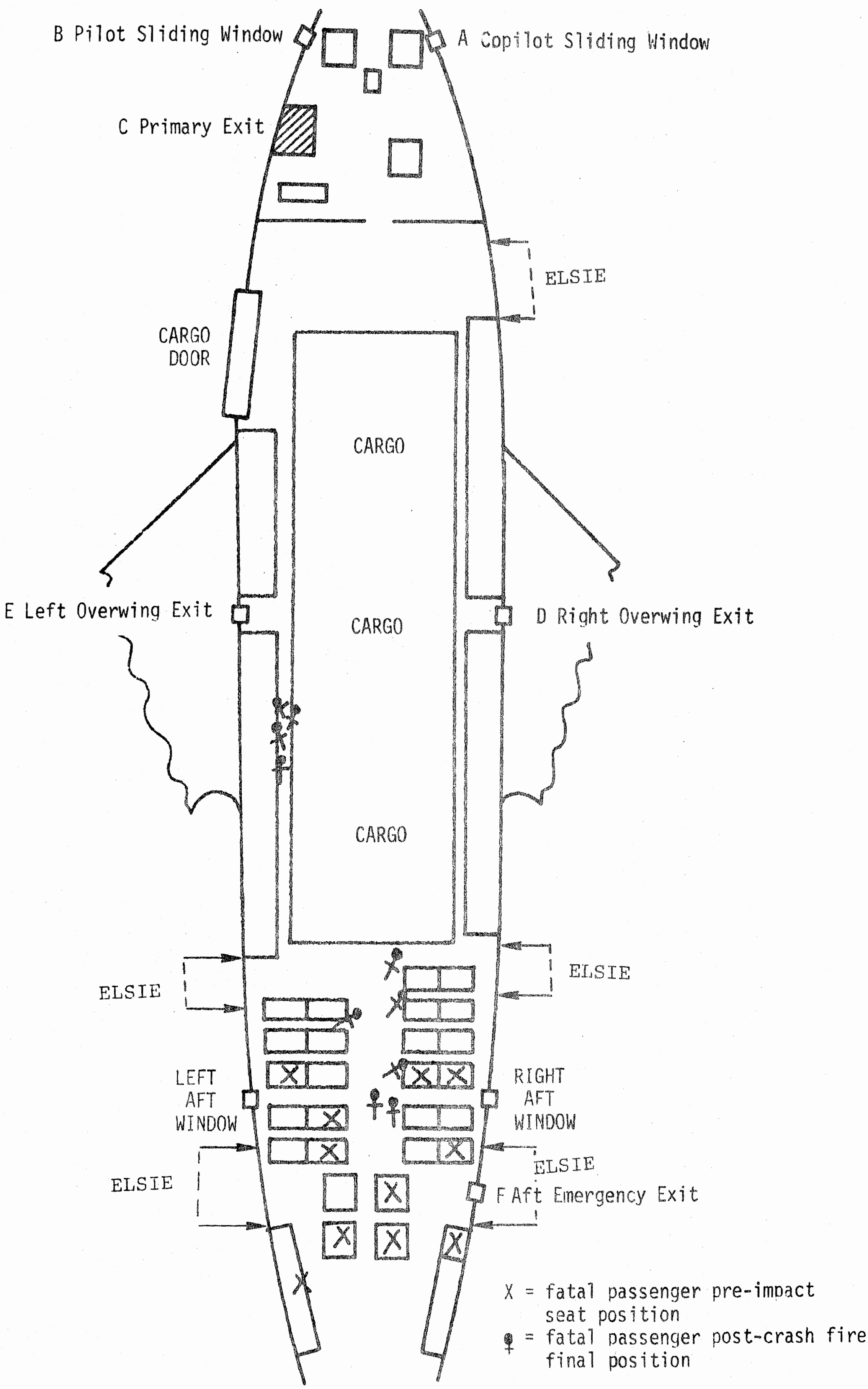


Figure 1. Location of Emergency Egress Exits and Fatalities in KC-135 Crash. Installation of ELSIE Systems at All Present Exits and in Additional Locations Indicated is Recommended.

fatalities which occurred aft of the left overwing exit due to aisle blockage from small cargo, and the apparent inability of those passengers in the aft compartment to egress through the right or left aft escape windows, even though one individual was identified as sitting in the aisle seat adjoin the left aft window. In this configuration, 26 individuals used airline type seats, but six passengers sitting over the boom pad area would have had great difficulty in assuming the recommended ditching and crash landing position as found in TO1C-135KA-1, pages 3-52, even if they had been prewarned of the crash. Survivors reported that they had a great problem in attempting to evacuate through the available emergency exits from any seated position.

Case No. 2. Aircraft ran off runway, aborting takeoff. No fire or smoke. Low impact and all crew used restraints. However, crew had HGV-2A/P helmets but none worn; there were only five sets of survival gear, including life jackets, for six crew-members. There was no preflight crew briefing given. The boom operator was unable to use the rear escape hatch due to aircraft altitude, and exited through left overwing escape hatch. The alarm bell was activated prior to going off runway. Need of impact activated lights reiterated by investigators.

Case No. 3. Emergency abort crash landing on runway on takeoff. Fire in left wing area extinguished and all crew evacuated without injury. However, the pilot experienced difficulty with the emergency rope which became entangled around his right foot, and was released by the I.P. (Instructor Pilot). Difficulty in identifying and reaching pilot's emergency rope storage compartments was reported, and it was recommended that crew wear gloves to prevent rope burns, and that an additional emergency escape rope be installed at the crew entry chute. No alarm bell was used.

Case No. 4. Emergency abort on takeoff, stopped aircraft off runway with brake assembly fire. Alarm bell used and instructor pilot (IP) on interphone instructed crew to evacuate as soon as stopped, but passengers had no interphone communication. Passengers opened rear exit hatch but closed it due to smoke and flame, and ran forward to left wing exit hatch, noting jam of people up at front entrance exit ladder.

Case No. 5. After takeoff, aircraft lost altitude, crashed, burned and was destroyed with major injuries to four crew members, a fatal head injury was received by a Navigator riding in the boom operator's seat who was not wearing a seat belt. Evacuation was accomplished in less than one minute using left and right cockpit windows. Distance was 5-6 feet above ground level and escape ropes were not used. The I.P. got stuck in the right cockpit window. Although none of the crew were wearing helmets or parachutes, the flight medical officer noted that parachutes should not be worn on takeoff or landing because of interference with emergency escape.

Case No. 6. Aircraft hydroplaned on icy runway and went off runway on landing roll. The pilot activated the alarm bell prior to stopping, and no fire occurred. Both the pilot's and copilot's windows jammed and could not be used. The pilot escaped through the aft emergency escape hatch, using the escape rope. The copilot and navigator evacuated through the crew entry door. Eleven other crew members were facing aft and four were facing forward. Of these, nine egressed through the aft emergency door, five through the crew emergency door, and one went out the wing emergency exit. The pilot's shoulder harness inertial reel failed to lock, and because his left hand was busy with nose wheel steering during the landing roll, it was recommended that the pilot's inertial reel lock switch be changed from the left to right side so it can be more easily locked in emergency situations.

Case No. 7. On night formation takeoff, the KC-135 aircraft overran an F-4 on the runway ahead, impacting at 80 knots, and swerving to right off runway on fire. There was no briefing whatever of the crew prior to takeoff; the tower supervisor had overslept and was not on duty. The alarm system was activated after impact. Three crew chiefs and a boom operator exited through the overwing escape hatch, with the latter receiving knee and scalp injuries in exiting. The remaining four crew members evacuated through the cockpit side windows. Although the escape rope was used on the pilot's side, the I.P. was unsuccessful in getting it out the copilot's window.

Case No. 8. During instrument flight rules (IRF) approach in rain storm, impacted short of runway. The airframe came to rest inverted in three main sections and was destroyed in the subsequent fire and explosion. There were 78 fatalities; the three pilots and two of the three flight-deck crew receiving major injuries. Heat from fire and smoke inhalation resulted in 95% of the fatalities, and it was estimated by the flight medical officer that in the absence of fire, 70 of the 78 fatalities would have survived. All of the surviving crew received major injuries from acute chemical smoke inhalation. Due to the inverted position of the aircraft, the surviving navigator was unable to find an escape exit, and exited from an emergency exit cut aft of the copilot's seat by the rescue crew. Three pilots and one engineer escaped from the copilot's side window, although it had jammed and had to be broken out with a crash axe. The crew experienced considerable difficulty in locating the flight-deck crash axe, and it was recommended that it be relocated near windows and a canopy shattering tool be installed. Except for a single tier of three seats thrown clear when the fuselage broke up, all seats remained intact in the impact. No alarm was given, and the report did not state whether any briefing was given to passengers by the crew.

Case No. 9. A WC135B encountered control problems on takeoff and crashed on right side of runway. The nine crew members evacuated within 45 seconds and were uninjured. A small nose-section fire was extinguished. The pilot used the pilot's escape window without using a rope as the nose was on the ground, and the copilot and flight engineer went out the copilot's window. The navigator exited over left wing from aft compartment. The navigator received strain due to the side-facing position of his seat. It was recommended that T01C-135A-1, Figures 3-11, p. 3-46, be changed to show the navigator seated facing aft in any emergency landing.

CIVIL AIR TRANSPORT EMERGENCY EGRESS

Civil air transport accident experience has been more extensive than military to date, and emergency egress situations more numerous. Many crash impacts and subsequent emergency evacuations provide information valuable for consideration of the military configuration as well. In this regard, reports of all jet air transport accidents have been obtained from the National Transportation Safety Board, as well as preliminary accident reports for 1970 and 1971. This material has been supplemented by several studies of evacuation experience by the Air Force (Sawyer, 1967; Brown, 1969; Chesterfield, 1969; Reagin, et al., 1970; C-5A Report, 1970[1]), and by FAA investigators (Mohler, et al., 1965; Hasbrook, 1962; Garner and Blethrow, 1966, 1970), and especially from the recent classic study of three major crash evacuations by Snow, et al. (1970). These data are still being analyzed and will be included in a subsequent report. To 1968, some 47 civil accidents (including non-jet air transports) had been identified as having involved emergency evacuation systems. However, the 114 fatalities resulted from only five accidents and 105 of these 114 fatalities occurred in just three accidents studied by Snow: a United Airlines DC-8 crash in Denver in 1961, a United Airlines Boeing 727 crash at Salt Lake City in 1965, and a TWA Boeing 707-331 crash at Rome in 1964.

More recently, on 27 November 1970, a Capitol International Airways, Military Air Command (MAC) charter McDonnell-Douglas DC-8-63F aircraft crashed during an attempted take-off in freezing rain at Anchorage, Alaska (Leroy, 1971). Fire occurred before the aircraft came to rest, followed by several explosions. Forty-five passengers and one cabin attendant did not survive because they failed to evacuate the aircraft--a 46th passenger died the following day. One hundred seventy-three passengers and nine crew members survived this accident.

[1]C-5A Emergency Ground and Ditching Egress Test Report. 1970 (Unpublished).

This aircraft is normally configured to carry 250 passengers with 45 rows of seats and a 46th row single seat on the right side. However, when used for military charter, the configuration is changed to 219 passengers to allow more space between rows. There were 219 passengers and a crew of ten aboard, for a total of 229 occupants. Passengers included six dependents; two women, three young females, and a two-week old infant.

The crash occurred without prior warning. While the aircraft was still moving the left overwing exit was opened and fire came into the cabin. Upon a second impact, major structural damage occurred. At this time, with fire evident on the right side, a number of the military passengers unfastened their lap belts and reportedly attempted to get away from the fire area, but were caught by the third impact, which threw them forward and injured several. Some seats failed, others found themselves outside the aircraft, still strapped in their burning seats.

Five of the twelve cabin exits were not utilized because they were either jammed, blocked, or not opened. Of the two main left entry doors, one was jammed and inoperative. There were two galley service doors; one was blocked and inoperative and the other partially blocked. The two forward exits, of the four net escape exits, operated effectively, but the two aft exits were not opened. Three of the four over-wing exits were opened. The cockpit-cabin door was blocked by four feet of debris. One of the left-hand forward escape slides ended in a pool of fire.

There was a failure of the emergency exit lights, which might have contributed to some failures to evacuate. Since survivors had been seated in all parts of the aircraft, it has been termed a survivable accident. All deaths were attributed to fire and smoke inhalation, although cyanide was also found in the smoke. Eighteen of 19 blood samples taken at random from survivors exhibited carbon monoxide saturations of from 17.3% to 68.6%. An interesting finding, similar to that found in the Salt Lake City 727 crash, was mechanical obstruction of the trachea, bronchi, and bronchiolles by a black carbonaceous material evidently produced in the cabin fire. Human factors study of this crash is not yet complete; however, the pattern of fatalities due to fire and smoke inhalation is similar to that of previous major survivable accidents and emphasizes the need for an emergency protective smoke hood and adequate emergency exit lighting, and suggests the need for improved egress exits such as might be provided by an ELSIE system.

Within the past few months, several airline non-crash evacuations have occurred. In January, a Delta Douglas DC-9 ran off the runway on landing at Jackson, Mississippi, coming to a stop with both main gears mired in mud and the nose gear collapsed. Five crew members and 22 passengers evacuated without injury. In May, a Piedmont Boeing 737 with five crew and 59 passengers aboard, was evacuated when a fire warning light occurred on engine start. The emergency chutes were employed and passengers evacuated without injury.

The possibility of emergency evacuation occurring which is not initiated by flight crew, nor even with flight crew aware that an evacuation is in progress, should be considered in military aircraft on the basis of two such recent occurrences. In April, a TWA Boeing 727 had landed at O'Hare International Airport, but because a gate was not yet ready, had to hold on the ramp. The flight engineer attempted to start the auxillary power unit, but unbeknownst to the crew, flame from the APU start was observed on the right side of the aircraft by some passengers and a TWA supervisory stewardess riding as a non-revenue passenger. As a result, an emergency evacuation was initiated through the two left window exits and subsequently through the rear stairs. The three scheduled stewardesses were not aware that an evacuation was in progress until they saw passengers leaving by these exits. The flight deck crew was completely unaware that an evacuation was in progress (opening overwing exits does not activate any cockpit warning lights). They were about to continue taxiing when the forward stewardess knocked on the cockpit door, and concurrently a warning light went on as the rear door was opened. The flight deck crew then shut down and advised passengers to exit through the rear stairs. No emergency evacuation alarm was sounded. Four serious and seven minor passenger injuries occurred in jumping from the left wing landing edge nine feet to the concrete ramp.

The second case occurred on 15 May involving a United Airlines DC-8, with 45 passengers and seven crew aboard. Prior to boarding at San Francisco, the crew had been alerted to a bomb threat. As the first engine was being started, a pneumatic air hose broke loose and began to flail about, knocking down the ramp crewman and disconnecting his interphone. The explosive noise of the hose parting and subsequent unidentified noise of the flailing against the aircraft caused the nervous stewardess to commence evacuation. Overwing exits, rear exit slide, and an aft exit slide were employed, and the aircraft was evacuated in 40 seconds. Six passengers received serious injuries when they jumped to the ramp from the wings.

The subsequent evacuation of a Boeing 747 at San Francisco has also pointed up problems with emergency evacuation equipment and shown that a new generation of escape devices will require new techniques. Some of these problems pertinent to Air Force aircraft will be included subsequently in this report, together with further analysis of civil air transport evacuation experience.

JET TRANSPORT DITCHINGS

Jet air transport ditchings are rare, with only one intentional civil instance, involving a DC-9, reported to date. One C-141 crash into the sea during takeoff has also occurred, as well as one civil (DC-8) crash ditching during an attempted landing however, there was no intent to ditch in either of these cases. Because of the rarity of this crash impact and egress experience pertinent human factors findings in these cases are summarized as follows.

(1) A Scandinavian Airlines Systems McDonnell-Douglas DC-8-62 crashed on 13 January 1969 in Santa Monica Bay approximately six miles off Los Angeles International Airport. This aircraft was attempting an instrument approach to Runway 07R which resulted in "an unplanned descent into the water" (National Transportation Safety Board, 1970a). The aircraft was destroyed by impact, with the fuselage breaking into three pieces, two of which sank in 350 feet of water. The third section, including the wings, the forward cabin, and the cockpit, floated for about 20 hours before being towed into shallow water where it sank (and was later recovered). Of the 45 persons aboard the aircraft 3 passengers and 1 cabin attendent drowned; 9 passengers and 2 cabin attendents are missing and presumed dead; 11 passengers and 6 crew members (including the captain, the second pilot, and the systems operator) were injured in varying degrees; and 13 passengers escaped without reported injury. There was no fire. The flight recorder was recovered and indicated water impact had occurred at 155 knots airspeed and +1.5 G vertical acceleration at the C.G., taildown.

The six crewmember survivors were located in the forward portion of the aircraft, with 18 passenger survivors from the forward tourist cabin that remained afloat, and 6 passenger survivors from the aft cabin section. The cockpit filled with water to one-third depth. Passenger survivors reported only one impact which they described as a very hard landing. The impact was followed by rapid deceleration. Quantities of water were forced up through the cabin floor, and the center aisle between seat rows 2-11 were disrupted, with portions missing entirely and leaving openings down to the baggage compartment. This condition made evacuation difficult. The surviving crewmembers, assisted by a nonrevenue captain and stewardess, evacuated passengers from the cabin onto the wings through the overwing exits, and into life rafts. Time from impact to rescue was estimated as from 45 minutes to 1 hour.

The survivors reported several egress problems, mainly associated with the panic conditions following the impact. A major problem that could have affected survivability following this accident was the reported rapid collapse of two life rafts when they were punctured by the jagged wreckage (despite double tube construction). It was suggested that an improvement would be to compartmentalize the tubes and connect them with one-way flow valves to increase life-raft reliability. The "Fasten Seat Belt" sign was on but the "No Smoking" sign had not yet been turned on. All occupants apparently had seat belts on, but the nature and cause of occupant injuries as to whether received at impact or during evacuation was not reported. Failure of life-jacket lights was reported. Difficulty was noted in finding the life-raft cover release pull string. In the darkness on the wing life rafts had to be turned over several times to locate, and it was suggested that life-raft covers should have a ball handle and/or luminous point to facilitate finding the lanyard for the life-raft inflation. The emergency cabin lights operated, although it was reported they did not remain lighted long. Some of the survivors reported that the standard seat belts had extra long free ends which delayed their release, since they had to interpret what the problem was during a time of panic, as well as requiring both hands to release the belt.

(2) On May 2, 1970, an ALM Dutch Antillean Airlines DC-9-33F ditched 29 miles ENE of St. Croix, V.I. very-high-frequency omnirange (VOR) in the Caribbean Sea. This flight departed J.F. Kennedy International Airport, New York for St. Maartens, Netherlands Antilles, with 55 adult passengers, two infants, and a crew of six aboard. At St. Maartens, after aborting one automatic direction finder (ADF) approach and three circling approaches, they diverted to St. Thomas, and changed course to St. Croix, due to fuel shortage. This is the only known intentional ditching of a scheduled jet air transport aircraft to date. Twenty-three occupants, including two infants and the stewardess, did not survive.

The captain instructed the purser to brief the passengers for a possible ditching approximately 10 minutes prior to the ditching, and to have the passengers don life jackets as a precautionary measure. No further instructions were given. The navigator, with the help of the purser and a male passenger, repositioned the liferaft from the coat closet into the galley area, with some difficulty. Passengers reported difficulty in removing life vests from the storage pockets under the seats. The steward put life vests on the two infants aboard.

There was no "prepare to ditch" warning given by the crew prior to water impact, nor was a "brace for impact" warning given. Neither the navigator nor the purser had time to fasten his seat belt before impact. The steqard was seated on the liferaft package, facing aft. The stewardess position at impact is uncertain. Some passengers were seated upright;

some had assumed a brace position; others were standing, donning their life vests, when impact occurred. There were reports of seat failures. Some passengers did not have their seat belts fastened at impact. Other passengers reported being thrown from their seats despite having fastened seat belts (although the report does not provide this information, similar instances have previously occurred when long belt ends whipped and released buckles in the metal-to-webbing type seat belts). One couple reported that they had unfastened their belts prior to impact in order to be able to evacuate faster. Evacuating passengers observed unconscious or apparently lifeless passengers subsequent to impact. The pilot had a life vest on as well as shoulder harness and seat belt. The copilot wore his shoulder harness but no life vest. The impact deceleration was reported to be severe, longitudinal, with a minor left lateral component.

Post-impact, the copilot, navigator, purser, and steward evacuated through the galley door after having difficulty with the life raft, which inflated in the galley area. A passenger seated next to the right aft overwing exit opened this exit as soon as the aircraft came to rest and exited, followed by at least 22 other passengers. Two passengers from the first row exited through the cockpit window, swam to the left side of the fuselage and opened the left overwing exits from the outside, and helped a man and woman passenger egress.

None of 5 liferafts aboard was deployed. The Navigator found the emergency-escape slide from the galley service area floating in the water and inflated it. Many passengers and the copilot congregated around this flotation device. Life rafts subsequently dropped were not located or could not be returned to the passenger area due to rough seas with six to eight foot swells. Forty persons, including 35 passengers and five crew members, survived (National Transportation Safety Board, 1970 C).

(3) A crash occurred 13 April, 1967 in Cam Ran Bay during takeoff of a C-141A aircraft. After the pilot noted the controls felt "mushy" on takeoff, the aircraft struck the water at about 140 knots, and was destroyed. Water contact was in a flat left-wing low attitude, with wing flaps extended to 75%, landing gear full down, and the spoilers in the ground position. Seven crew members were fatally injured or drowned, one (the loadmaster) received major injuries, and one (the pilot seated in the left seat) received minor injuries of the face and limbs. The two survivors were transferred to the hospital 1 hour 9 minutes post-impact.

Insufficient information is available to evaluate the C-141 ditching characteristics from this crash, since the aircraft was not in recommended ditching configuration--the gear was down, flaps in approach position, spoilers deployed, and air speed excessive. All cockpit seats were found with the seat belts unfastened and inertial reels automatically locked (except for the copilot's seat).

Both seat-belt assemblies failed (side-facing) that the loadmasters were using in the aft compartment, coming loose from the rings.

Although the probable cause of fatalities was drowning, the investigation noted that the aircraft commander and one flight engineer had head injuries which might have rendered them unconscious post-impact. Similarly another engineer reportedly had a crushed left chest which could be attributed to impact. Although the surviving pilot was wearing an upper torso restraint, the accident report does not indicate whether the fatally injured crew members were wearing upper torso restraints.

The flight-deck interior was submerged within seconds after water impact. The pilot (IP was in right seat) attempted to stand up but found this seat belt was still on. After releasing it he started swimming up, was pounded back by the wing section, and finally climbed on a wooden pallet. The surviving loadmaster was slammed into the bulkhead between the galley and flight deck entra ce when his seat belt failed. As the aircraft was immediately filled with water he got tangled up trying to swim out, and finally found a hole, either the open troop door or a gaping hole inside. He did not open any escape hatch. He did not think anyone was killed by impact but rather trapped and drowned.

No warning was given to any of the crew prior to the ditching, although the surviving loadmaster, who was on interphone, could tell there was some sort of emergency from the cockpit conversation. Just prior to impact the pilot tried to warn the IP. The crash circumstances of this accident preclude any conclusions concerning evacuation under normal ditching, except to indicate that there may be little egress time post-impact. However, failure of the side-facing seat belt assemblies, and the possibility that two of the flight deck crew were not wearing upper-torso restraint could have contributed to lack of survival.

The poor egress and survivability experience represented by this single C-141A crash-ditching to date had been previously predicted in a study by McIntire (1967). Using Army paratrooper subjects, emergency evacuation time in the C-141A was investigated under simulated ditching conditions. McIntire's review of prior ditching and water-crash cargo-transport accidents showed that high-wing aircraft either head up and sink immediately, or they are heavily damaged and quickly sink to the wing level; in both cases flooding the passenger compartment within 5 to 30 seconds. The most rapid ditching evaucation time reported in the C-141 tests was 230 seconds when life rafts were not deployed, and 337 seconds (5.6 min) when the life rafts were deployed. The average time found required to evacuate 114 passengers and 6 crew members and to deploy life rafts and survival equipment was 480 seconds. McIntire concluded that "if a high wing transport like the C-141 goes into the water, and if the cabin remained level and does not fill with water, and if there were no injuries, 114 passengers and six crew members will require approximately 450 seconds to escape the aircraft and deploy their survival equipment. In an actual emergency, it is reasonable to expect that the escape time will be longer" (1967). Since a maximum time of 30 seconds is available prior to the aircraft sinking, the probability of passenger escape in this situation is poor. Note that these simulated tests did not involve fire or smoke hazards, which could considerably increase these evacuation times.

The accident experience relating to C-135, C-141, and comparable civil air carriers which has been summarized in the foregoing provides a realistic operational background necessary for identification of requirements and problems in crash impact protection and egress.

This operational experience also serves as a background for more objective assessment of the potential effectiveness of proposed concepts considered to be within the current state of the art.

SECTION III

OPERATIONAL CONFIGURATIONS AND OBSERVATIONS

C-141A CONFIGURATIONS

The Lockheed C-141A Starlifter is a high-wing four engine turbofan--powered freighter and troop carrier operated by the Military Airlift Command. It is the flying element of Logistics Support System 476L, designed to provide global-range airlift for the MAC and strategic deployment capabilities for the U.S. Strike Command (includes the Strategic Army Corps and Composite Air Strike Forces of Tactical Air Command). This aircraft was FAA type certified in January, 1965, but has not been certified for civil air carrier use. Maximum capacity is 138 troops, 123 paratroops, or 80 litters, and a normal crew of 5.

However, several alternative seating arrangements are used operationally and each presents different problems of occupant seat-restraint system protection as well as influencing potential crash impact evacuation flow. When the aircraft is used as a troop carrier, seating accommodations are provided for 154 ground troops or 123 paratroops. A number of other troop-carrying configurations are also possible, in combination with the seats. Figure 2 (A) shows the troop seating arrangement for 154 troops in a maximum density configuration, or for 131 troops when a comfort pallet is installed. Seats consist of two outboard sections of single rear-facing seats, and a medial row of double, rear-facing seats. However, in cases where paratroops are carried the rear-facing seats are replaced by four sections of side-facing net seats (Figure 2, Section AA) capable of holding 123 paratroops without a comfort pallet, or 104 paratroops with a comfort pallet installed. There is also a modification of this latter arrangement (C-141A Kit #1) consisting of one row of inboard facing canvas seats positioned along each side of the cargo compartment.

When the seating arrangement consists of 46 three-place rear-facing seats without a comfort pallet 138 troops can be carried, or 120 troops in 40 three-place rear-facing seats when a comfort pallet is available (Figure 3). Such seats have either 2-inch or 3-inch lap belts with no shoulder harness, and are stressed for 16G impact loads.

Figure 4 illustrates a typical litter arrangement. The C-141A is capable of accomodating a maximum of 80 litters in three-and four- litter-deep vertical arrangements, with the litter passengers' heads facing forward.

A C-141A crew normally consists of a pilot, copilot, flight engineer, navigator, and loadmaster(s) when passengers are carried, but may also include nurses, corpsmen or flight surgeons when litter patients are carried. Figure 5 shows the flight-deck crew positions. Up to nine personnel can be accommodated on the flight deck, if the collapsible I.P. seat, two aft auxillary crew seats, and two seat provisions on the lower aft bunk are utilized. The pilot's, copilot's, navigator's, and flight engineer's seats are designed for 16 G impact, while the I.P. seat (located to the rear and between the pilot and copilot seats) and the two aft auxillary crew seats are probably not stressed for over 9 G. There is no information on design of the two lower bunk seat-restraint limits. All flight-deck crew seats are forward-facing, except for the navigator's and flight engineer's seats, which are normally side-facing, but which swivel and can be placed in a forward-facing (or rearward-facing) position.

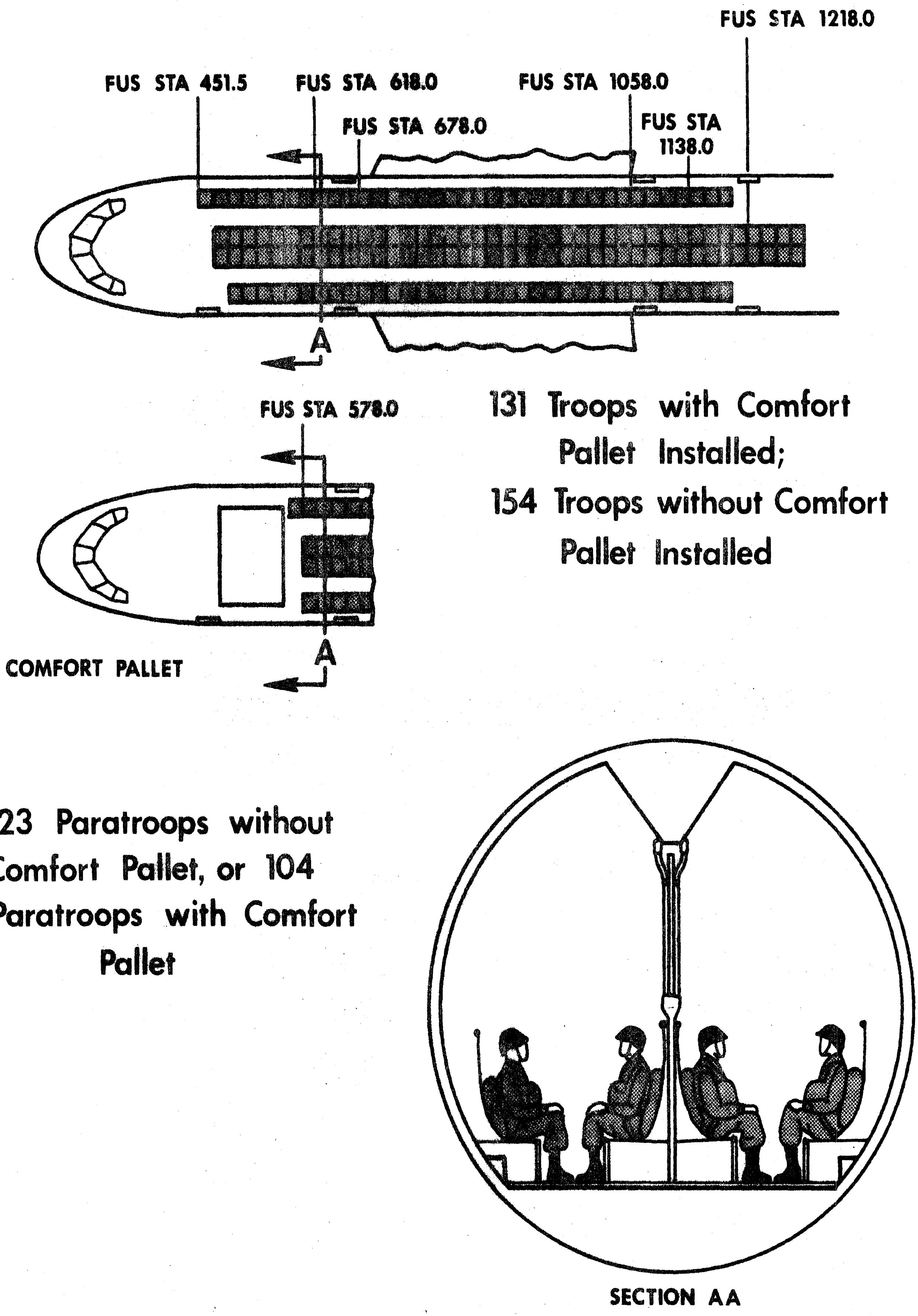


Figure 2. C-141A Typical Troop Seating Arrangement (Maximum Density) with Net Side-Facing Seats (T.O. 1C-141A-1).

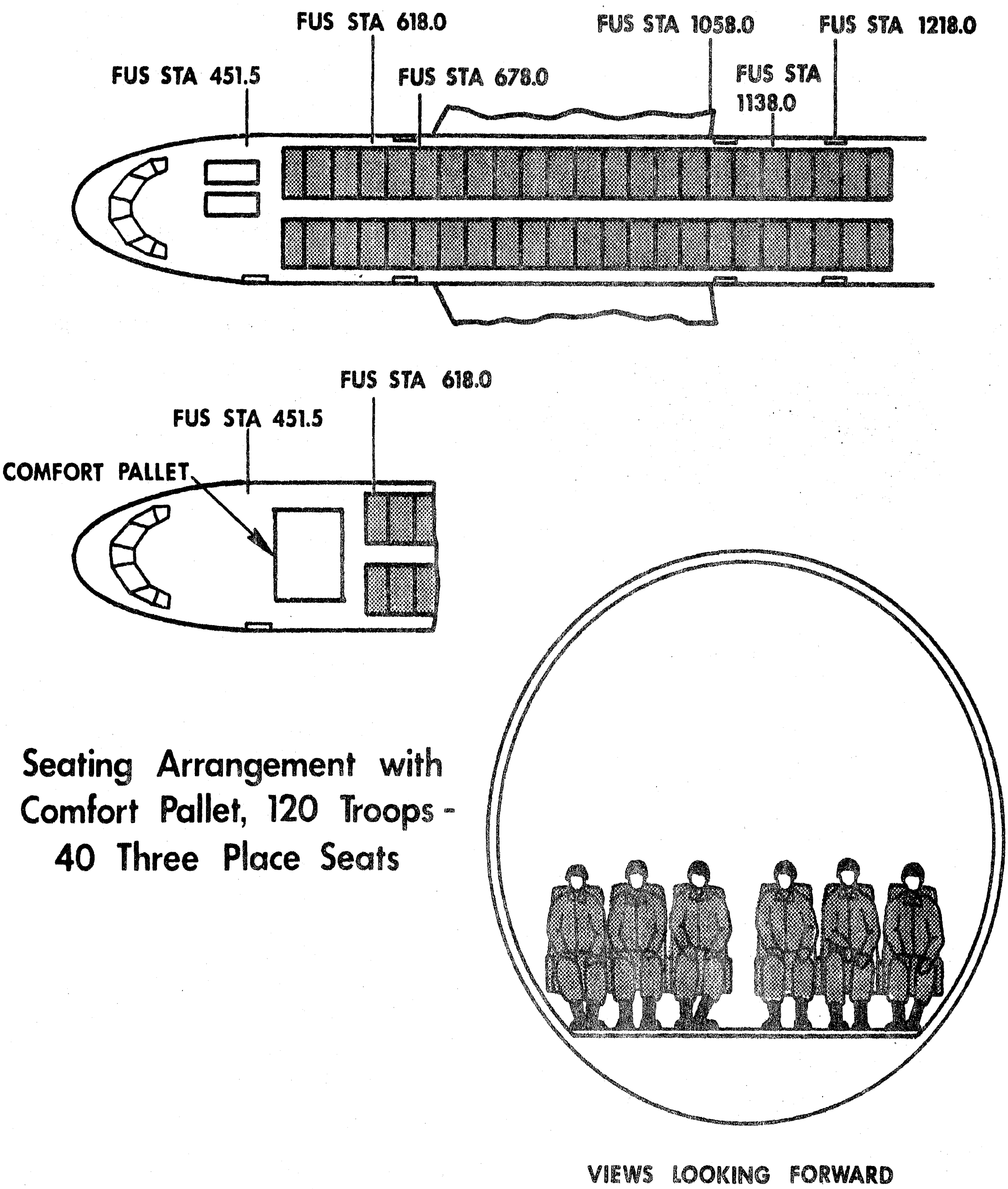


Figure 3. C-141A Typical Troop Maximum Density Seating Arrangement with Three-place Rear-facing Seats (T.O. 1C-141A-1).

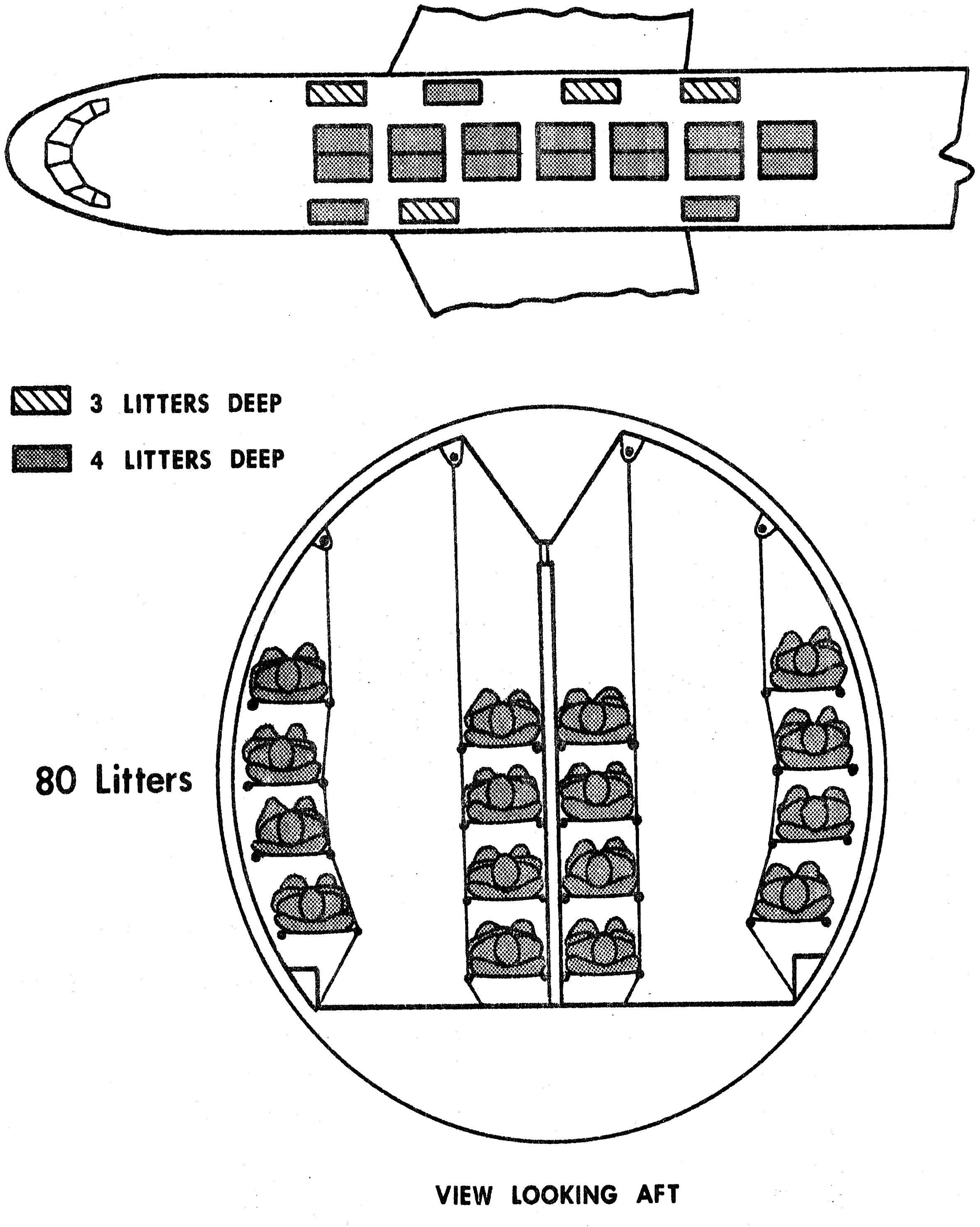


Figure 4. C-141A Typical Litter Arrangement (T.O. 1C-141A-1).

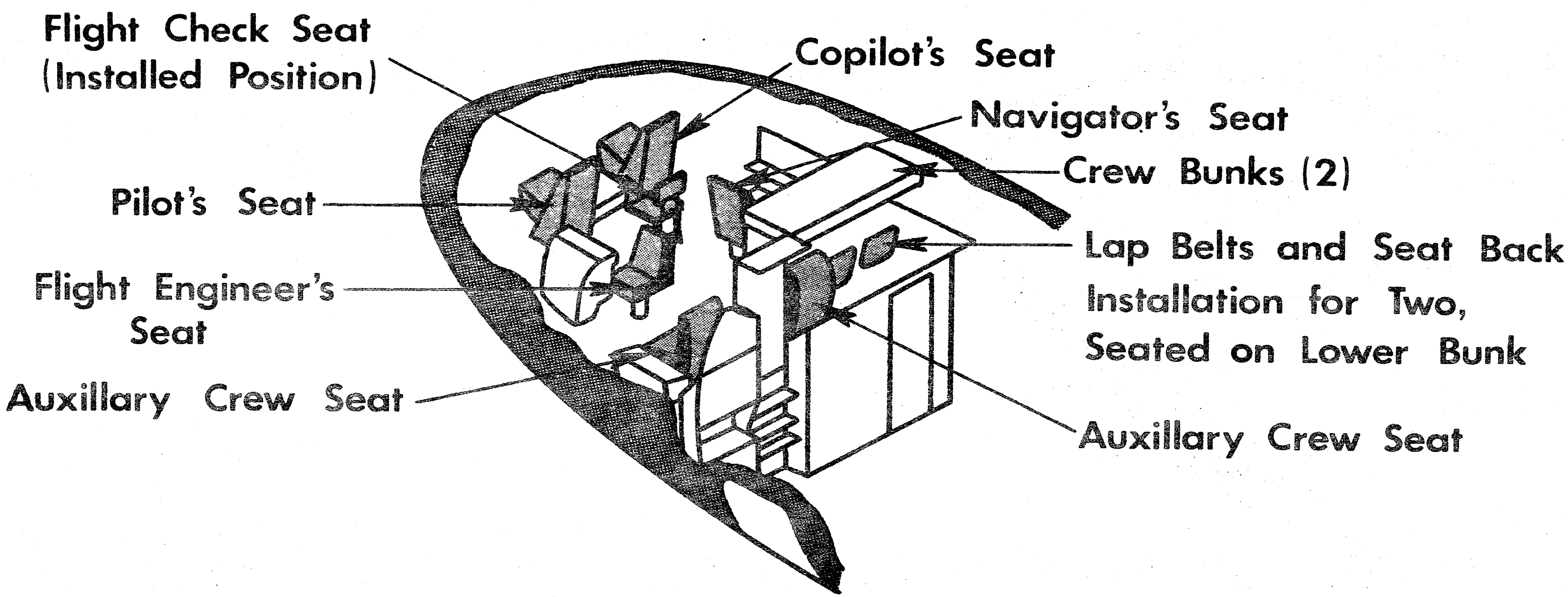


Figure 5. C-141A Flight Deck Layout, Crew Positions, and Emergency Equipment Storage.

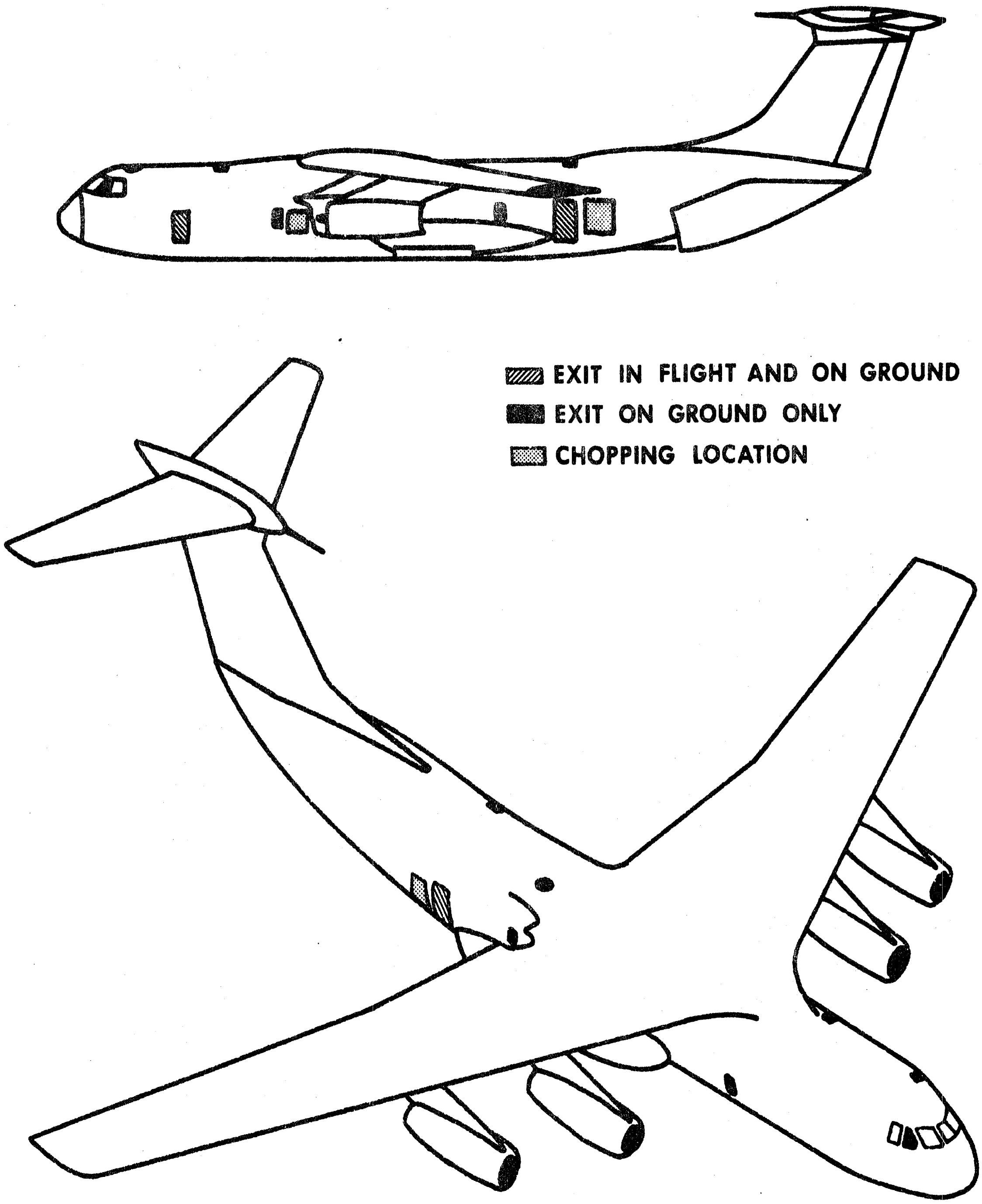


Figure 6. C-141A Location of Emergency Escape Routes and Exits.

C-135 CONFIGURATIONS

The Boeing C-135 cargo carrier or troop transport (and KC-135 tanker) is a low-wing long-range four engine aircraft, primarily in use with the Strategic Air Command, with over 800 being in service. Normal crew consists of five; a pilot, copilot, flight engineer, navigator, and Loadmaster. The pressurized and air-conditioned cargo compartment has provisions for seating up to a maximum of 126 troops. Military Airlift Command operates three VC-137B models, holding a crew of 7 or 8 and 50 passengers, and one VC-137C, with a crew of 7 or 8 and 49 passengers which is used for the President and government officials. This aircraft is modified from the Boeing 707 Civil Air Carrier version.

Troops or personnel can be carried in all configurations of the aircraft as specified in T.O. 1C-135A-9. In a cargo configuration passengers may be carried seated in collapsible seats of nylon fabric, supported by metal tubing, stowed on each side of the fuselage. These side-facing seats will hold 75 individuals, and each seat position is designed to be equipped with a lap belt, shoulder harness, and stowage bag for a portable oxygen bottle.

Figure 7 illustrates a typical operational seating arrangement for 65 troops which the authors observed at Lockbourne AFB. Still another configuration was previously illustrated in Figure 1. In both of these cases the aircraft also carry cargo as well as passengers. As shown in Figure 7, there are provisions for 55 troops in folding nylon side-facing seats positioned along each side of the fuselage and in the tail section. These seats are equipped with shoulder harnesses and lap belts. In addition, there are 10 rear-facing seats in the aft section of the cargo compartment. The seats have either 2-or 3-inch wide lap-belts. There are also four crew bunks.

A passenger configuration (with no cargo carried) consists of 42 aft-facing track-mounted triple-seat units mounted on either side of the fuselage for six abreast seating; a capacity of 126 troops can be carried. Where the aircraft is utilized for aeromedical evacuation, 44 litters and eighteen triple aft-facing seat units for 54 passengers can be mounted.

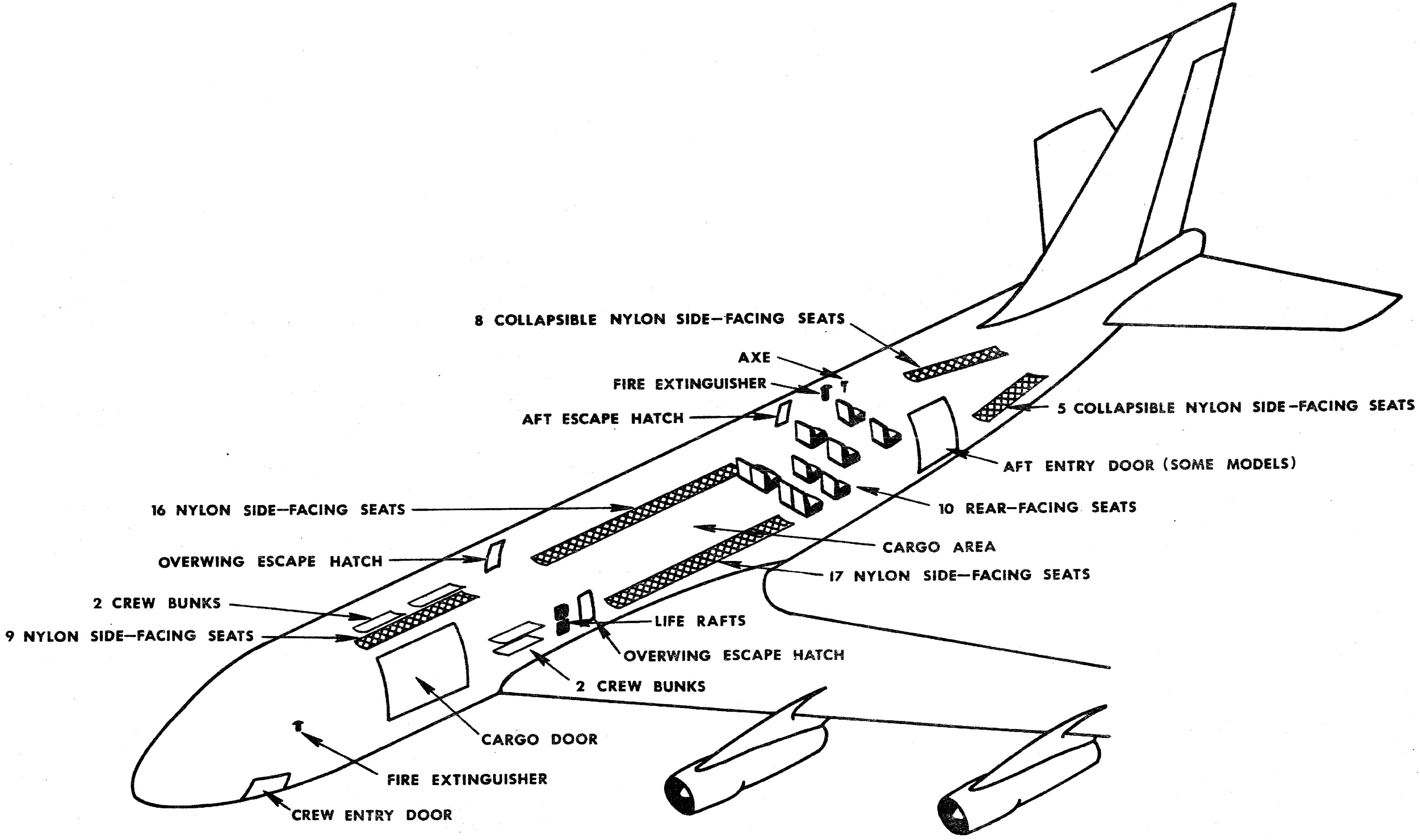


Figure 7. C-135A Typical Troop Seating Configuration.

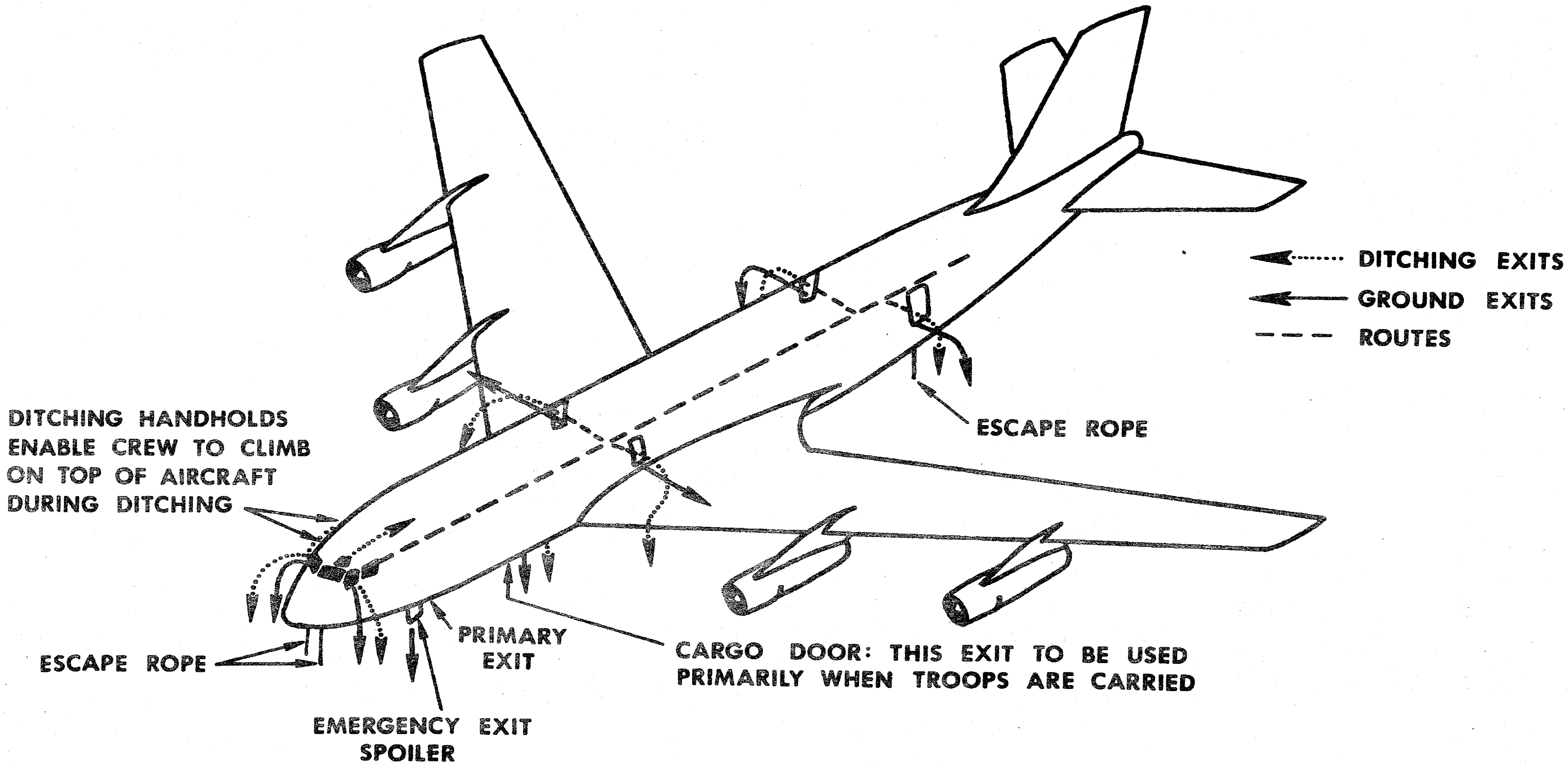


Figure 8. C-135A Location of Emergency Escape Routes and Exits.

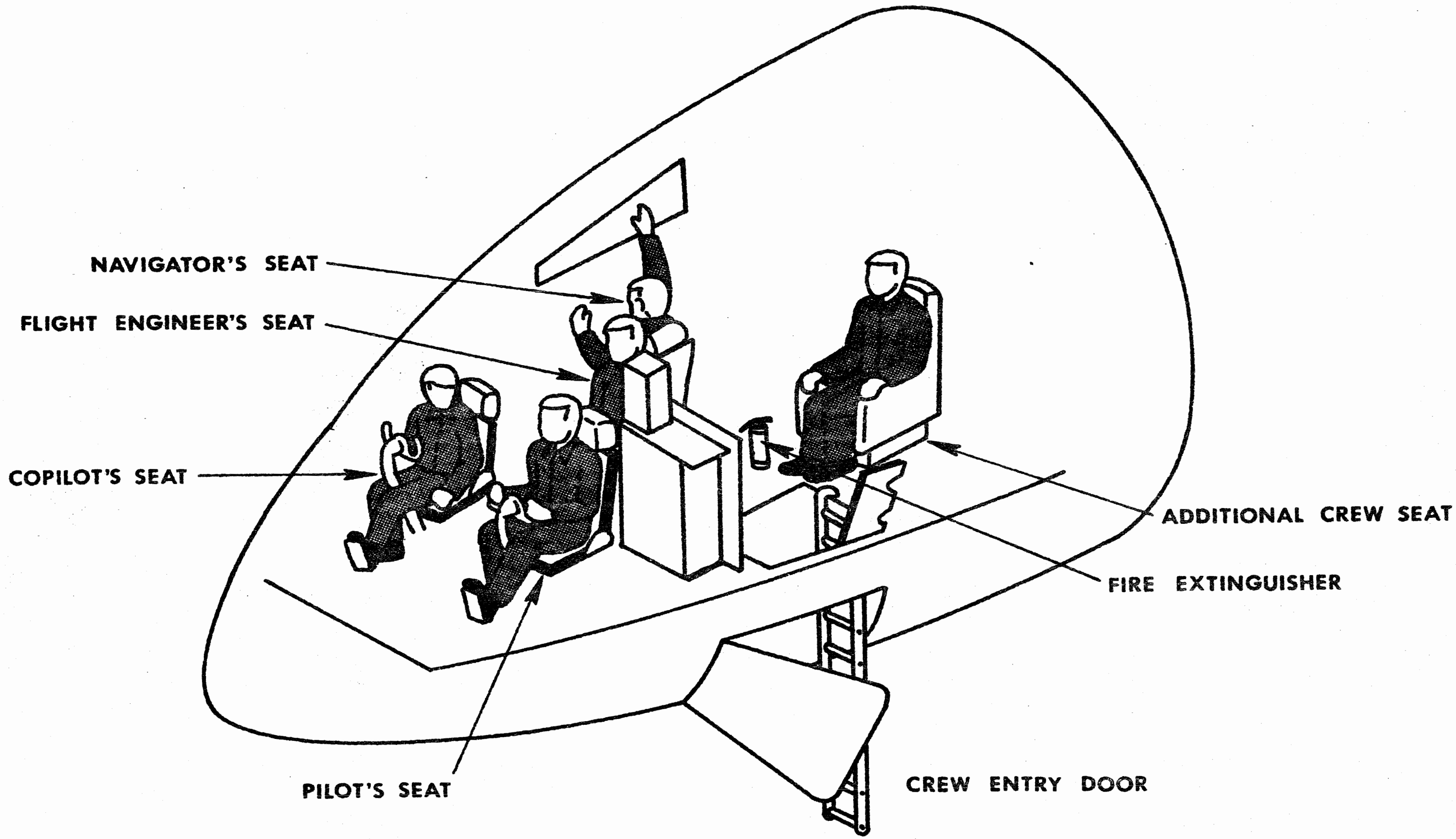


Figure 9. C-135A Flight-Deck Layout, Crew Positions, and Emergency Equipment Storage.

C-135 AND C-141 CRASH IMPACT AND EMERGENCY EGRESS OBSERVATIONS

Analysis of USAF air transport crash safety and crew-passenger emergency egress previously conducted by Reagin et al. (1970), Brown (1969), and Sawyer (1967) have indicated that serious deficiencies exist in most of the aircraft studied. In order to determine the nature of current operational procedures and configurations for the C-135 and C-141 aircraft, inspection of several aircraft considered by Air Force authorities as having typical operational configurations was conducted, as made available. Three C-141A (MAC) aircraft were examined at Norton AFB, California and one KC-135A (SAC) aircraft was examined at Lockbourne AFB, Ohio. This was necessary in order to more realistically analyze the previous accident experience, and to better evaluate advanced concepts in light of current experience and typical operational configurations. Since the actual number of aircraft inspected was extremely limited, they may not validly represent the total Air Force air transport inventory for these aircraft. Nevertheless, our observations showed that there may be a considerable difference between the technical manual (T.O.) for the aircraft and field operation in relation to the emergency egress items studied. Further, they confirmed for the most part the earlier reports of deficiencies by the Combat Egress Working Group, as well as pointing up some additional areas of concern. The following summarized these observations.

C-141A:

(1) No path markers or exit arrows were found in these aircraft.

(2) There were no emergency instruction cards located in these aircraft.

(3) In one aircraft the sign "EMERGENCY EXIT" inside the main (left) entrance door was almost completely chipped away by wear, and the edges of both the sign and exit orange-yellow painted outline band had been spray-painted over so that they could barely be seen at close range in daylight. They could not have been seen from a distance or under poor light or smoke conditions.

(4) The yellow exit outline around all escape doors, hatches and windows was faded, painted over and obscured on two aircraft, and worn on a third.

(5) There were no signs or arrows indicating the location of either crash axes or fire extinguishers. None of the crash axes or fire extinguishers in any of these aircraft were painted, all being bare metal. Figure 10 shows a typical unpainted, unmarked fire-extinguisher located under the inboard-aft crew flight-deck seat. The unmarked, unpainted fire axe was located on the wall behind the seat back.

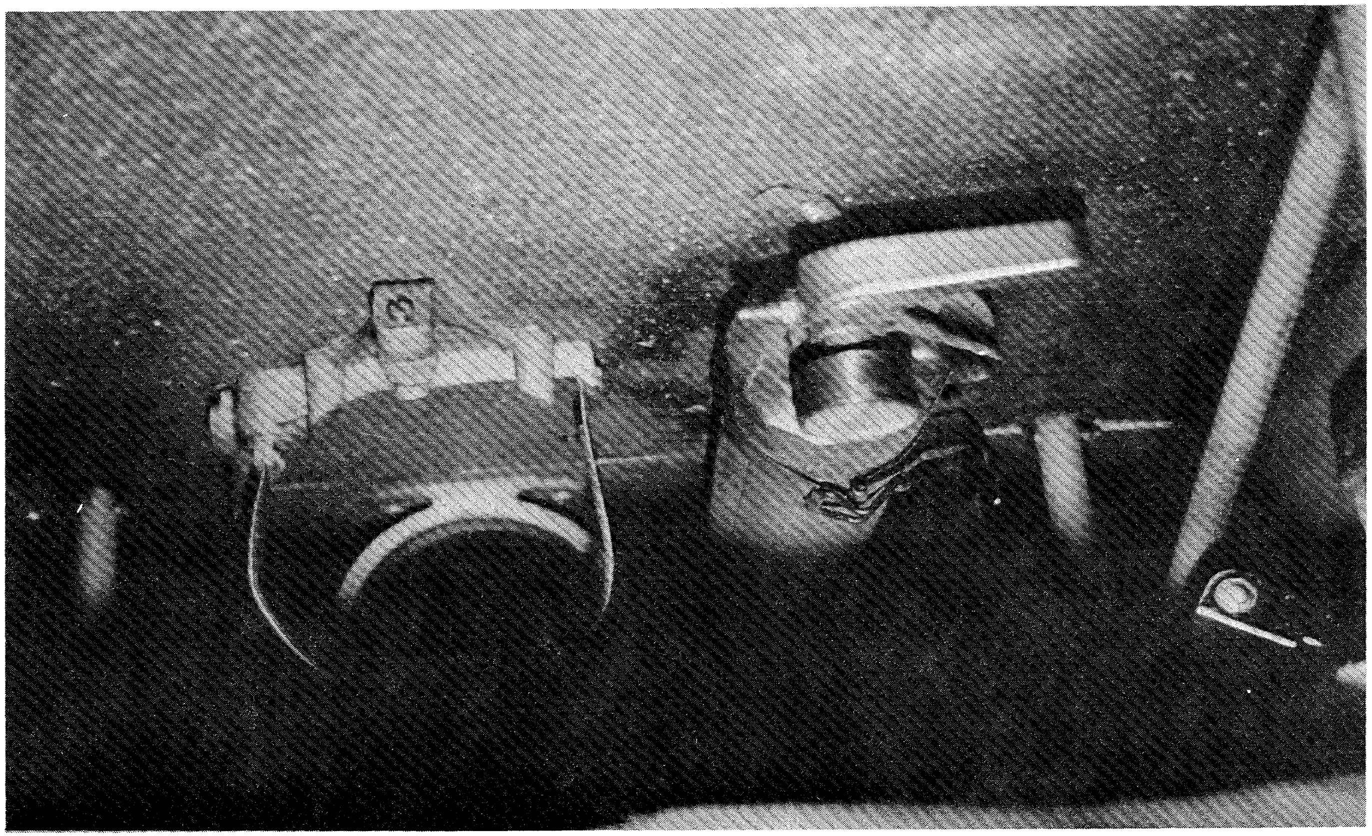


Figure 10. Typical Unpainted Unmarked Fire Extinguisher Found Under Crew Seat on C-141 Flight Deck.

(6) The emergency rope (and rope ladders) were marked with small letters on yellow signs, but can not be seen from a distance; some ropes were knotted and some were not.

(7) There were excellent slip-proof flooring devices installed along the cargo floor.

(8) On the flight deck of one aircraft the sign "Exit Release Pull Handle" adjacent to the crew aft roof escape hatch was facing to the right side of the aircraft, requiring an awkward head rotation in order to read the sign. On a second aircraft the "Exit Release Pull Handle" sign was missing entirely from this escape hatch.

(9) There was no crash impact internal exit emergency illumination system in the aircraft examined. At night or under smoke conditions exit signs could not be seen.

(10) There was no external exit emergency lighting system.

(11) No illumination or marking of escape paths.

(12) Side-facing webbing troop seats along both cabin walls blocked all cabin side exits except for forward entry door.

(13) A number of seat belts were old, frayed and worn, and it would be doubtful that they could pass minimum static load tests (MIL W4088E Revision, or F Revision Type 24 for 2-inch belts of 5500 lbs. minimum tensile strength or even under older AF Tech Order 13A1-1-2, requiring only 2000 (2250) lb. webbing strength). A wide variety of both 2-inch and 3-inch seat belts were noted.

(14) No rear-facing seats were found in any of the three aircraft examined. The extensive use of side-facing seats without upper torso (shoulder) restraints may be compatible with troop-cargo loading but is the least desirable of the three seating orientations (aft, forward, or side facing) from a human tolerance viewpoint.

(15) In one aircraft it was found that the seat (lap) belts provided on the lower crew bunk of the flight deck were attached to a bracket which was fixed to the bulkhead behind the bunk by small gauge machine screws. No load plates had been installed behind the installation.

(16) Three of the flight-deck crew seats could have had upper torso restraint installed.

(17) The main crew entry door was of a roll-up design requiring two-handed complex motion. It would appear to be very susceptible to jamming in any case when the fuselage was distorted in a crash, and was of poor human factors design for emergency egress.

KC-135A:

(1) A wide variety of seat belts were found, including both 2-inch and 3-inch width, with many seat belts being frayed and worn on crew seats.
(2) Only a single emergency egress briefing card could be located in the cabin; a second one was found on the flight deck.
(3) This aircraft was equipped with 10 rear-facing seats in the art portion of the cabin, but 55 passengers had to sit in poorly protected side-facing folding troop seats (see 5 below).
(4) Plywood passenger decking installed did not contain skid-proof or slip resistant material.
(5) Side-facing troop seats along both sides of the cabin and in the tail section; all upper-torso restraints in neatly folded installations. However, the shoulder portion was installed over the rear frame so that if the restraint was worn as installed the upper part of the harness would be 4-inches to 6-inches too short. This would force the occupant to loosen or extend his lap belt greatly to meet the upper shoulder belt attachment points. We understand from the crew chief and a loadmaster that this restraint is commonly worn this way by unbriefed passengers since it is easy to get into and out of. However, when worn in this manner the restraint is loose, too high over the abdomen (not pelvis), and could undoubtedly cause injury to the occupant in a crash impact. Yet in order to wear properly this system as installed, the upper harness must be free underneath the upper seat wall bar, and in this case offers very little upper-torso restraint since the attachment point is near the base of the seat. Serious attention should be given to improving these upper torso restraint attachments.
(6) Emergency exit markings and door outlines conformed to regulations and were in better condition than observed in the C-141 aircraft, but still could not be observed from some passenger seat positions.
(7) There were <u>no</u> aisle or path directional markers or lighting.
(8) All axes and fire extinguishers were unpainted, unmarked, and inconspicuously located, although far better placed than in the C-141.
(9) The pilot and co-pilot cockpit windows appeared to be extremely small for the egress of a large person, or one wearing heavy flight clothing or equipment. It is easy to understand accident

reports noting that crew members have gotten stuck during emergency egress.

(10) The metal frame back to the pilot's or copilot's head rests could be struck by the navigator or flight engineer during forward impact if they were not wearing upper-torso restraint.

SECTION IV

PASSIVE RESTRAINT SYSTEMS

The objective of this section of the report is to evaluate the use of passive restraint systems, particularly airbags, for impact attenuation in the case of crashes of transport aircraft. A major effort in accomplishing this objective was the gathering of background material on the protective capabilities of the various inflating occupant restraint systems (IORS) which are undergoing prototype development at the present time and on the specific component hardware which is used in building up systems.

A history of the IORS from the time of conception to the present rule-making activities of the Department of Transportation prefaces this section. This is followed by a general discussion of the principles involved in designing a seat-restraint system. The various features of current prototype airbag restraint systems and components are then described including sensors, bag and diffuser design, tolerable sound levels, human volunteer performance tests, and operating temperature ranges. The section on passive restraint systems is concluded by an analysis of alternatives to the airbag.

BACKGROUND INFORMATION

Most studies of occupant protection carried out before the early 1960's were concerned with various types of belt systems. In the majority of cases, these systems were intended for use by aircraft occupants. Inflatable restraint systems also may have been closely associated with aircraft in conceptual developemnt. Although the "air cushion" was evolved at least by 1918 as a seat (Mosley, 1918), and used in Webster's Schneider cup winner and other aicraft such as the DeHaviland Moth, its use as abdominal support was suggested in 1933 by Wing Commander Marshall of the Royal Air Force, who devised an air cushion belt for acceleration protection. During World War II there were reports of use of premature inflating of the Mae West on life rafts prior to crash landings as impact protection (one of the principal investigator's 7-man crew did this during a B-25 crash landing in April 1951) (Snyder, 1967). However, use of a gaseous inflatable restraint system for crash protection may date from the work of Pekarek, a Czechoslovakian engineer with the RAF, who devised the "Pekarek Safety Cell" in 1943-1944.

In 1952 Jordanoff reported a manually triggered airbag restraint system. Hetrick in 1952, and later Bertrand in 1955, filed for a patent on an airbag filled on manual switch application with automatic deflation after a time delay. In 1959 a restraint system utilizing air inflation was proposed to the

Air Force by Snyder for astronaut protection, but the Chance-Vought System was developed instead. The concept of an air-bag restraint for automotive occupant crash protection was probably first initiated at General Motors about 1958.

During the early 1960's the concept of an airbag restraint system gained a strong advocate in C. Clark. His early reports were followed by more widely circulated publications in Stapp Car Crash Conference Proceedings. The preinflated Martin Airstop system, developed by Clark, has been crash tested in several aircraft crash tests, including the FAA crash test of a DC-7 transport at Av-Ser at Deer Valley, Arizona, in April 1964 (Clark, 1966a). This was followed by a NASA rear-facing seat crash test of a C-45 into a hill at 80 mph in April, 1965 (Clark, 1966b), and a series of 10 forward-facing crashes carried out at National Aviation Facilities Experimental Center (NAFEC), Atlantic City, in November 1965, at impact speeds up to 87 mph into snatch wire arresting gear (Clark, 1966b). These early aircraft tests have been more recently followed up by additional FAA tests and proprietary studies within the general aviation industry.

The first full-scale testing program involving living test subjects (baboons) restrained by airbag systems was reported by Snyder, et al., in 1967. The level of protection offered by the air-bag system appeared to be higher than for other systems evaluated in that program. Shortly after this series of tests was reported, Ford Motor Company and Eaton, Yale and Towne, Inc. collaborated in a report presented at the January 1968 SAE Automotive Engineering Congress held in Detroit (Kemmerer, et at., 1968). The feasibility of concept, systems development, performance requirements and the implication of producing inflating restraint systems on a large-scale production basis were discussed and conclusions were drawn such as: (1) inflating restraint systems can reduce occupant loadings; (2) energy absorption must be provided to prevent excessive occupant rebound by means of a bag pressure relief system; (3) an inflating restraint system can be automatically activated by a crash sensor and deployed in the short time between crash initiation and the second collision of the occupant with the vehicle interior; (4) a parameter study is needed to determine system performance as occupant size is varied; (5) an operational criterion for sensors is needed; (6) reliability must be demonstrated; and, (7) the effects of noise should be investigated.

Later in 1968, a project (Contract No. FH-11-6962) was initiated at the Highway Safety Research Institute (HSRI) under contract to the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation (DOT). Part of this project was to conduct a detailed analysis of work carried out on airbag restraint systems ot determine their feasibility, and the remainder was to conduct an experimental impact-sled test program involving dummies restrained by airbags.

The topic of human auditory response to an airbag inflation noise was covered in a report issued by Nixon in March 1969 and in a further paper presented at the annual conference of the American Association of Automotive Medicine in November 1970. A more recent report has been issued by Bolt, Beranak, and Newman, Inc. in April 1971. This latest work was sponsored by NHTSA. These reports generally minimized the noise problem for the general population in the case of right front passenger airbag inflations in the presence of human volunteers. Although early industry work had indicated pressures of 5 psi might be expected (Van Wagoner, 1967), subsequent developments have not validated such high pressures.

Later in the spring of 1969, initial impact-sled tests involving pre-inflated airbags restraining 50th percentile male dummies were carried out at the Highway Safety Research Institute. Rapidly inflating airbags were in use for all sled tests conducted after June 1969. By the end of that month the system had been tested up to 30 mph in frontal collisions involving dummies both restrained and unrestrained by supplemental lap belts.

Extensive activity was begun in government, industry, and independent research organizations on July 1, 1969, as the Secretary of Transportation issued an advance notice of proposed rule-making on inflatable occupant restraint systems. At an open meeting sponsored by the Department of Transportation, the great potential for these systems was demonstrated as well as potential problems of an out-of-position occupant and the danger to a child passenger of inadvertent actuation.

During the winter of 1969-1970 the importance of supplemental knee support was demonstrated and implemented in hardware both by a low-deploying, knee-catching airbag produced by General Motors Corporation and by an energy-absorbing lower instrument panel developed at the Highway Safety Research Institute for use with an airbag deployed from an automobile upper instrument panel. By spring 1970 successful tests were carried out at HSRI at 40 mph impact velocity and in right front oblique impact.

A conference held at the General Motors Proving Grounds in May 1970, sponsored by the North Atlantic Treaty Organization, and hosted jointly by the U.S. Department of Transportation and the U.S. automobile industry yielded an extensive document on the state of the art of passive restraints up to that date. A wide range of views and technical data were presented by representatives from government and industry. This document remains the most comprehensive source of information on inflating occupant restraint systems outside Docket No. 69-7 covering the current NHTSA.

Since the NATO Conference, technical data have been presented at several meetings including the 1970 Stapp Car Crash Conference held at The University of Michigan (Gragg, 1970 and Clarke, 1970), the 1971 SAE Automotive Engineering Congress held in Detroit (Irish, Jones, Johnson, Streed, Hammond, Trosien, and Pflug, 1971), and the 1971 Stapp Car Crash Conference held in San Diego (Robbins, Melvin, Clarke, Martin, 1971). Additional research will be presented at the 1972 SAE Automotive Engineering Congress to be held in Detroit (Melvin, Jones, and King, 1972).

Several final reports have been submitted to DOT during the summer of 1971 covering two contracts (FH-11-6962 and FH-11-7612). The first of these was mentioned previously and the second covered the subject of deployable head restraints. Authors include Robbins (three reports) McElhaney (three reports) and Melvin (one report), (see References).

Besides the active developmental work being conducted in the automotive industry and its suppliers, several organizations are currently being funded for various studies by the Department of Transportation. Among these are the Cornell Aeronautical Laboratories[1], Wayne State University, the Daisy Track at Holloman AFB, Mini-Car, Inc., Dynamic Science, Inc., Southwest Research Institute, and Beta Industries, Inc. Reports covering these studies which have been recently initiated are not yet available.

PRINCIPLES OF RESTRAINT

If the right front passenger of an automobile is not wearing a restraint system and the vehicle is involved in a collision, the following sequence of events is observed to take place in many cases. First, he slides forward in the seat until the knees contact the instrument panel structures. Second, his torso pitches forward and the head contacts the windshield, breaking it. Extremely high G-loadings can be registered in the head during this portion of the event. Third, the neck and upper torso are stopped by the upper instrument panel structures. Fourth, the lower portion of the upper torso continues its downward motion causing the head to be bent to the rear (hyperextension) relative to the torso. The occupant will then rebound back into the seat or be ejected through the windshield depending on the shape of the instrument panel structures.

The three basic problems in providing occupant protection, demonstrated by this example, are present in aircraft as well as automobiles. The first of these is to restrict the motions of the occupant from contact with structures causing injury. In the case of crew members, the structures would consist of the myriad of equipment and controls present in the cockpit of the aircraft. Occupants of troop seats must be restrained from contact with their neighbors. Passengers of rear-facing seats appear to be

[1] For addresses of companies and other organizations listed in this report, see Appendix B.

in the best position to avoid this problem provided seat structural strength is sufficient to resist crash impact loads.

The second problem in providing impact protection is limiting the acceleration G-loadings and forces applied to the body based on human tolerance data. The problem faced in designing aircraft seating has one factor not often found in automotive crashes—vertical G-loading as the aircraft falls. This indicates that seat cushion design for aircraft application has greater importance than in the automotive case. This problem has additonal importance in that the tolerable loadings in the spineward direction are lower than for front-to-rear loading. In designing an impact protection system for aircraft use, it is thus as necessary to consider the energy absorbing properties of the seat cushion as it is to consider the properties of an upper torso restraint, whether it be an airbag or an Air Force harness. Therefore, in developing specifications for impact protection, the relevant life support system can be defined to consist of both the seat and the restraint system.

The third problem in providing impact protection is limiting extensive motions between adjacent body elements as in hyperextension, described in the sequence of events possible in a collision.

A lap belt is effective in avoiding complete ejection from a seat but is not capable of avoiding all potentially injurious contacts with other aircraft structures. This is particularly true with crew seating positions where the occupant faces forward. In those cases the upper torso must be restrained. This is accomplished successfully by a variety of active belt restraint systems and can also be accomplished by passive restraint systems such as the airbag. The lap belt may be eliminated to yield a purely passive restraint system provided provision is made to catch the knees and lower part of the torso by suitable energy-absorbing structures. This can be accomplished either by additional passive bag deployment or by crushable panels.

Current generation airbags and upper torso belt systems do not provide the solution to the restraint problem in side G-loadings. Dummy test subjects in side impact, restrained by standard lap belts and single diagonal harnesses, have been observed to slide under the belts and end up almost entirely off the seat (Robbins, 1971a). The lap belt is insufficient to restrain the pelvic region and the shoulder harness does not prevent the upper torso and head from contact with structures adjacent to the seat if they are present. Although the authors have not seen sled test results, it seems likely that this problem could be experienced with the troop seats observed in air operational KC135A aircraft during this project.

Some insight into techniques for preventing motions to the side were gained in studying the protective potential of children's restraint systems (Robbins, 1970). In this case side impact tests were conducted on a Volvo child seat which provided padded structures at the side of the user. This effectively reduced side motions and distributed the loadings over the body. This concept of side-impact protection was also incorporated effectively in a prototype integrated seat-restraint system built and tested at the Highway Safety Research Institute (Robbins, 1971a).

The major problems in rear impact protection are load distribution and provision for head restraint. These features have been effectively included in rear-facing seats. A supplemental lap belt is necessary, however, to prevent ramping up the seat back (Melvin, 1971) and rebound after impact.

To summarize, the three basic problems in occupant protection have been discussed with respect to their effect on aircraft crew and passenger seating. The problems are: (1) ejection from the seating position; (2) application of excessive forces to the body; and, (3) the occurrence of large relative motions between adjacent body segments.

SYSTEM COMPONENT DEFINITION

An inflating occupant restraint system can be defined as consisting of four basic components: (1) sensor-initiator; (2) gas source; (3) the deployable bag; and (4) the diffuser. Each of these components has its own set of properties. Many of the small supplier companies for the automobile industry concentrate their efforts on one or another of the components.

The sensor-initiator consists of some sort of inertial switch or other device capable of sensing that a crash is about to or has begun to occur. The signal from the sensor is then fed to an initiator which triggers a supply of gas to the deployable bag. In the case of pyrotechnic gas sources, the initiator is an igniter whereas for the stored gas systems, the initiator is an explosive squib which fractures a diaphragm sealing the stored gas bottle. In all cases the necessary electrical signal is provided by a power source such as a battery although a detonating cord has been proposed by one supplier.

Several types of gas sources are being proposed at the present time. The most commonly used is a bottle of stored air or nitrogen. The bottles are, of course, bulky and heavy, weighing up to 20 lbs. in the case of a single right-front automobile-occupant restraint system. The second gas source system is pyrotechnic and, because of the solid fuel use, is much lighter and compact. However, in some cases the gases are somewhat dangerous to breathe. A third system is a hybrid form combining the two. Most often this consists of a pyrotechnic device providing rapid inflation supplemented by stored gas delivered over a specified period to provide some potential for protection in multiple impacts. Aspirator systems, representing an extension of the techniques used to inflate escape slides, are also undergoing early prototype development at present.

A variety of materials have been proposed for the inflating cushion itself. Among these are coated fabric and films. Coated fabrics have been selected in all cases known to the present authors because of high strength and favorable weight. Fabrics such as nylon, dacron, rayon, glass, and cotton have been studied with nylon most commonly adopted.

CRASH SENSORS. A variety of crash sensors have been proposed and studied during the current activity surrounding inflating restraint systems. Generally these can be grouped into four categories: (1) electro-mechanical; (2) inertial guidance; (3) radar proximity; and (4) sonar proximity.

Three commercially available crash sensors have been evaluated in detail at HSRI in the course of fulfilling the requirements of DOT contract No. FH-11-7612 (Melvin, 1971). One of these was developed by Eaton Corp. and the other two by General Motors.

The Eaton Autoceptor Crash Sensor (see Figure 11) is an uniaxial mechanical spring-mass system which fires when the mass is displaced a predetermined distance. The spring holds the mass against an end of the sensor in order to produce a bias force against the mass.

The Delco Electronics Mechanical Crash Sensor Model 8-1000 (see Figure 12) is a ball sear type mechanism fired by displacement of a mass which is restrained by magnetic force. The sensor is essentially omni-directional in a plane and nominally set to trigger on an 11 G, 80 msec haversine shock wave which is a rough representation of an average rear end automobile collision.

The Delco Electronics Safety Sentinel 4 Electronic Crash Sensor (see Figure 13) is omni-directional in a plane. It consists of a ball restrained by magnetic force. A fixed ring surrounds the ball which can be displaced by deceleration until it contacts the ring, thereby energizing the firing switch. The system is double redundant, self-diagnostic and is set (at delivery) to trigger on a 16 G, 60 msec haversine shock wave.

The Eaton and Delco sensors have been subjected to tests at HSRI. Each of the sensors was mounted on the ram of a Plastechon high-speed universal testing machine. This hydraulically actuated, electronically servo-controlled machine was programmed to subject the sensors to a variety of acceleration-time profiles. A Setra Model 110 sacelerometer was mounted on the ram to measure the acceleration input to the sensor.

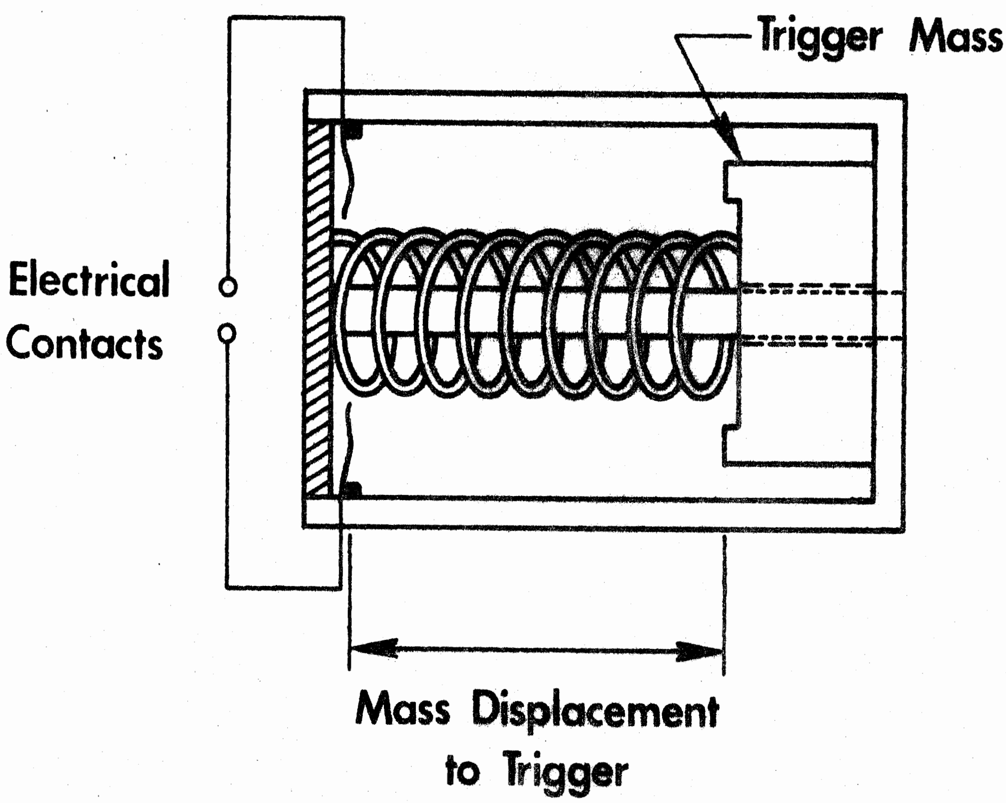
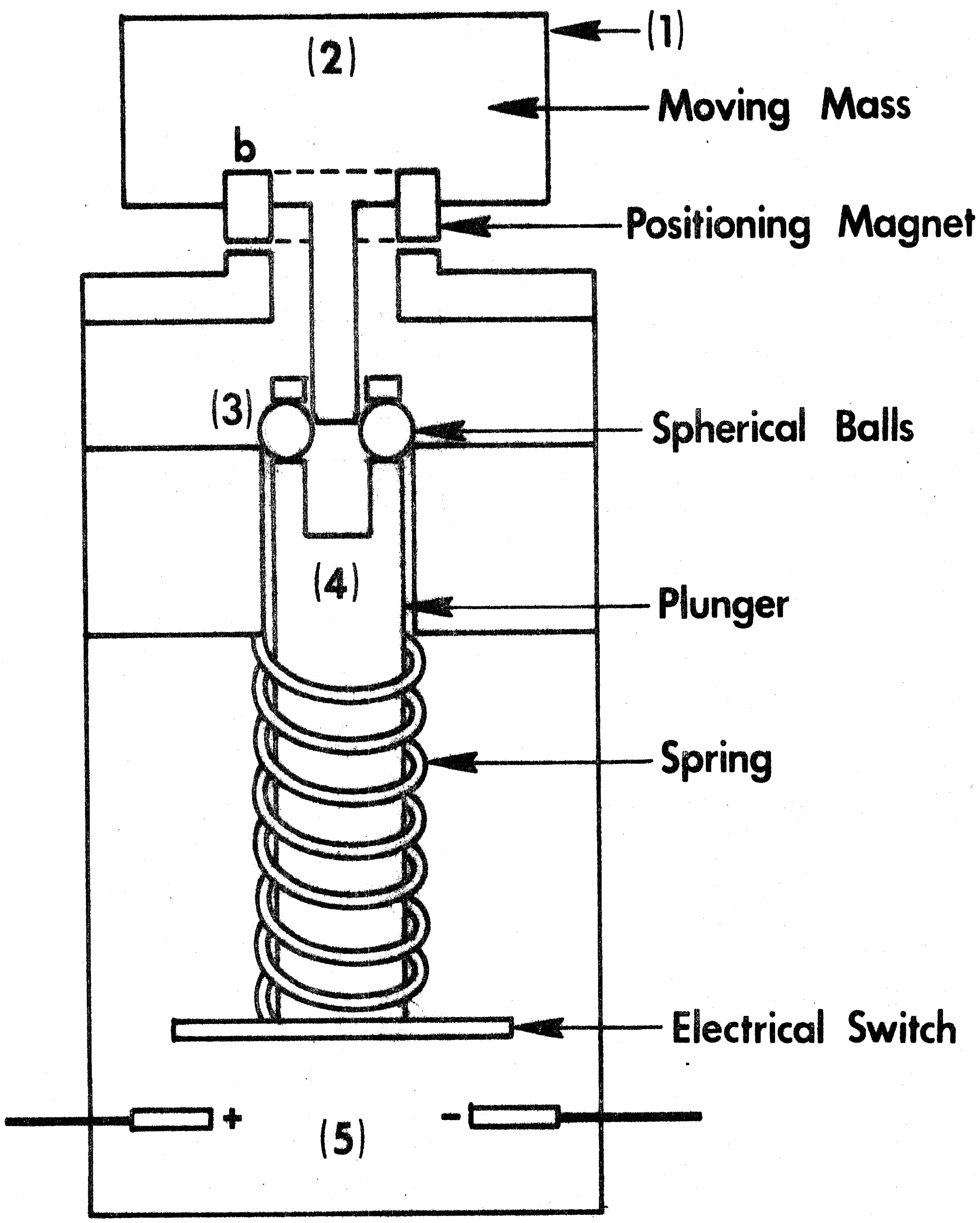
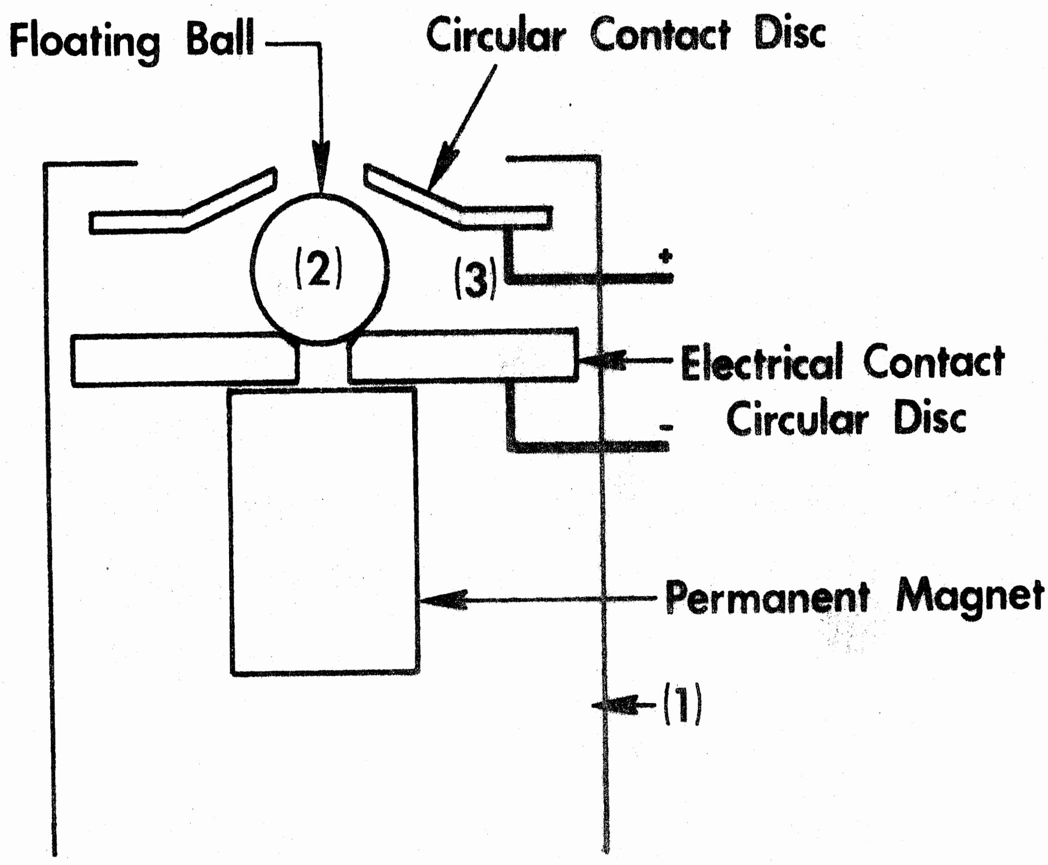


Figure 11. Eaton Autoceptor Crash Sensor.



(1) Deceleration is applied.
(2) Mass moves breaking magnetic field.
(3) Unrestrained balls move into plunger.
(4) Spring forces plunger down.
(5) Circuit is closed and airbag fires.

Figure 12. Delco Electronics Mechanical Crash Sensor.



(1) Deceleration is applied.

(2) Ball breaks magnetic field and rolls on surface.

(3) Contact between two discs closes circuit and fires airbag.

Figure 13. Delco Electronics Safety Sentinel 4 Electronic Crash Sensor.

The accelerometer output was filtered through a Burr-Brown filter meeting SAE J211 channel class 180 specifications. An automobile 12-volt battery was the power source for the sensors. Typical results are shown in Figure 14. It should be noted that for these 30 G pulses which are typical of the initial sheet metal crush in a motor vehicle barrier crash, the airbag would have been triggered in from 10 to 14 msec.

Tests were performed on the Eaton sensor to establish the effect of off-axis acceleration on trigger time. Two different amplitude (11 G peak and 24 G peak) acceleration-time profiles were used. The sensor was subjected to the same pulse each time at angular increments of 10° off-axis, starting at 0 and increasing until the sensor would not trigger. For the 11 G pulse, the G-switch triggered at 24 ms. At 20° off center, the triggering was delayed at 33 ms. and the sensor would not trigger for larger off-axis angles. In the case of the 24 G pulses, the sensor triggered at 15 msec for a direct frontal pulse. This was delayed to 20 ms for a 30° oblique pulse. The system did not fire for larger angles (See Figure 15).

These results lead to two observations which may be made concerning sensing an aircraft transport G-pulse. First, the pulse is not estimated to be unidirectional along the longitudinal axis of the aircraft. Rather, both horizontal and vertical components of the impact will be present. The vertical component may be as great or even greater than the horizontal component in some cases. Second, a unidirectional sensor which is used for sensing one component of an aircraft impact must not be sensitive in its operation to accelerations in directions other than the direction of its axis. The Eaton sensor, for example, could possibly "stick" due to friction when impacted from the side. Omnidirectional sensors would be necessary for use in an aircraft crash incident.

The sensors tested at HSRI can be modified to fit a range of different crash pulses. Thus, it is possible that current designs could be modified for Air Force application. This could be done by modifying the G bias. In the Eaton system, this would require stiffening or softening the spring element to either increase or decrease the bias. It would be necessary to modify the magnetic characteristics in the Delco systems. The mass displacement limit is also variable in the various cases. This would affect the time duration of the G-pulse required to trigger the bag inflation.

All of the commercial sensors evaluated were of basically simple design although the Delco sensors had sophisticated electronic components associated with them. The sensors were potted in tough plastic and hermetically sealed to such an extent that the effects of environment and tampering on the basic sensor components are minimal. Normally, they are mounted by screws on the front firewall of the vehicle.

Several other sensors and sensor techniques have been developed which were not available for testing at HSRI. These include a system developed by Toyota, a concept for using

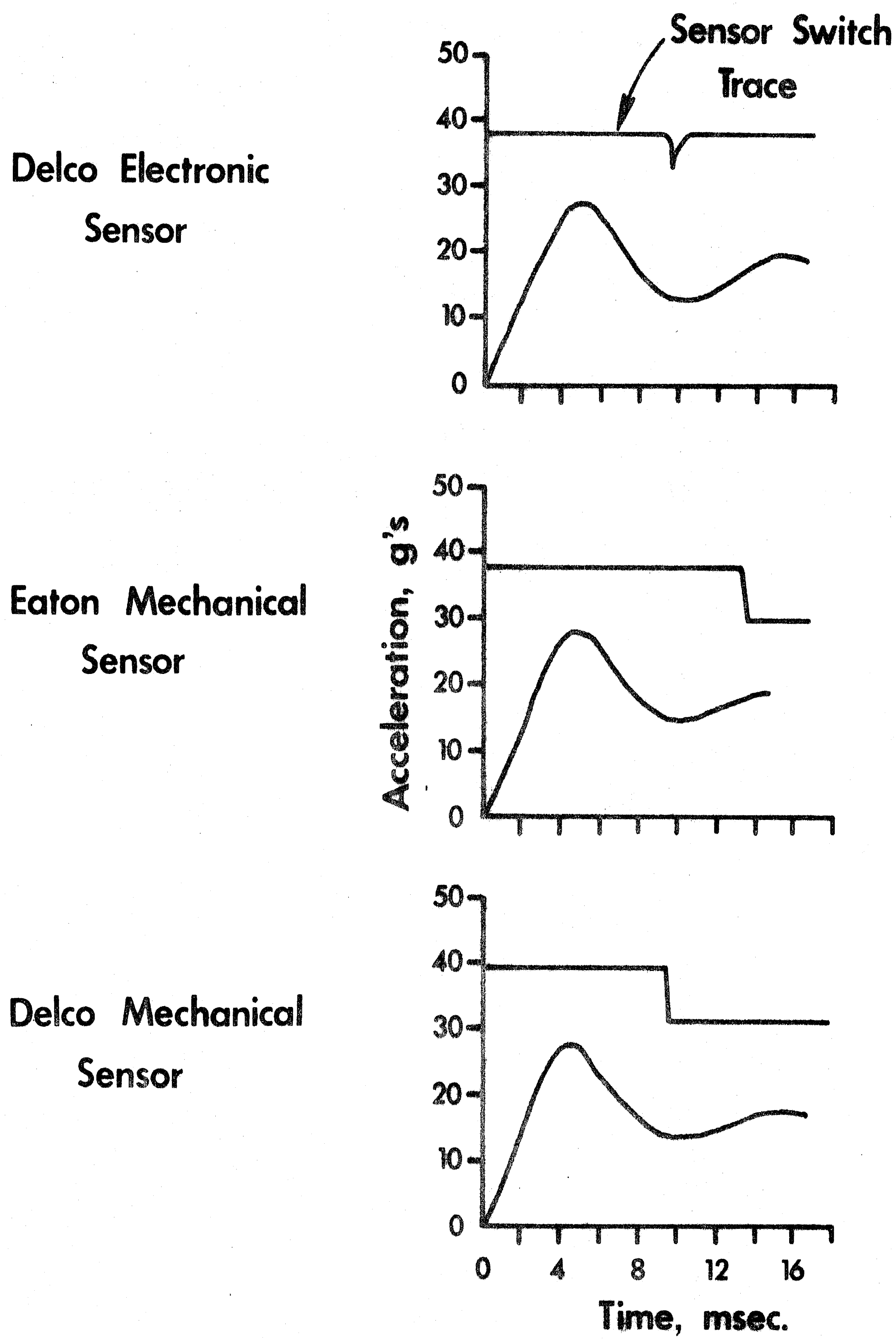


Figure 14. Crash Sensor Response Tests.

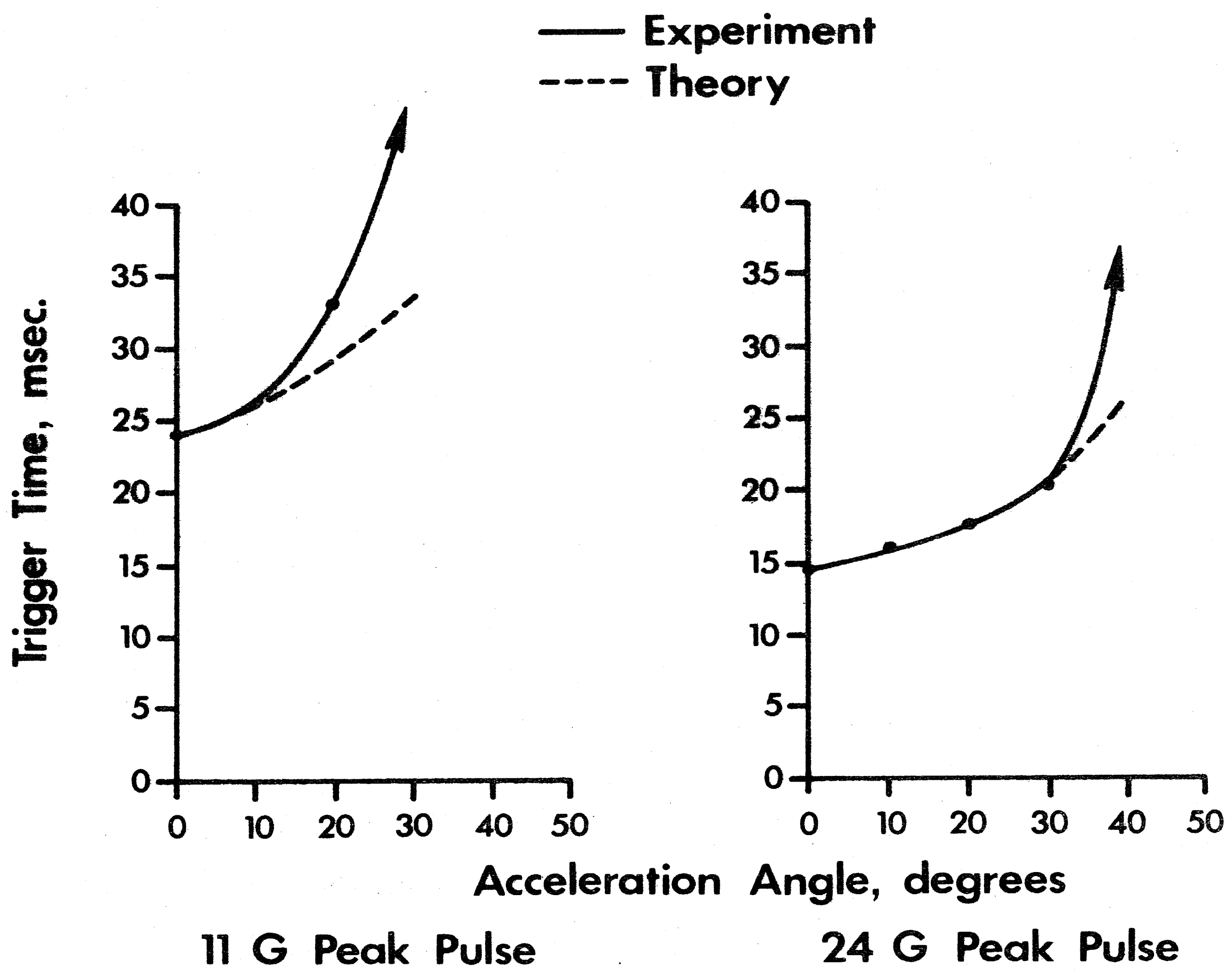


Figure 15. Eaton Sensor Response to Off-Axis Acceleration.

the outputs from an inertial guidance system, and several anticipatory sensors.

A sophisticated sensor has been developed by Toyota (Yamada, 1970) which calculates and predicts the collision before it occurs by sensing relative speed and distance between the car and the object of the collision (see Figure 16). The sensor includes an oscillator, circulator, detector, amplifier, and computer. A microwave is continually emitted which can sense an object. The Doppler effect by reflection of the wave triggers the IORS. This system is not G-dependent and requires only that an object be within a collision envelope around the vehicle. It is commonly known in the auto industry as the "radar sensor."

An additional system which is being investigated for its feasibility is the inertial navigation system (INS). In this case onboard gyroscopes and accelerometers which are already part of this system could be monitored by a special hazard predictor logic circuit to sense emergency situations. This could be coupled with onboard radar equipment to give a rather complete picture of the aircraft's safety status relative to impact. Data on INS have been obtained from the Delco Electronics Division of General Motors. The INS system is currently used on commercial jet transports such as the Boeing 727 and 747 and are retrofitted on some Boeing 707's. This system has also been installed in one operational EC-135 according to AC Electronics.

A comprehensive examination of anticipatory sensing devices has been carried out by the Transportation Systems Center for the National Highway Traffic Safety Administration in order to determine basic system constraints and required operational characteristics (Hopkins, 1971). Two promising methods, including microwave radar and ultrasonic sonar, were selected as deserving further study.

The radar sensor, consisting of standard microwave components and solid state circuitry, was fabricated in an early prototype form and installed on a test vehicle for study. See Figures 17 and 18.

This sensor triggers when the automobile on which it is mounted encounters a simulated target of large size at velocities greater than 15 mph. This was routinely shown by running into large cardboard boxes covered with aluminum foil. A sensitivity potentiometer can be adjusted to give various threshold target sizes. Adjustment for triggering can vary the minimum size of an aluminum foil patch from less than 10 square inches to more than 200 square inches. For a target of given size, triggering is both a function of sensitivity and a function of position. The large target causes triggering farther from the auto than the small target.

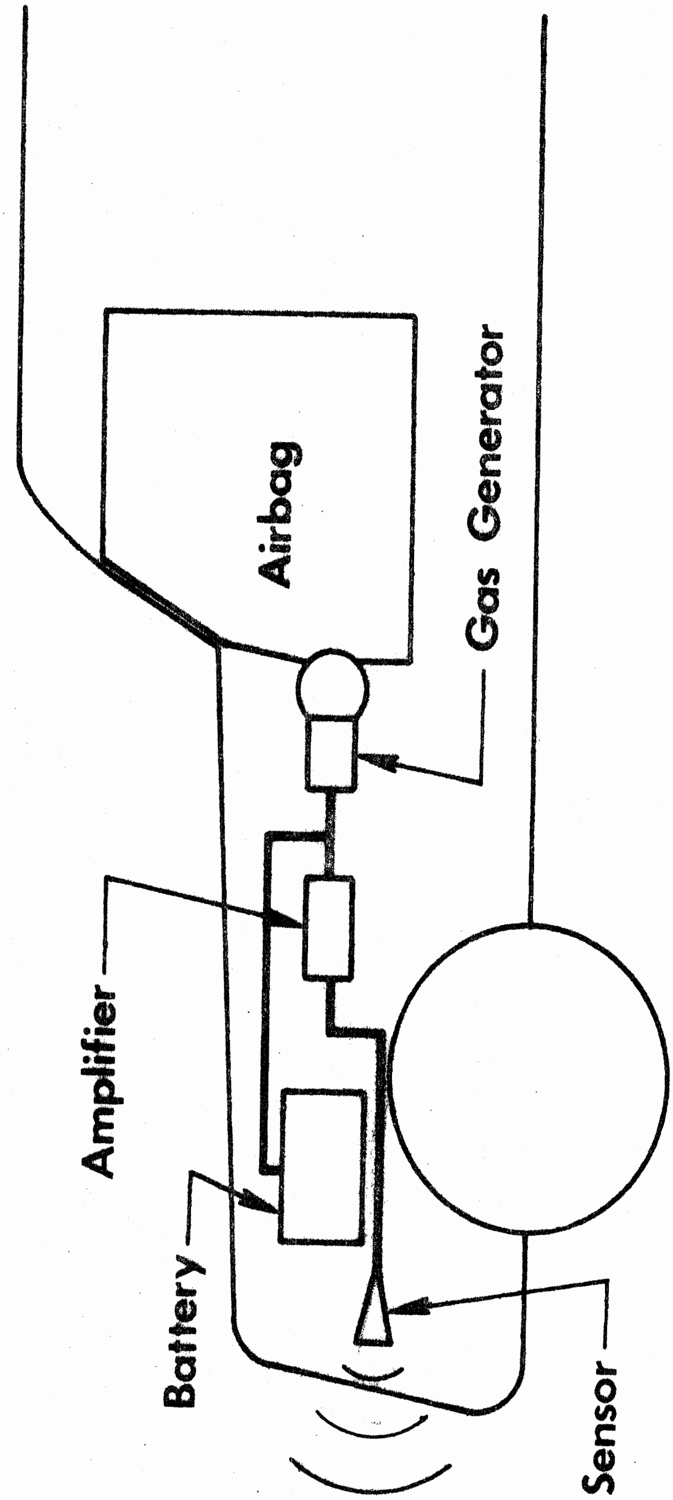


Figure 16. Toyota Radar Sensor.

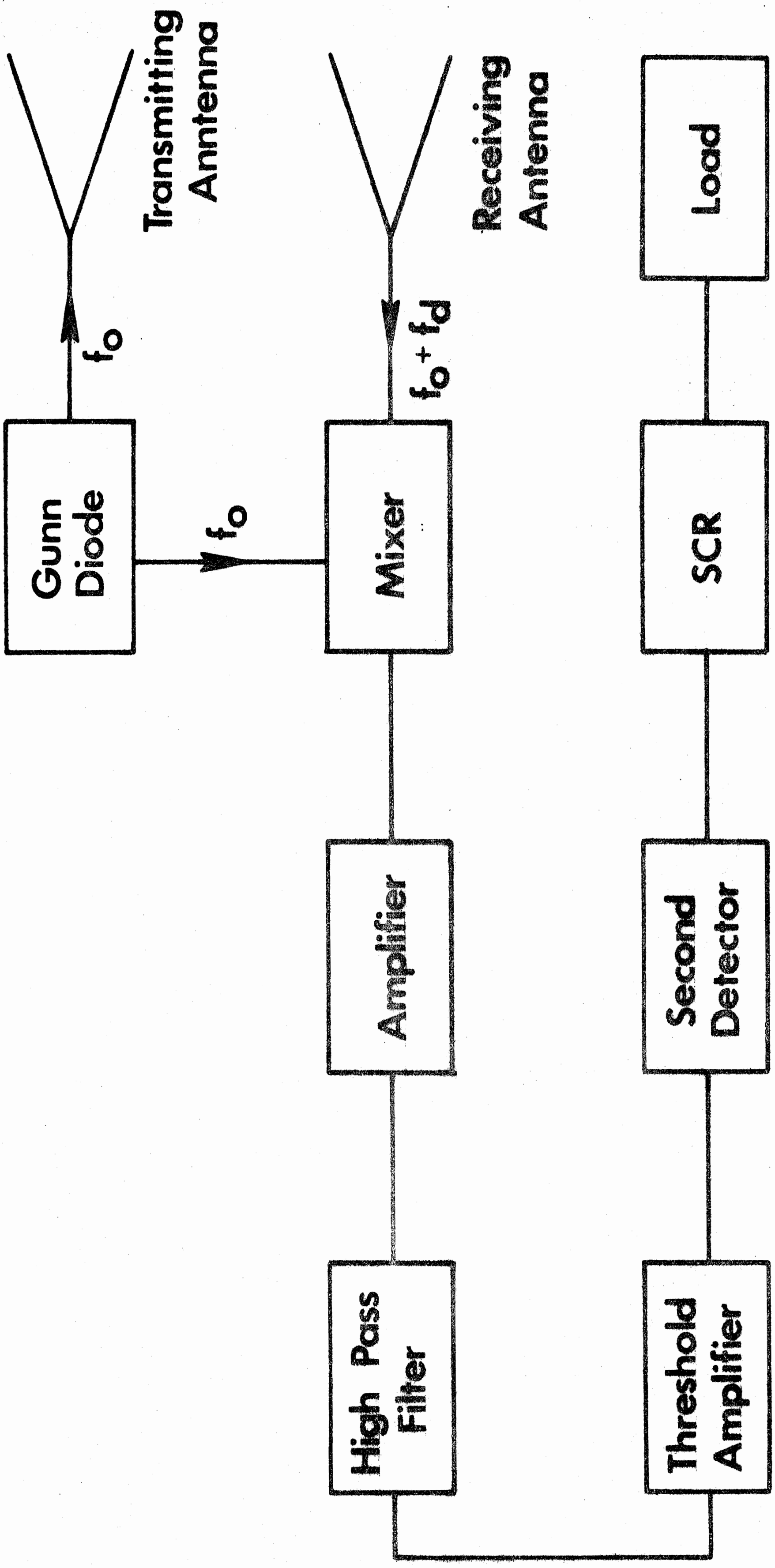


Figure 17. Microwave System Block Diagram

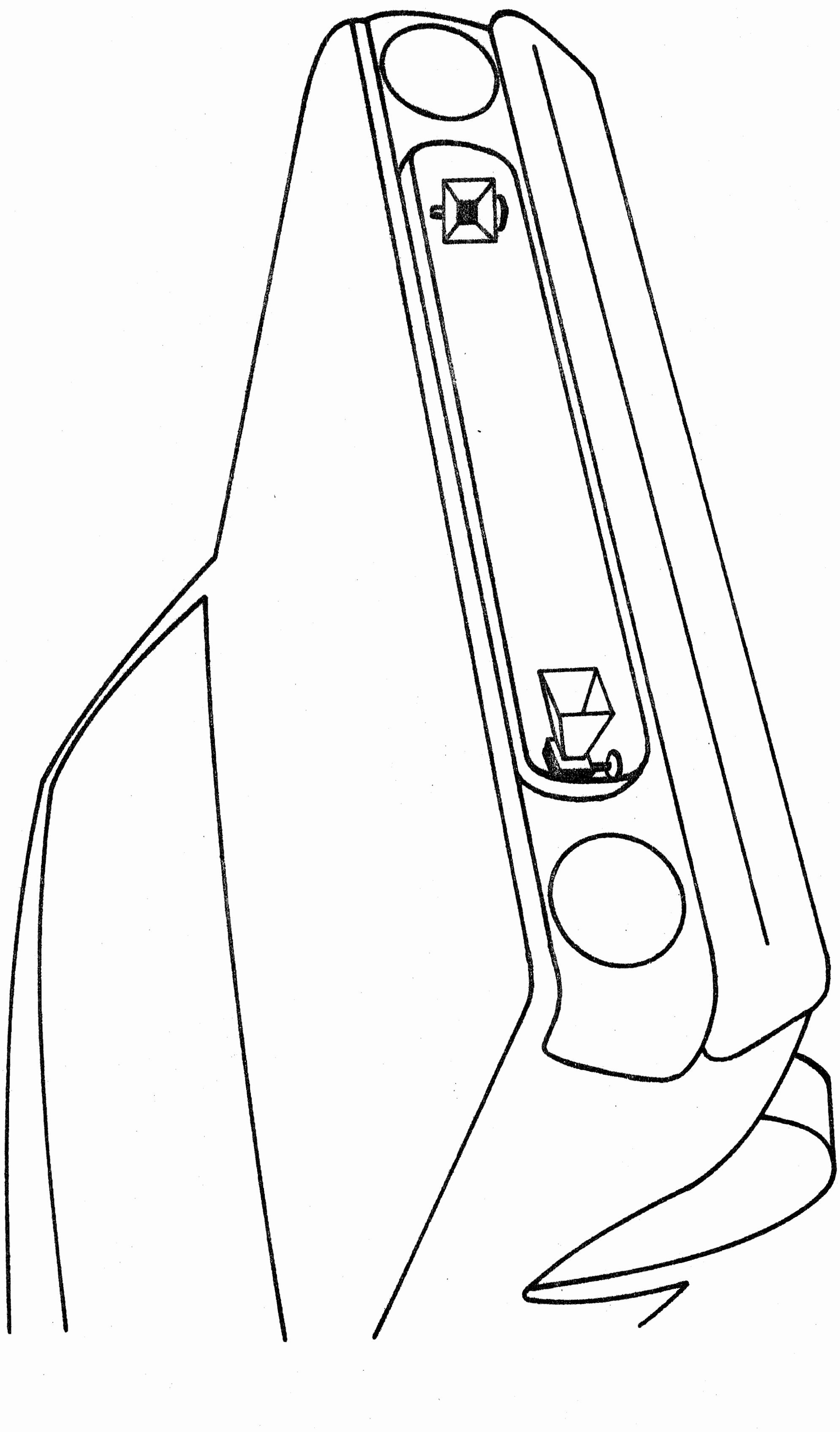


Figure 18. Microwave System on Vehicle

To measure system response to real and false signals, the auto is rolled up to various objects and the Doppler signal recorded. Among the subjects have been trees, concrete posts, telephone poles, other vehicles, concrete walls, and a corrugated metal roadway. With the exception of the corrugated roadway, all targets gave large magnitude signals when compared with the normal road surface. Discrimination depends strongly on antenna pattern and electronic circuit parameters and it has been recommended that much more data be collected to better define optimum prototype designs.

Integrated microwave packages have been developed for use in systems such as described. These contain the microwave diode source, power samples, antenna terminals, and detector diode all in one small rugged package.

The sonar approach is a translation of the radar sensor into acoustic form. A transmitter and receiver are mounted on the front of the auto. A 40 KHz oscillator provides the signal and the receiver feeds this back to an amplifier and mixer providing the Doppler output signal. A 12-volt battery provides power. Schematics of the circuit and vehicle mountings are given in Figures 19 and 20.

Laboratory tests were conducted to study sensitivity and target discrimination. These showed that ultrasonic waves were relatively insensitive to the composition of several target materials (metal, plywood, plexiglass, cardboard, and ceramic). A substantial signal has also been measured for a human body moving toward the system. Only early prototypes, subjected to vehicle tests, have had difficulties in electronic circuitry and demonstrated susceptibility to other high frequency noise present during driving.

SENSOR RELIABILITY. The primary function of a sensor is to notice the beginning of a crash event and to present an electric signal which will initiate bag inflation. This electric signal must be produced within a very short critical time period in order for the restraint system to exercise its protective function. If there is a failure of performance in either of these aspects of sensor function, the restraint system will be useless. Late firing of the airbag could even be injurious.

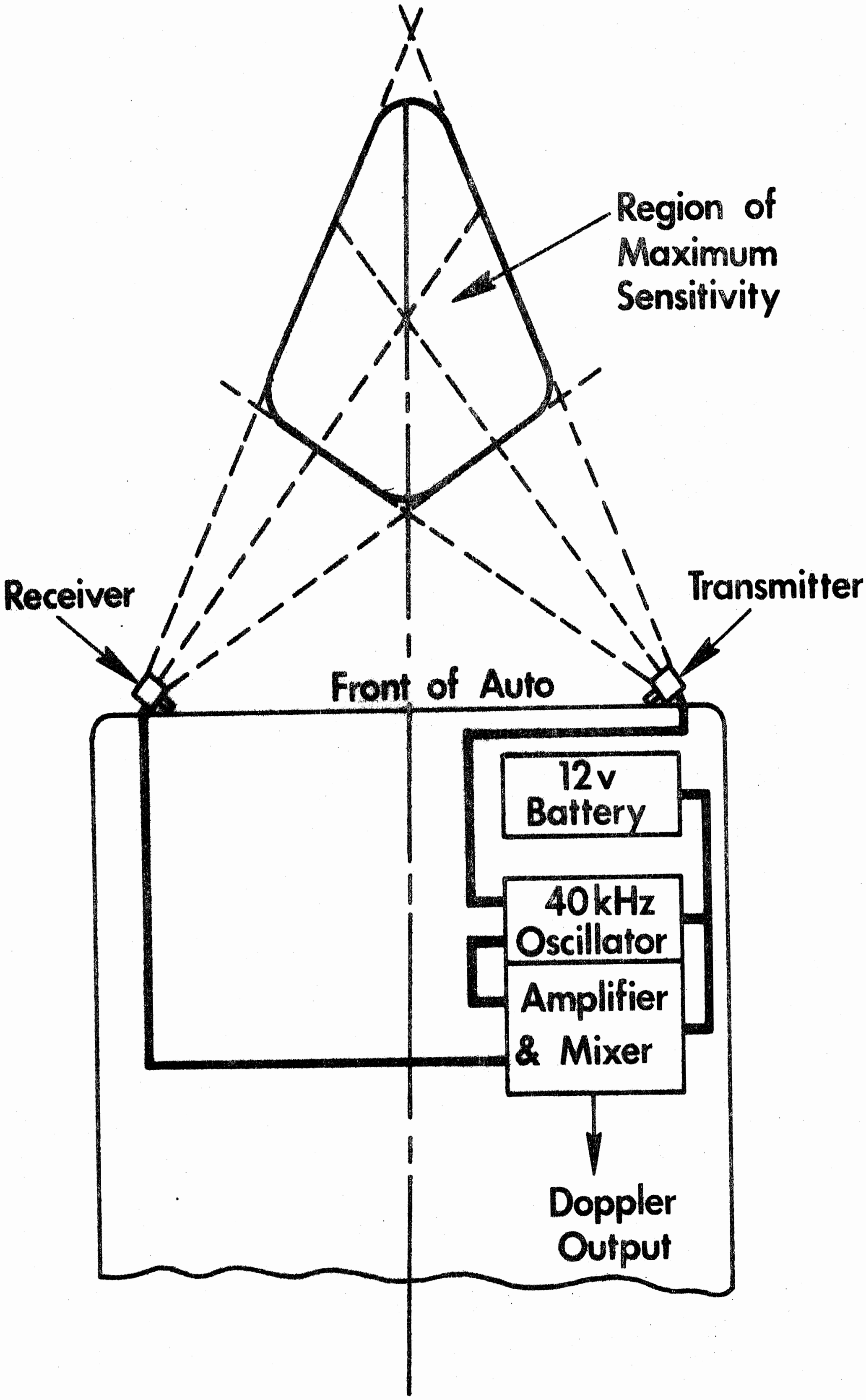


Figure 19. Acoustic System Block Diagram.

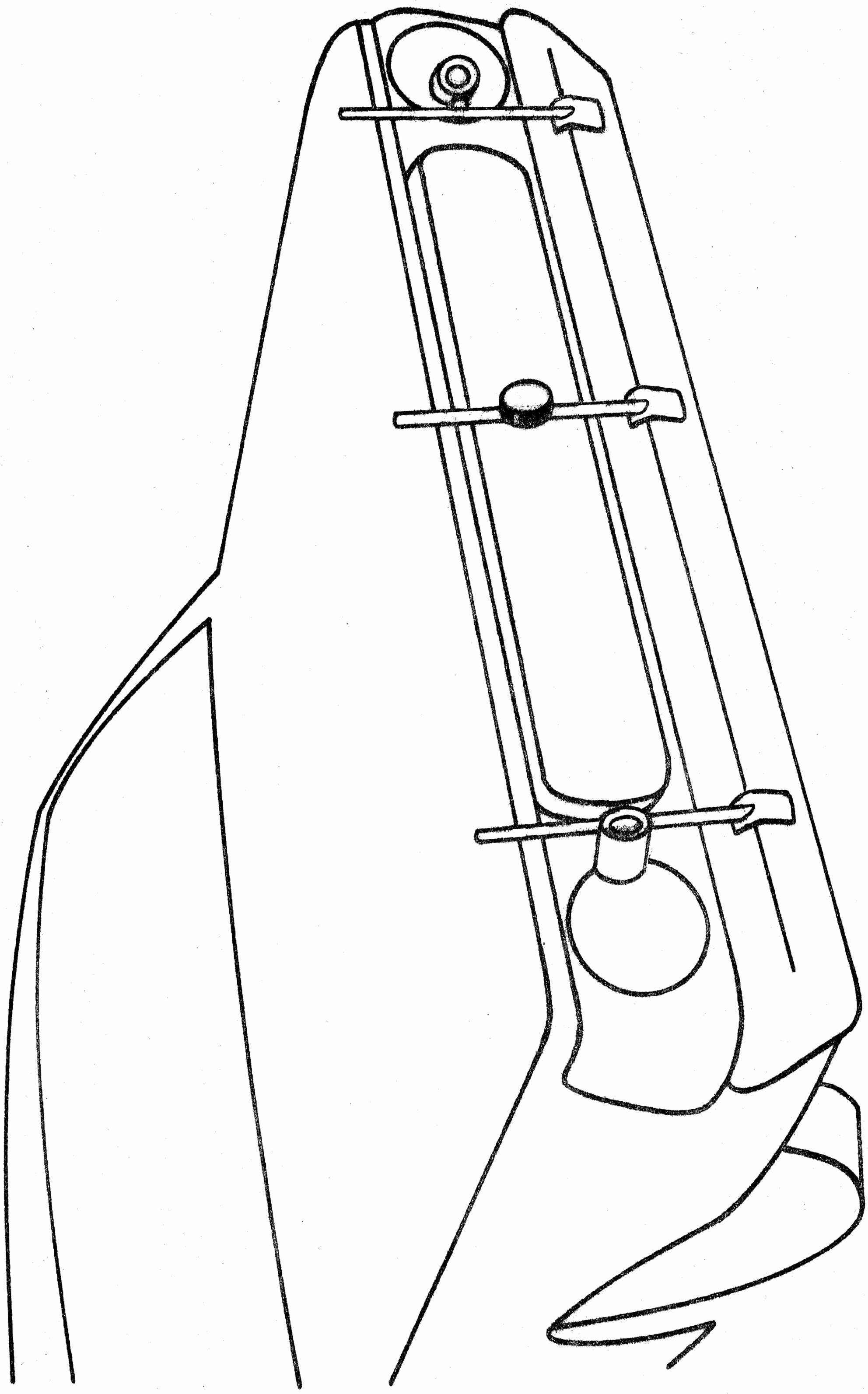


Figure 20. Acoustic System on Vehicle.

What information must a sensor obtain in order to function? In the case of G switches, the information is concerned with the level of deceleration or acceleration. In order to discriminate between the ordinary bumpiness of flight and a crash impact it is necessary to provide dual information on the deceleration level and time duration of the pulse.

Information is currently being gathered to more clearly define the crash deceleration pulses for automobiles. This information is absolutely necessary in order to design a restraint system which will not deploy when you hit a pothole in the road or bang a fender in the parking lot, but which will deploy as needed in more severe impacts. It is still easy to begin a heated controversial argument concerning sensors as they relate to automobiles even though a great deal of developmental research has been conducted in the last few years.

Unfortunately little information on crash G-levels is available for aircraft. None has been gathered on large transport aircraft such as the C-135 and C-141. Some very rough estimates may be possible using crash reports involving these aircraft but this information would be insufficient to design a reliable sensor.

There are two alternatives to a G-sensing crash sensor. The first of these is a radar sensor which observes large objects in the vicinity of the aircraft, predicts an imminent collision, and then triggers the restraint system. This system has the advantage that it is automatic and also that it is not dependent on deceleration data which is not yet available. However, much development work remains to establish an actuation envelope and the level of reliability. The second alternative is active deployment of the restraint system by the appropriate member of the flight crew when a crash situation is likely.

The conclusion which can be reached from this discussion is that only sketchy information is available for the selection of a reliable sensor system for the deployment of inflating occupant restraint systems in jet transport aircraft. The data gathered in automobile crash testing is not directly applicable because of differences in crash pulse (automobile pulses are shorter, more violent, and with a horizontal acceleration vector component).

INFLATION GAS SOURCES. Four basic types of systems have been identified and considered in this study: stored air, augmented air, pyrotechnic and aspirator. Some of the companies active in this area are Olin Corporation, Allied Chemical Company, Thiokol Corporation, Eaton Corporation, Rocket Research Corporation, Ensign-Bickford Company, and other domestic as well as foreign manufacturers.

It is concluded that there are seven generations of inflation systems which have been developed or are under development today. These are:

1. Stored gas system. This system provides a rapid supply of non-toxic gas for any size bag system. The stored gas system is by far the heaviest and most bulky of the systems being considered for introduction into motor vehicles. The air bottle, a thick-walled cylindrical pressure vessel with spherical caps at the ends, has a volume of 160 in^3 and a filled pressure of 3500 psi for a right front passenger installation with a volume of 10 ft^3. Representative systems have a weight of approximately 20 lbs. Because of the propellant properties of the bottle, a substantial structure is required to support it during bag inflation. The system has the advantage of a cool operating temperature and nontoxic gases.

2. Stored gas system with modulated flow. This is the same as the stored gas system with the exception that the gas delivery valve regulates flow to provide a gentler stage of initial inflation. This reduces the inflation sound level and the impact of the bag on an out-of-position occupant.

3. Augmented air system. This consists of a solid propellant which, when ignited, heats a small volume of stored air and then inflates the bag. The size of the package is much smaller than a stored gas system but there is some danger of toxic fumes. The system proposed by Olin Corporation supplements propellant energy with stored air. A prime advantage of this system is smaller storage volume. Specifically, a ten cubic foot bag requires only 60 in^3 of storage compared with 160 in^3 for a pure stored gas system. Olin has chosen aluminum alloy for system fabrication. As a result the Olin system compares favorably from the viewpoint of weight with the pure pyrotechnic device. An additional advantage is that the gases generated by the augmented air concept do not present a toxicity problem. However, when combined with the smoke which could be present in an aircraft crash, toxic levels would develop more quickly than would be the case when a pure air system is used. An additional advantage over a pure pyrotechnic system concerns bag surface temperatures which have been measured to not increase more than 70° F above the test ambient air temperature. An augmented air system of this type appears to have some advantages over either a pure stored air or a pyrotechnic inflation device.

4. Augmented air system with staging. This is the same as the augmented air system with the exception that not all the propellant is ignited in low level impacts thus leading to a soft bag for low level impacts and a hard bag for high level impacts. Staging has also been proposed as a concept to deal with the problem of multiple impacts. Stages of inflation could be added for each impact. This concept has been proposed informally by Eaton Corporation in their activities with Rocket Research Corporation.

5. Liquid-cooled, solid propellant gas generator system. A solid propellant provides the gas source which is then liquid cooled, usually by freon. Although there is a definite saving of weight, there may be problems with toxic fumes due to the freon.

The use of a pure-gas generation inflation system has several advantages as well as disadvantages when compared to a stored-gas system. A typical system is approximately 12 inches long and has a diameter of 3 1/4 in. The shape is roughly cylindrical. The weight of prototypes is approximately 7 lbs. offering a considerable advantage over the stored-gas systems. During inflation, the gas generator operating pressure is 3000 lbs. which is comparable with the stored-gas system. A possible disadvantage is the bag surface temperature which can easily exceed 200° F. Because of the fact that a propellant is required for actuation of the system, certain federal regulations must be met in the transport of systems, either in bulk prior to assembly in a vehicle or by the vehicle owner himself. The legal problems in installing gas generation systems in motor vehicles have not yet been completely solved. Additional controversy arises over the presence of toxic gases resulting during inflation. The major problem appears to be carbon monoxide. Most of the gas generation systems appear to be minimally acceptable relative to carbon monoxide. Serious consideration must be given to the toxicity problem because of the fact that the aircraft could possibly be full of smoke due to the crash. Any additional toxic fumes in a marginal environment could present a serious problem.

6. Solid-cooled, solid propellant gas generator system. This light system in the early stages of development appears to avoid toxicity problems with the addition of a mechanical filter for solid particulate matter and a chemical filter for toxic fumes. See Figure 21.

7. Aspirator systems. Three types of systems are under early development. In the first of these air is mixed with the propellant gas to fill the bag with cool gas. In the second, the support structure for the bag is inflated by a gas generation system and the remainder of the bag by aspiration of cabin air. The major concern is that the amount of ambient air used decreases as inflation time decreases. For a jet transport the available inflation time is probably sufficient to make this system particularly attractive. See Figure 22.

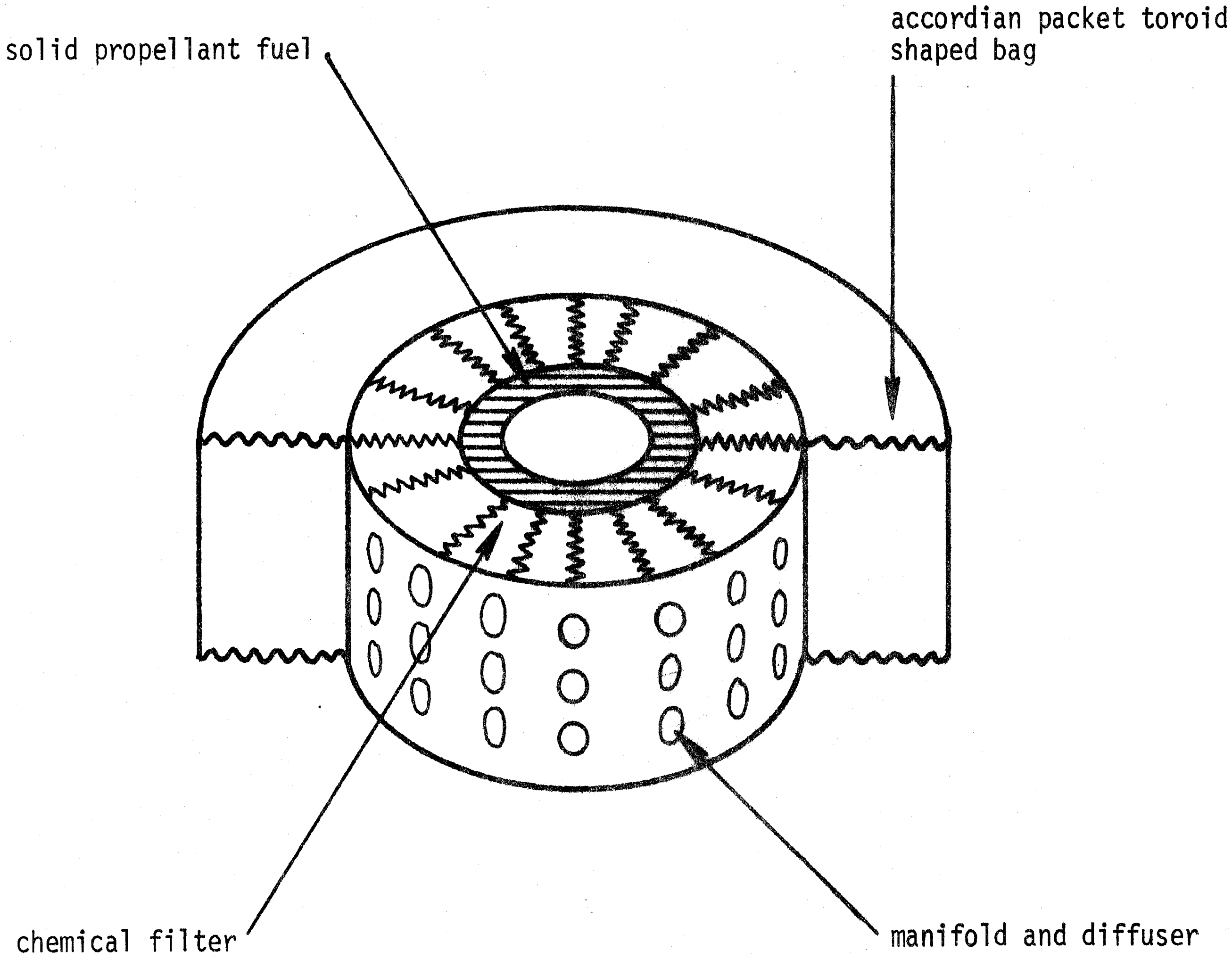
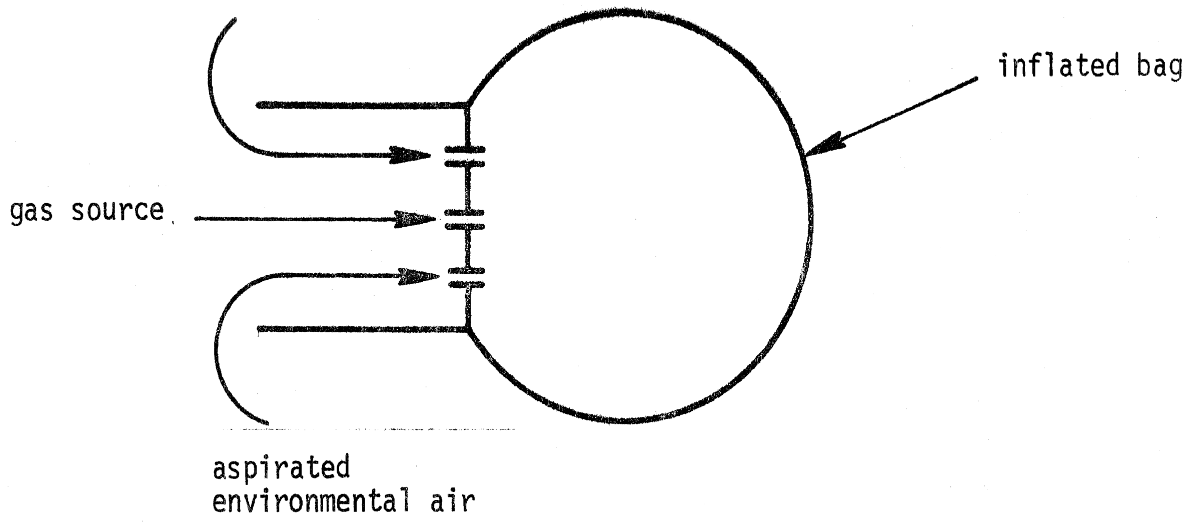


Figure 21. Solid-Cooled, Solid Propellant Gas Generator System.



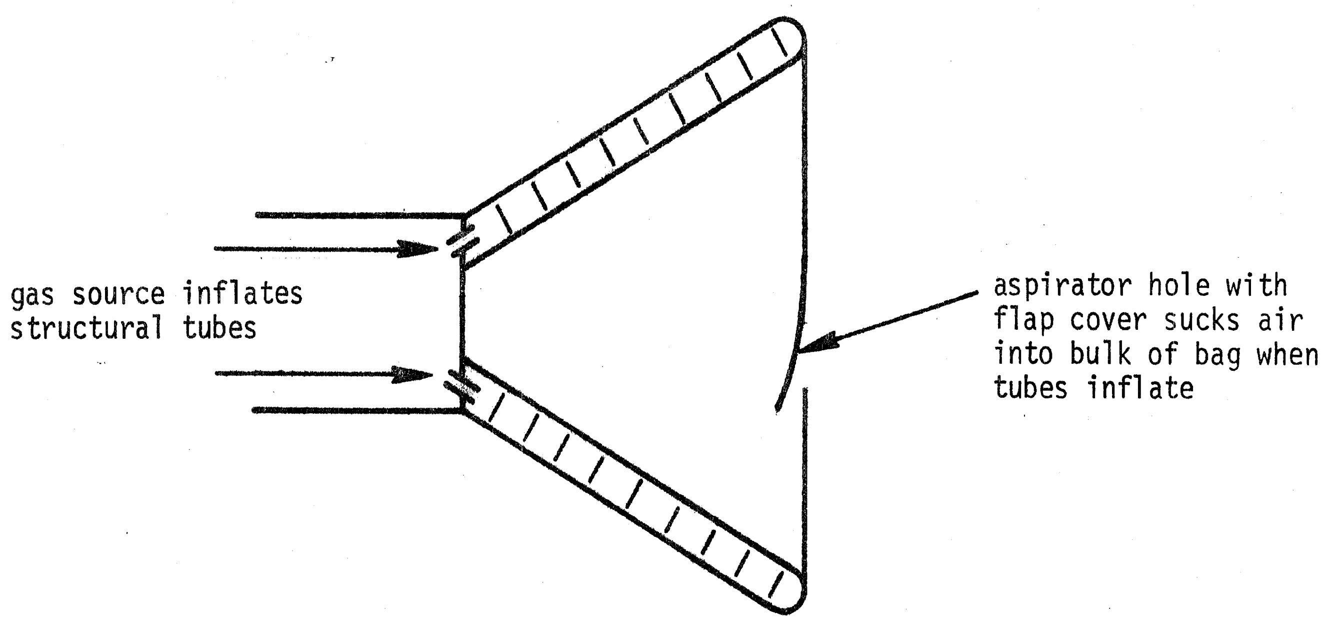


Figure 22. Two Types of Aspirator Systems.

A third aspirator system is the self-deployed air-induction inflation system which has been proposed by Rocket Research Corporation. In this system a series of about 20 small thrusters are attached to the bag material. The thrusters are ignited by the sensor and actually push the bag out while drawing air into the bag. The mass of the individual thrusters is very low and the thrust forces are distributed over the air-bag material. Therefore, if an occupant would contact the system during deployment, the local mass concentrations should not be large enough to cause injury. A considerable weight saving is inherent in this system because there is no need for stored gas or for a diffuser. A rough estimate of the weight of inflation hardware is 2 lbs. The weight of the gas source alone in the other augmented air systems and in the pure pyrotechnic system is 7 lbs., while the weight of the air bottle in the pure air system is about 20 lbs. Rocket Research Corporation is aiming to draw 80 to 90% of the inflation gas required to fill the bag from the vehicle interior. This obviously will result in a lower over-pressure in the vehicle which would be a great advantage when many systems are deployed. No data have yet been obtained concerning deployment accuracy of this system. If protective performance equal to the other systems is available and the low percentage of gases are found to be non-toxic, it would be a likely candidate for use in USAF transports, provided problems of heat where the thrusters contact the body of the occupant are solved.

AIRBAG DESIGN. Several factors should be considered from the viewpoint of the design of the bag itself. Among these are bag size, baq shape, material, and use of vents.

The size or volume of the bags which have been designed for automotive use is very dependent on the occupant position within the vehicle. A driver bag may have a volume as small as 1 ft^3 whereas a right-front passenger IORS usually has a volume of 10-12 $feet^3$. In a transport aircraft application, the back of the seat in front of an occupant is much closer than the instrument panel and windshield which would be in front of a right-front auto occupant. Because of this it is likely that a bag used in a jet transport could be smaller, possibly only half the size of its automotive counterpart.

The shape and deployment of the bag for aircraft use would be governed by approximately the same principles which apply to automotive use. A bag deploying from a position in front of the occupant's knees would provide a cushion for the knees and for the torso of the occupant. A bag deploying at chest level from a position in the seat back in front of the occupant would have to be supplemented by an energy absorbing structure designed to minimize motion of the legs. Both of these designs have been tested widely and can provide equally high levels of protection. The high deploying bag concept has slight advantages in that the bag can be deployed more rapidly.

Several factors have governed the selection of fabric materials as a base for an airbag rather than a film material (Streed, 1971). Among these are: (1) the need for a high strength-to-weight ratio for the material due to the necessity of using as thin and flexible construction of material as possible, in order to meet compact packaging requirements; (2) the necessity for this construction to be almost insensitive to temperature of storage and deployment; and, (3) the need for ultimate reliability in resisting snags or tears coupled with minimal thickness and tear resistance, since tear resistance is the most outstanding property of a woven fabric.

Three factors govern the use of coatings on most fabrics which have been chosen for application in airbags. The first of these is the ability to control the gas permeability of the fabric. Second, a coating serves to protect the fabric and occupant from heat if a pyrotechnic inflation device is used. Third, a coating on the fabric gives the designer more flexibility in the design of the airbag since it permits seams with any contour, that are as strong as the fabric itself, as compared to the limitations imposed by the use of an uncoated fabric with its need for sewn or adhesive bonded seams.

Fabric requirements are based on high strength-to-weight ratio and maximum elongation, minimal weight, temperature insensitivity, high cover factor, and capability of coating by commercial process. Candidate materials are nylon, dacron, rayon, glass, and cotton. The most desirable properties seem to be embodied in a 5.5 oz. ripstop nylon.

Air-bag systems may be either vented or unvented. Generally driver bags installed in the steering column are unvented whereas the right-front passenger systems employ venting techniques. One of the main functions of a driver bag is to distribute the load uniformly over the chest. Energy can be absorbed during collapse of the energy absorbing (EA) column. Passenger bags of current design require some type of venting primarily to allow energy absorption and to prevent potentially dangerous rebound of the occupant into the seat back. Present venting systems consist of either plastic patches which blow out allowing gas to escape from the bag or porous panels which allow the gas to escape through the bag material itself. Both of these techniques have been employed in passenger bags which have been extensively tested on the impact sled at HSRI. No large differences in performance have been noted when a 50th percentile male dummy is used. It is possible that there may be some advantage in using porous panels in that patches have been observed to blow out during the rather wild contortions observed in an airbag during deployment permitting premature venting of gas from the bag. In other words, it is possible that the porous panels could be designed to provide more consistent performance than is possible with blow-out panels.

DIFFUSER DESIGN. The diffuser is that component of the system which delivers the gas supply to the deploying bag. As such it controls the rate and direction of flow into the bag. Therefore, the design of the diffuser is critical in providing a successful deployment.

Most diffuser designs with which the authors are and which are used in right front inflating restraint systems consist of a cylindrical steel tube with a series of vertical slots through which the gas supply can flow. One important variable is diffuser diameter (as diameter is increased, slot area is also increased). Initial air-bag tests at HSRI were conducted using a diffuser with a diameter of 2 inches. It was found that a small out-of-position dummy occupant placed close to the bag experienced potentially dangerous G-loadings on the head and torso due to bag inflation alone. When the diameter of the diffuser was increased to 3 inches, thus reducing the initial velocity of the deploying bag, the G-loadings were reduced to acceptable levels based on current human tolerance data.

Another aspect of diffuser design which is being studied at HSRI is the effect of the slots on sound pressure levels (Nicholls, 1970). The gas dynamics of the reservoir blowdown-bag inflation process have been considered and characteristic values of the more important parameters have been computed by the use of a somewhat simplified mathematical model of the system. A series of steady-flow tests have been made over a range of pressures to determine the noise level produced by various types of slots. Schlieren photographs (still and high-speed movies) have been taken of the flow from the slots. The preliminary data indicate that interference effects between the individual jets leads to higher noise levels than would be expected from an increase of mass flow rates alone. Further steady-flow tests of various slot configurations have been planned. It is anticipated that these steady-flow tests will be compared with projected blowdown tests of a typical air-bag system in order to define the characteristics of the major noise generating mechanisms and thereby indicate the techniques most likely to result in reduction of peak noise levels.

SOUND FROM INFLATING RESTRAINT SYSTEMS

The most complete and detailed study of the sound emanating from an inflating restraint system has been conducted by Bolt, Beranek, and Newman, Inc. (Allen et al., 1971) under contract with the National Highway Traffic Safety Administration

(Contract No. DOT-HS-006-1-006). The three purposes of their study were to: (1) establish tentative criteria for exposure to airbag noise; (2) find the noise levels expected in motor vehicles; and (3) estimate the percentage of the population, if any, whose hearing might be permanently affected by widespread exposure to the noise of inflatable restraint systems. In addition they have reviewed and discussed in detail previous efforts such as those of Nixon (1969, 1970).

These purposes were accomplished and their tentative conclusions are summarized in the following. They have estimated, based on tolerance data developed during the project, that exposure to a full complement of motor vehicle airbags inflated simultaneously could lead to hearing damage in 15% to 30% of the exposed persons. This indicates a considerable problem with airbags of 1970 vintage. After interpreting the limited available information they concluded that various special groups (young, aged, infirm, or those with hearing related problems) are not substantially different from the normal population and therefore could be included in recommendations based on their general tentative criteria.

The possibility of reducing the sound levels to more acceptable levels using available acoustical engineering techniques has been pointed out and recommended. For example, they estimate that a reduction of 15 db. in air-bag noise would insure that essentially the entire exposed population would be protected from hearing damage.

Because of the tentative nature of their noise criteria the following research studies should be conducted: (1) psychoacoustic studies of the temporary threshold shift produced by pulses of noise and/or pure tones at the frequencies, levels and durations anticipated for air-bag deployment; (2) analyses of the noise signal as a function of frequency, duration, and occupant position for each of the several sources of noise in a deployment of a realistic airbag; and (3) complete literature survey covering all types of impact noise exposure along with the physical and clinical aspects.

The diffuser system most prominently employed in delivering gas to an air-bag system (a manifold with slots) has been subjected to a limited set of tests at The University of Michigan by Nicholls (1970). The noise levels were determined for one-, two-, and three-manifold-type slots on a steady-flow basis over a range of pressures. Still and high-speed Schlieren photographs were taken of the flow from the slots.

The preliminary data have indicated that interference effects between individual jets leads to higher noise levels than would be expected from increase of mass flow rates alone. The conclusion reached is that the manifold slot configuration is capable of producing very high noise levels, when a large number of slots are supplied with expected operating manifold pressures. Although the configuration of the reservoirs, throat, and the manifold entrance section may, directly or indirectly, contribute to the overall sound level, the potential for noise reduction appears to be greatest in the area of manifold "slot" design. Both automobile manufacturers and suppliers are working on this problem with some apparent progress.

It is apparent from reading the few reports available on this subject that only a beginning has been made on the two fundamental problems relating to noise from airbags: (1) What is human tolerance to noise generated by air-bag systems? and, (2) What design factors are involved in reducing noise levels by application of acoustic engineering principles? A good deal of research remains to be accomplished in this subject area.

HUMAN VOLUNTEER PERFORMANCE TESTS

A variety of test results have been reported during the past year where human volunteers have been used to examine various aspects of air-bag performance. The tests were carried out on the Daisy Track at Holloman Air Force Base under both Air Force and Department of Transportation sponsorship. Pertinent reports have been issued by Gragg (1970), Bendixen (1970), McElhaney (1971), and the Department of Transportation (1971). A variety of conclusions have been made based on these tests which are quite favorable for airbag performance.

The preinflated-bag tests reported by Gragg (1970) may have application to jet transport aircraft in that there may be a short time before a crash occurs for the occupant to position himself in the restraint system. The conclusions were as follows: (1) the legs are able to transmit considerable force during an impact verifying the work of other investigators; (2) the bag is most effective when the occupant is in contact with it prior to impact so that he loads the bag before the belt eliminating the phase lag which can occur between belt and bag loading; (3) a version of this type airbag would reduce the incidence of head and thorax contact with hazardous interior surfaces during crash landings, materially reducing the fatalities and trauma resulting from such impacts; (4) the airbag gave the sled subject a relaxed, confident feeling prior to impact and they were enthusiastic in their acceptance of the device; and (5) it was difficult to control the amount of bracing of the subjects' legs (this factor appeared to be related to the subjects' emotions).

A comparison between lap belt, Air Force harness, and air-bag restraint systems was also reported by Gragg (1970).

The airbags were deployed upon impact for this test series. In addition to similar results related to subject bracing, the following conclusions were reached. First, the lap belt plus airbag lowered both impulse and peak force loadings to the pelvis when compared to the lap belt only (obviously because the loading is distributed between two devices during the air-bag tests)[2]. Second, the Air Force harness produced slightly less reduction of the pelvic loading when compared to the lap belt only (when the stiff belt system is snug, as was the case in these tests, the occupant tends to interact with the lap belt before reaching peak interaction with the softer bag). Thus the bag, as currently used, can do little to reduce pelvic or knee loads. The combination of an energy-absorbing lap belt in combination with the airbag can be shown to aid in overcoming this problem in phasing the forces applied to the occupant. Third, the lap belt plus airbag increased the foot loading significantly when compared to the lap belt only and the Air Force harness. Because of the potential of the legs for carrying impact loads this redistribution of loading is desirable.

McElhaney (1971) conducted an analysis of data gathered in a test program conducted by Bendixen (1970) at the Daisy Track, Holloman AFB. The data gathered in these tests is summarized in Table 3. Tha analysis indicated that a lap belt plus a rapidly inflating bag performs significantly better than the lap belt alone because they reduced: (1) linear and angular head motion; (2) linear head acceleration; (3) shoulder motion; (4) pelvic pain; (5) foot pan load; and (6) seat-back rebound load. Most of these observations agree with the results of Gragg.

The most recent data are in a report issued by the Department of Transportation (1971) to its Docket 69-7 concerned with Motor Vehicle Safety Standard No. 208 on occupant passive restraint. The tests were designed to be "mechanically equivalent to inadvertent inflation of an airbag in a vehicle (moving) at constant velocity." The subjects were in various positions and postures in the body buck. Quoting from this report:

"Static evaluation testing was terminated on February 17, 1971. During the test series, one subject's apprehension about additional exposures (the subject received marked abrasions, contusions, edema, and erythema to the right side of his chest on his second exposure) caused him to be

[2]Note: Remarks in parenthesis are observations based on HSRI air-bag research such as that reported by Robbins (1971).

TABLE 3. SUMMARY DATA PEAK VALUES

Restraint System	Run No.	Subject No.	Weight #	Height cm.	Pulse g's	Lap Belt #	Foot Pan #	Seat Back Rebound #	Neck Pain	Pelvis Pain	Chest g's	Head* Δx in	Head* Δy in	Head* Δθ degrees	Head* $\Delta\dot{x}$ ft/sec	Head* $\Delta\dot{y}$ ft/sec	Head* $\dot{\theta}$ rad/sec	Head* $\Delta\ddot{x}$ g's	Head* $\Delta\ddot{y}$ g's	Head* $\ddot{\theta}$ rad/sec²	Shoulder* Δx in	Shoulder* Δy in	Knee* Δx in	Knee* Δy in	Thigh* Δx in	Thigh* Δy in	Thigh* Δθ degrees
Lap Belt Only	4795	144	158	169	8.3	240	717	594	-	-	7.0	13	9	47	29	10	8	11	5	200	7	2	1	1	1	1	5
	4796	146	199	176	9.8	563	384	975	+++	-	8.8	18	18	75	34	31	29	13	14	800	15	6	3	3	3	1	12
Pre-Inflated Bag	4800	151	178	177	9.4	683	131	140	-	-	9.6	18	5	65	29	6	22	10	4	1100	11	2	0	1	2	1	21
Lap Belt Only	5082	118	136	180	11.6	666	150	410	-	-	10.5	25	27	108	37	41	33	18	16	400	21	13	4	4	4	3	11
	5081	128	155	171	12.4	949	245	163	++	-	18.3	28	27	127	39	46	45	24	18	1600	19	8	5	5	4	2	20
	5077	144	158	169	12.6	687	445	673	+++	-	12.6	21	16	110	32	16	16	11	8	500	14	3	1	2	1	1	6
	5078	127	177	185	11.5	703	340	551	++	-	8.5	17	12	85	32	20	24	11	8	500	14	5	1	2	1	1	10
	5079	151	178	177	11.4	1030	282	760	++	+	22.1	19	16	100	37	28	45	17	18	1700	16	6	1	3	1	1	16
	5080	146	199	176	10.1	530	605	949	+++	-	17.3	15	14	72	31	23	24	11	10	400	11	6	1	2	1	1	9
Lap Belt Plus Hybrid Airbag	5095	118	136	180	11.0	603	101	240	+	-	15.2	13	1	20	36	3	14	25	3	550	1	1	1	1	1	1	8
	5094	128	155	171	11.9	147	283	880	-	-	15.0	11	2	62	36	5	31	19	5	1000	4	1	1	2	1	1	14
	5097	144	158	169	12.4	500	920	808	++	+	16.2	17	6	100	44	16	43	22	14	1200	1	1	1	1	1	1	7
	5096	127	177	185	13.0	990	262	980	++	-	17.2	15	6	70	41	13	30	20	14	700	3	1	1	1	1	1	6
	5099	151	178	177	12.1	1126	122	430	-	+	14.8	9	2	27	9	34	17	18	8	250	4	2	1	1	1	1	29
	5100	146	199	176	10.0	500	590	1348	-	+	17.2	8	3	19	33	8	26	32	10	1000	0	0	3	3	3	1	14
Lap Belt Only	5179	118	136	180	14.6	800	540	360	++	-	11.4	18	20	13	33	29	36	13	10	550	15	13	0	4	1	2	12
	5175	128	155	171	15.3	903	404	500	++	-	16.4	25	27	138	38	41	36	19	11	700	15	11	1	3	0	1	13
	5177	144	158	169	15.4	808	755	440	-	+	14.6	22	18	122	36	24	25	13	12	1050	16	7	0	3	0	2	9
	5174	127	177	185	16.8	1050	474	640	++	++	15.9	25	25	128	36	36	35	17	13	900	16	10	1	3	0	2	12
	5178	151	178	177	15.0	1163	370	860	++	-	18.3	18	18	23	33	29	41	14	11	650	18	9	0	3	1	2	16
	5176	146	199	176	15.4	1120	714	760	-	+++	23.4	23	22	102	31	29	39	13	10	1500	19	11	1	4	1	2	13
Lap Belt Plus Rapidly Inflating Airbag	5225	118	136	180	11.6	600	301	N/A	-	-	12.1	7	3	40	30	5	26	12	10	1100	3	1	1	5	2	1	15
	5224	128	155	171	11.3	780	560	N/A	+	-	12.1	7	4	38	19	8	27	8	4	480	8	2	0	2	0	1	12
	5226	144	158	169	11.8	510	686	N/A	-	-	11.6	10	3	76	34	6	22	8	5	600	6	1	1	2	0	1	3
	5227	127	177	185	11.8	600	368	N/A	+	-	11.6	7	1	43	32	3	14	10	4	600	4	2	2	1	2	1	6°
	5228	151	178	177	11.8	890	144	N/A	+	-	16.2	7	3	61	27	10	20	9	14	600	3	2	0	3	1	1	10

- = No reported symptoms ++ = Persisting symptoms 24 hours

+ = Immediate Symptoms Only +++ = Persisting symptoms 48 hours

*From photometric analysis

replaced. But, it can be stated, with qualifications apparent in this and the following paragraphs, that no serious injuries were recorded on any of the subjects. Subjects were exposed to all positions as described in the protocol with the exception that no subjects were positioned closer to an undeployed system in the leaning series than a thorax-horizontal angle of 61° (this showed a distance from face padding to folded airbag of 11.93 inches, from face padding to instrument panel of 6.67 inches). Also, in order to get to these limits, the following provisions of the protocol were used:

> 'Additonal duplicate tests may be conducted at the discretion of the medical investigator. Likewise, in order to continue collecting Kinematic data, means of protection may be used as required.'

A more exact description of the means of protection utilized to attain these limits, especially of the 'hands on the dash' and the 'leaning forward' positions, will be included in the final report, as adequate face protection was used in all of the leaning tests and under-arm protection was used for all arms forward tests for thorax-humerus angles from 74° through 60°."

"Subject P on test SF-74, leaning at 68°, complained of headache and immediate post-run disorientation and confusion. Subject M on test SF-76, also leaning at 68°, developed a frontal headache which persisted for three days. Subject E on test SF-88, leaning at 61°, developed a mild concussion. The learning tests were then terminated by the medical investigator at a thorax-horizontal angle of 61° because in his opinion further testing would have imposed an undue injury hazard to the subjects."

Most of the data presented in the previous paragraphs are favorable to the air-bag restraint system. It does appear, however, that additional work must be conducted to fully evaluate the effects of the airbag on a poorly positioned occupant. As additional information on the human test programs conducted at Holloman becomes available, it should be used to amplify and complete this analysis.

OPERATIONAL TEMPERATURES

Limited information is available describing the temperature range over which air-bag restraint systems may be expected to operate due to the fact that most devices are in the prototype developmental and test stage. A variety of stored air, augmented air, and pyrotechnic inflation sources have been stored at temperatures ranging from 180° F-300° F without any decrement in performance. These systems, intended for automotive use, must be expected to resist rather extreme temperatures because of potential positioning in the instrument panel area of a motor vehicle.

Although most reported test inflations have been conducted at 70 ° F the augmented air system developed by Olin has been subjected to operational temperature extremes without serious performance decrement. A range of -25° F to 180 ° F was covered.

Most air-bag fabrics have satisfactory mechanical properties in the temperature range of interest but the coating materials show more variability. Materials such as neoprene show excellent stability and strength retention at temperatures as high as 200 ° F to 220 ° F. At the lower end many coating materials became rather brittle at -20 ° F. Neoprene may possibly be satisfactory to -50° F and natural rubber to -70 °.

ALTERNATIVES TO INFLATING RESTRAINT SYSTEMS

Both Nissan Motor Company, Ltd. (Maki, 1970) and Hamill Manufacturing Company have proposed passive net restraint systems for automobile occupant protection. General Motors is also known to be active in this area but published data are not known to be available. Deployable nets have both advantages and disadvantages when compared with airbags. It should also be noted that both types of systems require the use of a crash sensor, the problems of which have been described previously.

Net material is highly suitable as a restraint material. It is lightweight, can be fabricated with excellent shock-energy-absorption properties, and is sufficiently strong.

Configurations have been tested involving both front- and rear-seat automobile occupants as well as the driver. Gross body motions were observed to be arrested but certain biomechanical details will require further studies. One of these is the localized loading of the mesh on the skin of the occupant. Mesh size appears to be an important variable in system design. Another problem is the observation of whiplash as occupant motion is arrested. It appears that a net must be designed with mechanical properties which vary with the impinging occupant body segment. For instance, the head should be allowed to penetrate the net to a greater extent than the chest at a lower load.

Net restraint systems are free of the noise and pressure problems occurring with airbags. The mechanism is simple and following solution of the biomechanical problems this system should be at least as competitive as airbags for application in jet transport aircraft.

SECTION V

SCHJELDAHL SMOKE HOOD AND OTHER MASK PROTECTIVE DEVICES

BACKGROUND

The need for protection of passengers and crew from the effects of toxic fumes, inhalation of smoke and flame has been indicated in investigations of both civil and military jet transport accidents. Smoke inhalation has been shown to be a significant factor in the incapacitation of passengers resulting in their inability to evacuate the aircraft prior to its destruction by fire.

A review of survivable USAF passenger carrying aircraft accidents resulted in the conclusion that fire was a prime factor in limiting the successful egress of the passengers (Reagin, et al., 1970). Studies by Sawyer (1967) of 196 cargo-transport accidents involving 1899 occupants occurring from 1962 to June 1967, indicate the overall incidence of fire was 35%. Of these 69 USAF cargo-transport accidents involving fire during this period, 16 resulted in major or fatal fire injuries, 74% (or 139) of the 189 fatalities were attributed to fire, resulting in "the risk for aircrew was 34%, whereas 93% of all passenger fatalities were due to fire" (Sawyer, 1967). Reviewing 40 selected USAF passenger-carrying accidents from 1964 through 1968, Brown (1969) found that many fatalities occurred even though the crash itself was survivable. This was confirmed by a recent review by the authors of 30 C-135 accidents occurring from 1964 to date, and 14 C-141 accidents from 1968 to date. In one case involving a C-135 accident, a small onboard auxillary power unit caught fire upon impact, and 11 passengers died from smoke inhalation when they failed to evacuate in time. In this accident 30 passengers were uninjured.

It has been found that the collapse through smoke inhalation of only one passenger can have a direct and very deleterious effect upon passenger evacuation flow, particularly when the affected individual is located at a critical point, such as in the aisle, or blocking an overwing emergency exit. In the typical jet transport accidents which have been investigated to date, decelerative forces are often found to be relatively low and structural deformation impeding escape minimal. Injuries are generally minor and sustained during escape rather than at impact, yet it is not unusual for all deaths and major injuries to be caused by smoke and fire.

Experimental fire tests, conducted by the Air Line Pilot's Association (ALPA), of instrumented aircraft outfitted with current interior materials indicate that smoke density approaches saturation in two to two and one-half minutes (Heine, 1966). In these experiments temperature rise approaching intolerable levels (480° F) occurred at the fifth and sixth minutes, followed characteristically by a flash fire with temperatures rising in excess of 1600° F in one or two minutes. Smoke density and temperature measurements in other tests indicate stratification and localization, with flash fires reported to travel through the fuselage at a rate of 68 feet per minute (Marcy, 1965).

In order that evacuation may be accomplished before the cabin or flight-deck areas become uninhabitable due to elevated temperatures, the protection of the human respiratory system is of critical importance. The occupant must remain mobile and in a conscious state post-crash in order to effectively evacuate. Clinical investigations have shown that shock may not be an important factor, accounting for a low (20%) fatality in burn cases (Phillips, 1960), while respiratory tract trauma, with or without superimposed respiratory tract infection, may account for nearly 50%. Yet where facial burns are incurred, more than three-fourths of the victims may develop respiratory difficulties due to inhalation of flame. It has been reported that if the lower respiratory tract, consisting of the trachea, main bronchi, and secondary bronchi, is burned, a fatality is usually inevitable (Cornell, 1960).

Carboxyhemoglobin determinations performed on victims of three (DC-8, 727, 707) jet transport crashes studied by Snow, et al., 1971, may serve as one index of the overall lethality of the thermal, as opposed to gaseous, elements of the accident environment. In a DC-8 crash occurring in Denver in 1961, 16 passengers died of carbon monoxide poisoning while attempting to evacuate subsequent to a low-force impact. A post-crash fuel fire outside the cabin generated a large volume of dense smoke and noxious fumes which were funneled through the passenger cabin as soon as the exits were opened (Hasbrook, et al., 1962). In this case the carboxyhemoglobin determinations were all above 30%, the level at which definite symptoms of CO poisoning such as vertigo, shortness of breath, and impairment of judgment normally appear (Henderson and Haggard, 1943; Flight Surgeon's Manual, 1962). Some three-fourths of the concentrations found exceeded 50%, the threshold of collapse and unconsciousness; and in several victims, the levels were greater than 80%, indicating that they may have died of CO poisoning before fire reached them. High concentrations of carboxyhemoglobin, indicating relatively long exposure times, occurred in the DC-8 crash where fire was not present within the cabin. In a Boeing 727 crash there was fire on board throughout the evacuation and the intermediate CO Hgb values in the Boeing 707-331 crash, where the thermal element predominated, were relatively low, indicating extremely short exposure time with fire and blast as the principal lethal agents.

Civil airlines are required by Federal Air Regulation to demonstrate that all passengers (maximum passenger capacity) can be evacuated within 90 seconds to the ground or ramp steps using only the exits on one side of the aircraft (FAR 25.803(c)). Yet in actual emergencies even this short time span required for evacuation may be insufficient. Life Sciences recommendations as a result of one C-135 accident included a recommendation that the number of passengers should be limited to those able to evacuate in one minute from three exits. Intensive human factors investigations of civil jet air transports have been conducted (Hasbrook, et al., 1962; Carroll, 1952; Snow, et al., 1971). The problem of smoke as a major factor in evacuation was pointed up dramatically by the crash in Rome of a Boeing 707-331 (Snow, et al., 1971), in Salt Lake City of a Boeing 727 (United Airlines, 1966; Snow, et al., 1971) and in Denver of a Douglas DC-8 (Hasbrook, et al., 1962; Snow, et al., 1971), in which 105 of 261 passengers aboard died in attempts to escape during the one to three minutes prior to the build-up of a lethal thermotoxic environment with the cabin. Figure 23 shows the dense smoke and flames typical of post-crash fires. This crash on December 28, 1970, a Boeing 727 at St. Thomas, V.I., involved 46 passengers, 2 infants, and a crew of 7, with 2 fatalities (National Transportation Safety Board Press Release 71-31, 1971). If passengers in this type of accident can be protected from the immobilizing and incapacitating effects of inhalation of smoke, toxic gases, and flame, for only one to two minutes of additional evacuation time prior to the buildup of intolerable temperatures within the cabin, it seems that a significant increase in passenger survival can be attained. In some situations, however, even more evacuation time may be required.

A recent Air Force study of emergency escape and survival from transport aircraft has concluded that "a simple lightweight bag-shaped smoke hood...would lengthen the survival time by providing three to four minutes of clean air to breath inside the hood. In addition, the hood would provide adequate visibility enabling the passenger to see escape hatches and allow mobility to complete the evacuation of the aircraft. By providing additional survival time and visibility, the evacuation and survival would be enhanced. Individual smoke hoods can be made available by attaching a hood to each seat in the aircraft." (Reagin, et al., 1970).

The Schjeldhal smoke hood is the most prominent of protective devices developed to offer respiratory protection. Although patents (No. 3,562,813 and 3,521,629) are held by

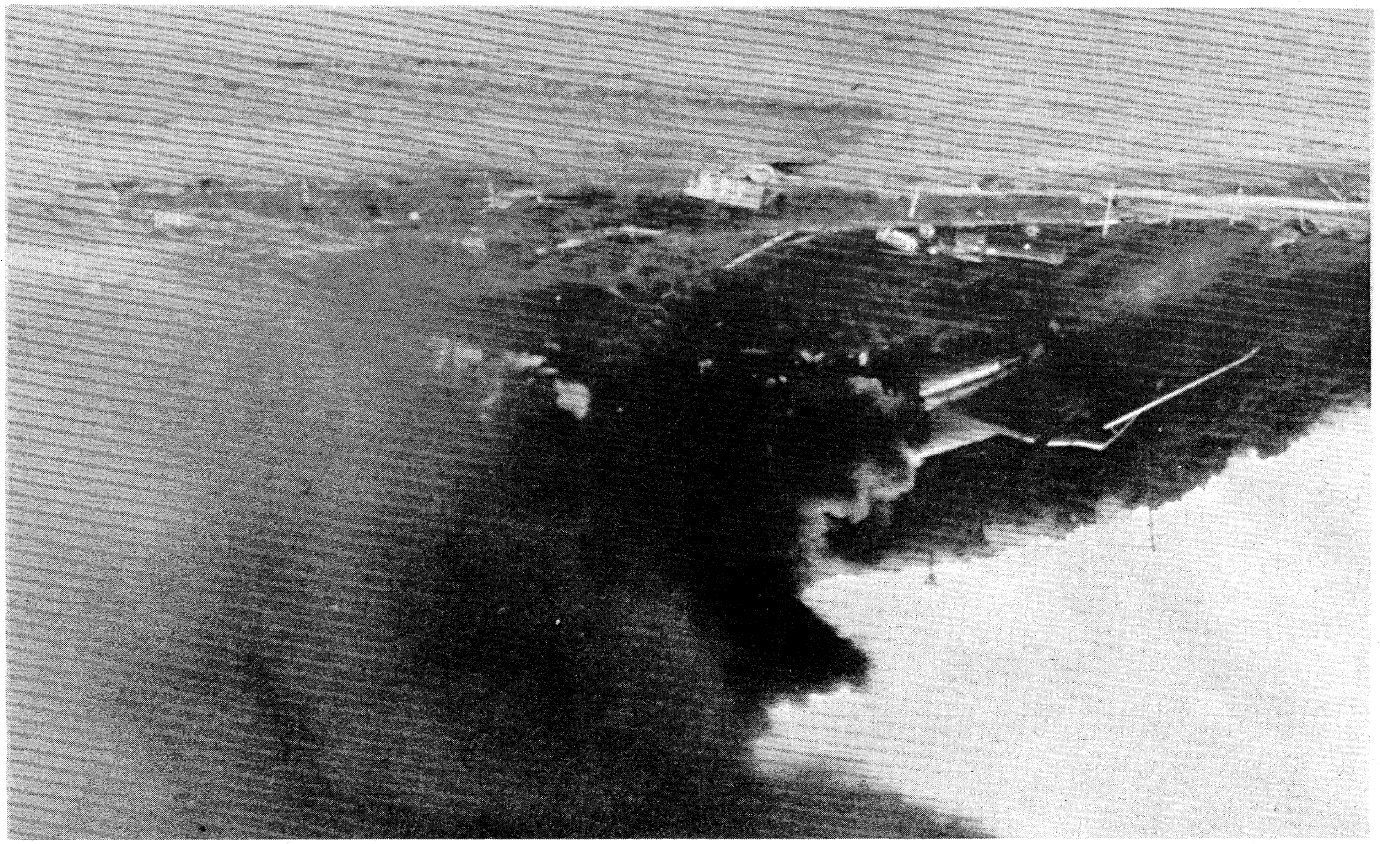


Figure 23. Dense Smoke and Fire Following Crash of Boeing 727 at St. Thomas, V.I.

the G.T. Schjeldahl Co., Northfield, Minn. 55057 (Reynolds, 1970; Origer, 1971), initial research and development was apparently as a result of an invention by E.B. McFadden, Chief of the Survival Equipment Research, Protection and Survival Laboratories, Civil Aeromedical Institute, FAA, in Oklahoma City (McFadden, 1966). As a result of investigation of the Salt Lake City Boeing 727 crash evacuation, 11 November 1965, McFadden constructed several working models of polyethylene (non-flame resistant) hoods to test feasibility of the concept. Learning that Dupont Chemical Company had a polyimide flame-resistant and transparent plastic film, he contacted the Schjeldahl company in December, 1965 to fabricate five polyimide hoods. However, in these experimental hoods the adhesive was of insufficient strength. By May, 1966, the defective adhesive hoods were replaced by five more using a Schjeldahl proprietary adhesive, and were followed in September, 1966 by Schjeldahl fabricated hoods with metallic coatings (Reynolds, 1966).

The results of the initial study (McFadden, et al., 1967) and a recent comprehensive multidisciplinary investigation (McFadden and Smith, eds., 1970) represent the most exhaustive studies published to date of this protective device. In 1968 a subjective proprietary study of the Schjeldahl smoke hood and other smoke protective devices was completed by the Aerospace Industries Association of America (1725 De Sales Street, N.W., Washington, D.C.) under a Crashworthiness Development Program, Technical Group Report (Aerospace Industries Association, 1968a; 1968b), and in October 1969 several French tests of the early type "D" model were conducted (Mouton and Armond, 1969).

TEST DATA

Initial development and testing of the smoke hood was conducted at the Civil Aeromedical Institute (CAMI) laboratories at Oklahoma City under the direction of E.B. McFadden in 1966, and the following summarizes this work (McFadden, et al., 1967). Experimental transparent hoods were fabricated under contract by the G.T. Schjeldahl Company. Primary design criteria involved:

1. Design and operation simplicity.
2. Smoke inhalation protection for a limited (2 1/2-8 min.) duration.
3. Omnidirectional visibility and donning.
4. Lightweight and compact in size.
5. Device should not melt or burst into flame when worn on the head or face.

Secondary design considerations were determined to be:

6. To prevent inhalation of flames and respiratory damage.
7. To protect the face and hair from direct contact with flames.
8. To provide protection from conductive and radiant heat.

9. To extend passenger escape time by maintaining passenger mobility and continuation of evacuation.
10. Esthetic considerations involving prevention of disfiguring facial burns.

These hoods were constructed of "Kapton,"* a high temperature polymide film, and selected because of its nonflammability, transparency, and its characteristic of not melting when exposed to extreme heat. Char levels for Kapton are stated to exceed 1472 F. Kapton also exhibits a high tensile strength, folding endurance, low shrinkage, and insolubility in organic solvents, and inertness to fungi. Conventional heat-sealing techniques could not be used to fabricate the hoods since polyimide film has no melting point. One initial series was fabricated utilizing high-temperature adhesives. A second series was fabricated with a transparent reflective metalizing coating. Some 21 samples of polyimide film were successively coated with varying thickness of gold, silver, and aluminum, with and without a protective coating over the metal. Evaluation was made for infrared emissivity and reflectance, heat, and optical transmission.

The normal volume of the hood was calculated to be about 18.5 liters exclusive of the volume occupied by the wearer's head. Human testing was conducted with subjects wearing the clear, uncoated, amber-colored, polyimide hoods and the coated silver polyimide hood for eight minutes of infrared radiation exposure with the filament of the lamps located 22 inches from the front surfaces of the hood. The metalized polyimide film was shown to develop up to 90% infrared reflectance. When the clear hood was used, skin temperatures of 115-117° F approached the limits of voluntary heat tolerance. A maximum skin temperature of 100° F resulted under the same conditions while subjects wore the coated silver hood. When the heat sources were moved to a point 6.5 inches from the front surface of the hood (lamp lens within 1-2 inches of contact) forehead skin temperature averaged 106° F. Some reduction in visibility with both clear and metalized hoods was found. It was cautiously concluded from this investigation that the Schjeldahl smoke hood had potential usage for short term emergency protection; however, additional tests and development were required "prior to any specification for operational use in aircraft" (McFadden, et al., 1967).

In a subsequent study by the Civil Aeromedical Institute, FAA, (edited by McFadden and Smith, 1970) just released, specific items were evaluated as suggested by the results of the initial tests. This combined multidisciplinary physiological, medical, and psychological investigation examined leakage, toxic effectiveness, vision, acoustic

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1E.I. duPont de Nemours Corp., Wilmington, Delaware.

characteristics, effects of safety briefings, and simulated evacuation tests through dense smoke.

The initial tests reported in 1967 (McFadden, et al.), as well as the FAA Flight Standards full-scale evacuation tests (Federal Aviation Administration, 1968), and studies carried out by the Aerospace Industries Association Crashworthiness Development Program Technical Group (1968) had revealed specific design deficiencies in the original prototype. The primary deficiencies noted were:

1. Neck Seal. Passengers and crew evacuating from jet aircraft could not be relied upon to consistently tighten the drawstring neck seal.
2. Vision. While polyimide surface aluminization was shown to provide excellent radiant heat reflectance and sufficient transparency for adequate vision under normal illumination levels, it was found that evacuation test subjects experienced vision difficulties when exposed to the .05 foot-candle emergency illumination as provided in jet transport aircraft.
3. Useful air supply. Limitations in time duration of hood effectiveness in rebreathing (partially due to neck seal).

The current state of the art of the Schjeldahl smoke hood is thus represented in these areas by this 1970 evaluation, which was designed to investigate (1) the degree of protection against incapacitating agents provided by the hood; (2) the hood limitations in terms of useful air supply, vision, and audition; and (3) the utility of the hood. The specific findings of these studies are summarized as follows:

1. Leakage Evaluation (McFadden, et al., 1970)

As a result of the earlier findings concerning poor neck seal with the drawstring hood ("Type D"), a new neck seal consisting of a septal (membrane) of heat-resistant urethane was developed ("Type S") which fits closely about the neck upon donning. The objective was twofold; to determine life-support capabilities with respect to quality of the contained air supply and to the metabolic rate of the wearer.

Ten hoods of each type were tested utilizing ten male and ten female naive subjects. Temperature exposure was limited to 140° F. Respiratory rate was continuously monitored with an impedence pneumograph which also provided estimates of relative tidal volume (i.e., the volume of air breathed in and out in a single breath). Oxygen consumption, carbon dioxide production, heart rate (ECG), hydrocarbon concentration, and loss of air were measured.

The most marked difference between the septal and drawstring hoods was the observation that CO_2 accumulation and O_2 reduction in the septal type (S) tended to progress in a relatively uniform linear fashion, while with the drawstring (D) hood this tendency was interrupted when the CO_2 concentration reached a level which induced hyperventilation. This increase in depth of breathing (pumping action) characteristically resulted in a gross leakage and leveling off of CO_2 concentrations with the earlier drawstring (D) hood. Overall leakage of the drawstring (D) version was markedly greater than with the septal hood (S). However, it was noted that repeated usage of the septal seal (S) hood resulted in a trend toward greater leakage (fatigue of the elastic polyurethane seal) which could be a factor if hoods were to be donned repeatedly during drills or precautionary evacuations, and it was recommended for this reason that seals be replaced after each usage.

These investigations point out that the results of these tests illustrate that no hood which is designed to meet the criteria of accessibility and economy of storage, can be expected to provide absolute protection and life-support for indefinite periods. A CO_2 concentration of 5% was reached in septal seal (S) hoods within 1.4 to 4.0 minutes, depending on the temperature and degree of physical exertion. A projection to 8%, the generally accepted minimum allowable concentration, is reached in 3 minutes under exercise conditions and 6.4 minutes under rest "cool" conditions; in 2.2 minutes under exercise and 4.9 minutes under rest "heat" conditions.

Information concerning metabolic rates of semi-hysterical people attempting to escape a burning aircraft are not known; however, these authors believe this should not exceed the O_2 consumption of the exercising subjects. They conclude that the 8% tolerance time of approximately 120 seconds obtained for this group seems a conservative estimate of the time during which the average evacuee could benefit from the hood, and that the newer septal seal (S) type hood provides excellent fume protection.

Some cautions were also expressed. Pentane gas was selected as the single model agent as a compromise between gases of higher and lower molecular weight, fat solubility, and other chemical properties, as well as because of safety up to the flammability limit of 1.4% concentration. But toxic gases with greater diffusion potentials than Pentane may occur in aircraft fires, including HCN, CO, HCL, and aldehydes. Failure of a particular device can occur even under the best of manufacturing controls as was pointed up by an incident reported by these investigators. "An Experienced investigator wearing approved (Bureau of Mines) full-face regalia with air supply, became incapacitated by a leakage of lachrymator gas while serving as a safety man for another investigator who was wearing a type S septal seal smoke hood. The man equipped with the hood discovered the accident and led the visually incapacitated "safety man" from the chamber" (McFadden, et al., 1970, p. 15). Another possible risk is that an individual who is abnormally insensitive to CO_2 may suffer from insidious hypoxia when the O_2 is consumed (normal individuals will be forced to remove the hood by the sensation of suffocation).

2. <u>Toxic Environment Effectiveness</u> (McFadden and Gibbons, 1970)

The objective of this study was to determine the effectiveness of the newer septal seal (S) protective smoke hood in preventing inhalation of toxic substances similar to those produced in the combustion of aircraft fuel and cabin interior materials. Test subjects were exposed to a heavy black smoke environment consisting of significant quantities of carbon monoxide (CO concentration from 450 to 950 ppm) and soot particles resulting from combustion of JP-4 fuel and water-soluble oils. Seven adult (4 male, 3 female) subjects were tested in an octagonal maze smoke chamber in a clockwise direction while conducting a switching task until they had been exposed to at least 90 seconds of test.

This study was based on the well-established affinity of blood for carbon monoxide (CO), which is several hundred times greater for CO than O_2. Since it is more easily passed through membranes due to its small molecular size, it is particularly important that the smoke hood prevent inhalation of this gas. During the chamber exposure subjects traversed linear distances of 108 to 220 feet, which were considered to exceed those required in the movement to emergency exits in aircraft, and were able to perform a relatively large number (11 to 25) discrete switching operations under these conditions. This study confirmed the effectiveness of the septal seal (S) smoke hood in a toxic environment under evacuation conditions requiring both movement to exit areas and ability to perform manipulation operations.

3. <u>Vision</u> (Lewis, 1970)

Since the earlier FAA tests examined optical transmissions of the Schjeldahl smoke hood by spectrophotometric measurement, and found deficiencies in vision under emergency lighting (.05 foot-candles) conditions, the purpose of this study was to evaluate the optical transmission of the hood by visual photometry and determine the effect on visual acuity.

Nine male and three female subjects were tested, utilizing both the hood without aluminization (from type S) and the aluminized with a clear band (from type D). The visual acuity tests were designed to represent a worst-case situation. Thus subjects were adapted to an illumination in excess of that provided by normal aircraft interior lighting, and was set at 30-foot-candles measured at seat level, and exceeding the 15-to 25-foot-candles provided by aircraft reading lights and the 5-to 15-foot-candles general illumination at armrest height. Simulated emergency illumination was obtained by adjusting the voltage of a tungsten lamp to provide 0.05-foot-candle illumination. Test procedure involved the subject seated 10 feet from the test target and adapated to normal illumination for 1 minute. Basal acuity was measured, after which subjects were instructed to don the smoke hood after lights were turned off and read each test card as rapidly as possible. Matched tests were conducted without the smoke hood, and each subject made eight runs, four in each condition.

Results showed that visual acuity in these tests was reduced under emergency illumination to 0.68 without the smoke hood, compared to a further reduction to 0.55 while wearing clear smoke hoods (type S). With aluminized hoods (type D) visual acuity was reduced to a level below the measurement capacity. It was reported that clear smoke hoods (type S) have optical transmissions of about 75-80% (similar to transmission of optical glass sunglasses). A difference of 5% between the uncoated patch test samples and the clear areas from aluminized samples was considered to be due to the coating used to protect the aluminized surface. While visual capacity was reported to be significantly affected by wearing clear hoods an increase in emergency illumination would compensate. It was found that type D aluminized hoods reduced vision under conditions of emergency illuminization to the extent that they were "visually unusable."

4. <u>Acoustic Attenuation</u> (Tobias, 1970)

The purpose of this study was to determine the extent to which the smoke hood may act as a barrier to the transmission of sound. This is of especial importance in an emergency evacuation if passengers are unable to hear crew instructions.

Thirty male and female subjects were each tested twice, once with and once without wearing the hood. Each subject wore the hood for two periods of 100 seconds each. It was concluded that the Schjeldahl (type S) smoke hood does not interfere with the transmission of sound waves. A barely discriminable maximum threshold shift of 3dB at 5000 H_2 was reported.

5. Safety Briefing Effects (Smith, 1970)

The utility of the smoke hood during an actual evacuation primarily depends upon the passenger or crew's success in using it and it was considered that this is probably a function of the effectiveness of the preflight safety briefing. This psychological study was therefore designed to determine to what extent does increasing the amount of information presented during safety briefings influence the degree of hood-donning success as measured by both ease and speed of donning and the extent of hood inflation, incidence of positive and negative feelings about hoods, and willingness to use them. In addition it was considered important to ascertain (1) how much of the information presented during breifings is retained, as a function of the amount presented; (2) the effectiveness of demonstrations; (3) sex hood-donning ability differences; and (4) whether practice will result in a significant performance improvement.

Naive subjects used were 35 females and 68 males between ages 17 and 31; 22 observers were pretrained for behavioral observations. The study was conducted in an aircraft cabin with seating modified to allow observers to directly observe subjects. A pocket containing a compactly folded Type S smoke hood (6" X 7" X 1 1/2") was firmly taped on the seat-back in front of each subject, and positioned so that the upper portion would tear off when a subject pulled on either of two red tabs located at the upper corners of the pocket. A tape recording presenting six variations in briefings provided a greeting, statement of emergency exit locations, description of the use of oxygen, and statement of the location and purpose of the safety hood. Each subsequent briefing (with a different group of subjects) increased the amount of information given about the smoke hood, although the stewardess gave the same demonstration during all briefings. At the conclusion of each briefing the subjects were told that on a signal they were to don the smoke hoods located on the backs of the seats in front of them as quickly as possible.

Results of the hood-donning efficiency indicated that subjects (95.2%) felt that the instructions were clear. Observers, however, noted that 90.3% of the subjects encountered some sort of a problem in donning the hoods, although all were reported to have gotten the hood on both quickly and satisfactorily. Finding and spreading the neck seal and completely inflating the hood so that it would contain a maximum amount of air seemed to present the biggest difficulties. It was judged that giving instructions about getting the hood over glasses could be helpful.

Some 73.4% demonstrated satisfactory retention of safety information, with no difference in retention rates between demonstrated and non-demonstrated items (in fact it was reported that subjects in five of the six groups did better on non-demonstrated than demonstrated items). Subjects did poorest in retention of information related to exits, and on how long to wear the hood. Previous hood donning experience was found to significantly reduce the time of donning as well as problems encountered. It was suggested that passengers seated next to windows may have more difficulty in hood donning than aisle passengers due to space limitations.

It was concluded by Smith that increasing the amount of information presented during briefings about the use of protective smoke hoods had little effect on donning time but resulted in less problems in donning over glasses, better inflated hoods, and more positive feelings about the hood use. All stated they would use the hood in an emergency although some expressed reservations about a shortage of air in the hoods.

Recommendations resulting from this investigation were reported as follows:

1. General safety briefings should probably contain more information about the use of safety devices.
2. The portion of the briefings dealing with safety hoods should include mention of the adequacy of air supply.
3. The opening in the type S hood's septal seal neck should be modified to make it easier to find (perhaps by outlining in a contrasting color).
4. Consideration should be given to using a larger, less compact hood package, with possible enclosure of self-distending devices.

6. Dense-Smoke Evacuation (McFadden, 1970b)

This final investigation in the 1970 FAA study of the smoke hood was designed to determine the reactions of a naive group of subjects to smoke-hood use during simulated evacuation in the presence of heavy smoke.

The test evacuations were conducted in an L-749 Constellation Cabin, with motion picture analysis (smoke completely obscurred visibility), sound recordings by means of a tape recorder, and with one escape slide inflated and in place and the exit door (at left rear cabin)partly open prior to tests. The smoke-hood packet was inserted in the seat-back pocket. The type D drawstring hood was used in these tests. One group of 64 subjects evacuated without smoke and without using the hoods, then in a second test used hoods in dense smoke to evacuate upon activation of an audio alarm. A second group of 64 subjects made their initial evacuation under smoke conditions while wearing a smoke hood, and a second test without the presence of smoke or wearing hoods.

Smoke was produced by means of a theatrical smoke generator to an extent that visual cues were virtually eliminated. This series of tests was intended to measure the flow of a maximum number of passengers through only one exit.

It was found that the presence of smoke was the primary variable influencing speed of evacuation, although the use of hoods alone was reported to have had little significant effect on evacuation rate. Subjective questionnaire results indicated the experience gained in evacuating without smoke was beneficial when subjects subsequently evacuated under smoke conditions.

The six recent studies summarized in the foregoing indicate that currently available smoke hood devices do protect the individual from the respiratory effects of smoke and provide him with an air sample which is relatively uncontaminated and adequate for evacuation from current civil jet transports. However, there still remain some limitations, primarily that the hood does not increase visibility in smoke other than preventing eye irritation, and the air supply is limited. The septal seal neck of the new type S hood has been shown to be a distinct improvement over the older drawstring type D in preventing the penetration of noxious substances into the hood air sample. Several problems pointed out relating to the passenger locating the seal for donning, and the decrement of the seal through repeated usage are solvable. Results from these briefing tests indicate that even with a minimal briefing most passengers should be able to use the hood adequately. The major improvement, which is being explored in subsequent experimental developments, would be the incorporation of a self-contained oxygen supply and carbon dioxide removal agent. In view of the foregoing studies the FAA felt that development of a safe "get-me-out" smoke protective device had progressed to the point where its use in civil air carriers should be mandatory.

In January 1969, a Notice of Proposed Rule Making was published in the Federal Register which would amend Part 121 of the Federal Air Regulations to require that protective smoke hoods be carried on all civil air carriers. Citing results of earlier studies, the "FAA concludes that, if protective smoke hoods were provided in large transport airplanes, the probability of occupant survival in airplane crashes would be significantly increased; that the economic burden of fitting airplanes with such hoods is reasonable in relation to expected benefits; and that prototype hoods have been tested and evaluated to a sufficient extent to justify a requirement (with a reasonable implementation period) at the present time." (Protective Smoke Hoods.., 1969, p. 466).

The FAA received 23 comments as a result of this Notice of Proposed Rule Making. Of the major aviation associations which commented, the Airline Pilots Association supported the proposal; however, the Air Transport Association, Aerospace Industries Association, Airline Stewards and Stewardesses Association, and the Airline Dispatchers Association were strongly opposed. The Flight Safety Foundation (FSF) opposed the rule on a basis of a medical evaluation submitted by consultants of the Air Transport Association of America, a supporter of the FSF. The National Transportation Safety Board (NTSB) concurred in the FAA intent, but expressed concern over a possible increase in evacuation time and limitation of available oxygen with use. The major comments involved questions of hood safety, is it practical, would it slow down evacuation time, and are the specifications listed justifiable? As a result of analysis of the comments received related to this proposed rule, the FAA withdrew Notice 69-2 in September 1969[2], despite the strong objections of the FAA Office of Aviation Medicine which claimed that conclusions were based upon conjecture and in some instances taken out of context. It was further noted by the Office of Aviation Medicine, FAA, (OAM) that a person who was actually a survivor in the Salt Lake City Boeing 727 crash was strongly in favor of the smoke-hood concept, as were 9 of 13 survivors of National Airlines Flight 106 which experienced an emergency evacuation due to smoke on 23 March 1969 and responded to an NTSB questionnaire.

In view of the strong difference of opinion expressed between the medical and regulatory arms of the Federal Aviation Administration concerning the value of the smoke hood concept in post-crash emergency evacuation, the basis for rejection of the 1969 FAA proposed smoke-hood requirement for Civil Air Carrier aircraft should be reexamined both in relation to military air transport aircraft requirements, and with consideration for subsequent advances in the state of the art. In this regard, the results of several reports bearing upon the questions posed seem particularly pertinent and are summarized as follows.

1. The "Riley Report." Appended to the Air Transport Association of America (ATAA) comments on the protective smoke hoods for emergency use by passengers and crew members (Docket No. 9344, Notice 69-2) were opinions expressed by Dr. Richard L. Riley, Professor and Chairman, Department of Environmental Medicine, The Johns Hopkins School of Hygiene and Public Health, and Dr. Solbert Permutt, Professor of Environmental Medicine in the same department, consultants to the ATAA. They were of the opinion that the early CAMI study failed to give adequate consideration to the hazard of hypoxia created by the smoke hood itself, and therefore that the smoke hood "does create a significant hazard in itself." They were especially concerned with the possibility of fatal

2Federal Aviation Administration. 1969. Final Project Report on the Disposition of Notice of Proposed Rule Making 69-2 on Smoke Hoods. (Unpublished report) September.

accidents occurring as a result of prolonged breath holding, and cited an investigation by Craig (1961) of eight near drownings and five drownings in which it was believed that hyperventilation before breath-holding and exercise may delay the onset of the urge to breathe ("white-drowning"). In this case, before the partial pressure of CO_2 increases significantly, the O_2 may decrease to a degree incompatible with high-level cerebral function. In other words, when the individual hyperventilates he drives out the CO_2 and soon uses the O_2 faster than CO_2 builds up. They also disputed that everyone will remove the smoke hood once the CO_2 reaches a certain level. The arguments presented in this report were based upon a critical review of the early CAMI report (McFadden, et al., 1967), aircraft evacuation movies, evacuation evaluation of the Aerospace Industries Association report (AIA Report CDP-2, 1968), and inspection and donning of type D and type S hoods.

Their views were subsequently concurred in by Dr. Fenn of the University of Rochester, Flight Safety Foundation (FSF) consultant, who read their report and concluded, "There is a real danger in the use of a gas-proof bag of that sort because it can lead to suffocation and unconsciousness when the oxygen is sufficiently depleted" (FSF comments, Notice 69-2, 1969).

2. French Tests. In October 1969, the Aeroport de Paris carried out two tests by three volunteers of the early type D (drawstring) smoke hood loaned by the FAA.[3] Volunteers were all pilots and tests were carried out in a smoke-filled cabin of an obsolete Starliner transport at Orly. Although these tests were limited and of a subjective nature, the conclusions and comments resulting should be noted.

They observed that the smoke hood was easily donned, there was no smoke penetration, there was effective protection of the face from flame (but the plastic neck collar burned when placed by itself directly in flame), hearing appeared normal, visibility was 360°, and the hood design allowed it to be donned in any position. However, they also noted a problem with moisture condensation from respiration within approximately one minute after donning which lowered visibility. In this regard, this observation was made at close to normal temperature and it was postulated that such moisture might not occur in the heat of an actual fire. Another critical comment involved a lack of air experienced at about 75 seconds, and a maximum usage limit of 2 to 2.5 minutes. The lack of visibility in a smoke-filled cabin was also noted, as well as the fact that one of the three masks tested tore "rather easily," although the report did not state where the tear occured or under what conditions.

3Mouton, L. and G. Armand. 1969 Test of Fireproof Anti-Smoke Hoods, Paris. 14 October (Unpublished report).

They proposed the combined use of the oxygen mask and smoke hood to increase the breathing time, although noting the fire danger from use of O_2. This report concluded that the smoke hood represents considerable progress in fire protection and contributes to preventing passenger panic. They suggested improvements consisting of: (a) reinforcing plastic collar; (b) using improved heat-resistant plastic in collar; (c) extending hood below collar to protect it; (d) providing chest shielding; and (e) considering combining with an oxygen mask to provide prolonged survival time.

3. National Academy of Science-National Research Council Evaluation.

In 1970, at the request of the Office of Aviation Medicine, FAA, to the NAS/NRC, critical evaluations of the smoke-hood device (apparently based primarily on the most recent FAA studies, McFadden, et al., 1970) were conducted by three members of the Space Science Board (NAS/NRC Space Science Board Report, 1970).

In the comments received, several potential hazards were pointed out. The narcotic effect of higher CO_2 concentrations have led to sudden unconsciousness, without warning at 9.2% level CO_2 (white, et al., 1952), and when asphyxiation to the point of respiratory failure is brought about by inhaling pure CO_2, resuscitation has not been successful. Hypoxia was also felt to be a serious hazard due to the limited supply of oxygen. Another point brought up concerned the possibility of an airline having a legal problem regarding a determination of cause of death in the case of a lethally-injured individual found wearing a smoke hood following a fire. Hood material deterioration characteristics were questioned, as well as reusability. The tolerance of hood-wearing on people with cardiac disease or pulmonary dysfunction is unknown, and the wearing time in egress at higher elevations was questioned. What are the problems in fitting infants, children, and people with abnormal neck size into the type D or type S hood?

While one reviewer, experienced in CO_2 toxicity, stated that he doubted he would wear the smoke hood as an alternative to evacuating a smoke-filled cabin, other evaluations, while cautious, appeared to indicate in general that progress had been made. The necessity for ease in donning, a minimum of instruction for use, good vision, and a self-contained oxygen supply and CO_2 removal agent was emphasized. This report undoubtedly represents the most thorough medical critique of the smoke-hood development of the type D and type S hood. The more advanced self-contained air supply type of hood presently under development appears to meet the most serious circiticisms; however, other factors pointed out such as deterioration characteristics, legal problems, and effect upon cardiac or pulmonary patients, as well as for infants, apparently remain unknown.

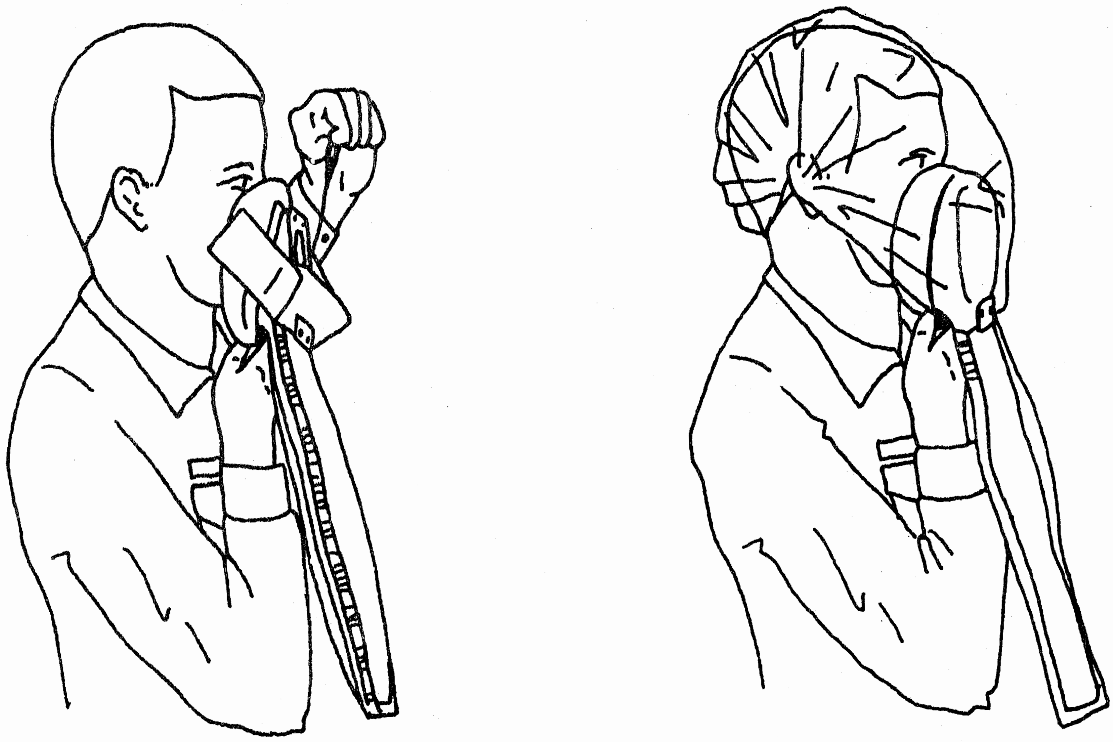
4. <u>AIA Smoke-Hood Evaluation</u>. As part of the Crashworthiness Development Program of the Aerospace Industries Association of America, evaluation and testing of aircraft crash-egress smoke masks was conducted in 1967-68 and a limited distribution of results prepared in July 1968 (Aerospace Industries Association, AIA CDP-2, 1968). A Boeing McDonnell-Douglas team evaluated prototype "masks" at the McDonnell-Douglas Laboratories at Long Beach and the Boeing Company Laboratories at Renton, Washington. These are the only comparative tests known for a number of prototype devices. In September 1967, 28 companies were sent an invitation to participate which described suggested requirements for smoke and fume protective devices which could be used for escape from an aircraft fire. As a result, eight companies submitted 10 prototype devices: the Schjeldahl hood (drawstring (D) version), Boeing mask, John Hand hood, Racine Glove Company hood, Sierra Engineering Corporation hood, two Life Support Systems hoods, Scott-O-Vista mask, and two Mine Safety Appliance Company devices, as illustrated and described in Figure 24.

Tests included subjective smoke tests, in which a volunteer subject entered a 340 c. ft. smoke chamber wearing a previously donned and adjusted hood, and remained until breathing became intolerable for that individual. White irritant smoke was initiated from a smoke bomb device. These tests were reported as indicating that small amounts of leakage had a significant effect on the wearer, making the subject want to remove the mask. One test was conducted in a noxious environment produced with a 1 ft. sq. pan burning in a 15 ft. mock-up utilizing a Boeing mask with a modified mouthpiece and nose seal. The rebreather bag of the Boeing design exibits a volume of only 2 liters (less than 1/10 the volume of the Schjeldahl hood) which is initially inflated by air from the lungs (containing 3-4% CO_2 and 16-18% O_2). Three exposures of increasing but unspecified duration were reported as successfully tolerated, but in a fourth exposure of a planned 150 second duration, the subject lost consciousness at 130 to 140 seconds. It was concluded that this resulted from a lack of oxygen. No information is available as to the number of subjects, number of tests, or number of each hood type tested. Apparently no objective testing was conducted.

It was reported that eight evacuation tests were conducted in an abbreviated 727-200 mock-up, using only Schjeldahl, John Hand, and Boeing masks due to limited availability of other devices. There were smoke and varying illumination conditions, instructions were given, and information was reportedly obtained by use of motion picture photography, questionnaires, and voice recorders. Results indicated that donning time ranged from 8 to 14 seconds. Hoods were frequently not zipped up or properly tightened and the Boeing mask mouthpiece often was not gripped in the mouth. Subjects were reported to lift the devices above their eyes to improve visibility. Devices used in light smoke and with 0.1 candle average cabin illumination resulted in a 30 percent decrease in evacuation rate (but the report does not indicate over what). Devices used in a dark cabin with smoke were reported to be 33 to 52 percent slower when compared to evacuation in dark conditions with no masks or hoods. Device usage increased when clearer instructions were given in briefing. This study concluded that use of the devices tested was not satisfactory; that visibility was decreased and evacuation slowed about 30%. Although these conclusions were not objectively documented by in-depth tests of the devices examined, it represented a major attempt to survey the state of the art at that time.

Figure 24. Description of Commercially Available and Experimental Smoke-Mask and Smoke-Hood Devices

1. Boeing Mask



Physical Description

Two-liter polyimide (Kapton) rebreather bag mouthpiece, mounted on polyurethane nose-blocking pad accordian-folded polyimide heat shield, weight 6.5 oz., designed to install on seat back with only handle showing.

How Used

Grasp handle, blow up rebreather bag, hold mouthpiece with teeth. Pull thermal shield over head, rebreathe air in bag.

Figure 24, con't.

2. John Hand Hood

Physical Description

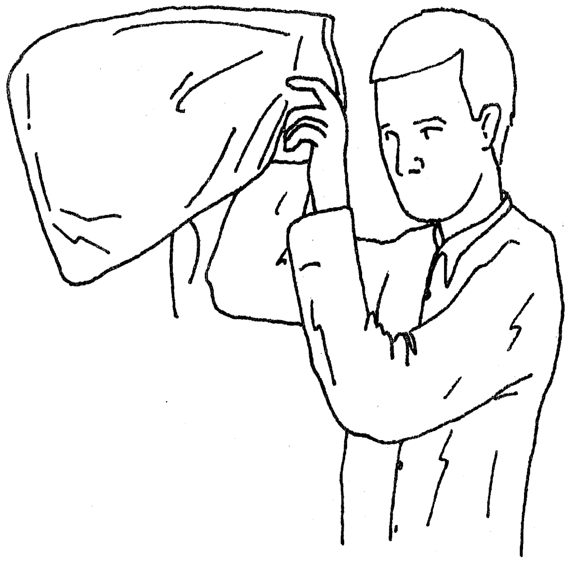
"Vinyl-coated fiberglass hood, clear fluorocarbon(Aklav)-film view window, open-cell foam neck seal, with zipper closure, weight 6 oz.

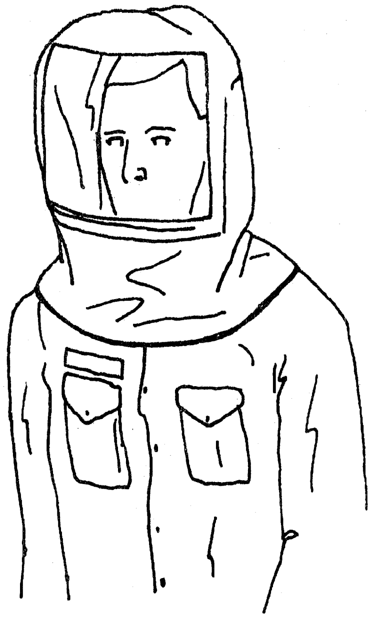
How Used

Unfold hood and don over head. Position viewing window. Pull zipper down to join neck seal.

Figure 24, con't.

3. Racine Glove Company Hood





Physical Description

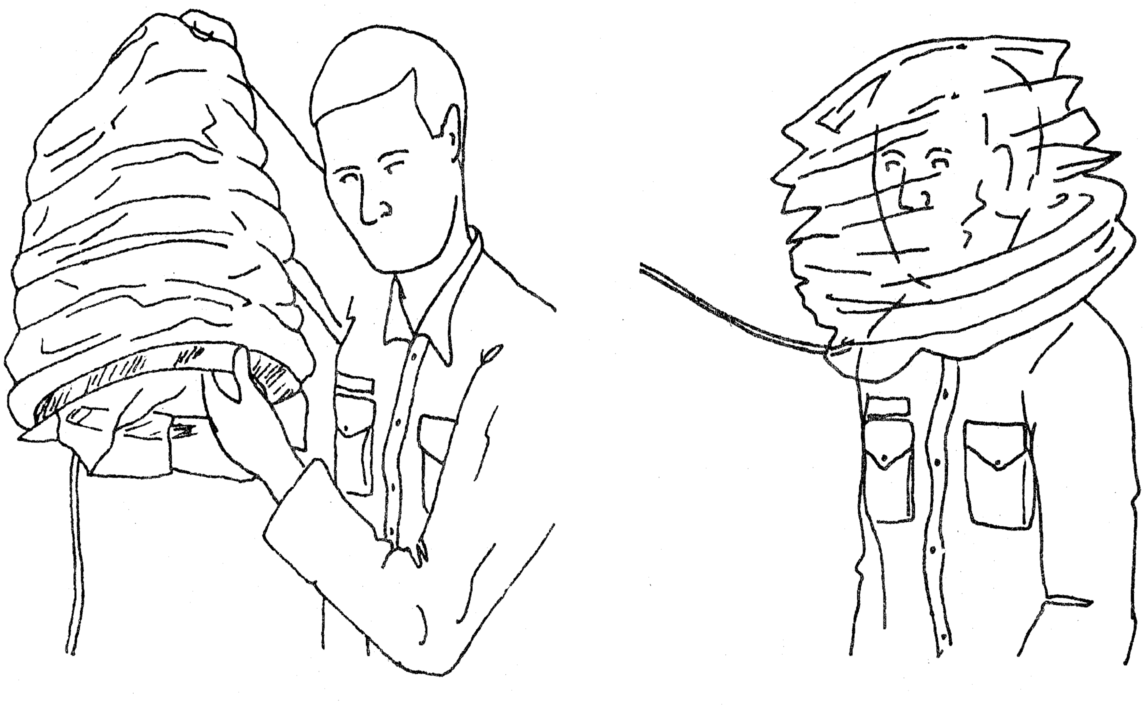
Aluminized rayon hood polyimide(Kapton)-film view window. Coil-spring holddown in hood lower rim, stainless-steel vent screen on hood back.

How Used

Remove from container. Automatically unfolds by coil-spring action. Place hood over head and position view window. Place hold straps under arms and fasten down about chest with Velcro tape.

Figure 24, con't.

4. Sierra Engineering Corporation Hood



Physical Description

Accordian polyimide(Kapton)-cylinder with flat top, supplemental air is vented into top which inflates a toroidal neck seal, air supply not yet designed, weight 8.3 oz. (without air supply).

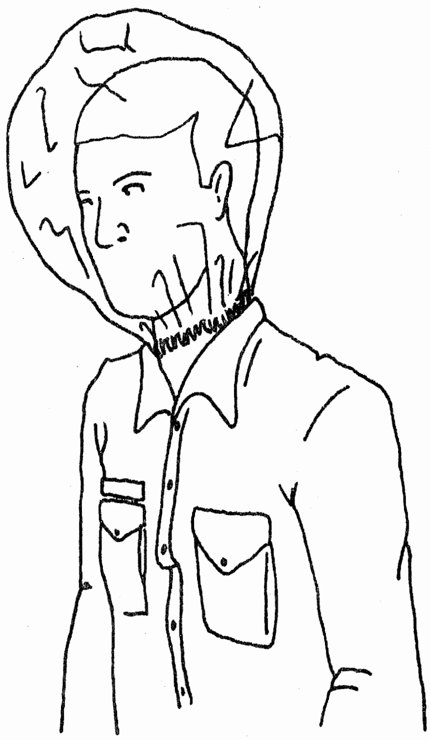
How Used

Place hood over head. Activate supplemental air supply.

Figure 24, con't.

5. Life Support Systems Hoods

A. Elastic Neck Seal Type



B. Lanyard Neck Seal Type

Physical Description

A. 1-mil polyimide(Kapton)-film hood, elastic neck seal, weight 0.7 oz.
B. 1-mil polyimide(Kapton)-film hood, sliding ball and lanyard seal, weight 1.3 oz.

How Used

A. Unfold and pull over head.
B. Unfold and pull over head, push elastic ball up lanyard to form tight neck seal.

Figure 24, con't.

6. Scott-O-Vista Mask

Physical Description

Polycarbonate-plastic (Lexan) "bubble" facepiece, set in high-temperature-resistant rubber frame. Sealed filter canister for removal of smoke, fumes, CO, from inhaled air. Mask held to face by elasticized headband, voice amplification by a vibrating resonator, weight 9.2 oz.

How Used

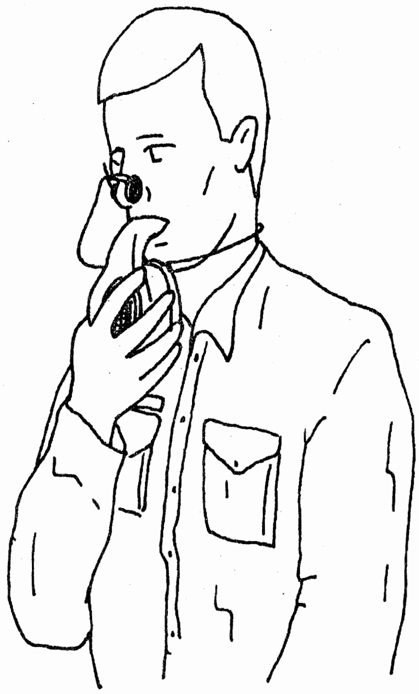
Pull seal from canister air inlet. Place mask over face and pull band over head.

Figure 24, con't.

7. Mine Safety Appliance Company Devices

A. 88180 Canister Device (commercially available)

B. Self-Rescuer



Physical Description

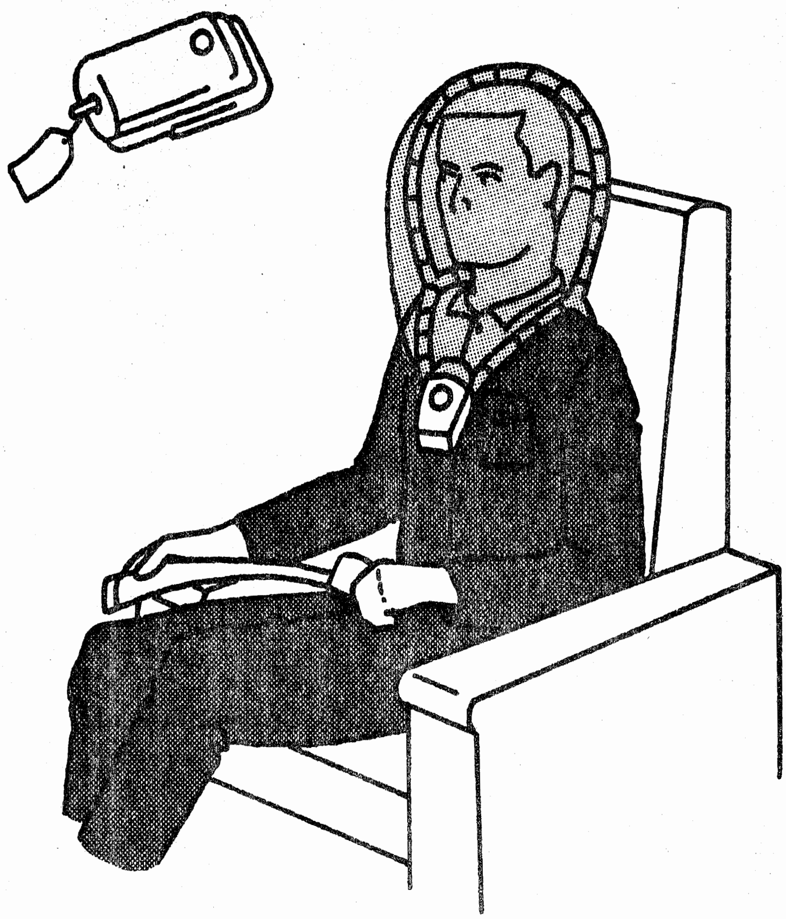
A. Protects against dust, gases, vapors, but no CO removal, weight 24 oz.
B. Removes large smoke particles and CO, weight 18 oz.

How Used

A. Remove or break seal. Place mouthpiece firmly in mouth. Put clip on nose.
B. Remove or break seal. Place mouthpiece firmly in mouth. Put clip on nose.

Figure 24, con't.

8. North American Rockwell Hood



Physical Description

Include three components: transparent hood, neck closure system, and compressed air supply. A short-range radio receiver could be incorporated for instructions from the crew.

How Used

Would be designed to fold into packet on seat back. Pull hood out of packet, don over head, and pull down into position.

Figure 24, con't.

9. North American Rockwell Smoke Mask

Physical Description

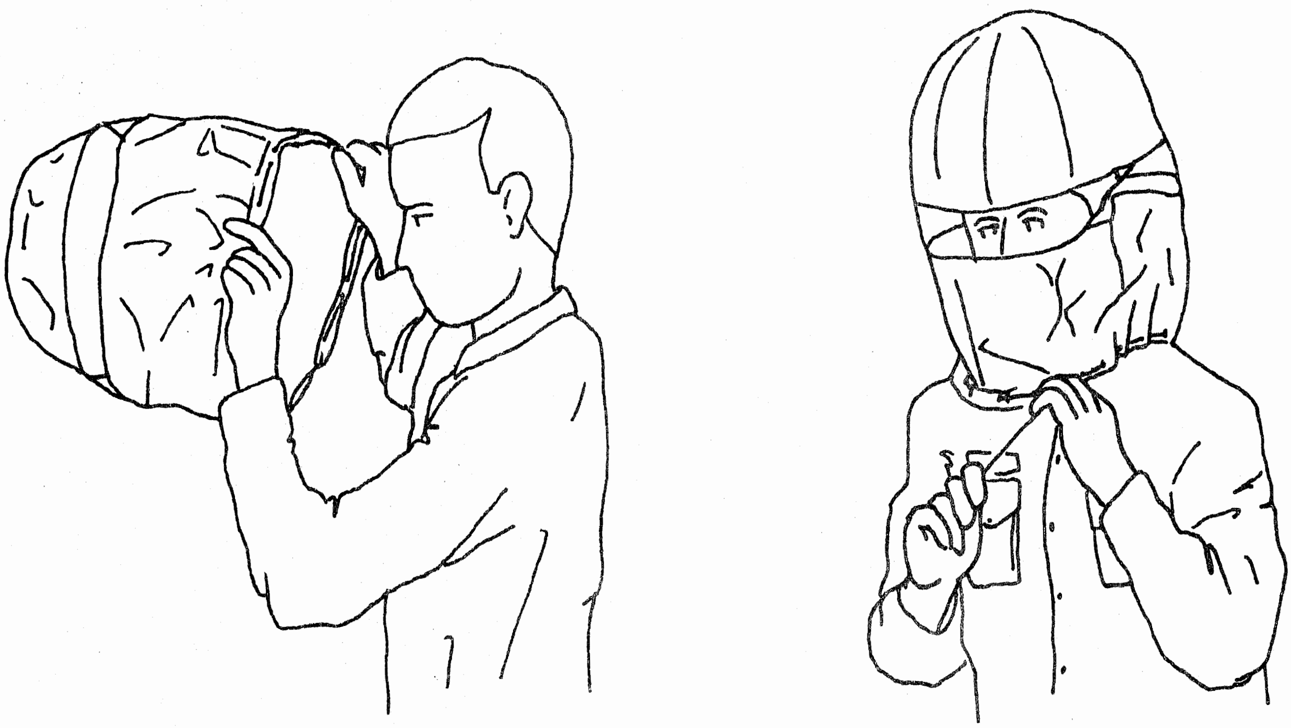
A moist cloth of several layers large enough to cover the mouth and nose. An elastic band fits around the head.

How Used

Sealed in a plastic bag, the moist cloth would be held to the mouth and nose by hand, and by an elastic band over the head.

Figure 24, con't.

10. Schjeldahl Hood "D" (Drawstring) Model
G.T. Schjeldahl Company, Northfield, Minn.



Physical Description

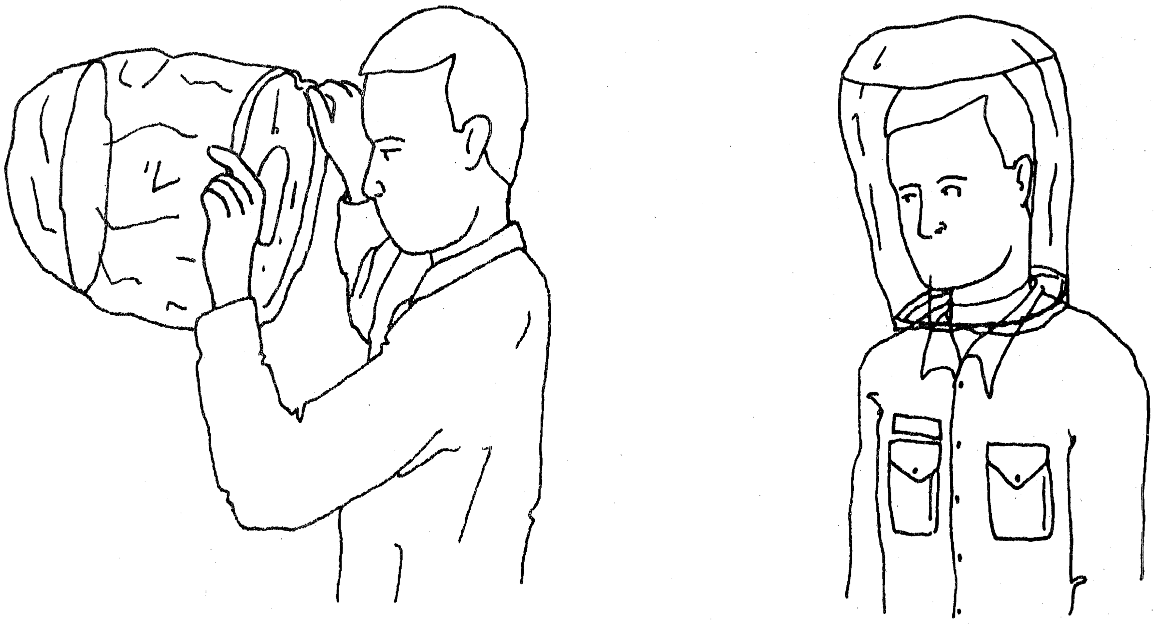
Metalized polyimide(Kapton) hood. Volume 26.5 liters. Cylindrical with domed top. Elastic fiber-glass neck drawstring. Two-inch vision band.

How Used

Unfold from container, take breath of air, slip over head, draw neckband snugly.

Figure 24, con't.

11. Schjeldahl Hood "S" (Septal Neck Seal) Model
G.T. Schjeldahl Company, Northfield, Minn.



Physical Description

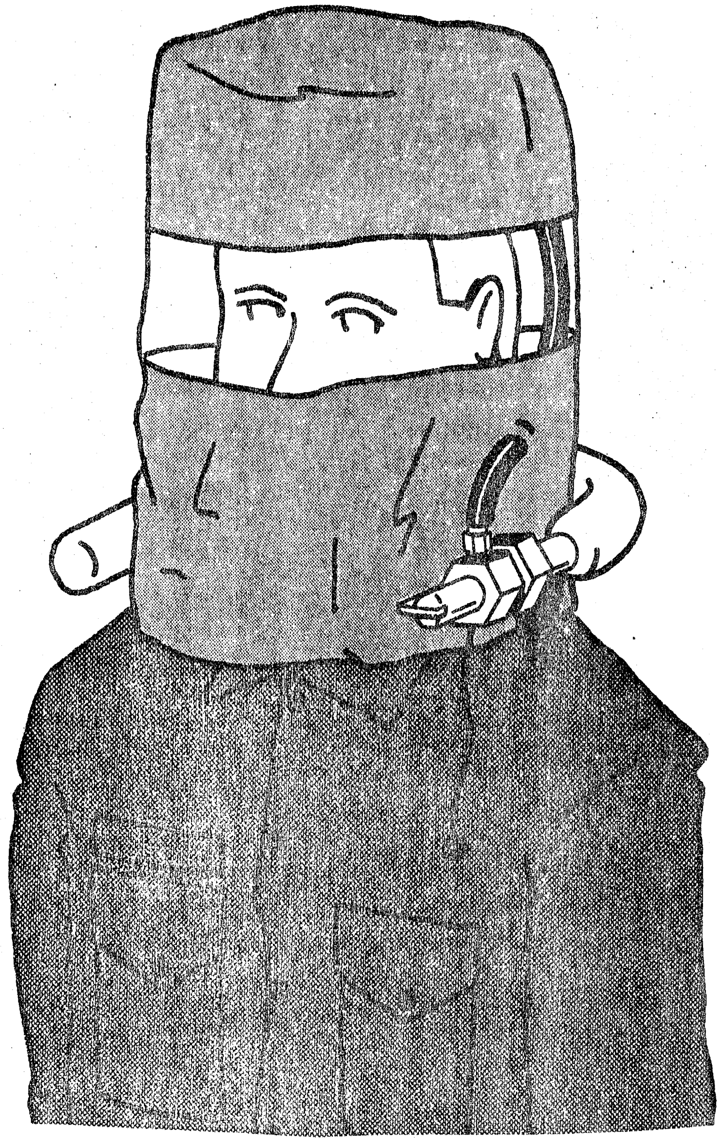
Cylindrical with domed top. Volume 26.5 liters. Annular neck ring of elastomeric film. Clear hood, except for metalized polyimide domed top.

How Used

Unfold from container, take breath of air, slip over head.

Figure 24, con't.

12. Experimental FAA/Schjeldahl Hood (Self-Contained Air Supply)
G.T. Schjeldahl Company, Northfield, Minn.



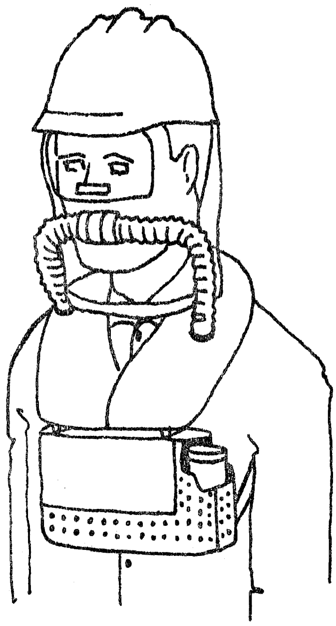
Physical Description

Clear cylindrical hood with metalized polyimide domed top. Annular neck ring of elastomeric film 2 mil (Kapton). V-shaped compressed air cylinder with rubber tube into hood; lanyard mechanical initiation. Compressed air unit snaps to hood, stabilized by two shoulder tabs. Air supply duration can be carried, 4-15 min.

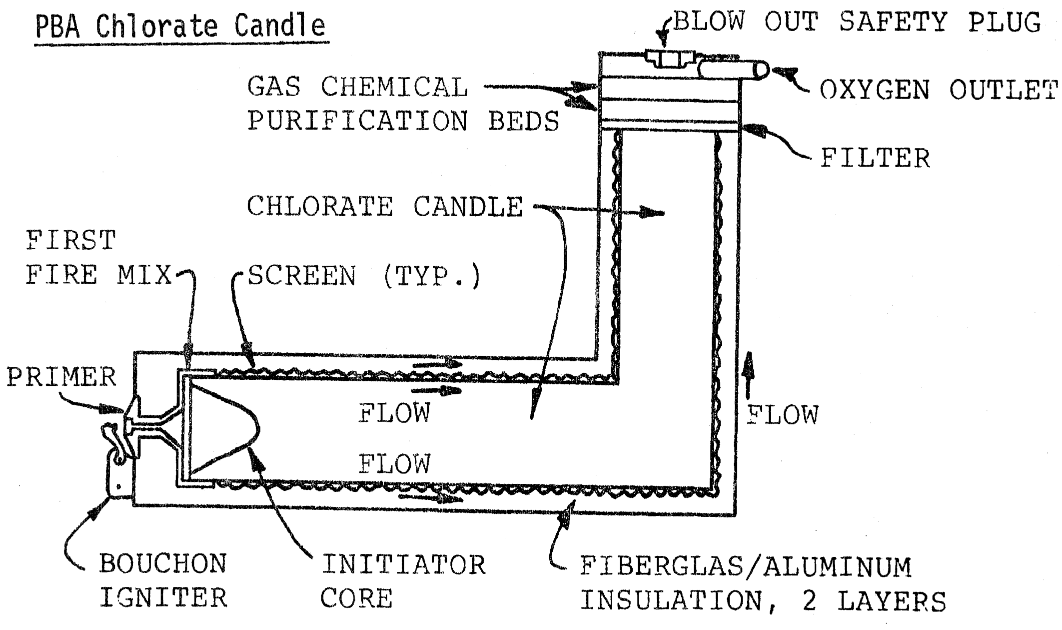
How Used

Draw over head, pull lanyard.

13. Westinghouse/Schjeldahl Portable Breathing Apparatus (PBA) Hood (Experimental 10 units designed and fabricated under U.S. Bureau of Mines Contract, 1971).



PBA Chlorate Candle



Physical Description

Mylar-plastic hood with rubber neck seal, celluloid-lense eyepiece, 8" x 7.5" x 3" carrying case with chlorate candle, mouthpiece with dual scuba-type air hose, polycarbonate heat shroud.

How Used

Place hood and heat shield over head. Bite mouthpiece, adjust carrying case with strap. Don helmet (designed for mine rescue).

DISCUSSION

The main objective of this portion of the study is to evaluate the practical usefulness of the smoke hood, with particular attention to psychological and physiological effects on the wearer in a flame, toxic fume, and smoke post-crash environment. Considerations of visibility, ease of donning, time of use, and optimum neck-seal devices are being determined as well as other smoke-mask concepts as applied to passenger and crew-member emergency evacuation needs. The majority of the information and testing has been specifically related to civil air carrier application. Thus, some of the objections outlined in the preceding summary of test results may not be valid in the military environment.

Civil air-carrier organizations appear to have opposed FAA proposed smoke-hood requirements primarily on grounds of cost (about $15.00 each), pilferage, and the hazards of too long use. Some support for the latter opinion has been expressed in both the ATA Riley report and in FAA-solicited comments from NAS/NRC scientists. It has been noted that the narcotic effect of higher (9.2% level CO_2) concentrations of CO_2 can lead to sudden unconsciousness, and after asphyxiation to unsuccessful resuscitation. Similarly, it has been suggested that there is a danger of hypoxia due to a limited supply of oxygen. Both of these objections, as well as the concerns cited related to insufficient time duration of air supply in the Schjeldahl hood, appear to be solved by the experimental FAA/Schjeldahl hood designed with its own self-contained compressed air supply. In this system varying durations of air supply are available depending upon orifice characteristics and cylinder size, but a five-minute modification has worked well in preliminary tests. By using compressed air instead of oxygen, the fire hazard from O_2 is reduced.

It should be noted that there has been a general desire to increase the breathing time of the smoke-hood protective device from its present 3-6 minute (FAA tests) rebreathing capability (AIA found Boeing system provided only 50 sec., Schjeldahl "D" hood 1-1/2 minutes), to 15 minutes or more. However, it appears questionable whether accident experience will substantiate such a time requirement. The civil airlines are required to demonstrate that their air transport aircraft can be evacuated in 90 seconds or less, and as a result of one C-135 crash the USAF Directorate of Aerospace Safety recommended that passengers be limited to that number which can safely egress in one minute. FAA burn tests have demonstrated that after three minutes current aircraft interiors are no longer habitable due to heat. If a chemical generator is employed in the smoke hood to increase breathing time, it also increases complexity of actions necessary by the user, and would require instruction. The fire and explosive hazard is increased in any cases where either unconfined oxygen or an inadequately protected pure oxygen supply system is exposed to a high-temperature environment. Thus, there may be a reasonable argument to dispute a requirement for a longer air supply than currently provided in the Schjeldahl rebreathing hood. The Schjeldahl smoke hood is utilized on the FAA Administrator's N1 Jet Star, as well as the Gruman Gulfstream aircraft of the Federal Aviation Administration. A modification by NASA is used by launch tower technicians for flame protection, and it is also used by various chemical companies.

Attempts to increase the time of usefulness have involved addition of a self-contained oxygen generator (fire hazard), and consideration of a chlorate candle (as in C5A Pallet seating system). The Westinghouse/Schjeldahl smoke hood, developed under the "Coal Mine Rescue and Survival Program,"[4] has a J-shaped canister containing a chlorate candle and 6" x 3" lithium hydroxide CO_2 absorbent, which has apparently enabled subjects to breath for a period of one hour. The hood itself was not rigidly tested in this program, nor was it designed for aircraft fire protection.

Adaptation of the emergency oxygen mask for inflight fires and smoke emergencies has generaly not been successful because the dilution value allows in outside (smoke) air. This could also increase the potential fire hazard under some conditions. Attaining a cabin pressure of 14,000' (during loss of cabin pressure) automatically trips the emergency oxygen system; however, the automatic oxygen regulator only provides a minimum of oxygen flow at this altitude (approximately 0.5 liter normal temperature pressure dry 70°-760mm dry (NTPD), expanding to only a liter or so in terms of body temperature pressure saturated, 37°-ambient - saturated (BTPS). At rest an individual breathes approximately 7 liters per minute, therefore the difference between approximately one liter and seven must be composed of air which may contain smoke and toxic gases.

The most advanced modification of the Schjeldahl smoke hood for air transport passenger egress involves the addition of a self-contained compressed air supply. Prototype units have been fabricated by Schjeldahl under contract to FAA, with cylinders fabricated under contract to U.S. Divers. As shown in item 12 on page 102 this consists of an 1100 psig cylinder clipped to the hood at neck level. Activation is by pulling a cord which initiates a mechanical puncture of the cylinder, allowing compressed air to flow directly into the hood. The flow rate can be adjusted by changing orifice flow control fittings to provide various flows and durations. Experimental durations of four to eight minutes have been tested to date at the FAA's Civil

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[4]Bureau of Mines, 1971 Coal Mine Rescue and Survival System. Contract HO-101262, Westinghouse Electric Corp. (Unpublished).

Aeromedical Research Institute, Oklahoma City. Tests of an orifice providing a four minute forty-seven second duration flow calibration has been found to provide the following flow rates:

Start -	8.5 lpm
1 minute -	5.8 lpm
2 minutes -	3.5 lpm
3 minutes -	1.8 lpm
4 minutes -	0.7 lpm
5 minutes -	0.1 lpm

In addition, this modification of the smoke hood has been improved in other respects. The hood is constructed of extra-heavy Kapton (2 mil) instead of the standard 1 mil polyimide film (Kapton) used in the standard rebreathing hood. This provides improved aging characteristics (shelf life). However, little is known of the aging characteristics of the elastic polyurethane film of the neck seal. The hood has been completely metalized, except for a two-inch visibility band.

Although tests of this development are still underway, some results available to date show the following characteristics when the hood is donned and activated:

1. After activation the hood begins to inflate somewhat like a balloon. Once inflated, the cylinder is lifted up off the shoulders. With the hood distended vision is improved.

2. The neck seal acts as a relief valve, and CAMI measurements indicate only 1 to 2 mm Hg of positive pressure can be built up inside the hood. A slight eardrum pressure may be experienced, similar to diving four to five feet under water.

This experimental modification of the Schjeldahl smoke hood appears to offer a solution to a major objection to its usage in current civil air transport aircraft by providing a self-contained air supply. The compressed air cylinder offers a means of increasing the air supply to allow greater egress time duration capability, and thus improved occupant protection. However, this also increases the complexity of the device and ironically degrades the simplicity of the original hood. For successful use, briefing or training becomes more important, since a manual action is required by the passenger after donning in order to initiate the air supply. On the other hand, even if the wearer neglects to pull the cord to initiate the air supply at all he still has the same protection as the rebreather hood.

The logical follow-on development will involve overcoming these disadvantages while retaining the advantages of a longer duration air supply. This means that instead of manual operation the device should become passive, with automatic actuation of the air supply when the device is donned. Experimental development of a smoke hood with self-contained automatic air supply is being considered by the Civil Aeromedical Institute of the FAA at Oklahoma City. However, to date this is still in a concept stage.

Table 4 provides a summary analysis of the Schjeldahl septal neck seal (Model S) smoke hood, which has been evaluated as the best available device within the current state of the art, and is a production item. Among the factors which tests to date have indicated may be problems are deterioration characteristics, durability, reuse, fit on other than adults, donning over glasses, vision, effect upon cardiac or pulmonary dysfunction passengers, legal problems, CO_2 buildup, hypoxia, and hood fogging. Most of these problems appear solvable or insignificant for military transport emergency use. (Despite these problems, it is significant to note that the FAA Administrator's aircraft is equipped with this particular smoke hood as emergency equipment, and that the Federal Air Surgeon routinely travels by air with such a protective device carried in his briefcase).

A detailed analysis of the system safety, maintenance, hazards, reliability, and human factors of the various smoke hoods and smoke masks available within the state of the art have been made and a smoke-hood mask functional-flow fault tree is shown in Figure 25.

It is concluded that the currently available Schjeldahl rebreathing smoke hood with septal neck seal (Model S) can provide significant protection from smoke, toxic fumes, and flame in post-crash fire emergency egress and its demonstrated merits far outweigh any potential risks or problems. It is recommended that until improved devices with automatic air supply are available the current Schjeldahl type smoke hood be provided as a standard item of emergency equipment for all occupants of military Air Transport aircraft.

TABLE 4. SUMMARY OF PRELIMINARY DESIGN FOR SCHJELDAHL SMOKE-HOOD SYSTEM

AMBIENT ENVIRONMENT	MENTAL DEMANDS	HAZARD EXPOSURE	PHYSICAL DEMANDS
.Polyimide (amide) films capable of protecting in excess of 1400° F. .3-8 minutes O_2 supply. .Visual acuity not impaired at low 0.05-foot-candle levels of illumination (models). . Infrared emissivity and reflectance excellent . .Optical transmission not satisfactory with model D excellent with model S.	.Simple to don. .Tests show simple verbal briefing adequate. .Requires no mechanical aptitude or skill. .Requires little training, little judgement, ability to follow relatively simple written or oral instructions. .Requires moderate recall.	.Available O_2 when CO_2 critical level of about 8% reached; sensation of choking will cause subject to remove hood. .Flammability protection: excellent. .Toxic hazards excellent (with Model S), fair (with Model D). .Irritability protection: excellent (with Model S) fair to poor (with Model D). .Hazard level category II - marginal, can be counteracted or controlled without injury to personnel or major system damage (MIL-STD-282).	.Simple to don with normal use of hands. .Can be donned with one hand with some difficulty. .Requires little expenditure of energy. .Readily learned by demonstration.

	HUMAN FACTORS (MIL-STD-1472A)	SYSTEM SAFETY (MIL-STD-882)	TASK EXPOSURE
	.Some difficulty in quickly locating neck seal (needs color outline) .Instructions adequate .Can increase donning time and decrease problems in donning with prior experience.	.Present hood cannot remain in use beyond 3-6 minutes. .Hazard Level II.	.Potential effect of improper task performance on system operation critical.

EQUIPMENT CHARACTERISTICS	RELIABILITY (MIL-STD-785)	MAINTENANCE (MIL-STD-470)	POTENTIAL VALUE
Material: metalized polyimide (Kapton). .Weight. Not signif. .Size (stored): pocket (in use) 16" high 12" diameter. .Volume: 26.5 liters .Shape: cylindrical, with domed top. .Closing (Model D): Elastic fiberglass neck drawstring (Model S): Annular ring of elastomeric film (3"). .Heat resistance: polyimide film with reflective coating. .Vision: (Model D), 2" vision band (Model S), clear hood.	.General - excellent (only failure determined to date occurred when one mask ripped in coal-mine test). .Life cycle decrement undetermined.	Accessibility: excellent .May be problem with decrement with repeated usage (seal breakdown) . .Periodic inspection and replacement would probably be necessary. .Effect on depth and frequency of maintenance requirements at each level. .Facilities, support equipment, skill levels and number of individuals required to be determined.	Tests to date indicate offers excellent protection to head and face in flammability. .Advanced model "S" septal neck seal model offer greater protection from toxic fumes, smoke, and eye irritability than earlier neck draw-string "D" model. Tests of "S" model clear hood indicate no significant vision acuity decrement under conditions of low illumination. Limitation of 3-6 minutes breathing time can be increased by modification with self-contained O_2 generator or compressed air source.

Figure 25. Smoke Hood/**Mask** Functional-Flow Fault Tree

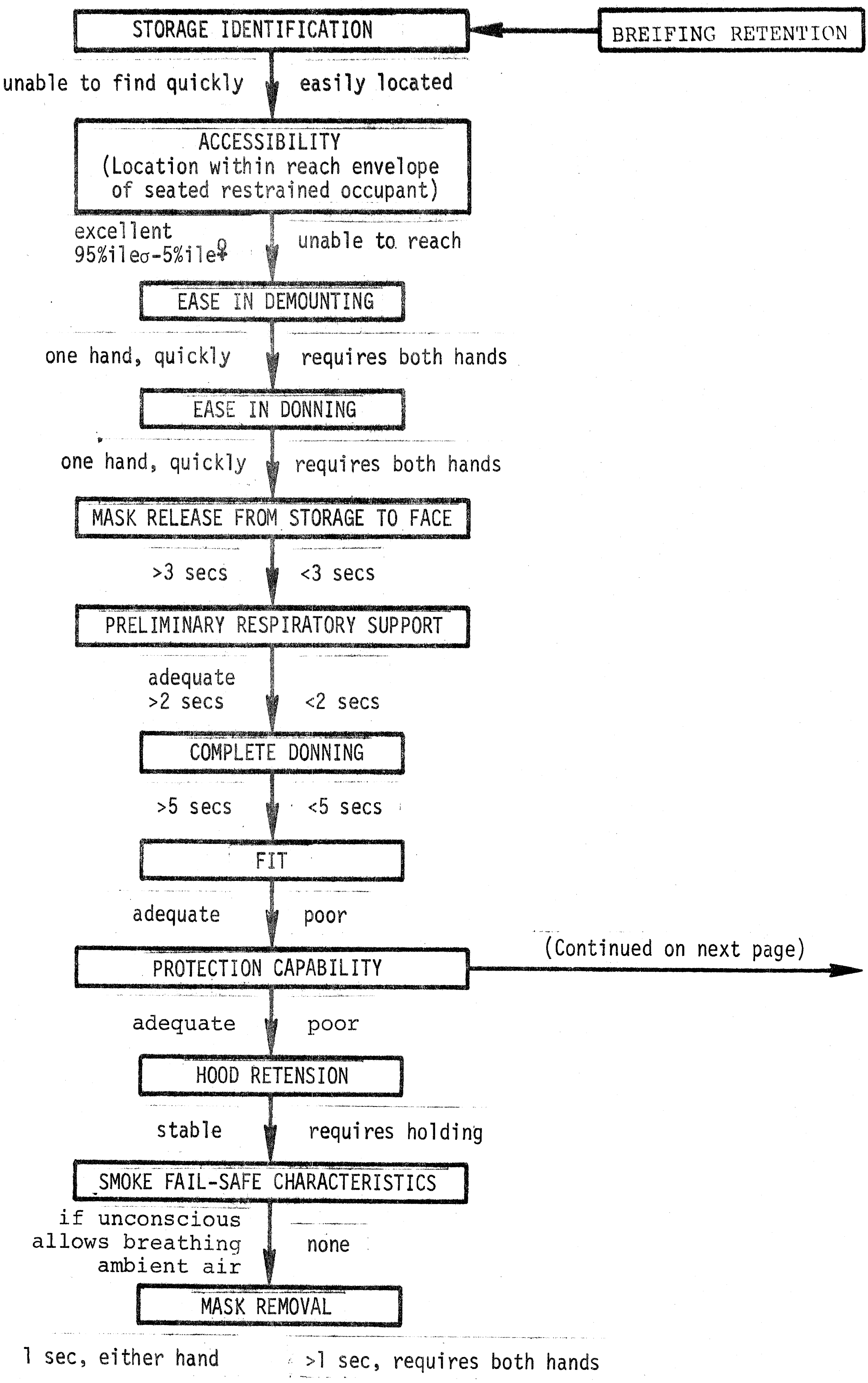
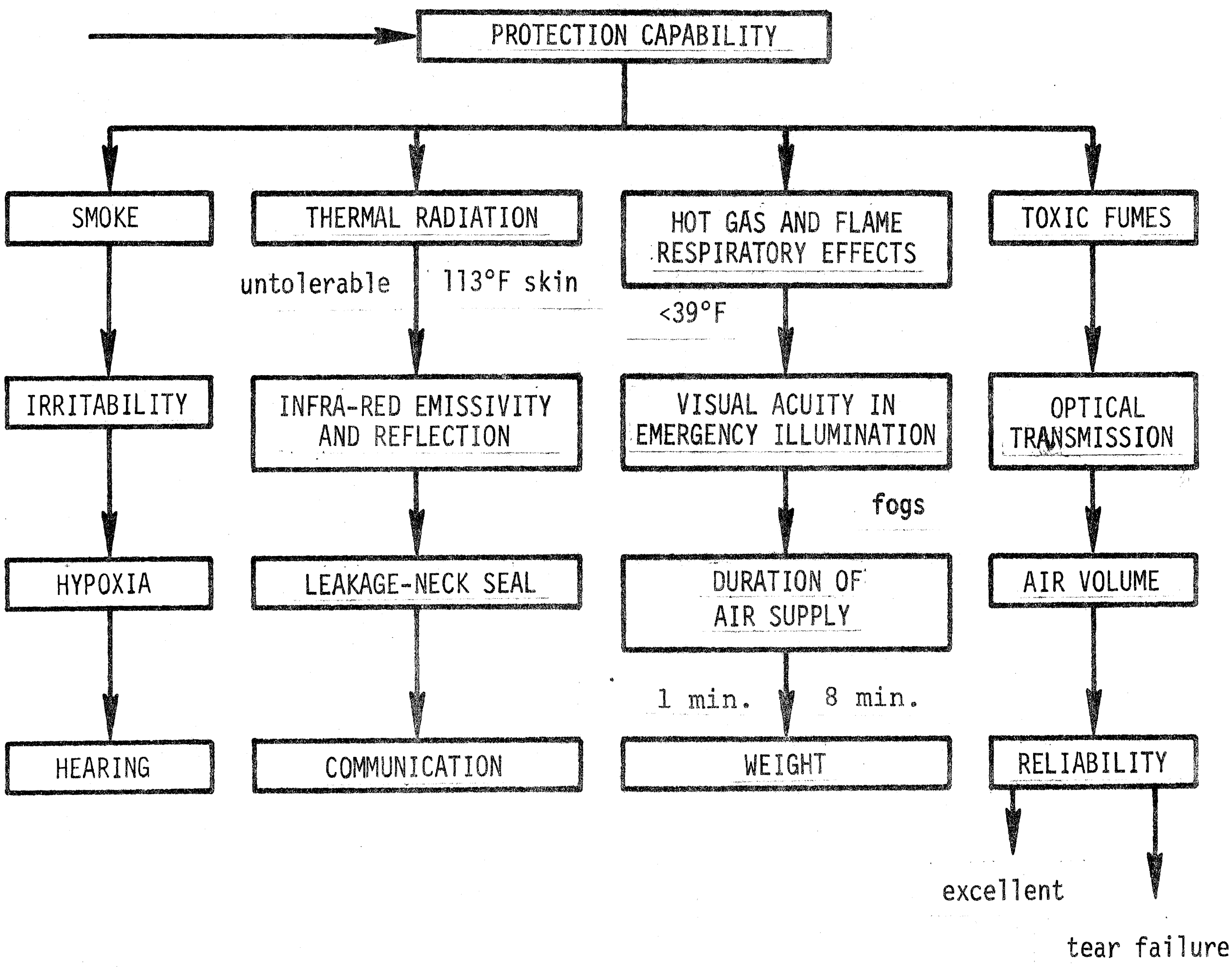


Figure 25, con't.



SECTION VI

AISLE AND EVACUATION MARKERS

Accident data from a number of studies indicate that in most "survivable" jet transport crashes to date occupant survival has been largely determined by the ability of uninjured passengers to leave their seats and find an exit before succumbing to fire or smoke. The aisle and evacuation path markers, placards, lights and other devices to assist in the efficient and orderly evacuation in case of a crash emergency must be considered with respect to known human factors considerations such as size, illumination, color, background, form, location, and ease in understanding, as well as reliability, maintainability, and system safety aspects.

The objective of this portion of the study was to evaluate aisle markers and emergency evacuation path markers such as reflective tapes, signs, arrows, and nonradioactive luminous strips for use in marking evacuation routes. In addition, consideration was given to products which could be applied to floors, wainscotings, and other interior surfaces, and require either a self-contained power supply or no power supply at all. Aisle width requirements were also examined.

OPERATIONAL DEFICIENCIES

Current operational deficiencies with respect to aisle and evacuation path markers which were observed during inspection of a limited number of MAC C-141A and a single C-135A aircraft have been previously noted in Section III. If these aircraft were typical of present military air transport aircraft these findings suggest that the passenger (and even crew) has no significant emergency egress assistance from markers during evacuation. Major points relating to the total inadequacy of path marker systems observed in these aircraft are:

1. No path markers or exit arrows were found in these aircraft.
2. There were no emergency instruction cards in the C-141A (the C-135 had only one for the entire aircraft).
3. In one C-141A aircraft the sign "EMERGENCY EXIT" inside the main (left) entrance door was almost completely chipped away by wear, and the edges of both the sign and exit orange-yellow painted outline band had been spray-painted over so that they could barely be seen at close range in daylight. They could not have been seen from a distance or under poor light conditions.

4. The yellow exit outline around all escape doors, hatches, and windows was faded, painted over, and obscured.
5. There were no signs or arrows indicating the location of either crash axes or fire extinguishers (and they were bare metal, unpainted.
6. On the flight deck of one C-141A aircraft the sign "Exit Release Pull Handle" adjacent to the crew aft roof escape hatch was facing to the right side of the aircraft, requiring an awkward head rotation in order to read the sign. On a second aircraft this escape hatch was missing the "Exit Release Pull Handle" sign entirely.
7. There was no crash impact exit emergency illumination system in the C-141A. At night or under smoke conditions exit signs could not be seen.

MIL-A-25165B(ASG), Amendment-1, 29 May 1969 specifies: "3.5 <u>Emergency exit electrical lighting and identification</u>: all cabin lighting used to identify exits shall conform to MIL-L-6503 and MIL-L-25866 and shall be battery powered. Batteries shall be similar to commercially available, rechargeable nickel-cadmium batteries, and shall be CFE. All exit lights must be able to withstand 20 g crash loads for 0.10 second pulse duration and they shall be energized by an inertia switch during a crash, also by the loss of normal aircraft power."

8. There was no external exit emergency lighting system.
9. No illumination or marking of escape paths.
10. Although slip-proof flooring devices were installed along the C-141A cargo floors, in two of the three aircraft inspected no aids to footing were provided in the C-135A passenger decking.
11. The emergency rope ladders were marked with small letters on yellow signs, but could not be seen from a distance. It is doubtful they would be useful at night or under smoke conditions.

These, and a number of other areas where operational egress deficiencies were observed, have pointed to particular needs which have been useful in considering application of advanced technology or concepts in these areas.

AISLE WIDTH

Due to the variable cargo-passenger configurations of these air transport aircraft there is no standard aisle width. For civil jet transports minimum aisle width is specified by Federal Air Regulation FAR 25.815 as not less than 15 inches measured less than 25 inches from the floor; and 20 inches measured 25 inches or more from the floor for air transport aircraft having a seating capacity of 20 or more passengers. A recent incident points out an unanticipated problem with current (FAR) civil air carrier aisle widths. As a result of inflight turbulence encountered by a Boeing 727, six passengers and one stewardess were hospitalized and 15 passengers and one stewardess received minor injuries (Flight Safety Focus, 1971). Injuries were caused by failure to wear seat belts during the turbulence, failure of overhead storage bins, and failure of economy seat head rests; however, following landing great difficulty was encountered in removing injured passengers because the aisles were too narrow for standard stretchers.

On military aircraft minimum aisle width conditions occur when maximum capacity seating accomodations are required for troop movement. Examples are when 154 troops are carried in the maximum density seating (Figure 2) configuration of the C-141A in which four rows of side-facing nylon collapsible seats extend the length of the cabin area. In instances where troops are being airlifted for long distances and must remain in these cramped quarters for long periods of time, significant decrement in their task performance has been reported (Knapp, 1971). For example, the aisle spacing between the inner and outer-facing rows, on each side of the cabin, is so small that it has been found that at night a passenger cannot proceed up the aisle to a comfort station without climbing over (and waking up) many others. In practice, therefore, Knapp reported that passengers climbed along the center netting rather than use the crowded aisles. When two rows abreast of triple aft-facing seats are used in the C-135 the aisle width is also minimal. However, even when cargo is carried, the spacing left along the sides for passengers to reach an exit may also be minimal. In the case of the C-135 crash illustrated in Figure 1, note that the spillage of small cargo into the left-hand aisle effective-tively blocked that aisle completely, contributing to the fatalities of four individuals. It is not uncommon for already narrow aisles to be further littered with debris and baggage after a crash.

Since the aisle width specifications of the FAR were established in a 1951 study (King), and there is known to be a significant generational body size increase, current anthropometric data were examined to provide a means of comparing a 15-inch minimum aisle width (at 25-inch floor height) with the potential aisle user. In this regard the 1967 anthropometric survey of USAF flying personnel[1] shows that the mean airman hip breadth is 13.88 inches, the 95th percentile is 15.15 inches, and the 99th percentile is 15.84 inches. If an allowance for clothing is made, it appears that a 15-inch aisle width at hip height will

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[1]Clauser, C. 1971 Anthropometric Data on the USAF Flying Population - 1967. Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. Unpublished data.

be a tight fit for much of the potential male Air Force user population, and many would be forced to go through this narrow a space sideways, which would also slow down evacuation time. Females would exceed these male values by an estimated 1 to 2 inches; however, the most recent public health survey has not yet been published for the statistic of hip breadth in the general population.

To assist the passenger in emergency egress, several aisle and evacuation path-marker concepts have been proposed. These include the application of chemical luminescence for emergency signs, direction indicators, egress areas, and marking and identifying emergency equipment; ultraviolet light activation of egress signs or use of fluorescent spray; floor-level marker illumination; pulsating indicators; and tactile aids.

VISUAL PATH-MARKER CONCEPTS

CHEMILUMINESCENCE. Two principal systems which employ chemical reactions for the production of visible light ("chemical light") have been developed. One system, developed by E.I. dupont de Nemours and Co. and marketed by Remington Arms Company,[2] employs a chemiluminescent material which upon exposure to oxygen in the air produces visible light. This material is utilized in the form of long seal transplant plastic tubes for illumination of the side tubes of the escape slides carried aboard some civil air carrier transports. Activation of the inflation system injects air into the seal-tubes and therefore activates the material which can produce visible light in any width or length. Since only air is required to produce light from this chemical, advantages appear to be that it can be isolated from other lighting systems independently, presents no fire or explosion hazard, is reported to be fail safe, is lightweight and submersible, and has long maintainance-free standby life. This system can be applied to emergency signs, direction indicators, life rafts, life-jacket devices, egress areas, escape slides, and other devices; and can be used for marking and identifying emergency equipment, outlining emergency exit doorways, and illuminating controls. United Airlines has used chemical luminescence for several years to outline escape slides and to provide some exterior illumination.

"Cyalume," another system developed by the American Cyanamid co., employs two liquids which when brought together produce visible light which may be piped to various points in order to illuminate specific areas. Similarly a two-compartment container has been produced which, when squeezed, fractures a barrier or ampual of one liquid so that when they come in

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[2]Manufacturers of the various path-marker illumination systems discussed in this section are listed in Appendix B.

contact a visible light is produced. A variety of concepts utilizing these materials have been pursued. These include a Remington Chemical System suspended in a gel base which will float on water producing light all around a life raft or downed aircarft. A potential exists for development of pencils in a wax base or marker which may be used to write on surfaces in light. It is possible that the American Cyanamid two-liquid system can be packaged in a two-compartment aerosol container which, when activated, could produce a cloud of light in the air. Many of these potential uses are under current investigation and development. In general, chemiluminescence formulations producing the highest brightness also exhibit the shortest duration. And the longer the duration the lower the initial brightness.

Chemiluminescence was evaluated for the FAA in 1968 (Roebuck) and it was concluded that "reliability would be improved 100 percent" through use of this concept in egress path-marking applications. Test data, properties, and characteristiss are as follows.

The light output is a function of ambient temperature, the humidity of the activating air, and the form in which the product is prepared. Voltage influences brightness. A 600-volt electroluminescent light has a brightness of about 20 foot-lamberts. Duration of useful light output ranges from five minutes to four hours.

However, Strongin (1969) reported emission life as between a few minutes and two to three hours, with light outputs up to 35 microlamberts. The light spectrum covers the entire visible range, with a peak in the vicinity of 500 namometers wavelength (blue-green). Approximately 35 cc of air at atmospheric pressure are required to completely oxidize the active chemical in one square inch of a "chemical light" panel. Light output ceases after complete oxidation. Other characteristics of chemiluminescence areas follows:

1. Weight of "chemical light" devices: One square inch of light area of a panel weighs approximately 1/2 gram.
2. Heat generation: It is cold light, and is not subject to spontaneous combustion.
3. Light stability: Not affected by exposure to visible light.
4. Storage life: In its sealed container, and with storage temperature below 120° F, "chemical light" can be stored for about two years.
5. Chemical compatibility: It is compatible with inert materials such as saturated hydrocarbons, nylons, teflon, mylar.
6. Toxicity of active ingredient: The amount of exposure to the active chemical which will occur with normal use of a "chemical light" device will

have no harmful effect. However, if a large quantity of the active chemical contained in such a devaice is ingested, or placed on the skin or in the eyes, and allowed to remain for a long period of time, or if a concentration of its vapors is inhaded for a long period of time, mild temporary irritation may occur. Irritation can be avoided by washing out the chemical (or inhaling fresh air) immediately after such overexposure.

7. Testing of chemical-light devices: It is not necessary to turn on a "chemical light" device to determine whether it is in operating conditoon. A "passive" check can be made with ultraviolet light.
8. The characteristics which make "chemical light" useful in solving unusual lighting problems are the following:
   (a) unlimited variety of shapes and sizes in flexible or rigid form
   (b) requires no power supply
   (c) isolated system; submersible
   (d) long standby life
   (e) lightweight and unbreakable
9. Reuse: Requires replacement of sealed bags. The check for capability to light is performed by exposing to ultraviolet lamp and is inexpensive.
10. Duration: Can be produced for variable times, sufficient for most crash egress requirements.
11. Crashworthiness: Excellent.
12. Toxicity: No toxic effect reported.
13. Vision: Greatly improved.

Chemical light could also be useful in marking emergency evacuation routes. While it has been reported to be very effective in increasing visibility under conditons of darkness, no information on visibility under smoke conditions has been noted.

Reflective arrows have been suggested (Brown, 1969) as an aid to emergency egress indicating passenger direction to the nearest exit. These could be placed on the cabin walls or along the aisles on the floor. However, this technique requires a light source for reflective illumination in the dark. Such arrow markers could be painted with a fluorescence paint or other techniques discussed could be used such as chemical light, to be seen in conditions of low visibility. However, retrorelfective materials which reflect light (they do not glow or emit light) are only useful as long as a light source is available.

ELECTROLUMINESCENCE SYSTEMS. Electroluminescence operates an alternating current (A.C.) and reportedly operates best at 75 to 175 volts at 400 cycles most common in aircraft.

Brightness can be varied considerably; for example, at 60 cycles resulting illumination is about 7 foot-lamberts, while at 400 cycles brightness goes to 50 foot-lamberts. Several technical papers provide detailed performance data (Howell and Neiburgh, 1966; Kaelin, 1966; Wheelright and Shonyo, 1966), there has been a proposed Society of Automotive Engineers A-20 Committee document on luminescence (ARP922), and there is available a bibliography providing 263 abstracts of work to 1963 (Department of Commerce, 1963). This technique has been used for some dials and panels but has not been used extensively. Disadvantages of the electroluminescence system include requirements for a relatively high-voltage energy source and problems associated with failure of the tape to bend at sharp angles as required in the packaging of slide rafts or escape slides.

ULTRAVIOLET-ACTIVATED PATHWAY SYSTEMS. These systems employ a floor covering treated with an ultraviolet system material which is activated by ultraviolet radiation sources or would utilize an ultraviolet light source and special fluorescent spray lacquer, or other material normally not visible in incandescent light, for evacuation marking on floors, walls, seats or emergency egress exits.[3,4,5] A patent application was made by Luminex, Inc., Santa Barbara, California; however, there is insufficient data available to evaluate this as a potential aisle-marker system. Evidently this concept would utilize an ultraviolet collimated (indirect) light source with battery power source. Aspects of toxicity, wear resistance, smoke scattering of light, and compatibility with other strong white lights is unknown. The principal disadvantages are the relatively high electrical power requirements for the ultraviolet sources and the relatively low level of visible light which may be rapidly obscurred by low concentration of smoke in the cabin. Alternative techniques appear to offer greater improvements at this point.

SELF-LUMINOUS SOURCES (TRITIUM). Current air carrier aircraft utilize self-luminous exit markers which employ gaseous radioactive H_3 (Tritium) sealed in a cerium glass

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[3]Howell, B. and R. Neiburgh. 1966 Contemporary Luminescence Lighting Performance. Paper presented at SAE A-20 meeting, Los Angeles, California, Sylvania Products, Inc., Salem, Massachusetts, and Honeywell, Minneapolis, Minnesota. November.

[4]Kaelin, G. 1966 Electroluminescence as an Aerospace Light Source. Symbolic Displays, Inc., 1188 Batavia Street, Orange, California.

[5]Wheelright, D.C. and H.N. Shonyo. 1966 Spacecraft Lighting. North American Aviation, Downey, California. March.

envelope. The inner surface is coated with a zinc sulfide phosphor (McFadden et al., 1965). Radioactive bombardment of the phosphor produces visible light. This assembly is embedded in a lucite envelope and since Tritium is primarily a Beta radioactive emitter there is no detectable radiation at the surface of the unit. If broken, the light Tritium gas dissipates into the atmosphere very rapidly. It is postulated that for an individual to absorb significant quantities of radiation through such a source, he would have to breathe the gas for a number of hours in a very confined area. Self-luminous life-raft sources have been developed for life rafts to aid in boarding and detection. The principal disadvantage is the relatively low level of illumination provided without exceedingly the allowable quantity of Tritium as permitted by the U.S. Atomic Energy Commission. A detailed radiation safety analysis has been made and published in the Federal Register (12 September, 1961) prior to the granting of a general license for use of Tritium self-luminous devices in aircraft (AEC, 1962). Recent developments have produced units with double the brightness of former units. Duration of luminescence is primarily a function of the half life of Tritium (12.6 years). The Tritium self-luminous light sources exhibit a very distinct advantage of reliability in that no external source of energy is required for activation. They operate continuously and do not require external mechanical and electrical devices for their activation. They also are insensitive to environmental extremes. Both U.S. Radium Corporation and Conrad manufacture radioisotope markers and make phosphors.

PHOSPHORESCENCE MARKERS. Phosphorescence involves the property of a material to emit light in the visible spectral range after all outside excitation of the material has ceased. Phosphorescent materials which are exposed to a light source (incandescent, fluorescent, sunlight, etc.), will continue to glow in the dark for extended periods of time after the removal of the light source. Such materials are basically available in the form of paint or plastic film with pressure-sensitive adhesive. There are two basic types: that with a blue color contains CaSnS pigment providing a low initial glow and low, long afterglow; the green-colored phosphorescence contains ZnS pigment which characteristically provides a high initial glow and some types have a long, low afterglow. These paints have been used in some aircraft dials and vinyl pressure-sensitive signs have been used by some air carriers (Strongin, 1969). They are applicable to exit signs where a power failure occurs, but are dependent upon prior excitation by an independent light source.

INCANDESCENT SOURCES. Incandescent sources are used extensively for general cabin illumination, specific illumination level requirements for aisles, and general illumination, as well as over emergency exit signs and spot illumination near exits. Most of these systems utilize rechargeable batteries at each source. These batteries are trickle-charged by the aircraft electrical system and are activated by a drop-out switch upon failure of the main aircraft system. The inertial switching system is no longer utilized extensively in air-carrier aircraft. Incandescent sources are also utilized to illuminate escape pathways on the wing by installation of light fixtures in the rear junction with the wing. Escape slides may also be illuminated by incandescent fuselage-installed light sources to meet requirements for illumination of the escape slide and the ground at the end of the slide. Small wiring harnesses utilizing miniature "wheat bulbs" were developed which may be affixed to the upper surface of the escape slide in order to illuminate the upper surfaces and define the geometry limits and attitude of the slide.

GASEOUS DISCHARGE SYSTEMS. Xenon strobe lights powered by small batteries have been developed and extensively utilized as survivor locator lights. In general these lights emit approximately 100,000 lumens per flash at a rate of from 50 to 60 flashes per minute. Small units emitting approximately 1 million lumens per flash have been developed for use on rife rafts by A.C.R. Electronics and other companies. This type of unit was evaluated in the FAA crash tests of transport aircraft carried out in Phoenix, Arizona in 1965. The unit was installed between the panes of the emergency exit windows as an aid in locating the exits from the outside of the aircraft in rescue. It was noted that even after the exits had been covered with about two inches of water foam the flash of the strobe light was clearly visible through this material under bright desert sunlight conditions.

FLOOR-LEVEL LIGHTING. Emergency evacuation environments involving degraded visibility due to smoke or darkness suggest that floor-level lighting could greatly assist passengers by speeding up egress time, since smoke least obscures the area of the floor. This lighting could be battery powered and automatically energized in case of loss of the main power supply, or activated manually by the crew. If lighting consisted of floor-level flood lighting, fluorescent or incandescent lamps could be mounted on walls or seats to illuminate aisles or exits, or electroluminescent lamps could provide illumination for pathway markings. Due to the variable cargo-passenger configurations in the C-141 and C-135 type aircraft, such a system might not be as practical as for a standard civil air-carrier aircraft.

DIRECTIONAL AISLE AND EVACUATION ON-OFF LIGHTS. In this system progressive on-off timed lamps provide an impression of movement (similar to segmented automobile turn lights, neon outdoor advertising signs, or runway landing light systems), which may catch the passenger's attention and direct them toward emergency exits. The lamp could be located on the ceiling, side of the fuselage, on the sides of aisle seats, or in other locations where they would be most visible during emergency evacuation conditions. These emergency lights can be controlled by heat sensitive sensors or impact sensors, as well as by the crew manually to indicate the best exits and provide best passenger flow. In this respect this system reportedly has the capability to increase exit and egress route visibility, distribute passengers to various exits, and assist optimum evacuation flow by directing passengers by control of light motion. By using heat sensitive sensors, lights on the side or in an area involving fire would not activate, leaving only pulsating lights on the nonfire side.

This concept could be manually operated by the crew or used in automatic mode. Crew control panels would consist of on/off (each unit), directional control (each unit), test control, and manual override. This permits the crew to manually control the initiation of the system and control the direction of the signal for control of passenger flow as well as test the system or use it as part of the preflight briefing.

For automatic operation, the system could be equipped with sensors which detect conditions requiring evacuation (g-load or heat) and unusable exit conditions (heat, structural deformation). This would permit the system to activate on detection of excessive impact and fire and then to select proper motion direction as related to the heat or structural damage to primary exits.

The directional signals would be located on the walls, possibly along the molding or luggage racks, as well as on the ceiling and floor for conditions of poor visibility or aircraft attitude other than normal. Another use would be in terminals where the signals could function both to direct boarding passengers and familiarize them with the signals. The signals can be composed of standard lamps or electroluminescent material. The later would permit inconspicuous installation until actuated. The lamps would momentarily illuminate progressively toward the preferred exit, thereby serving both as a directional indicator and exit locator aid. The intensity and flash rate of the lamps could be such as to permit the perception of movement and to insure visibility in expected degraded visibility conditions. These magnitudes would have to be selected by laboratory tests. It has been proposed that a slower flash rate could be used for boarding and deplaning under normal conditions than would be used for the emergency conditions.

All of the components of this system concept are within the current state of the art. Although no readily adaptable units have been identified as available, no foreseeable problems are evident as development difficulties. Maintenance and repair costs could be relatively low if high-reliability solid-state timing and control devices are used. Fail-safe logic for circuitry could be the greatest problem, and sensor reliability is also critical. A small effect on aircraft structure and interior decor is foreseen; however, space requirements are negligible.

This pulsating light offers a significant increase in informational content both as to exit location and recommended direction for egress over current techniques. The selection of flash rate and intensity is important for effectiveness in potential evacuation conditions of reduced visibility caused by darkness, smoke, or flame illuminated areas. Electroluminescent displays would require careful evaluation in this regard. The capability for manual operation by the crew must be carefully considered to insure operability and ability for correct selection of displays and directions. This must include determination of control location, visibility of crew, and awareness of conditions (external fire or hidden structural damage) which can determine the capability to operate the system. For this reason, the proposed system should be primarily designed for automatic operation.

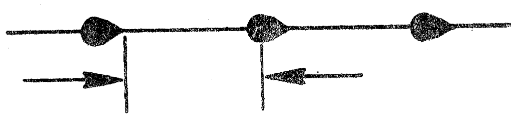
An evaluation of this system for the FAA was conducted by North American Rockwell (Roebuck, 1968) and at that time it was concluded that such a system would provide a significant improvement in passenger emergency evacuation flow under a variety of egress conditions. It was considered to be compatible with existing systems, and estimated that in cases of exit blockage or crowding this concept could improve flow by 10% or 30% "in situations requiring redirected flow."

TACTILE AISLE MARKERS

The purpose of tactual indicators would be to provide a means of directional identification of emergency exit location and/or equipment under conditions in which visual indication is not available. By reference to feel alone such markers could provide useful indicators. Other advantages over other path marker concepts are that tactile indicators would be available no matter what the aircraft attitude, and independent of any power requirements or environmental conditions. Markers could be placed on the floor (to provide directional information); the ceiling (for when aircraft is in inverted attitude); sides, backs, or tops of seats; or on walls to locate emergency equipment. Such indicators could be located to provide a continuous source of cues from any seat position to exits or emergency equipment.

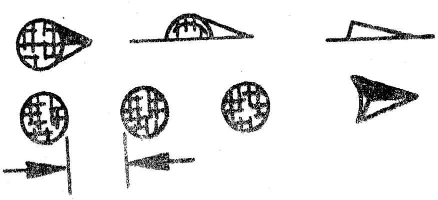
Limited research and development has been done on this concept. The idea has been advanced occassionally in the literature (Aviation Week and Space Technology, 1966), and description of the concept was included in the FAA evaluation of emergency evacuation concepts (Roebuck, 1966). From this report the following tactual indicators were suggested:

(a) Wire, cord or other runners with periodic direction indicators (arrows)



Particularly useful on ceiling where the possibility of interference with egress is minimum. Technique allows continuous and therefore very rapid use.

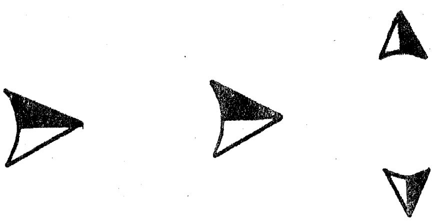
(b) Raised buttons or beads with pointed sides indicating direction or periodic arrow.



This technique is particularly useful on floor areas for crawling or where continuous hand contact can be maintained and where minimum disturbance of surface, carpet or upholstery is required.

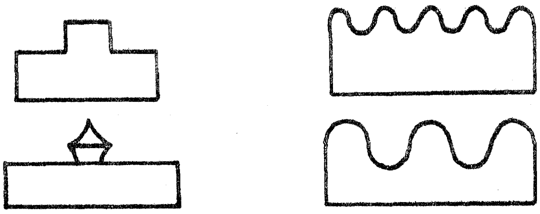
(c) Series of directional arrows raised to provide a tactual utilization capability.

These are similar to technique (b). Potentially, they could be combined with ultraviolet or chemical light indicators but should be system developed and evaluated to insure quick, reliable utilization.



(d) Grids or other special tactual indicators.

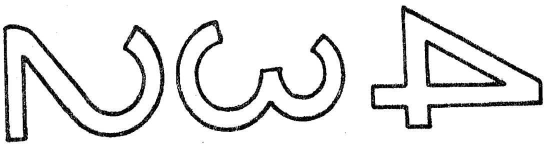
These are useful in indicating arrival at exit or equipment location; also useful on top of seat to indicate aisle with exit. These would be selected shapes proven unambiguous.



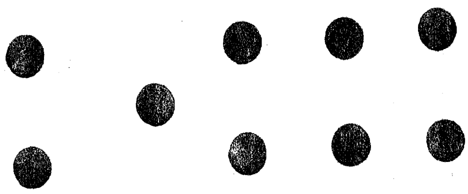
(e) Raised numerical indicators

This technique could be useful to indicate number of feet, steps, or seats to equipment or exit.

(1)



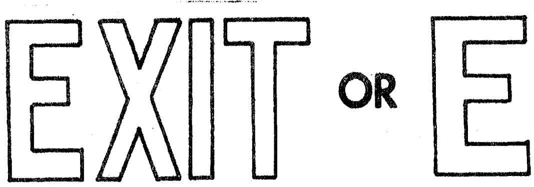
(2)



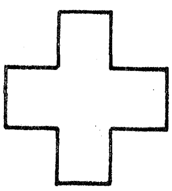
(f) Raised name, symbols, or abbreviation indicators

This technique could be useful to indicate what is at end of series of tactual indicators.

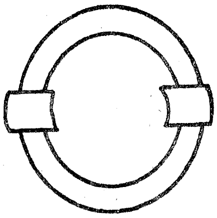
(1)



(2)



(first aid kit)

(3)  (life raft)

The tactual system would be designed as a backup system to the visual displays utilized for emergency egress. It would be most useful where visual cues are lacking, such as at night with no emergency lighting, or in conditions of heavy smoke. Since it would be a passive system however, it is preset and could be in conflict with other than normal egress patterns when passengers must be redirected. In this limited case it might actually slow up evacuation. The concept was rated as having very good cost effectiveness and was estimated as improving chances for survivability by 50% in cases where poor visibility influences emergency egress.

The Aerospace Industries Association (1968) conducted tests of the use of tactile aids for locating exits during adverse visual conditions. Fourteen subjects were individually tested under smoke conditions, using the accuracy of the direction indicated and latent response criteria to evaluate eight different tactile shapes. These forms were evaluated for two different thicknesses, 1/8 and 1/4 inches. Thus 16 different test conditions were evaluated. The tactile cues used in these tests are illustrated in Figure 26. The experimental design required the subject to place his left hand into a box that held the plywood tactile form and, by feeling this form, indicate it's direction. This was done as rapidly as possible by turning a knob on a display board at the top of a box with the right hand and subsequently pressing a button to shut off the timing device. None of the tactile forms in the box were visible to the subject.

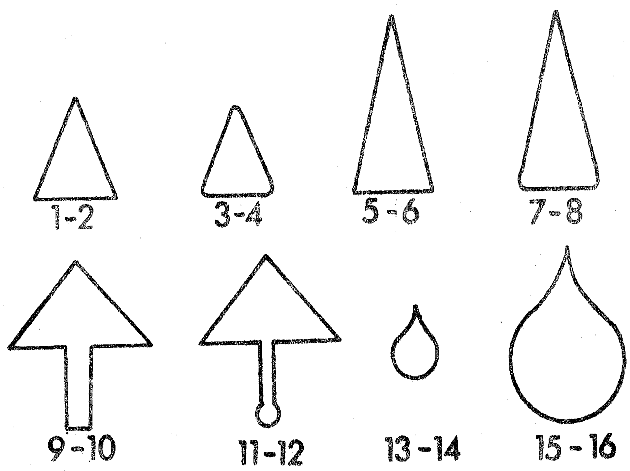


Figure 26. Shapes of 1/8 and 1/4 Inch Tactile Cues Used in AIA Tests

Results of these tests with individuals indicated that the teardrop-shaped (13-16) and elongated-triangle-shaped (5-8) forms were significantly better shapes in indicating direction. This was found in regard to quicker response times, resulted in significantly fewer errors and fewer reversal errors (180° out of phase). The thickness variation (1/8 to 1/4 inch) made no difference, and a subject preference was indicated for larger forms. The two-inch elongated triangle was recommended as the best tactile form tested. However, when groups of people were tested under evacuation simulation it was found that tactile cues were relatively ineffective. Subjects used them infrequently, preferring to hold onto the person ahead, and additional time was lost in using them.

OTHER CONSIDERATIONS AND REQUIREMENTS

In some accidents it has been found that crowding with disastrous results may occur when too many people try to use the same exit. This occurred, for example, in the DC-8 accident at Denver, the C-135 accident with 11 fatalities, and is observed through the numerous instances where only a few of the available exits are used, such as in the recent DC-8 Military Charter crash at Anchorage (all discussed in Section II). Thus, a directional aisle-marking system should consider the distance to the nearest exit.

New FAA standards have recently been put into effect relative to emergency lighting under FAR 25.812, Federal Aviation Regulations 1971. This new standard on emergency lighting systems includes emergency exit marking and locating signs, sources of general cabin illumination, entrance lighting in emergency exit areas, and interior emergency lighting independent of the main lighting system. Each passenger-exit sign and each exit-locating sign must have white letters at least one-inch high on a red background at least two-inches high, which can be internally illuminated electrically or by other than electrical means with an initial brightness of at least 160 microlamberts. The average illumination along the center line and the aisles at 40-inch intervals must not be less than 0.05 foot-candles. The passageway floor leading to the emergency exit must be lighted. In addition, exterior emergency lighting must be provided with illumination not less than 0.02 foot-candles at first step outside the cabin, not less than 0.05 foot-candles for a two-foot width along the 30% of the slip-restraint escape route required that is farthest from the exit, illumination of at least 0.02 foot-candles on the ground surface at each overwing exit (with gear extended), and illumination of not less than 0.03 foot-candles at the ground from each non-overwing emergency exit. This FAR further specifies that the energy supply to each emergency-lighting unit must provide the required level of illumination for at least 10 minutes.

In case of a crash landing where the fuselage is separated, the emergency lighting system must be designed so that "after any single vertical separation" not more than 25% of all emergency lights are rendered inoperative. Emergency slide lighting is excluded from these requirements, but must serve one slide only, be independent of the main emergency lighting system, and be automatically activated (ammendment 25-28; 25 September, 1971).

The FAA at present has no aisle and evacuation path-marker requirements as such for civil air carriers. However, FAR airworthiness standards for transport category airplanes (Part 25:811) requires emergency egress markings for exits which have several related items. Part 25.811(b) states that "the identity and location of each passenger emergency exit must be recognizable from a distance equal to the width of the cabin." If applied to the C-135A, this distance would be 10 feet 9 inches, or little more than three rows of passenger seats. This appears to be completely inadequate for the C-135 military configurations in particular, due to the distance between emergency exits. For example, on the left side of the passenger-cargo area there is over 45 feet distance between the rearmost passenger position and the left overwing escape hatch. It is very difficult at present to visually see exit signs and directions unless the passenger is seated adjacent to an exit area, or has been carefully briefed.

Society of Automotive Engineers (SAE) aeronautical recommended practice for emergency placarding (ARP577A, 1963; 3.3.3), in contrast, suggests that emergency exit "instructions should be legible from a minimum distance of 72 inches within a substended angle of at least 45°..." This appears to be one of the few instances in which an SAE recommendation may be exceeded by an FAA requirement (for larger aircraft). ARP-503B (published July, 1971), relates to emergency illumination; however, civil requirements differ from those of military standards (as specified in MIL-L-6503 and MIL-A-25165). Civil emergency exit marking is specified in FAR 25.812. Military specification MIL-A-25165B(ASG) concerning identification of aircraft emergency escape systems does not specify a distance or visual angle at which emergency exit identification must be seen by the passenger, although letter size is specified (3.8.2) as:

> "Size - 'EMERGENCY EXIT' signs inside the aircraft shall be preferably two inches high. The lettering of instructions shall be approximately 1 inch high where (sic) practicable, and shall in no case be less than 1/2 inch. 'EXIT RELEASE' signs on the exterior of the aircraft shall be at least 1 inch high."

Types of markers mentioned in the military specification in include use of decalfomanias, radioactive luminous markers, and reflective markings and emblems, but specifies that radioactive paints shall not be used.

Emergency exit sign size was recommended in the Aerospace Industries study to have a brightness high-to-low contrast ratio no greater than 3 to 1; a background-to-legend contrast ratio of at least 10 to 1; and it was found that flashing exit signs are not more effective (AIA, 1968).

In view of the apparent fact that the currently operational Air Force transport aircraft configurations studied do not have any directional markers or information available to the passenger regarding locations of emergency exits exceeding the ability of the individual to visually read the exit signs, aisle and evacuation markers would provide major passenger emergency evacuation assistance. Aisle and evacuation markers would result in a marked improvement in passenger evacuation flow, result in faster egress, and reduce post-crash confusion. Some concepts would also offer a means of finding an exit where no vision is possible (tactual) or where smoke or darkness have reduced normal visual cues (directional pulsating lights). The present state of the art offers several feasible and practical means of greatly improving evacuation through improved marker systems.

SECTION VII

PASSENGER WARNING AND PUBLIC ADDRESS SYSTEMS

The primary purpose of passenger and crew warning systems is to permit either the aircraft commander or any crew member to inform all other crew members and passengers instantly and simultaneously of an existing or impending aircraft evacuation. The alarm system currently utilized in Air Force transport aircraft is manually activated from the pilot's station. Normally this consists of a guarded toggle switch within reach of the pilot or copilot. The Handbook of Instructions for Aircraft Design (HIAD) (AFSCM 80-1; H.4.3.) specified that signal lights and alarm bells be installed in Air Force aircraft according to MIL-L-6503 and international military standardization programs (A10.1.1). Standard alarm bell signals are:

1. Immediately after takeoff: 1 long ring - brace for impact.
2. Inflight crash landing or ditching: 6 short rings - fasten belts securely, 1 long ring - brace for impact.
3. Inflight bailout: 3 short rings - don parachute, 1 long ring - bail out.
4. On the ground: 3 short rings - prepare to abandon, 1 long ring - abandon aircraft.

Previous evaluation of this alarm system by Reagin et al. (1970) in studying emergency escape from USAF transport aircraft concluded: "..the use of the emergency alarm bell was found to be practically worthless. In five of the accidents reviewed, the use of the alarm bell was a significant factor. It was used successfully in only one impending accident in which 30 minutes warning time was available for preparation of the landing. In two cases, the alarm bell definitely contributed to the panic of passengers. In another case, it was stated that it was used; however, the surviving passengers did not recall hearing it. And in the fifth attempted use, only two rings of the bell could be accomplished prior to impact. In the majority of the accidents where the alarm bell was not used, time and the priority of crew duties precluded its effective use."

Only two of 14 C-141 accidents involved crash emergencies. In a case of a crash into the sea on takeoff, the pilot didn't realize a crash was eminent until just before striking the water, and in a second case of an emergency landing following nosegear failure, subsequent to a rapid decompression, alarm bell use is unknown. Thus in only one C-141 accident to date was there probably an opportunity to use an alarm bell, but the preliminary accident report did not state whether the alarm bell was or was not used.

Review of the C-135 accidents listed in Table 2 (page 9) indicate that the alarm bell was utilized in only five of these cases; however, further analysis indicates that only ten of these involved a crash-landing situation where an alarm bell would have been expected to be used. Thus in C-135 accidents at least, the alarm bell has been used in approximately 50% of the cases where a crash landing and emergency egress were eminent. The major reasons for nonuse, as were also found in the report of Reagin et al., were lack of sufficient warning of impending crash event and crew duties in controlling the aircraft at a critical point in the flight path. In two cases where the alarm was not used the crash occurred on landing approach and was totally unexpected by the pilots; in two cases the crash landing occurred during takeoff with insufficient warning, and a fifth case involved control problems requiring the pilot's full attention. While these represent only a limited number of accidents involving only two types of aircraft, these cases do suggest that the alarm bell has been an effective device in the particular circumstances where used. In all five cases the alarm bell was reported to be heard by occupants, and was the primary pre-crash source of warning, even though in one case there was a communications failure.

Alarm bell experience in civil air carriers is more difficult to evaluate and has been varied. Apparently crashes during landing or takeoff phase, when pilots are fully occupied with crew duties, often occur suddenly and preclude activating an alarm. The recent crash of the MAC charter DC-8 aircraft operated by Capitol International Airways, during an attempted takeoff in freezing rain at Anchorage, Alaska, is a case in point. More puzzling, are cases where the alarm system is not used when there is adequate time for preparation. The ditching of the Dutch Antillean Airlines DC-9 in the Carribean Sea, for example, was anticipated by the captain far in advance of the actual event. Although he instructed the purser to brief the passengers for a possible ditching 10 minutes prior to the actual ditching, no further warning or alarm, visual or aural, was given prior to the impact. This resulted not only in many unrestrained and unprepared passengers; but even the crew was unprepared, with the navigator and purser both unrestrained at impact. As a result of this St. Croix Douglas DC-9 transport crash,deficiencies in the passenger warning system were evident which has spurred further studies. In this accident the regular public address system became inoperative prior to impact and some passengers were still standing up while donning emergency equipment at the time of impact. Because no one-minute warning was received, many passengers undoubtedly received injuries which might have been prevented with an adequate emergency signal system. The FAA is currently considering proposing rules requiring an emergency public address system which would be operable prior to takeoff.

Besides the alarm bell used by the Air Force and most civil air carriers, other techniques proposed include flashing, stroboscopic, and continuous light warning systems, while audible public address systems include warning horns, buzzers and bells, as well as verbal public address systems and bullhorns. In the event of a false alarm, averted emergency situation, or to reduce the noise and panic level once all occupants have been warned of an emergency, adequate means must be available to cancel the warning. Audible signals must be easily distinguishable from any other flight deck-cabin signal but not alarming to passengers causing undue panic.

One factor which may skew the statistics relates to crew training. In a type of long range air transport operation where accidents are rare and pilot proficiency in emergency procedures are also comparatively rare, one might expect less use of an alarm system when a critical crash emergency occurs, than in another command or mission where continuous practice of engine-out landings, or emergencies are simulated, under the same potential crash conditions. Most actual emergencies occur during takeoff or landing phases of flight when the crew is busiest. Thus when an emergency requiring the use of an alarm system occurs, it seems possible that prompt use or non-use during the brief time prior to impact may well vary with the particular pilot's proficiency in emergency procedures. The consideration of pilot training and emergency procedures skill (which is not necessarily a function of flight time) relative to alarm-bell usage is suggested by the major author who, as a former Air Force pilot, has experienced a crash landing on takeoff and has successfully used the alarm system to effectively warn the crew of seven prior to the crash. It would be instructive to review current alarm-bell usage in Air Force accidents in greater detail.

Review of Federal Air Regulations (Part 25; Part 121) reveals no specific requirements for civil air transport aircraft related to emergency evacuation signal systems except as related to the bullhorn (121; 309). In regard to this equipment, the FAA only requires that there be an emergency evacuation signal system and a statement of its location. The bullhorn is a battery-powered, lightweight portable megaphone. Figure 27 shows a typical installation in a civil air carrier aircraft, located in the aft section at the end of the overhead storage rack. However, a number of inquiries to SAE committee members, stewardesses, airline safety personnel, and crews, has not resulted in identification of any case of actual emergency egress usage of the portable emergency bullhorn carried in current civil

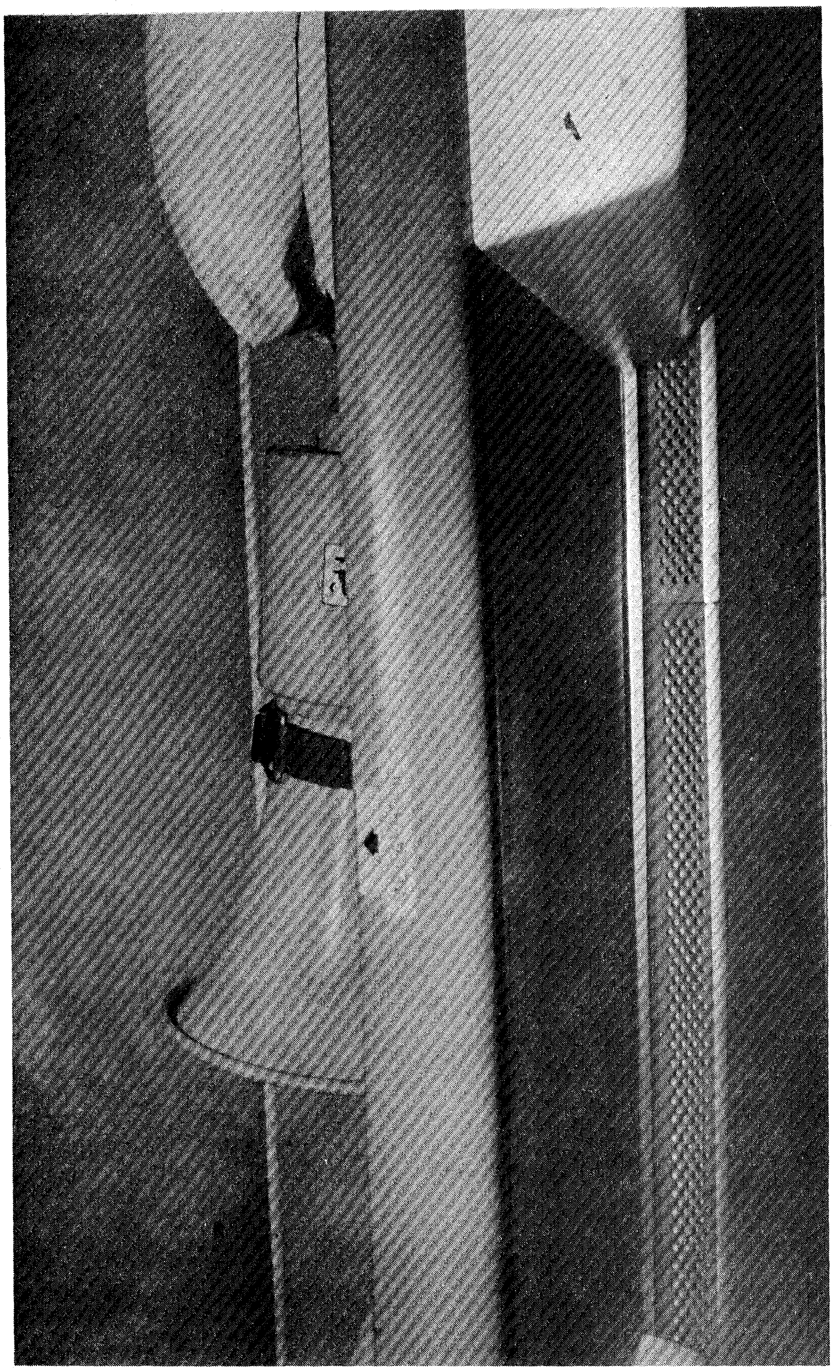


Figure 27. Typical Bullhorn Emergency Public Address System Installation in Civil Air Transport.

air transport aircraft. It has been reportedly used in nonemergency, nonstress situations when the cabin communications system has failed in flight.

In Aerospace Industries Association (1968) evacuation tests involving audible horn cues, the horn was ranked as least effective (behind seat placard, voice cue, and tactile cue) in usage, and most subjects (63%) felt their way out.

PORTABLE SOLID-STATE VOICE AMPLIFICATION DEVICES

Review of the current state of the art has not revealed any alarm-system concepts which appear to offer significant improvement over the current bell alarm, inadequate as it might be in its dependence upon manual actuation. The North American Rockwell study for the FAA (Roebuck, 1968) explored several systems. One concept involved use of a miniaturized solid-state voice amplification device worn about the neck on takeoff by the cabin crew. An advantage was that it was instantly ready to provide independent communication to passengers as a lightweight replacement for the bullhorn, and freed the hands. However it would be of no use until the individual wearing it is warned from the flight deck, thus does not solve the problem of initiating the initial alarm. A modification of this concept was the idea proposed that all crew wear miniaturized solid state intercommunication equipment on takeoff and landing. In this concept a flip-up microphone and head set would be connected to a long cord through bulkhead jacks and control switches at intervals of 8 to 12 feet apart. Using a battery-power source this would provide high-power 6-inch public address speakers at 12-foot intervals.

TWA EMERGENCY EVACUATION SIGNAL SYSTEM

For several years a Trans World Airlines has utilized combination aural-visual system in all of their aircraft. The TWA Emergency Evacuation Signal System was developed by TWA and described by Ogilvie (1968). Battery-powered, the audible alarm consists of 2800-cycle tone pulses three times per second, of 90 db intensity, thus differs significantly from engine noises or other confusing sounds. The present system is dependent on the pilot alone, for activation although the original system was designed so that it could be activated by either flight-deck or cabin crew. In the original version, a red light and solid-state flash provided a visual "EVAC" signal at the stewardess station to warn the stewardess, but not the passengers, of an emergency. In case a cabin attendent initiated an evacuation the captain was warned by a flashing red light on the pilot's panel. The idea behind this was that evacuation could be initiated by either cabin or flight-deck crew. However, the cabin initiation portion has been taken out of the system after several recent inadvertent evacuations have occurred; in at least one case passengers received egress injuries. Thus the current system remains a manually-activated alarm similar in concept to the Air Force type, except for the tone and intensity. Adaptation of this system might result in a more readily identifiable alarm if, as accident data seems to show the current alarm has not been heard or results in confusion in a significant number of cases.

To date no off-the-shelf device currently appears ideal. The current interest of the FAA in developing a better PA and alarm system and the indication that new FAA standards will be proposed, suggest that further improvements in the state of the art may be forthcoming. The requirements for a public address system for evacuation using an emergency electrical power source has been previously noted in a number of accident reports.

SECTION VIII.
OTHER IMPACT, ESCAPE AND SURVIVAL PROGRAMS, SYSTEM DEVELOPMENTS AND TECHNOLOGY

In addition to the technological concepts and developments discussed and evaluated in the areas of smoke and flame protection, passive restraints, aisle and path-marker emergency illumination, and passenger warning and public address systems, there have been efforts to develop other systems to improve the state of the art of emergency egress. The objective of the following section was to select and evaluate industry's developments and advanced concepts which have application to USAF transport aircraft. Some of these present alternative approaches. Eight different types of mechanical and inflatable slide or slide-raft systems are evaluated, as well as concepts in emergency in-flight egress, and exit area ablative coating. Major advances have been made in the development of high-energy emergency egress systems, but since an evaluation program is concurrently in progress by the Life Support SPO, Air Force Systems Command, Aeronautical Systems Division (ASD/AFSC) at Wright-Patterson AFB, inclusion here has not involved a redundant, detailed evaluation but rather brief discussion of these concepts, emphasizing the requirement and major contribution that such systems could contribute to emergency egress from air-transport aircraft.

SLIDE DEVICES

Emergency egress through door exits presents slightly different problems than for over-wing exits involving off-wing egress from low-wing transports such as the C-135. A number of external escape concepts have been reviewed, including inflatable stairs and slides, ramps, mechanical stairways, tube slides, hand-held slides, escape ropes, rope ladders, telescape poles, and nets.

INFLATABLE ESCAPE SLIDES. Inflatable escape slides represent the best current operational device in usage. However, while inflatable escape slides have long been standard equipment on civil air carriers, they were reported to be used on only three air transports (C-121, C-9, and some C-135 aircraft) in the USAF air-transport inventory (Reagin, et al., 1970). canvas slides, rope ladders, and escape ropes still predominate operationally.

DOUBLE-LANE SLIDE. The double-lane inflatable slide consists of two single slides side by side, utilizing a center support tube common to both sides, and inflatable tube side rails. This system is designed to provide two-abreast egress utilizing type A doors, allowing double lines. To date, optional exit preparation time for arming and deployment is about 10 seconds. Optional egress speeds have been found to utilize slide angles of between 35 and 50 degrees while angles below 25 degrees can be utilized as a walkway if the slide incorporates an inflated member as the sliding surface, rather than a fabric web slide used on many current types. Tests by the American Institute of Aeronautics and Astronautics (AIAA) have shown that double-lane inflatable escape slides provide a uniform egress rate of 108 passengers per minute. Stowed volume is approximately 5.1 cu. ft. for a 34-foot length, 101 pound weight, and 36 lb. inflation-system weight.

DOUBLE ESCAPE SLIDE WITH CENTER DIVIDER. This concept was proposed by McDonnell-Douglas (Roebuck, 1968) and is a modification of the double escape slide described above. In this version an inflatable semi-rigid separator "fence" in the middle of the slide would provide in effect two adjacent slides, as shown in Figure 28. The advantage of this would be an effort to prevent persons sliding down side-by-side from getting tangled, or one passenger blocking egress from both sides. The primary purpose of the concept was to prevent hesitation caused by one passenger waiting for another beside him to get well down the slide before jumping. It would also provide an additional hand-hold. Suggested provision for chemical light along the top side of the dividers would provide better illumination. The inflatable divider section, while increasing weight, storage bulk, and inflation capacity, would provide additional longitudinal rigidity. It was estimated that this would improve passenger flow rate by up to 10 percent; however, no tests are reported to confirm this estimate.

COMBINATION INFLATABLE SLIDE AND LIFE RAFT. With the introduction of the wide-bodied jet transports a new concept relative to egress on land and survival at sea has been utilized. This concept relegates to the escape slide a dual function. The primary function would remain as an escape slide for rapid land evacuation of an aircraft, with an additional capability to function as a flotation device or life raft, following ditching at sea.

The slide/raft concept appears to offer distinct advantages from a logistics and maintenance veiwpoint as follows:

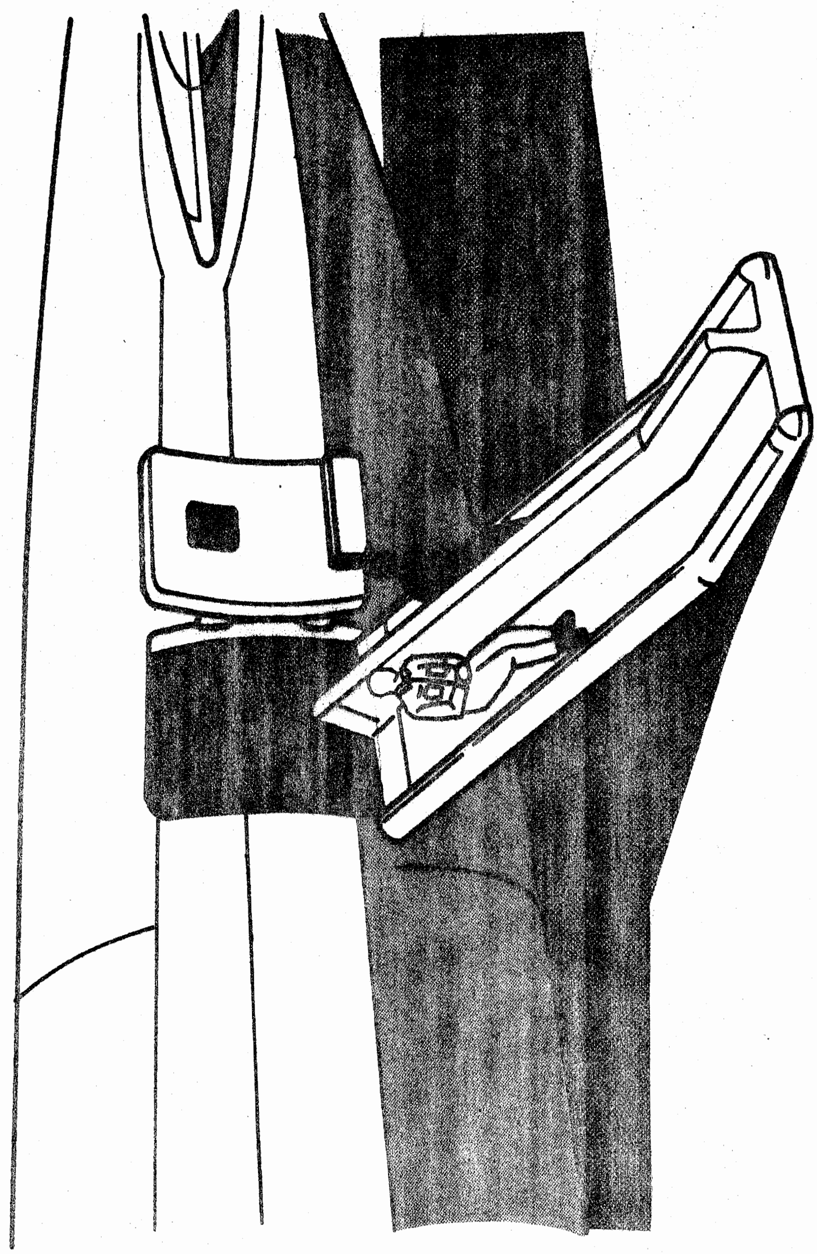


Figure 28. Double Escape Slide with Center Divider (after Roebuck, 1968).

1. Elimination of requirements for interior life raft stowage compartments. In certain seat density configurations of the Boeing 747, for example, twenty to twenty-three 25-man life rafts are required.

2. Reduction in weight. For the Boeing 747, this would mean elimination of some twenty 25-man life rafts, weighing 180 lbs each, for a potential weight saving of some 3,600 lbs. However, some weight is gained in slide redesign and enlargement into a slide/raft configuration.

3. The slide/raft is designed to be deployed outside the aircraft. The history of prior aircraft ditchings indicates that all too frequently survivors were unable (or failed) to remove and deploy life rafts stowed within the aircraft cabin before the aircraft sank.

4. Maintenance and inspection of the slide/raft system only is required as compared to both escape slides and life raft maintenance and inspection.

There are, however, several disadvantages of the combination slide/raft concept:

1. The number of slide/rafts are limited by the number of exits at which a slide/raft may be installed. For example, in one C-135 configuration, there are only two main cabin or cargo doors which could accommodate a slide/raft combination. Supplementary interior stowed rafts may still be required in some instances.

2. Frequently existing slide compartments are inadequate in volume to accomodate slide/rafts and their inflation systems.

3. Existing door hinges, structure, and exit hardware are often inadequate in design to support the added weight and volume of slide/raft combinations.

4. Lack of mobility. Weight and volume of slide/raft combinations are frequently such that in the event that an exit is not usable the slide/raft cannot be easily transferred to a usable exit for deployment.

5. High numerical occupancy. Some large slide/rafts are designed to carry in excess of fifty survivors. The loss or malfunction of one of these slide/rafts would have the same effect as the loss of two twenty-five man rafts.

Accidents such as the ONA St. Croix, V.I. DC-9 ditching, in which none of the five life rafts aboard the aircraft were successfully deployed and some thirty-one of the survivors utilized an inflated escape slide as their primary flotation device, has appeared to accelerate the application of the slide/raft concept.

Slide/rafts are generally manufactured of a high-strength fabric, double coated (both sides) with a urethane coating. Inflation systems most commonly utilized are of the high ratio-air aspirator type. High pressure cylinders using nitrogen, nitrogen-CO_2, or other mixtures of gases are used to operate the aspirators. Slide/raft operating pressures vary between 1.5 to 3.5 psig depending upon the design and configuration of the slide/raft. Manual or self erecting canopies are normally an integral part of the design. Some canopies, for example, are connected to one of the tubes and at some later point in time following deployment small valves are opened, inflating capstans which erect the canopy. Since these capstans are of relatively small volume the pressure drop in the main tubes is not significant.

One of the larger slide/rafts designed for the DC-10 is a double lane, 26-foot prototype, evaluated in open water using larger boats to create increased wave conditions. Figure 29 illustrates the slide/raft, designed by Pico. A usable seating area of 193 ft^2 was calculated for this configuration raft. The raft was loaded with 44 subjects (4.4 ft^2 per subject), 55 (3.6 ft^2 per subject), and 65 (3.0 ft^2 per subject). Under these conditions the slide/raft exhibited excellent buoyancy with all passenger loadings. Essentially rectangular in shape, slide/rafts tend to flex, bend and follow the contour of a swell. When the lower tube was deflated, freeboard was reduced and waves induced by boat action at times introduced water into the slide/raft, however, the remaining buoyancy was adequate to maintain flotation of the maximum number of occupants. When one of the two compartments is deflated the structural rigidity of the slide/raft is normally reduced with the two sides pinching inward, reducing the total apparent surface area of the slide/raft. Aircruisers, B.F. Goodrich, and Switlik also supply slide/rafts. Use of quick foams may be possible in the future (Salyer, et al., 1971).

The Federal Aviation Administration is preparing a Notice as Proposed Rule Making (NPRM 69-33 FAR 25.853(b)) stating standards for slide/raft combinations. In this, the FAA is considering that the device, wet or dry, should be designed to be capable of handling evacuees at a rate of at least 60 persons/minute for single width and 120 persons minute for double width evacuations for a duration of 70 seconds. It should be capable of operating in at least a 25 mph wind, must be inflated in not more than 10 seconds, 75% of initial nominal operating inflation pressure should be retained for 24 hours, and in regard to flammability the

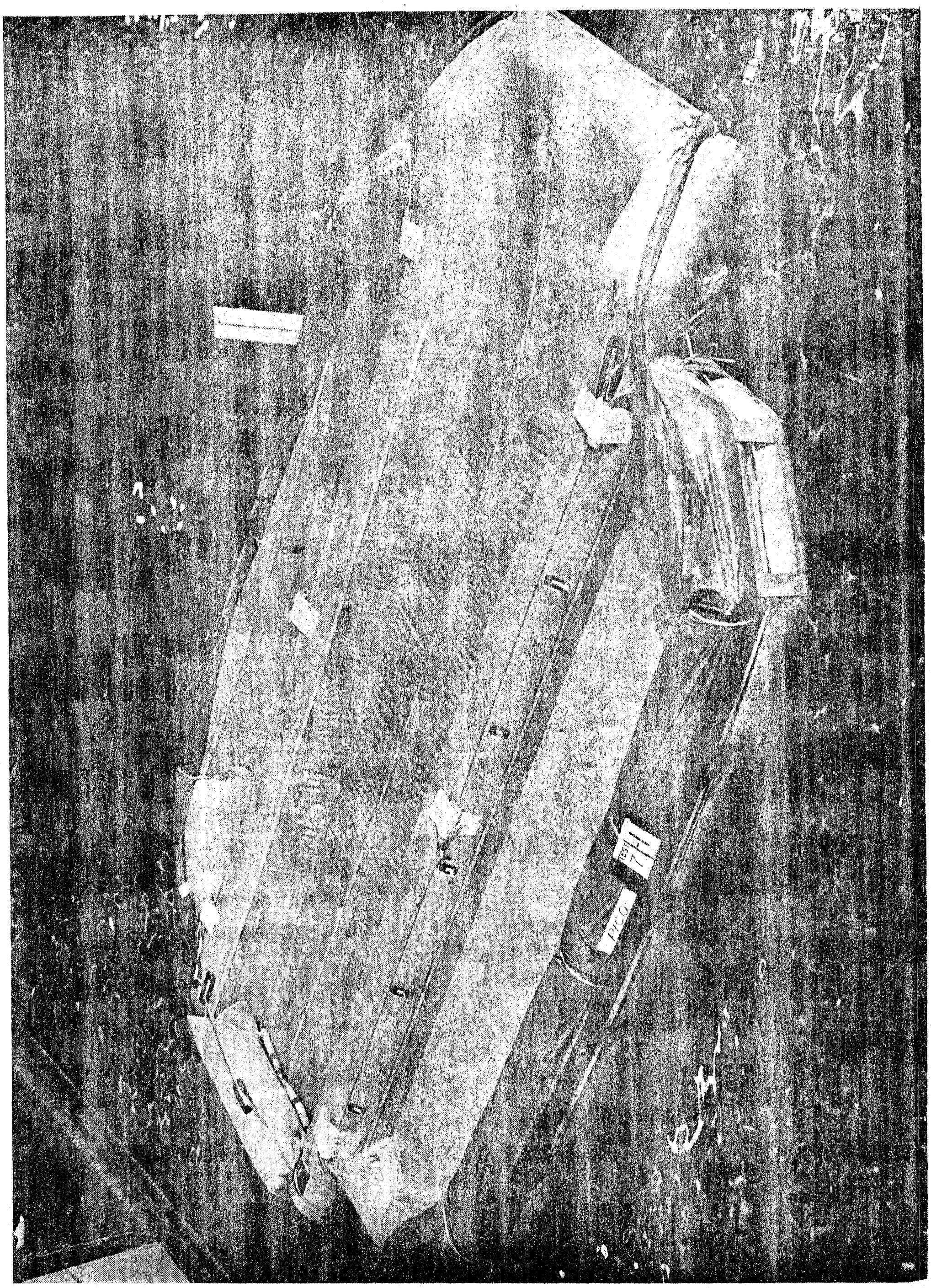


Figure 29. Combination Life Raft/Escape Slide Recently Certified for Civil Air Carrier Use on the McDonnell-Douglas DC-10 (courtesy of E.B. McFadden, FAA).

FAA is considering upgrading the present requirements of four inches per minute horizontal burn rate. To date specific FAR requirements for slide/raft combinations have not been issued. The Society of Automotive Engineers is proposing issuance of an aerospace Recommended Practice relating to survival kits for life rafts and slide/rafts, but this also is not yet published.

Current accident experience indicates that emergency egress slides do not always function to provide safe egress. Within the past year, for example, several accidents have demonstrated failure of current inflatable slide systems. In the Boeing 727 accident in December, 1970, at St. Thomas, the gear collapsed on the runway and the aircraft, carrying 46 passengers, two infants, and a crew of 7, struck a hillside beyond the runway at 30 to 40 knots. The fuselage broke into three sections. One slide was deployed but failed to reach the ground by seven or eight feet due to the fuselage attitude. In jumping from the end of the slide there were several serious injuries (See Figure 23). In the DC-8 crash at Anchorage, one slide ended in a pool of burning fuel. Movies taken of the Boeing 747 evacuation at San Francisco earlier this year show the escape slides being blown by the high wind, again resulting in injuries. An unpublished study of the Civil Aeromedical Institute, FAA, indicates that where actual crash-fire emergencies have been involved (as opposed to other emergency evacuations) current slide systems are not as reliable a means of egress as they are generally considered to be. Thus improvements in the state of the art appear necessary.

A different concept of an escape slide/raft device was proposed in 1968, involving an inflatable tubular structure as shown in Figure 30 (Roebuck). In this version flexible joint sections of the tubular escape structure would be designed to allow slide egress in any position, including from an inverted aircraft. Completely enclosed slides have not been used previously, and some protection from smoke and flames might result. Windows of flexible transparent plastic would provide light, with chemical light strips inside for night egress. It could be used as a ramp walkway. The floor and ceiling (identical) would be constructed of Goodyear "airmat" material which in case of a very shallow angle of egress, could be inflated by auxillary inflation bottles to a one- to two-inch thick stiff surface. The attached end is extended from the aircraft by a tubular, sliding cable-restrained bellows, capable of universal flexure to some + 25 degrees of arc, and torsion to about ± 30 degrees of arc. The bellows articulation would be

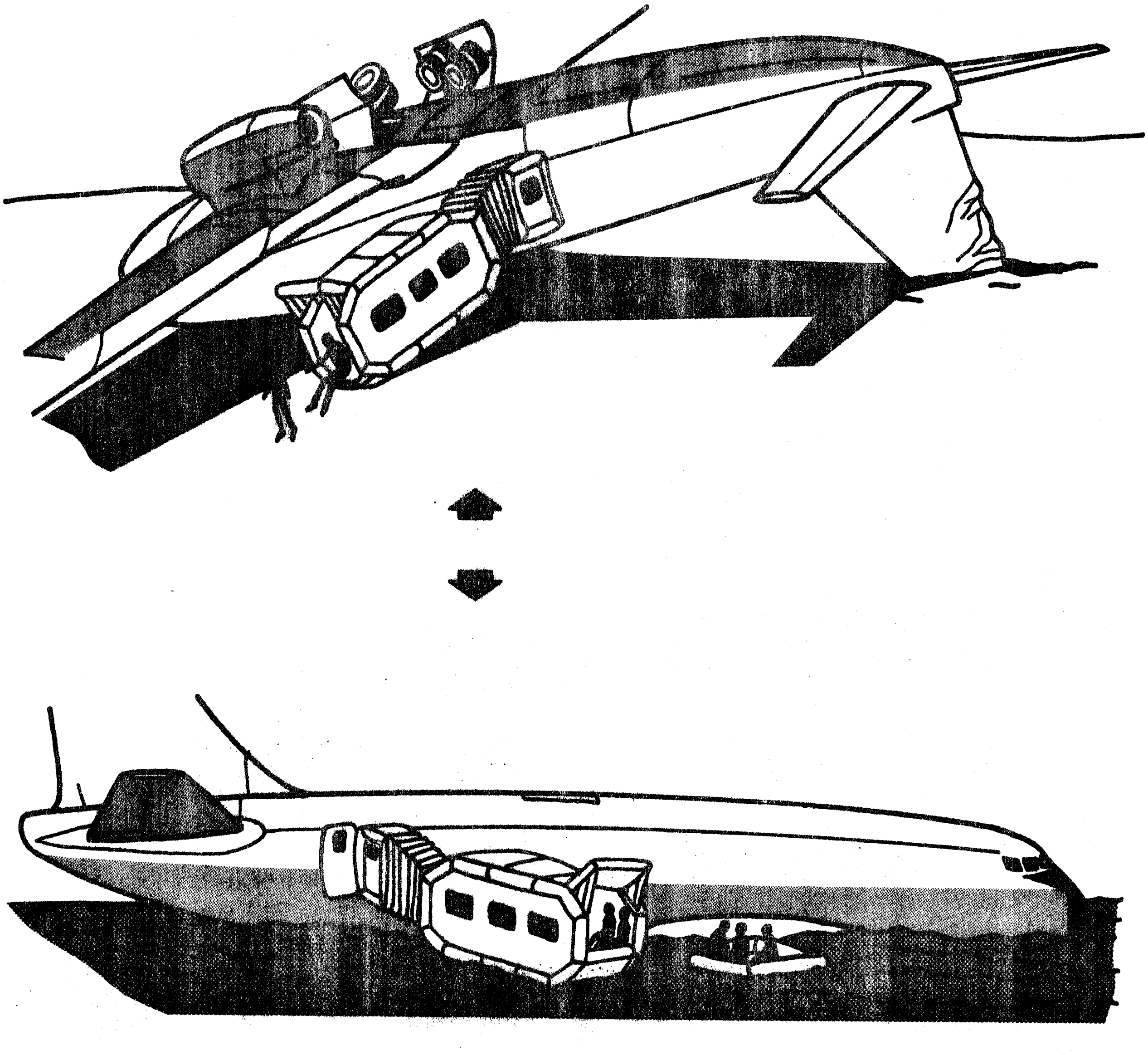


Figure 30. Concept of a Combination Inflatable Escape Slide/Life Raft (after Roebuck, 1968).

a larger version of the shoulder joint in a space suit pressure garment. This concept was reported to have an estimated increase in passenger flow rate up to 50 percent in ditching; however, if compared to current ditching life raft deployment requirements in aircraft such as the C-141A, the flow rate would probably be considerably greater.

EXTERIOR PLATFORM ESCAPE-SLIDE ENTRY. The purpose of this escape-slide concept (Figure 31) would be to attempt to reduce a traffic-flow bottleneck caused by psychological reasons at the emergency exit. The idea (Roebuck, 1968) is to get the passenger out on the wing (low-wing aircraft) and then utilize conventional inflatable slides, which would be automatically deployed from the platform package. This concept is within the state of the art and is a modification of some current designs.

SLIDE INFLATION DEVICES. With the increasing size of these devices, particularly for aircraft such as the Boeing 747 (and C-9); the need for greatly increased inflation volume; and requirements of achieving rapid inflation times, increased compactness, and less weight, the need for improved inflation devices has been emphasized. Many current inflation systems utilize compressed gas stored in 3,000 psi cylinders; however, if used in the larger and newer systems the high pressure gas supply would pose both storage capacity and increased weight problems. This has led to the development of cool-gas generators and more efficient aspirators as the current solution to providing better inflation for the large-capacity inflatable escape devices.

The conventional system of inflating escape slides is to thrust high-pressure gas from a gas reservoir through an aspirator and into the slides. The aspirator contains a nozzle that expands the high-pressure gas to below ambient pressure. The aspirator casing contains doors designed to open when the pressure within the casing body falls below ambient pressure. Thus, the entering air is entrained by the expanding high pressure gas, and the resulting mixture fills the inflatable escape slide. In the newer cool-gas generator system the high-pressure gas cylinder is replaced with a solid propellent charge within a gas-generating chamber plus a coolant chamber. When ignited this charge generates hot gas, which is then cooled by one of several alternate methods when exhausted into a secondary chamber. The resulting cool gas is then directed to an improved external aspirator and subsequently into the inflatable device. Figure 32 shows the cool-gas generation

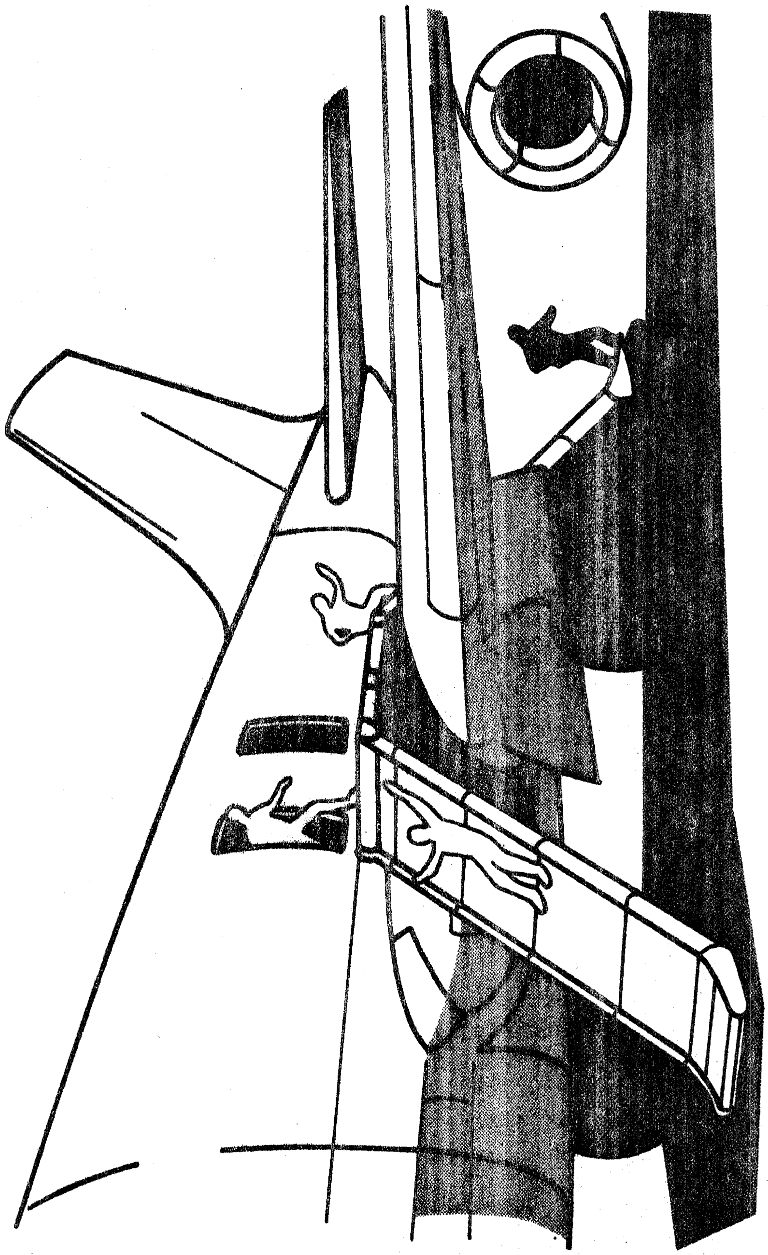


Figure 31. Exterior Platform Slide Entry for Over-Wing Escape (after Roebuck, 1968).

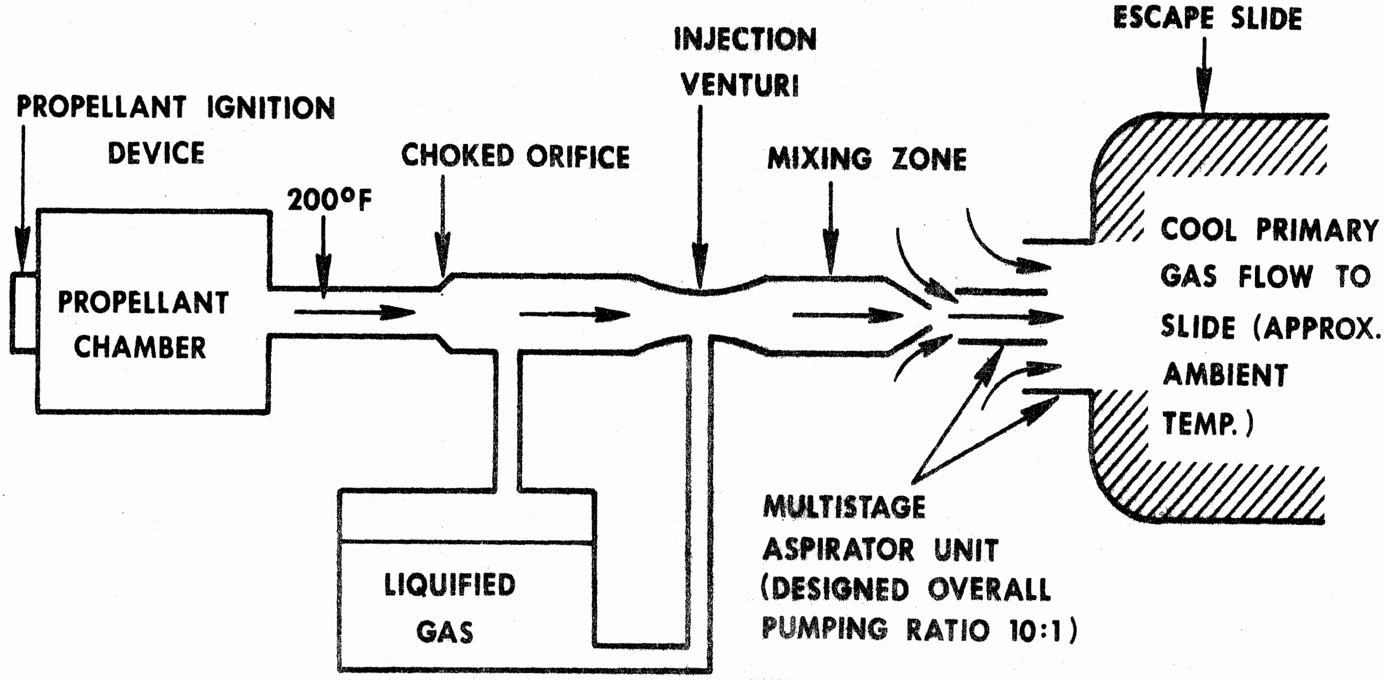


Figure 32. Cool-Gas Generator System for Inflatable Escape Devices.

system in schematic form.

Three types of gas generator systems include the solid coolant-solid propellant-aspirator system, the gas coolant-solid propellant-aspirator system, and the liquid coolant-solid propellant-aspirator system. In the solid coolant system the hot gas resulting from the solid propellant charge ignition is passed over a catalytic bed, which acts as the coolant agent, and the resulting cool gas drives the aspirator. Hardware for this concept has not yet been developed, and problems in gas temperature control have been reported, but it would be a relatively simple and easily maintained system although relatively costly. In the gas coolant system a 3,000 psi gaseous nitrogen mix is the primary coolant. By mixing with the hot gases generated by the ignition of the solid propellant charge the driving gas is delivered to the aspirator. It has been indicated to be effective over a temperature range of -40°F to +160°F, and is capable of inflating a 160 cu. ft. volume to a pressure of 1.4 psig in approximately 8 seconds. Its cooling ability comes from high-pressure-gas expansion, however weight requirements for high-pressure gas cylinders may be relatively high. The third method uses a liquified gas as a coolant. The hot gas generated by the ignition of the solid propellant charge is used to provide the latent heat of vaporization required to evaporate the liquified gas coolant. It is capable of inflating a 290-cu-ft volume to a pressure of 2.0 psig in less than 7 seconds, over a temperature range of -40°F to +160°F. A detailed analysis of inflation devices and current state of the art has been previously presented in Section IV; however, the requirements for use with inflatable restraints and inflatable escape slides differ considerably.

FOLDING ESCAPE SLIDE. Actually a combination on walkway and mechanical folding slide, this concept would consist of expandable pivoting structural elements which could be stored under type I and type II exits. It could be used as a firm ramp or evacuation slide. As shown in Figure 33, a specially contructed, lightweight, extendable truss structure would be constructed to support stairs which can be folded down to form the surface of a slide or ramp. An advantage over inflatable devices might be that it would not puncture or tear. An analysis of mechanical versus inflatable escape devices by AIAA (1968) showed that mechanical devices require greater storage volume and heavier structural support. It was determined that a mechanical stair is more hazardous due to the quick foot movements required in descent which could seriously impede evacuation flow.

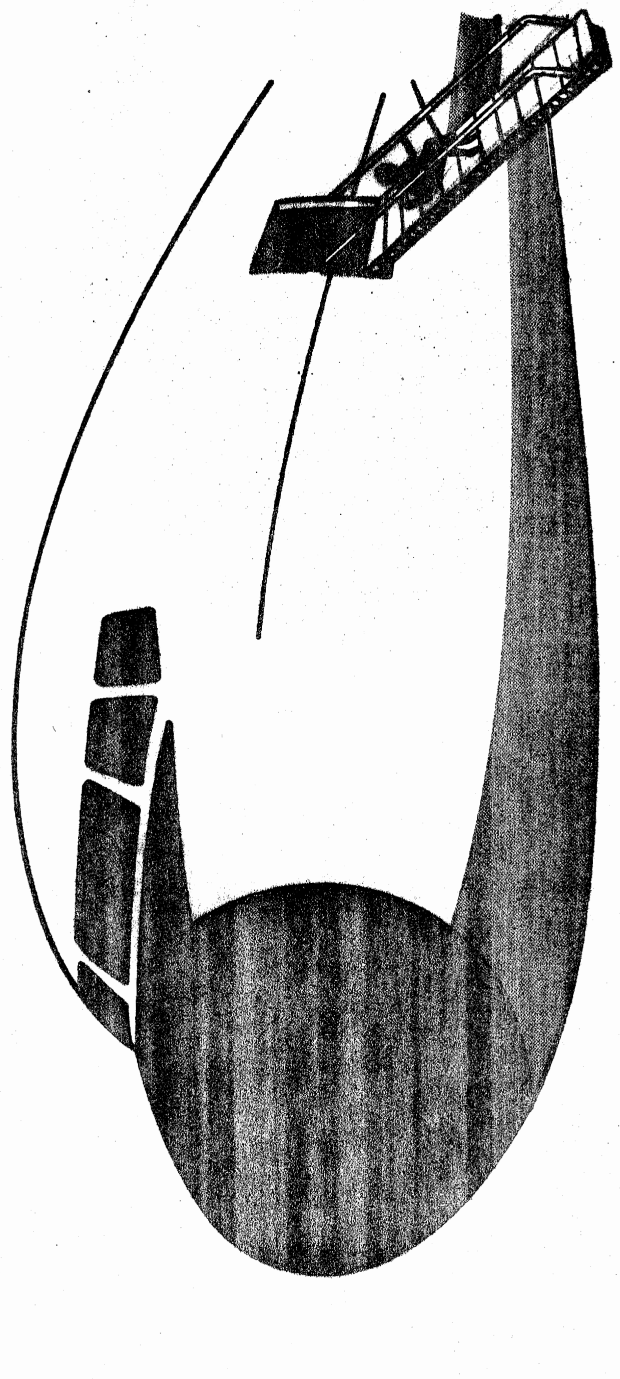


Figure 33. Mechanical Folding Escape Slide/ Stairway (after Roebuck, 1968).

SEAT BELT ESCAPE HARNESS AND EGRESS CONVEYOR SYSTEM

This concept envisions an integrated system utilizing the restraint system and seat cover to allow the passenger to hook on to an overhead conveyor system which would automatically carry him to an exit, as shown in Figure 34. There is some precedence for this type of seat mounted escape device in the current use of survival kits in the seat pack of many air crews. This concept was proposed in the FAA study by North American Rockwell (Roebuck, 1968). The seat back cushion would be designed to contain an anti-smoke and flame hood with self-contained air supply, which could be quickly deployed. The sides would contain a life vest which could be pulled out and wrapped around the body. The passenger would hook his seat belt to the back cushion system, and attach the entire system to an overhead hook on a cable. The seat cushion cover and back cover would supply a chair-like support, and the conveyor system would take the passenger to the exit, where a deployment strap disconnects the occupant either manually or automatically.

This is a complex system requiring a series of actions by the user. It is within the state of the art, however, and features a systems engineering design approach. Estimated additional weight was 3 pounds per user; however, by using seat cuchion cover storage, little extra volume might be required. A number of failure possibilities exist in the deployment, strength of parts, jamming of equipment, failure of the power source. It would be non-usable in accidents involving significant structural intrusion or distortion. If everyone had to be hooked up before it operated it would be ineffective; yet if it operated as a continual conveyor belt system from the moment of crash-impact, some passengers might have difficulty in reaching a hook-up or might be struck down by passengers already hooked up and being conveyed out. Another hazard exists in that the passenger might be conveyed to a non-usable exit or directly into a burning area, unless there was direction control. Such a device could prove hazardous if the system failed while passengers were still attached near the ceiling where the heat, smoke and fumes would be greatest and provide the poorest survival environment. Entanglement could be a further hazard, and this system might be difficult psychologically for many people to use without clear briefing and practice. It is not considered to be a reliable systems concept in this form, but could be further modified for consideration in a simpler more automatic mode.

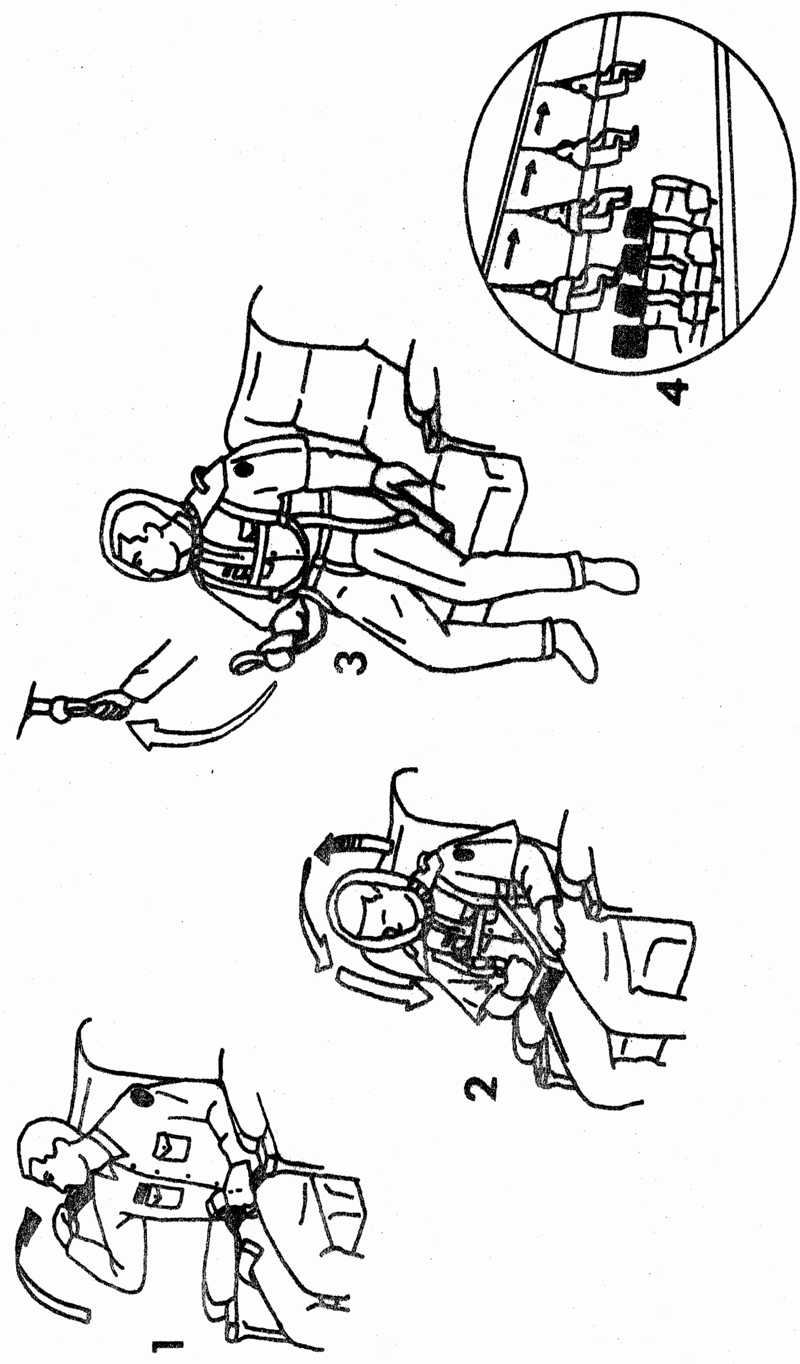


Figure 34. In This System the Passenger Attaches His Seat Belt (1) to Integrated Seat-Back Straps (2), Hooks into an Overhead Hook (3), and Is Automatically Conveyed to an Exit (after Roebuck, 1968).

CARGO-TYPE EMERGENCY EGRESS TECHNIQUES

This concept would facilitate the evacuation of passengers by providing large openings in the nose, sides, and tail of passenger aircraft. This might be accomplished by using techniques presently in service in pressurized cabin cargo aircraft having swing-nose, large doors, or clam shell or swing-tail loading capabilities. It was estimated that this system could reduce evacuation time and passenger flow rate by 90% and reduce use of wrong exits by 10 to 20%. No data is available to validate these estimates. Figure 35 shows a forward fuselage cargo-type exit.

CONVEYOR BELT CONCEPT

A number of escape system concepts have been proposed in the literature to assist in evacuation of passengers from their seats to the emergency exits. Most of these have not been discussed here because of obvious technical cost, weight, or feasibility penalities and were not considered better solutions, although most appeared to be within the state of the art. This includes such concepts as anti-smoke hoods or tunnels deployed in the aisles.

The moving walkway passenger conveyor system proposed to the FAA would consist of a forward conveyor belt intended to improve passenger evacuation time and reduce the problem of locating exits under smoke conditions (Roebuck, 1968). An individual reaching the aisle could presumably be taken to an exit if he were incapacited or injured. Such a system is within the state of the art, but is considered to be unpractical due to additional weight requirements, fail-safe aspects, the problem of "what if the conveyor belt is going in the wrong direction" to get to usable exits, as well as potential injury to disabled users who might get jammed against seats. This concept is illustrated in Figure 36. However, a further reason why such a concept would have limited utility is shown in Figure 37. This photograph was taken subsequent to the FAA crash test of a DC-7 aircraft at Deer Valley, Arizona, and shows the buckling of the fuselage typical of many air transport accidents. In such instances a conveyor belt egress technique would be useless. Figure 23 in Section V, showing a recent Boeing 727 crash, also illustrates the extreme fuselage distortion which is often found.

TELESCAPE SYSTEM

The telescape system consists of an exit mounted pole which can be extended to the ground for "fireman" type emergency exit. A major advantage is that it provides considerably more "ground reach" flexibility than standard inflatable escape slides; that is, the pole can be deployed

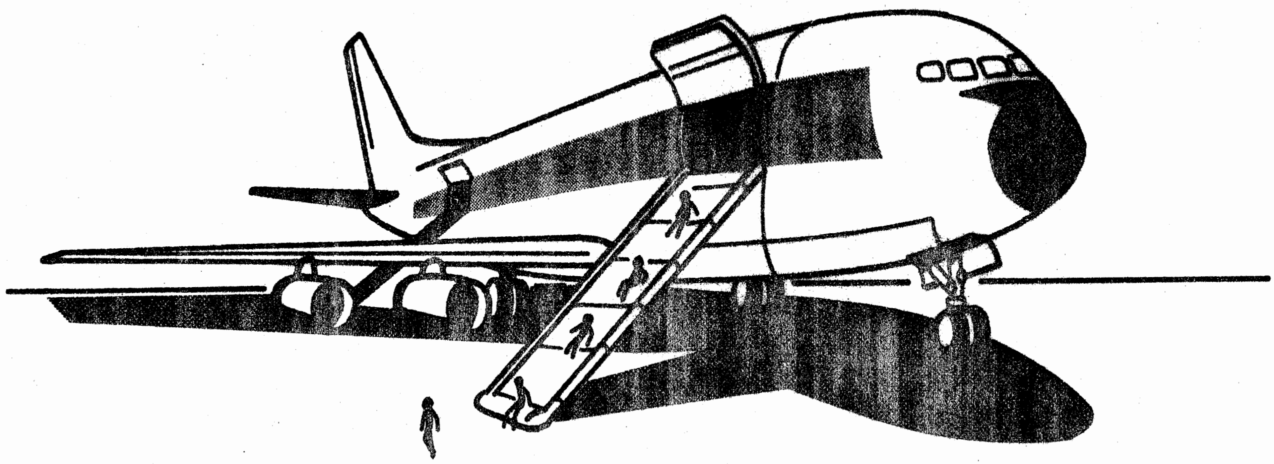


Figure 35. Cargo-Type Emergency Egress Technique (after Roebuck, 1968).

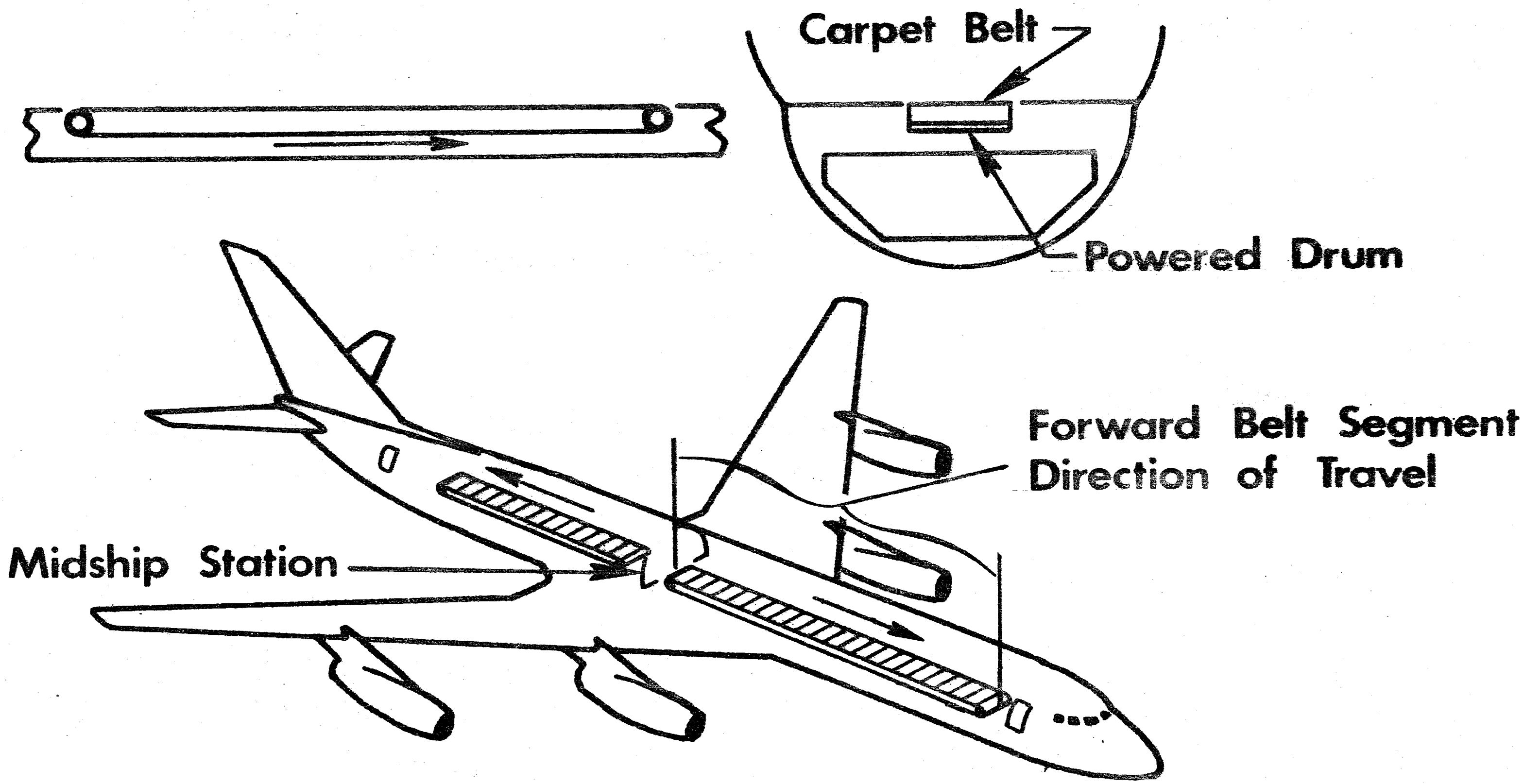


Figure 36. Passenger Egress from Seat to Emergency Exit Via Conveyor Belt (after Roebuck, 1968).

Figure 37. Post-Crash of Boeing 707 Accident Showing Typical Extreme Buckling of the Fuselage (courtesy of FAA).

and adjusted to the terrain condition within extreme angles with wide ranges of aircraft attitudes. This device was demonstrated at the Aeronautical Center, FAA, in Oklahoma City in May, 1962, and was subsequently tested in evacuation tests of a YC-131 aircraft. Development, tests, and analysis were under the direction of J.D. Gainer, Chief, Emergency Escape Section, Protection and Survival Laboratories (Gainer and Glethrow, 1962). Two group test evacuations were conducted with mixed passengers between 24 and 58 years of age, as well as a group of children 4 to 11 years of age, and individual tests were made of two different lengths of support arms.

In this system, the telescape is stored in a mounting near the top of the emergency exit. To use for an evacuation it is swung out into position (Figure 38) and extended to a ground point. (Figure 39).

A short support arm (9 3/4") and a longer arm (28 13/16") were tested, with 18" felt to be optimum. The mounting swings through 134° from the stored position against the exit bulkhead to the out and locked position. Extension is accomplished by a CO_2 bottle providing a pressure range of 30 to 33 psi at the Telescape pressure inlet. Once the internally extended tube, comprised of four sections, touches the ground a pressure of 20 psi was found sufficient to retain pressure within the tube and hold it in place.

Test passengers were found to use various techniques for sliding down this pole, and test evacuations were conducted at an average rate of 3.61 seconds per passenger on the first test and 3.31 seconds per passenger on the second test. A polished chrome finish proved satisfactory for surface friction, although less friction to prevent burns was recommended. Rate of descent was not injurious under the condition tested.

This concept has not had further tests conducted under no light, smoke, or other adverse conditions. For military adaption it would only be useful at door exits and could not be used in over-wing escape. Where air evacuation litter patients are carried it would probably not be useful. Insufficient information is available to compare the Telescape system with a rope egress; it is, however, a feasible escape device for military adaptation.

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[1] Garner, J.D. and J.G. Blethrow, 1962, "Evaluation Test on the Telescape System for Emergency Evacuation from Aircraft". Federal Aviation Agency, Civil Aeromedical Research Institute, Oklahoma City, Oklahoma. Report no. 1, (unpublished) October.

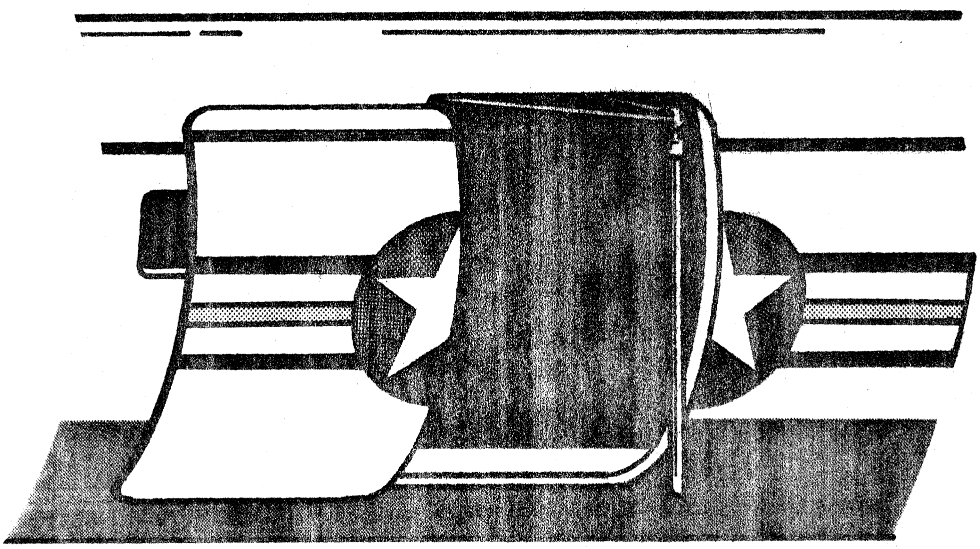

Figure 38. Telescape Swung into Position for Use at
Exit Door.

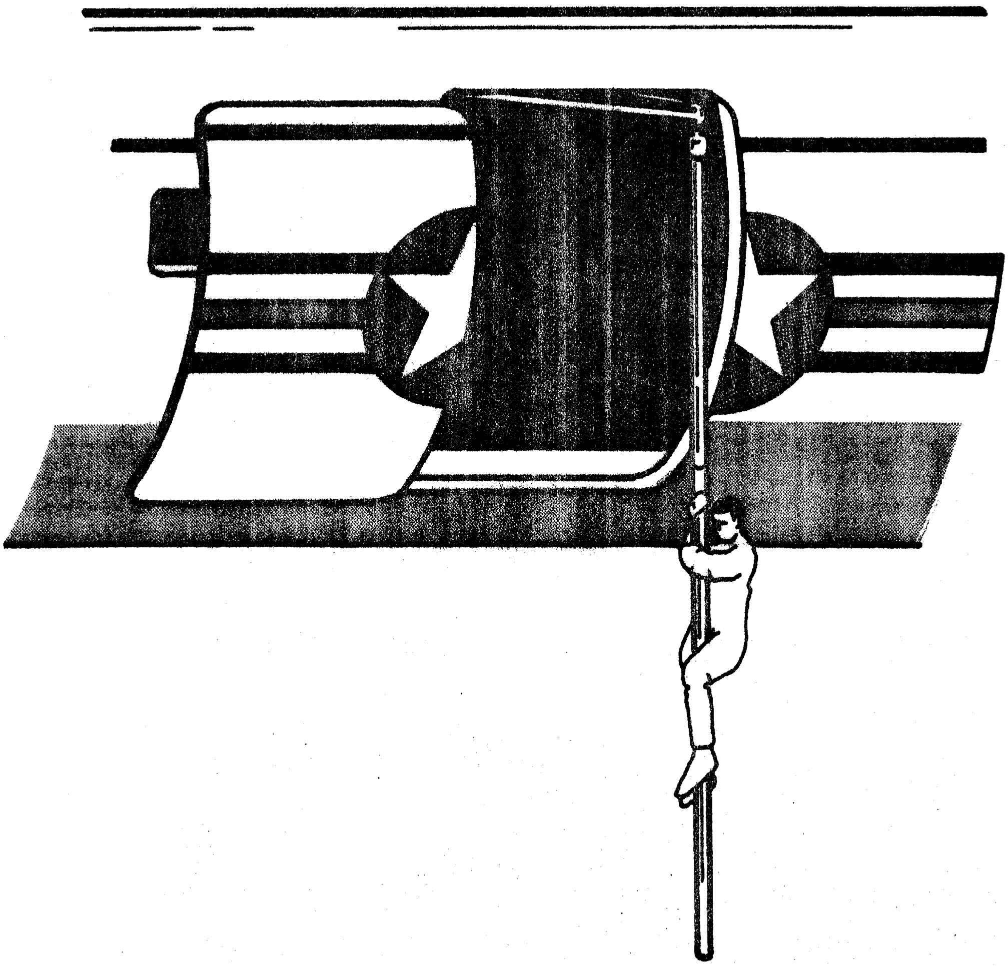

Figure 39. Evacuation Using Fully Extended Telescape Device (after Garner and Blethrow, 1962).

EXIT-AREA ABLATIVE COATING

Severe heating from exterior fires can distort an exit structure and prevent opening at a later time, even if firemen have cleared a flame-free path to it. New, lightweight ablative coating materials applied to areas around and over the exits could form an insulative layer which also resists flame by charring and off-gassing, carrying heat away from structure. The Apollo heat shield is a composite material based on epoxy resin. Although relatively soft, such materials could be covered by a thin, glass -fiber laminate for wear resistance. The basic ablative material is stabilized by a glass fiber laminate honeycomb bonded to the skin surface. For a reasonable evacuation period (2 to 5 minutes), a layer only 1/4- to 3/8-inch thick could provide protection against fires of JP-4 or other fuels which burn cooler than spacecraft reentry temperatures of 4,000° to 5,000° F. A typical exit area coating is illustrated in Figure 40.

This concept would primarily protect against flame and heat damage but is included in this section since it could improve exit-area integrity and identfication and thus might improve egress success. Emergency egress devices such as escape slides, tubes, or raft-slide combinations could have a flexible ablative coating to protect them for a short time duration against flame damage.

For exterior usage in exit areas there may be a drag penalty which would overweigh its practical employment. Maintenance and repair requires special equipment and supplies, and other problems include the increase of weight of doors and hatches with an ablative coating, making them more difficult to handle. Combustion products could also be highly toxic and even if used only externally the fumes could be blown inside. Advantages, however, are that it provides a longer time before structures it is applied to heat up, thereby offering a potential longer usage of emergency exits under heat and flame conditions. presumably it could also reduce this incidence of jamming.

HIGH-ENERGY CHEMICAL EMERGENCY EGRESS SYSTEMS

A major problem in emergency egress has been emphasized by a number of studies of both military and civil air transport accidents relating to the inadequacy or unavailability of emergency exits subsequent to a crash. An analysis of commercial air carrier accidents by the Flight Safety Foundation for the period 1957-1967 resulted in the estimate that 35 to 50 percent of the 794 non-survivors of survivable accidents could have been saved if adequate exits had been available. In 26 of the 34 survivable accidents

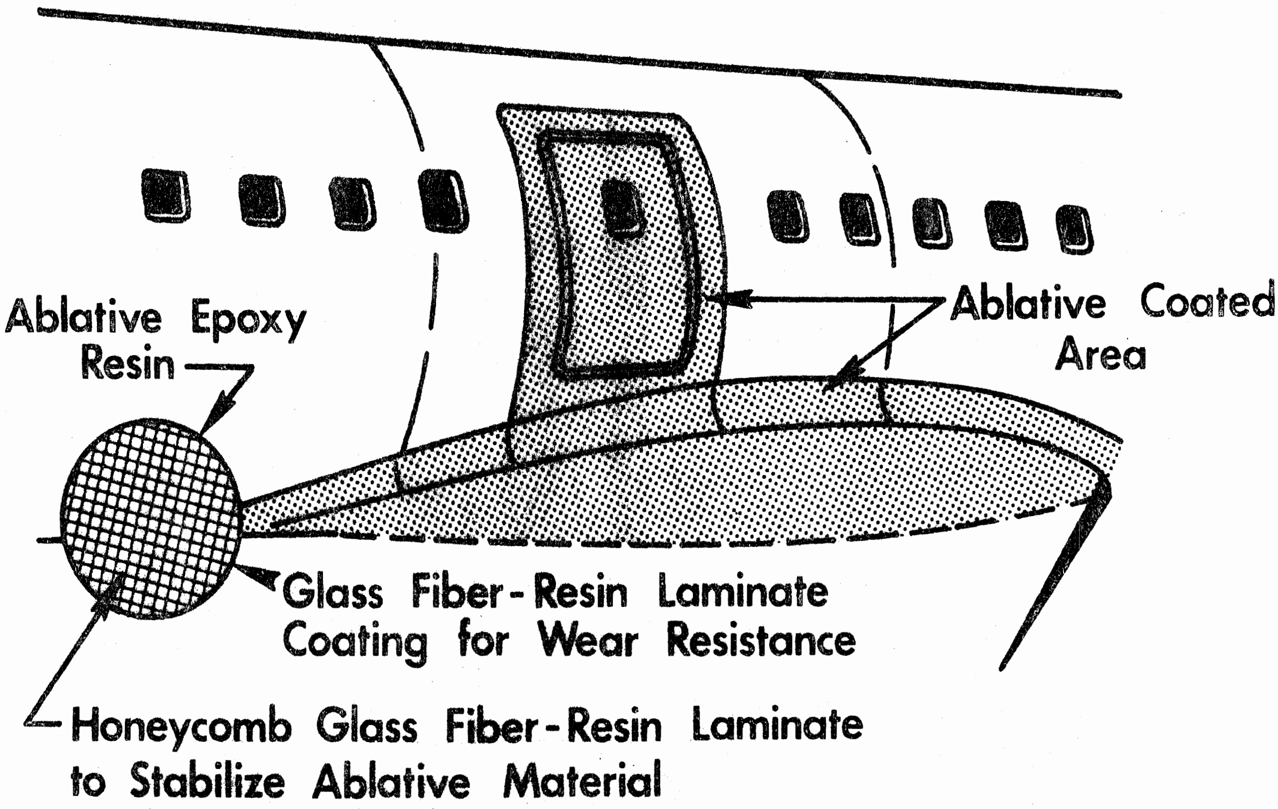

Figure 40. Emergency Exit-Area Ablative Coating (after Roebuck, 1968).

occurring during that period, it was reported that of the 215 exits available only 53 were used, a usage of only 24.7 percent. During emergency evacuation of 17 aircraft, 152 exits were available and only 44 (28.9%) used (Caldera, 1965, 1968, 1970). In other cases the exits were blocked, or passengers in panic and smoke conditions, could not identify exits. Examination of military air transport accidents support the need for larger, more readily available exits which will not jam. This appears to be of particular need in aircraft such as the C-135, where the number of passengers often exceed the critical evacuation flow capability of current exits. In the C-135 crash (case No. 1) discussed on page 8 and illustrated in Figure 1, page 12, the ELSIE system could have ensured that the available exits were open for egress, and probably resulted in far fewer fatalities. Optimum location of ELSIE exits of C-141 and C-135 aircraft involve structural and system considerations beyond the scope of this report; however, it would seem desirable to make available several large size openings in the fuselage than resently exist in the center and aft sections.

A solution to this problem appears to be utilization of the ELSIE (Emergency Life Saving Instant Exits) system which uses "jet cord" flexible linear shaped charges to blow emergency exits at predetermined strategic locations in the fuselage skin, or where available exits have become jammed. Figure 41 illustrates how this system might be applied to the C-141 aircraft. ELSIE has been developed under contract to the Life Support System Program Office ASD/AFSC, Wright-Patterson AFB, by Explosive Technology, Fairfield, California, evolving from their STEN (stored energy) concept developed in 1967 (Nicholson and Burkdoll, 1971; Burkdoll and Nicholson, 1971; Bogland, 1967; Explosove Technology, 1968; 1970). A similar concept for providing "supplemental emergency exit doors (Figure 42) has been reported by Space Ordnance Systems, Inc. of El Segundo, California, who designed the crew escape-module severence system for the F-111 aircraft and others (Brown, 1967). This system consists of a variety of shapes and lengths of linear shaped charges (LSC) which can be routed around any existing exit (to insure that it is instantly severed), or create a larger exit area for emergency use at any desired point. The five basic components are: a safe/arm mechanism, shielded mild detonating core lines, a flexible shaped cutting charge, and an interior initiation handle, and/or exterior initiation handle. ELSIE system characteristics are reported to be that it opens emergency exits in less than 0.001 second (with smooth edges), cannot jam, always jettisons outward, cannot be inadvertently operated but is instantly operable from the interior or exterior following a crash, and requires no special structures. To initiate, the safe-arm

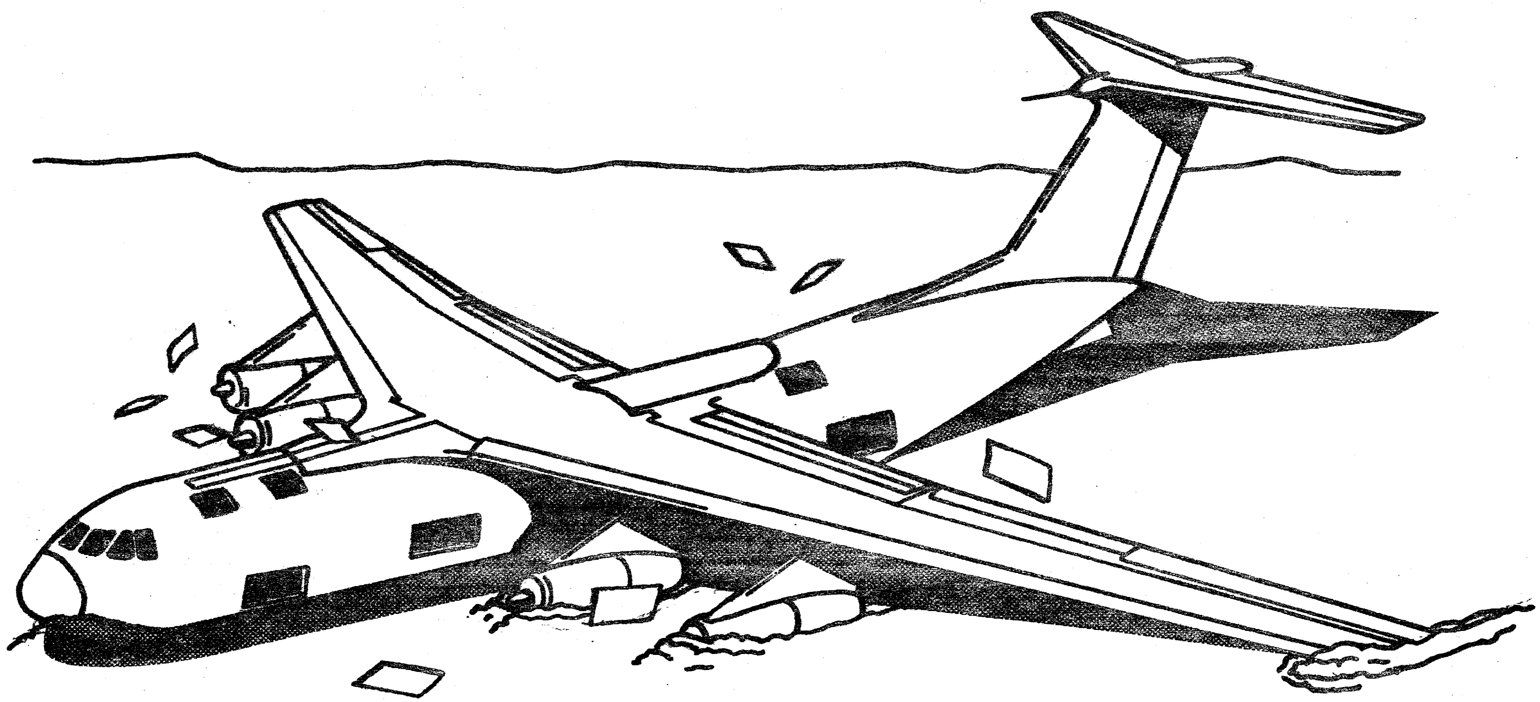

Figure 41. ELSIE System for Instantaneous Egress as Might be Conceived for C-141 Aircraft.

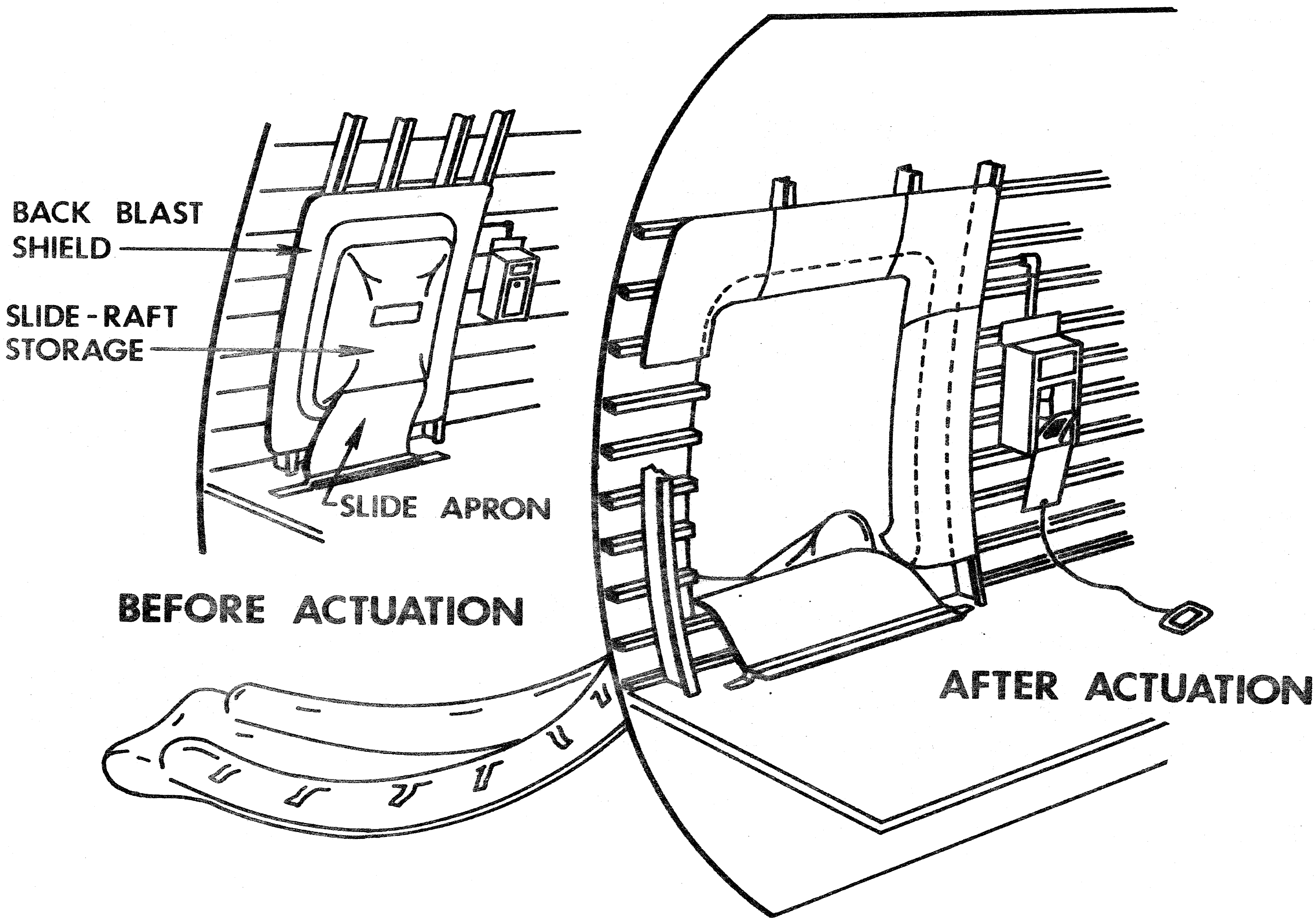

Figure 42. Experimental High-Energy Emergency Exit Configuration Showing Instantaneous Deployment of Slide/Raft for Subsequent Emergency Escape (after Caldera, 1970).

electromechanical device is electrically armed from the flight deck, then manually initiated at a ELSIE system station by pulling either the interior or exterior handle. Detailed technical evolution and specifications are reported in Nicholson and Burkdoll (1971), and in Burkdoll, et al. (1971). Subsequent to extensive ground tests, this is presently being tested operationally in a 130A gunship (Burkdoll, 1971), and will be extensively flight tested in an operational C131B aircraft. However, a number of objections to potential use of any "explosive" system has been strongly voiced by some representatives of civil air carriers (Pollard, 1971).

An evaluation of the liquid explosive emergency exit concept for application to civil transport aircraft has been conducted by the National Aviation Facilities Experimental Center, Atlantic City, New Jersey (Jaglowski, 1970; 1971), indicating that liquid components of nitromethane and a sensitizer can effectively create an emergency exit in a typical jet transport fuselage. However, it was found that nitromethane will freeze at -30°F and prevent subsequent detonation of the liquid-filled linear-shaped explosive charge. Another limitation of this system is "the liquid-filled linear shaped charge will operate satisfactorily following simulated crash impact conditions where no severe fuselage structural damage or deformation of the linear tubing occurs" (Jaglowski, 1971, p. 36).

Thus the solid explosive charge of the ELSIE system, which can operate at temperatures below -65°F, and is not affected by fuselage deformation, appears to be considerably more reliable than the liquid-charge approach under evaluation by the FAA. An important use of the ELSIE system would be to incorporate emergency equipment in the system so that activation would also automatically deploy slides, life rafts, or slide-raft combination or other devices. This not only would make available instantaneous (and larger)emergency exits, but also save considerable time presently required in effective deployment of these devices.

EMERGENCY IN-FLIGHT EGRESS

Little attention has been given to the problem of emergency in-flight evacuation from air transport aircraft other than standard bail-out techniques. The C-135, for example, has an entry chute spoiler at the primary in-flight flight deck exit, to protect the crewmen in bailout from windblast which could cause them to strike the aircraft structure. When all passengers and crew are equipped with parachutes, bailout can be accomplished successfully provided airspeeds are not too high and there is sufficient altitude and time. However, at high-speed high-altitude conditions even a well-equipped flight-crew may have difficulty. Uninitiated passengers, female and child or infant passengers, and litter-cases cannot be expected to bailout successfully, particularly under adverse conditions.

Yet close examination of current accident experience shows that in-flight structural failure as a result of extreme turbulence, mid-air collision, or other emergency such as fire, decompression, or explosion is not rare. For example, during 1967 (for which complete NTSB reports are available) 30 to 70 civil air-transport accidents involved injuries to crew or passengers or damage to aircraft during flight. Of these, six aircraft were destroyed with fatalities to 186 individuals. These involved such causes as in-flight icing and loss of control, mid-air collisions, fire and explosion in flight, and explosive decompression with substantial structural damage. In cases where catastrophic in-flight structural failure occurs there presently is no way of saving the occupants.

Several concepts, based upon current state-of-the-art technology, have been advanced to provide emergency egress in-flight. Snyder and Stapp (1969) outlined physiological tolerance factors necessary for survival, and evaluated current in-flight egress techniques, including ejection, encapsulated seats, and separable compartment systems.

Use of ejection seats in air transports does not appear feasible, since passengers would not normally be equipped to face temperatures to -67°F, the up to 20 G deceleration windblast, and oxygen deficiency in a 30,000 foot initial ejection environment. The structural modification necessary to eject 150 or so separate passengers would present unreasonable structural weight and cost penalties, and this technique was not felt feasible.

To avoid the problems of multiple fuselage exits, one technique would be to mount specially modified seats on rails in the floor which would be oriented from front to rear of the cabin. In case of in-flight evacuation emergency, the seats could be sequentially fired toward the tail, which would be separated to allow sufficient exit space, much as cargo is sometimes dropped from transports in combat. The seated occupant could then be automatically lowered to the ground by parachute. This method also presents timing problems in evacuation, in balancing the necessity to evacuate a large number of persons rapidly with their ability to tolerate the evacuation, and might not be feasible in aircraft having engines located at the tail. An alternative concept was recommended to Tactical Air Command in 1963 by Stapp for deployment of airborne troops in low-level operations (below 200 feet msl), using static lines on an accordian pleated, rip-stitched overhead webbing on guides.

The webbing would be towed out by a large drogue chute catapulted at 45° upward from the open rear of the fuselage, ripping the stiches as it evacuated the attached cargo and paratroopers 20 feet apart. Their chutes would be deployed by a hook as they emerged through the rear opening. For ease in assembly at night, they would remain attached to the webbing.

Modification of the current operational technique of aerial delivery of cargo has been proposed by Kendall (1970) utilizing the paracone technique. In this system the aircraft would be constructed as a shell with each floor made with rollers and hardware required in present USAF airborne cargo drops. All passenger seats would be mounted on pallets up to 24 feet long (9'x 24' x 436 pallet) holding 24 passengers. The paracone device and its inflation system would be packaged under the floor. Deployment would be identical to the current military airborne drop except that rather than open doors, the tail section would be blown off. Pallets would be propelled out the rear on rollers, the first pallet deploying an extraction chute to provide for deployment of the succeeding pallet. This concept would have the extracting chute stabilize the pallet in approximately 4-5 seconds, while the paracone deployed as is shown in Figs. 43 and 44. The paracone escape and recovery system would be self-sufficient, having rafts and survival equipment self-contained. Kendall has proposed the use of inflatable air bags for the pallet passengers to protect them from initial airblast during deployment.

The paracone consists of a cone-shaped expandable and pneumatically inflatable structure that utilizes the advantages of the parachute. It is constructed of expandable material which is lightweight and can be packaged readily and is reportedly more effective than the parachute as an aerodynamic decelerator. It is cone-shaped with an open end, and the payload, rather than being suspended as with a parachute, is located inside the open end of the cone with the inflated structure surrounding and supporting it. Between the impact attenuation floor and the payload is an inflation gas distribution plenum chamber which doubles as the flotation chamber in case of water landing. The paracone has been extensively tested with systems analysis and subsonic development by McDonnell Douglas. Drag coefficients of from 0.6 to 1.2 were reported, and impact velocities of 28 to 50 fps (27 to 30 G) for a time duration of 0.1 second measured (Kendall, 1970). His analysis indicated that the paracone can be successfully dropped at very low altitute (200 to 350 feet) and high velocity (300 to 600 mph). Application studies have been conducted for space booster recovery, emergency astronaut escape and recovery from orbit, vehicle recovery from orbit at velocities over 35,000 fps, vehicle landings on planets, zero velocity - zero altitude, supersonic and hypersonic ejection, airborne cargo drops, paratroop, and emergency bailout. This concept has been considered for application to the McDonnell-Douglas DC-10 transport aircraft.

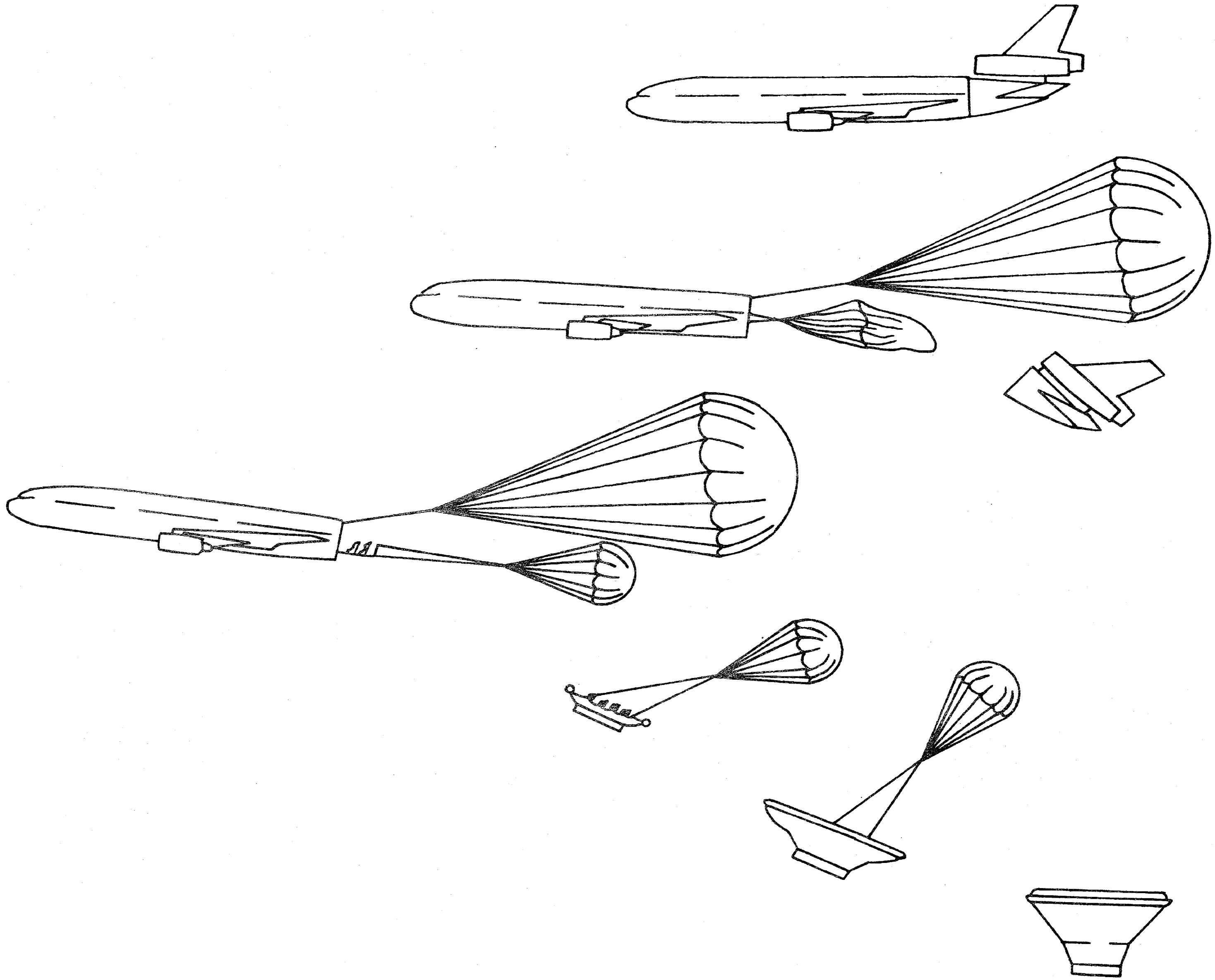

Figure 43. Paracone Emergency In-Flight Egress Concept (after Kendall, 1970).

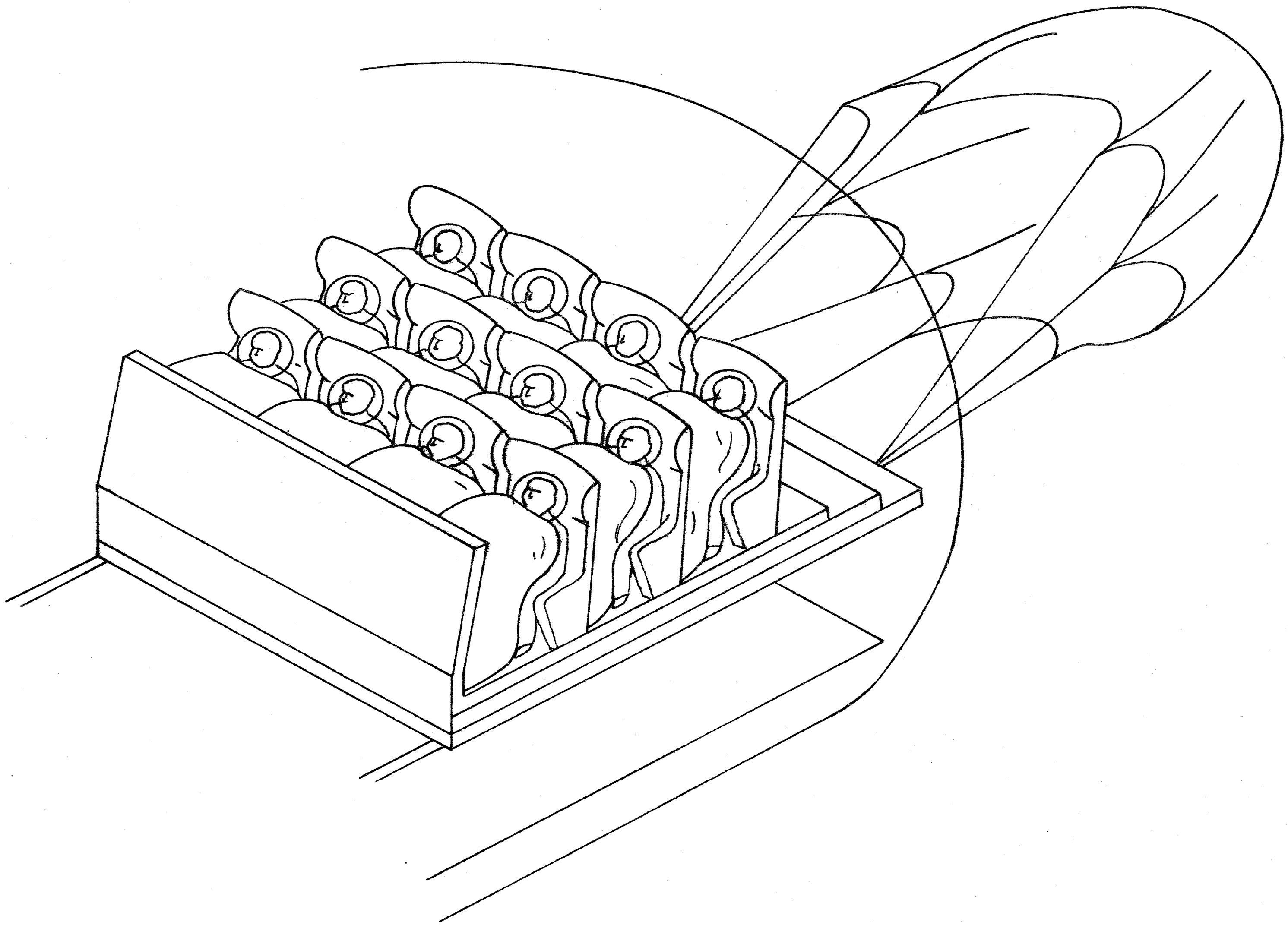

Figure 44. Pallet Passenger Packaging at Initiation of In-Flight Emergency Escape by Paracone Concept (after Kendall, 1970).

RAPIDJET

To provide fast in-flight egress for passengers or crew without the necessity of donning flight clothes or parachutes, and when "the presence of fire, smoke, poor visibility, aircraft manuvers, decompression, injuries, hypoxia, panic, or confusion impares the ability" of the occupants to put on their equipment, the rapidjet concept was proposed (McIntyre, 1969). The rapidjet installation would consist of an escape slide with power operated inner and outer doors, a series of individual crew escape modules, and the power drive unit required for module advance and release. The escape module for each passenger consists of an encapsulation bag or "cocoon" and a parachute pack. The open end of the cocoon is stretched across the escape slide entrance so that the crewman enters the cocoon as he jumps into the slide. Upon reaching the bottom of the cocoon, a sequenced release mechanism is triggered. This closes the open end and the cocoon and parachute pack are then released from the aircraft. The release of the escape module from the aircraft triggers an oxygen supply to a mask within the cocoon, and this activates an automatic parachute recovery system. As soon as one module is released, the remaining modules are power indexed toward the slide and another cocoon is positioned in the slide ready to receive the next passenger. This sequence is estimated to require 6 seconds.

As the escape module is released, a 4-foot diameter Hemisflo drogue chute is deployed to provide immediate stability, deceleration and controlled descent from high altitude. When descent is made to 15,000 feet altitude, an aneroid-controlled actuator opens the main parachute pack, and the 29.7 foot diameter "skysail" parachute is deployed by the drogue, utilizing the sleeve principle (four percent reefing is used for one second to maintain opening shocks under 10 G's). In egress below 15,000 feet a 3-second time delay is employed. The egress sequence and cocoon containment system is illustrated in Figure 45. This concept is passive in the sense that the only action necessary from the occupant, once he has jumped into the escape slide, is to use a control handle to release the parachute after the cocoon has landed. This system would not appear to be usable in a case where the aircraft was violently thrown about, or ended up in an unusual attitude, which would prevent passengers from reaching the escape slides. There might also be a reluctance for uninitiated individuals to "trust" jumping into any opening not knowing whether there would in fact be a chute to catch them or not. Also, at the given rate of 10 individual "bailouts" per minute per slide, it would take considerable total time to evacuate a loaded aircraft, under conditions in which little time would presumably be available.

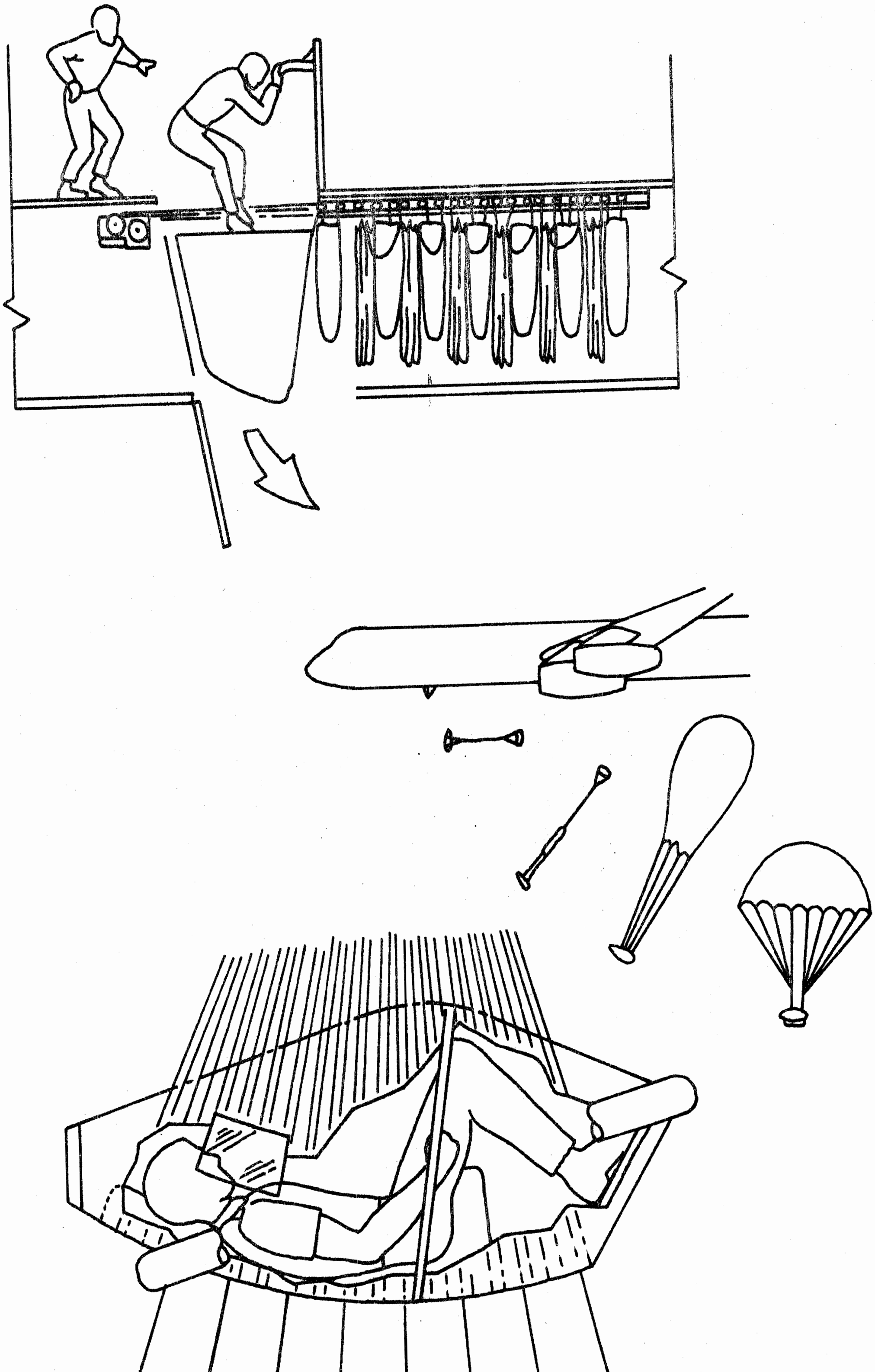

Figure 45. Rapidjet Emergency In-Flight Egress System, Deployment and Passenger Cocoon Container (after McIntyre, 1969).

PARACHUTE LOWERING OF FUSELAGE

Ordnance techniques have developed to the point where it is possible for the pilot to increase survivability by jettisoning under exact control various parts of the aircraft, such as an engine, the complete baggage compartment or large sections of the fuselage for fast passenger egress under very extreme conditions (Siper, 1967). In adapting this technique to in-flight evacuation the module could consist of a section of seats which would be separately encapsulated and ejected as a unit, or jettisoned from the fuselage in separate compartments. Fig.46 shows such a concept as advanced by Snyder and Stapp (1969) for in-flight emergency egress. However, such a technique would have to be designed into the aircraft structure of future aircraft, and retrojet could probably not be reasonably accomplished. A similar technique has been previously applied in solving the problem of saving helicopter crews and passengers from otherwise fatal mid-air emergencies (Arnold and Pollard, 1968; Teledyne, McCormick, Selph, n.d.). In the helicopter system this consists of using small explosive cutting charges which sever the tail boom assembly and rotor blades. Within 0.1 second of the severence of these structural components, a "drogue gun" fires a nylon line attached to a parachute deployment package directly overhead, deploying the main descent recovery parachute which then lowers the fuselage module. The parachute is reportedly deployed in less than 0.5 seconds from the activating signal, and is designed to lower the helicopter at a rate of about 33 feet per second or less. The components have been tested at the U.S. Navy's Weapon Laboratory, Dahlgren, Virginia, and tested at El Centro Naval Air Facility, and may be considered within the state of the art.

Perhaps, the most promising concept for mid-air emergency evacuation appears to be a combination of several of the above techniques discussed: (1) using explosive cutting charges to sever wings, fuselage engines, or tail; (2) deploying drag chutes to slow and stabilize the chutes to float the fuselage section to the ground gently and within safe limits (Fig. 37). The advantages of this system are that the passenger remains in his seat-cabin environment to avoid the extreme environmental conditions he might be subjected to in an open-seat ejection. Even the largest air transport could be lowered with a minimal ground impact velocity. As outlined above, this same concept has already been experimentally tested in rotocraft using current state-of-the-art components. The technique of ridding the disabled helicopter of encumbering and unstable structures and lowering the remaining modular package to the ground safely with parachutes, could well be adapted to air transport aircraft. Even in instances

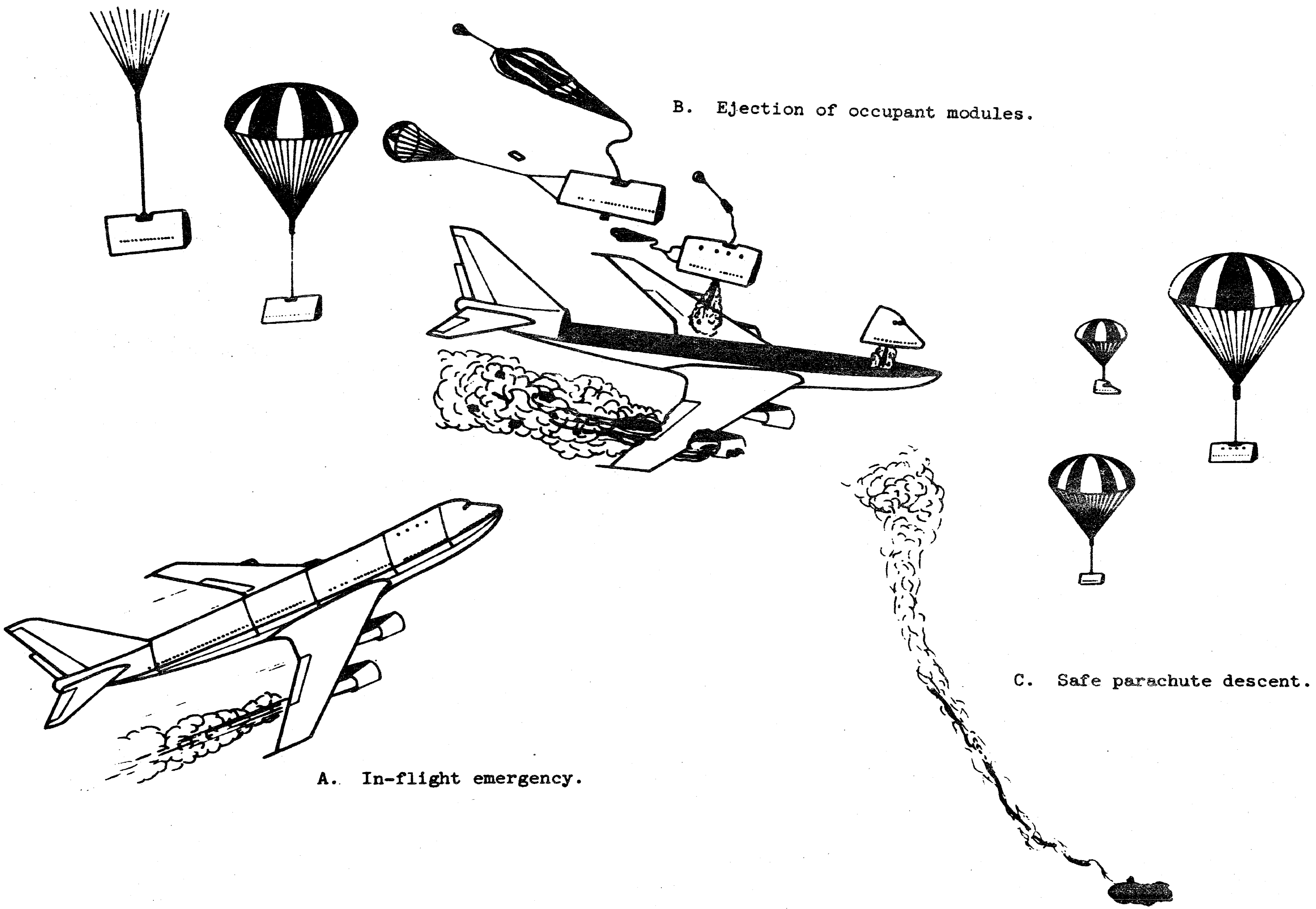

Figure 46. Concept of In-Flight Ejection of Encapsulated Compartments from Disabled Airliner.

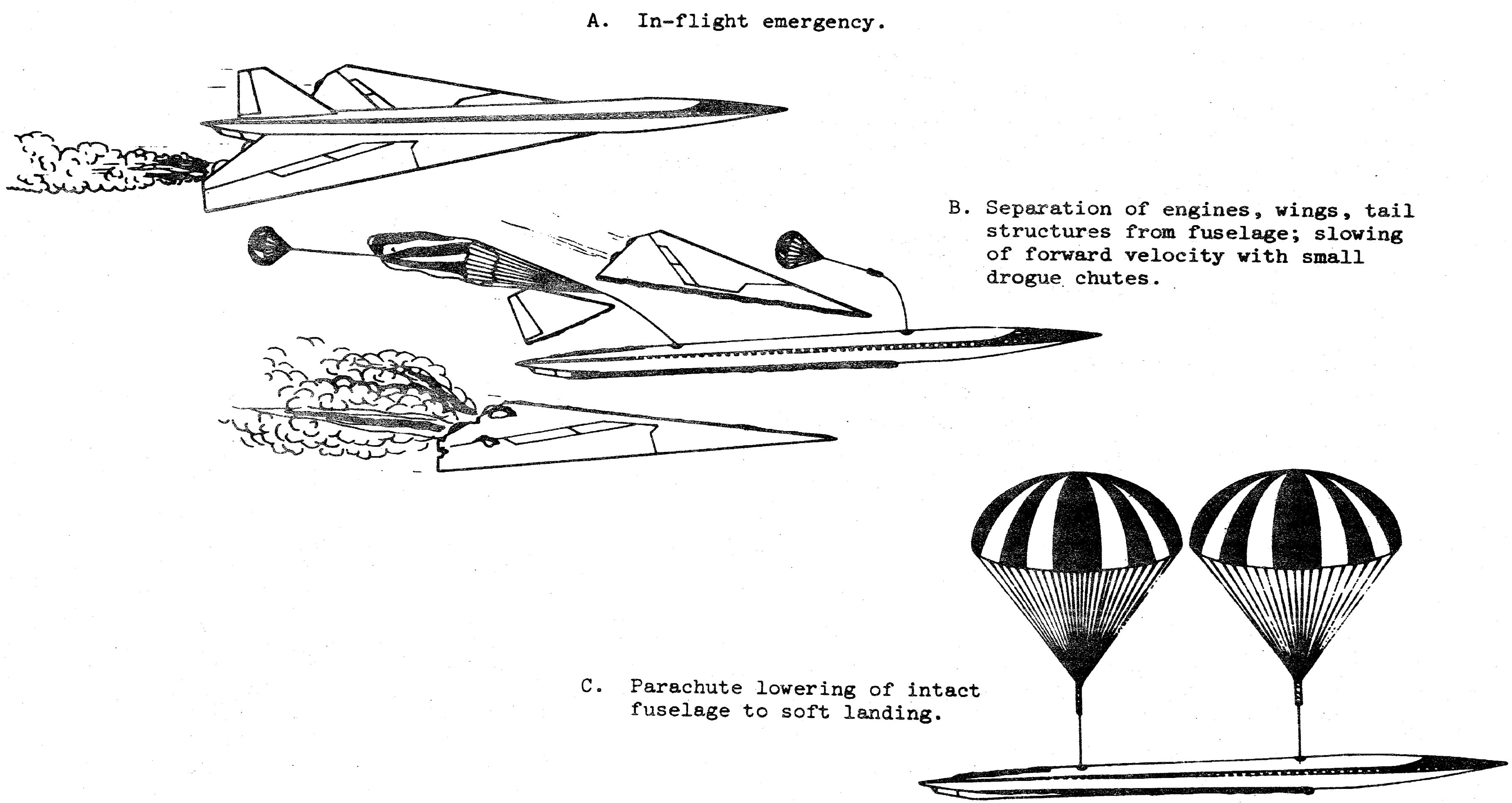

Figure 47. Concept of Safe Parachute Lowering of Passengers and Crew in Fuselage of Air Transport Aircraft Following Major Structural Failure in Flight (Snyder and Stapp, 1969).

where mid-air collision, in-flight explosiion, or structural failure result in rupture of the cabin area, transport occupants could be safely lowered to the ground by parachutes deployed from the fuselage since emergency oxygen systems would still be available to occupants, cold could be kept tolerable during brief exposure or descent, and impact forces could be kept minimal.

The area of emergency in-flight egress for occupants of air transport aircraft has been largely ignored, while research relating to advanced in-flight egress for air crews and space craft have made considerable progress. To realistically determine potential need for application of such concepts in military air transport aircraft further study of accidents are needed to provide a basis for determining the cases where such a system might have been effective in salvaging occupants from an otherwise fatal crash. From this brief survey of the state of the art it appears that some inflight egress concepts are certainly within the current state of the art.

SECTION IX

SYSTEMS ANALYSIS OF CRASH IMPACT AND ESCAPE

The objective of this section of the report is to present a systems study of the various concepts and hardware relating to crash impact protection and escape from the viewpoint of safety, reliability, maintainability, human factors, and technological considerations. An event-oriented flow diagram of crash impact and escape from an aircraft is presented to aid in assessing the feasibility of the various concepts and hardware under evaluation (Figure 38).

EVENT-ORIENTED SYSTEMS STUDY

Figure 38 provides a framework to determine the function level of each of the concepts included in this study. The various events of a crash are included from system installation to egress after a crash. Each item can critically affect survival in event of a crash.

The first item deals with system installation and configuration maintenance. If a device is improperly installed or maintained, survival of one or many is endangered. For instance, an improperly charged airbag inflation device could malfunction resulting in an undeployed restraint system. The occupant could receive an impact injury and become immobile. Preflight briefing and crew training has been included as the next event. Many studies have shown the benefit of a briefing on passenger use of restraint systems. Crew training must be adequate to insure proper use of exits.

When a survivable crash event is imminent, the crew may be aware or unaware. In documented cases, the crew has been unaware or unable to take action regarding a certain crash. In these cases, automatic arming of explosively-formed exits would be necessary.

Passenger warning can be effective in preparing occupants for a crash. Benefits include proper positioning and bracing for the most effective use of restraint systems. Also, the techniques of egress could be established to enhance its efficiency.

Because of the variety of seating configurations which may be found in the subject aircraft, front-, side-, and rear-facing seating have been listed separately. In addition, the out-of-position occupant is considered. Given current restraint systems technology and the differences in human impact tolerance to blows from different directions, the design goals may very well be different in each case.

The crash event itself certainly influences the survival

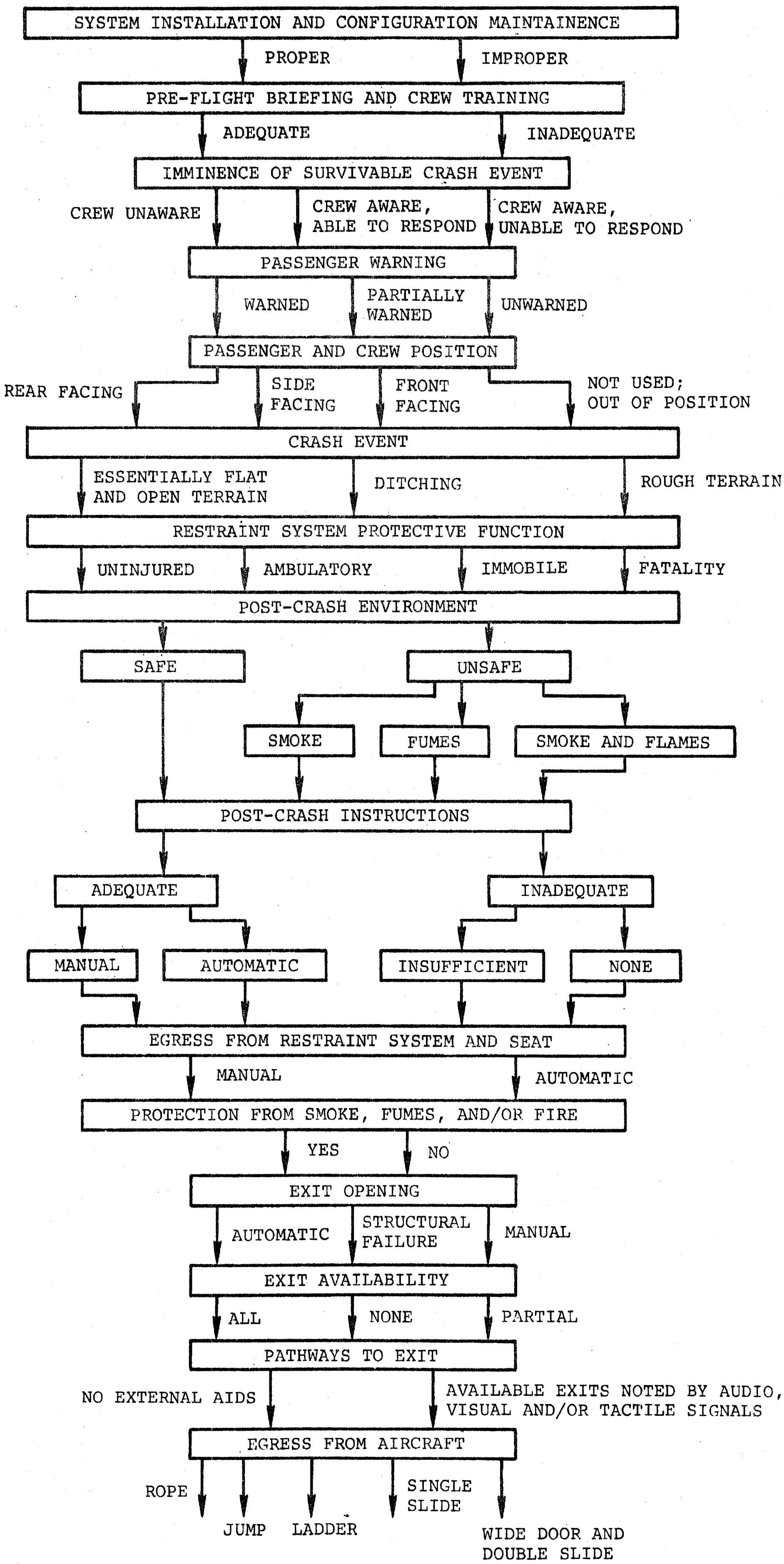

Figure 48. Crash Impact and Escape Flow Diagram.

problem. The optimum case is probably a crash on flat and open terrain. A high-wing aircraft has been observed to offer considerably less time for escape than a low-wing air craft in event of a ditching. Rough terrain most likely increases the likelihood of high-impact G-loadings, thus also affecting survival.

During the impact the occupants may range from uninjured to fatally injured. An immobile passenger presents nearly the same egress problem as a fatally injured passenger as he may block available exits thus preventing the escape of other passengers.

The post-crash environment strongly affects egress. Smoke and flames hinder most normal physical and psychological functions. The presence of automatic or live instructions can aid dramatically in egress.

Because of restraint system use, egress from these protective devices is included as a separate event. It is possible that time could be lost pushing airbag material out of the way in leaving seating positions.

Protection from smoke, fumes, and/or fire is believed to be important to survival. A few minutes added breathable air in a cluttered and smoky cabin could possibly be the difference between survival and asphyxiation.

Obviously, the exits must be opened to provide egress. Customarily, the crew opens normal and emergency exits. Occasionally, a structural failure provides a safe exit. Because of documented cases where not enough normal exits were available, the option for automatically produced exits is included.

It is often the case that some exits are unavailable. This is particularly the case when a fire exists outside the aircraft and when structural damage has jammed the doors.

Particularly in the case of darkness and smoke the routes to available exits can be difficult to locate. Audio visual and/or tactile signals can improve ability to egress quickly.

When an occupant reaches an exit, egress can be provided by several techniques. As some have proved more effective than others, a variety of egress techniques are included.

THE SUBJECT SYSTEMS

A total of seventy-four systems have been chosen for inclusion in the safety, maintainability, human factors, reliability, and technological analyses which follow. These are gathered from the previous sections of the report and can be grouped roughly in the following categories: (1) airbag inflation devices; (2) crash impact sensors; (3) airbag materials; (4) airbag coating materials; (5) crash impact restraint systems; (6) smoke hood concepts; (7) aisle and path markers; (8) warning and public address systems; and, (9) other technology. Most of these concepts are discussed at length in preceding chapters. Restraint systems concepts other than the airbag and its components have not been discussed previously and are included for purposes of comparison. The list is given in Table 5. The number with each system is used in the tables which follow for purposes of identification.

TABLE 5

LIST OF IMPACT PROTECTION AND ESCAPE SYSTEMS

Airbag Inflation Devices

1. Stored gas system.
2. Stored gas system with modulated flow.
3. Augmented air system.
4. Augmented air system with staging.
5. Liquid-cooled, solid-propellant system.
6. Solid-cooled, solid-propellant system.
7. Aspirator systems.

Crash Impact Sensors

8. Mechanical sensor.
9. Sensor using signals from inertial navigation system.
10. Radar proximity sensor.
11. Sonar proximity sensor.

Airbag Materials

12. Nylon
13. Polyester
14. Glass
15. Cotton

Airbag Coating Materials

16. Natural rubber
17. Butyl
18. Neoprene
19. Polyvinyl chloride (PVC)
20. Polyurethane
21. E.P.D.M.
22. Hypalon

Restraint Systems

23. Inflating occupant restraint system for passenger use in rear-facing seats
24. Inflating occupant restraint system for passenger use in side-facing seats
25. Inflating occupant restraint system for crew use in front-facing seats.
26. Rear-facing seats with lap belt
27. Passive net system (Nissan)
28. Passive blanket system (Hamill)
29. Front-facing seat with upper torso harness
30. Troop seat

Smoke Hood Concepts

31. Boeing mask
32. John Hand hood
33. Racine Glove Company hood
34. Sierra Engineering Company hood
35. Life Support Systems hood. (A) Elastic neck seal type
36. Life Support Systems hood. (B) Lanyard neck seal type
37. Scott-O-Vista mask
38. Mine Safety Appliance Company. (A) 88180 cansister device
39. Mine Safety Appliance Company. (B) Self-rescuer.
40. North American Rockwell fire hood concept
41. North American Rockwell fire mask concept
42. Schjeldahl hood. (A) Drawstring model
43. Schjeldahl hood. (B) Septal neck seal model.
44. Experimental FAA (Schjeldahl) hood. Self-contained air supply.
45. Bureau of Mines (Westinghouse/Schjeldahl) portable breathing apparatus. Chlorate candle.
46. FAA (Schjeldahl) hood. Advanced concept.

Aisle and Path Markers

47. Chemical illumination
48. Charge activated electro-illumination
49. Ultraviolet illumination
50. Phosphorescent illumination
51. Incandescent illumination
52. Self-luminescence (tritium)
53. Tactile markers
54. Floor level markers
55. Pulsating markers

Warning and Emergency Public Address Systems

56. Alarm bell
57. Bull horn
58. Solid state device
59. Operational TWA visual/aural system

Technology

60. ELSIE
61. Telescape
62. Escape rope
63. External platform slide entry
64. Integrated escape system
65. Folding slide
66. Cargo door
67. Ablative-coated exit
68. Passenger conveyor
69. Inflating slide/liferaft
70. Double slide
71. In-flight egress by paracone.
72. In-flight egress by rapidjet.
73. In-flight escape by capsule-chute
74. In-flight escape by fuselage parachute

SYSTEM SAFETY

A variety of factors must be included to conduct the preliminary hazard analysis and to estimate the safety of the subject systems. The seventy-four crash impact and escape concepts are rated with respect to twenty-five criteria such as noise level, human error potential, as given in Table 6, etc. The rating scheme for each of the criteria is defined in Table 7. As an example of the use of Table 6 consider the noise level of a stored-gas airbag inflation device. Noise level can be rated as: (1) no problem; (2) possible temporary threshold shift; and, (3) possible permanent hearing impairment. In Table 6 the stored-gas airbag inflation device received a noise level rating of "2" indicating a possible temporary threshold shift on the basis of experiments carried out using human volunteer test subjects.

TABLE 6. PRELIMINARY HAZARD ANALYSIS (SUMMARY)

HAZARD	AIRBAG INFLATION DEVICES: 1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air-staging	5 liq.-cool - solid-prop.	6 solid-cool - solid-prop.	7 aspirator	CRASH IMPACT SENSOR: 8 mechanical	9 inertial guidance	10 radar proximity	11 sonar proximity	AIRBAG MATERIAL: 12 nylon	13 polyester	14 glass	15 cotton
a. Noise level	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
b. Hazard level	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
c. Length of service	i	i	i	i	1	1	1	i	i	i	i	1	1	1	1
d. Flammability	1	1	1	1	i	i	i	1	1	1	1	2	2	1	3
e. Short term toxicity	1	1	2	2	2	2	2	1	1	1	1	i	i	1	i
f. Irritability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Thermal radiation	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
i. Hazards of propellants	2	2	2	3	3	3	3	1	1	1	1	1	1	1	1
j. System environmental constraints	2	2	2	2	2	1	2	1	1	1	1	2	1	1	1
k. Use of explosive devices	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
l. Compatibility of materials	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m. Effect of electrical phenomena	2	2	2	2	2	2	2	1	2	2	2	1	1	1	1
n. Inadvertent actuation	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1
o. Use of pressure vessels	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
p. Crash safety	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
q. Safe operation and maintenance	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
r. Training for O and M	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
s. Egress, rescue, survival	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
t. Fire ignition and propagation	1	1	1	1	i	i	i	1	1	1	1	2	2	1	2
u. Shock resistance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
v. Layout and lighting requirements	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	2	2	2	2	2	2	2	3	3	3	3	1	1	1	1
x. Vulnerability	i	i	i	i	1	1	1	i	i	i	i	1	1	1	1
y. Human error potential	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

HAZARD	AIRBAG COATING MATERIAL: 16 natural rubber	17 butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 E.P.D.M.	22 hypalon	RESTRAINT SYSTEMS: 23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear face seat + l.b.	27 passive net	28 passive blanket	29 front face seat - A.F.H.	30 troop seat
a. Noise level	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
b. Hazard level	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
c. Length of service	2	2	1	1	2	1	1	i	i	i	1	i	i	1	1
d. Flammability	3	3	1	1	2	3	1	1	1	1	1	i	i	1	1
e. Short term toxicity	i	i	1	1	i	i	1	1	1	1	1	1	1	1	1
f. Irritability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Thermal radiation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
i. Hazards of propellants	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
j. System environmental constraints	2	2	1	2	2	2	2	1	1	1	1	1	1	1	1
k. Use of explosive devices	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
l. Compatibility of materials	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m. Effect of electrical phenomena	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
n. Inadvertent actuation	1	1	1	1	1	1	1	3	3	3	1	3	3	1	1
o. Use of pressure vessels	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
p. Crash safety	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
q. Safe operation and maintenance	1	1	1	1	1	1	1	2	2	2	1	2	2	1	1
r. Training for O and M	2	2	2	2	2	2	2	2	2	2	1	2	2	1	1
s. Egress, rescue, survival	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
t. Fire ignition and propagation	2	2	1	1	2	2	1	1	1	1	1	1	1	1	1
u. Shock resistance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
v. Layout and lighting requirements	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	1	1	1	1	1	1	1	3	3	3	1	3	3	1	1
x. Vulnerability	2	2	1	1	2	1	1	i	1	i	1	i	i	1	1
y. Human error potential	3	3	3	3	3	3	3	3	3	3	4	3	3	4	4

N = not applicable
i = insufficient information

TABLE 6. PRELIMINARY HAZARD ANALYSIS (SUMMARY) Page 2 of 2

SMOKE HOOD CONCEPTS

HAZARD	31 Boeing mask	32 John Hand hood	33 Racine Glove Co.	34 Sierra Eng. Co.	35 LSS - Elastic seal	36 LSS - Lanyard	37 Scott-O-Vista	38 M.S.A.C. - canister	39 M.S.A.C. - self-rescue	40 N.A.R. fire hood	41 N.A.R. fire mask	42 Schjeldahl - drawstring	43 Schjeldahl - septal	44 FAA - air supply	45 B.M. - PBA hood	46 FAA Adv. concept
a. Noise level	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
b. Hazard level	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2
c. Length of service	2	2	2	2	2	2	2	2	2	2	i	2	2	2	i	i
d. Flammability	i	i	i	i	i	i	i	i	i	i	i	1	1	1	2	1
e. Short term toxicity	i	i	i	i	i	i	i	i	i	i	1	2	2	1	1	1
f. Irritability	i	i	1	i	i	i	i	i	i	i	1	1	1	1	i	i
g. Thermal radiation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
h. Isolate energy sources	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
i. Hazards of propellants	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
j. System environmental constraints	i	i	i	i	i	i	i	2	2	i	2	1	1	1	i	1
k. Use of explosive devices	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
l. Compatibility of materials	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
m. Effect of electrical phenomena	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
n. Inadvertent actuation	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3
o. Use of pressure vessels	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
p. Crash safety	1	1	1	1	1	1	1	i	i	1	1	1	1	i	i	1
q. Safe operation and maintenance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
r. Training for O and M	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
s. Egress, rescue, survival	i	i	i	i	i	i	i	i	i	i	1	1	1	1	i	1
t. Fire ignition and propagation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
u. Shock resistance	1	1	1	1	1	1	1	i	i	1	1	1	1	i	i	1
v. Layout and lighting	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	3	1	1	1	1	1	1	3	3	1	1	1	1	1	i	3
x. Vulnerability	2	i	i	i	i	i	i	2	2	i	2	i	i	2	2	i
y. Human error potential	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	i

AISLE AND PATH MARKERS

HAZARD	47 chemo-illum.	48 electro-illum.	49 ultra-violet	50 phosphorescent	51 incandescent	52 self-illum. (tritium)	53 tactile markers	54 floor-level markers	55 pulsating markers
a. Noise level	1	1	1	1	1	1	1	1	1
b. Hazard level	1	1	1	1	1	1	1	1	1
c. Length of service	1	1	1	1	1	1	1	1	1
d. Flammability	1	1	1	1	1	1	1	1	1
e. Short term toxicity	2	1	1	1	1	2	1	1	1
f. Irritability	1	1	1	1	1	1	1	1	1
g. Thermal radiation	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	2	2	2	2	2	2	1	2	2
i. Hazards of propellants	1	1	1	1	1	1	1	1	1
j. System environmental constraints	1	1	2	2	1	1	1	1	1
k. Use of explosive devices	1	1	1	1	1	1	1	1	1
l. Compatibility of materials	1	1	1	1	1	1	1	1	1
m. Effect of electrical phenomena	1	2	1	1	2	1	1	1	2
n. Inadvertent actuation	1	1	1	1	1	1	1	1	1
o. Use of pressure vessels	1	1	1	1	1	1	1	1	1
p. Crash safety	1	2	1	1	2	1	1	1	1
q. Safe operation and maintenance	1	1	1	1	1	1	1	1	1
r. Training for O and M	1	1	1	1	1	1	1	1	1
s. Egress, rescue, survival	1	1	1	1	1	1	1	1	1
t. Fire ignition and propagation	1	2	1	1	2	1	1	1	2
u. Shock resistance	1	1	1	1	1	1	1	1	1
v. Layout and lighting	2	2	2	2	2	2	2	2	2
w. Fail-safe design	2	2	2	2	2	2	1	2	2
x. Vulnerability	2	2	1	1	2	1	2	1	1
y. Human error potential	1	1	1	1	1	1	4	1	1

WARNING AND P.A.

HAZARD	56 alarm bell	57 bull horn	58 solid-state device	59 TWA visual/aural
a. Noise level	1	1	1	1
b. Hazard level	1	1	1	1
c. Length of service	1	1	i	1
d. Flammability	1	1	1	1
e. Short term toxicity	1	1	1	1
f. Irritability	1	1	1	1
g. Thermal radiation	1	1	i	1
h. Isolate energy sources	2	1	1	2
i. Hazards of propellants	1	1	1	1
j. System environmental constraints	1	1	1	1
k. Use of explosive devices	1	1	1	1
l. Compatibility of materials	1	1	1	1
m. Effect of electrical phenomena	1	1	1	1
n. Inadvertent actuation	2	1	1	2
o. Use of pressure vessels	1	1	1	1
p. Crash safety	1	1	1	1
q. Safe operation and maintenance	1	1	1	1
r. Training for O and M	3	2	2	3
s. Egress, rescue, survival	1	1	1	1
t. Fire ignition and propagation	1	1	1	1
u. Shock resistance	1	2	i	1
v. Layout and lighting	2	2	1	2
w. Fail-safe design	1	1	2	1
x. Vulnerability	1	2	2	1
y. Human error potential	6	6	6	6

OTHER TECHNOLOGY

HAZARD	60 ELSIE	61 telescape	62 escape rope	63 ext. plat. - slide entry	64 S.B. - escape harness	65 fold. slide	66 cargo door	67 ablative coat. exit	68 pass. conveyor	69 slide/life raft	70 double slide	71 in-flight/paracone	72 in-flight/rapidjet	73 in-flight/capsule	74 in-flight/parachute
a. Noise level	1	1	1	1	1	1	1	1	1	1	1	i	1	i	1
b. Hazard level	1	1	1	2	1	1	1	1	1	2	2	4	4	4	4
c. Length of service	1	1	1	1	1	1	1	i	i	1	1	1	2	1	1
d. Flammability	1	1	3	2	2	1	1	1	1	2	2	2	2	2	2
e. Short term toxicity	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
f. Irritability	1	2	2	1	i	1	1	i	i	1	1	i	i	i	1
g. Thermal radiation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Isolate energy sources	2	2	1	2	2	2	2	1	2	2	2	2	1	2	2
i. Hazards of propellants	2	3	1	2	3	2	1	1	1	2	2	3	1	3	3
j. System environmental constraints	1	2	i	1	i	i	1	1	i	1	1	i	i	i	i
k. Use of explosive devices	2	1	1	1	1	1	1	1	1	1	1	i	1	i	i
l. Compatibility of materials	1	1	1	1	i	1	1	1	1	1	1	2	2	2	1
m. Effect of electrical phenomena	1	1	1	1	1	1	1	1	i	1	1	1	1	1	1
n. Inadvertent actuation	3	3	1	2	2	2	2	N	3	2	2	3	3	3	3
o. Use of pressure vessels	1	2	1	2	1	2	2	N	1	2	2	i	1	i	1
p. Crash safety	1	i	1	1	2	2	2	1	3	1	1	i	i	i	i
q. Safe operation and maintenance	1	i	2	1	i	i	1	1	i	1	1	2	2	2	2
r. Training for O and M	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
s. Egress, rescue, survival	1	1	1	1	i	1	1	1	i	1	1	3	3	3	1
t. Fire ignition and propagation	1	1	1	1	1	1	1	1	i	1	1	i	i	i	i
u. Shock resistance	1	2	1	1	i	2	2	1	2	1	1	i	i	i	i
v. Layout and lighting	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
w. Fail-safe design	3	3	1	2	3	3	2	1	3	2	2	3	3	3	3
x. Vulnerability	1	2	2	2	2	2	2	1	i	2	2	2	2	2	2
y. Human error potential	6	6	6	5	3	3	6	1	3	5	5	6	4	6	6

N = not applicable
i = insufficient information

TABLE 7

PRELIMINARY HAZARD ANALYSIS RATING SYSTEM

a. Noise level
   1. No problem
   2. Possible temporary threshold shift
   3. Possible permanent hearing impairment
b. Hazard level
   1. Negligible
   2. Controllable hazard (marginal)
   3. Will cause injury without immediate action (critical)
   4. Failure will cause injury (catastrophic)
c. Length of service
   1. Estimated five year life based on manufacturer's data.
   2. Less than 5 years
d. Flammability
   1. Low
   2. Medium
   3. High
e. Short term toxicity
   1. None
   2. Moderate (could be dangerous in combination with other toxic gases)
   3. Dangerous (qualitative estimate)
f. Irritability
   1. None
   2. Moderate
   3. Disabling
g. Thermal radiation
   1. None
   2. Moderate
   3. Disabling
h. Isolate energy sources
   1. None present
   2. Necessary
i. Hazards of propellants
   1. None present
   2. Designed for safe handling
   3. Prototype systems for which data has not yet been developed
j. System environmental constraints
   1. Operates the same under all required conditions of temperatures, pressure, and humidity
   2. Performance varies with temperature, pressure and/or humidity
k. Use of explosive devices
   1. None present
   2. Hazard level 2 when installed
l. Compatibility of materials
   1. No problems known
   2. Possible problem

m. Effect of electrical phenomena (current, electrostatic charge, or electromagnetic fields)
   1. No problems known
   2. Hazard level 2
   3. Hazard level 3
   4. Hazard level 4

n. Inadvertent activation
   1. No problems known
   2. Research accomplished to solve problems
   3. Research needed

o. Use of pressure vessels
   1. None present
   2. Necessary component (Hazard level 2)

p. Crash safety
   1. Operable after and during survivable crash
   2. Marginal operation after or during survivable crash
   3. Not operable after or during survivable crash

q. Safe operation and maintenance
   1. No problems known
   2. Hazard level 2 (at least) at all times during operation and maintenance

r. Training for operation and maintenance
   1. None required
   2. Special training required
   3. General briefing required

s. Egress, rescue, survival
   1. Enhanced with use of system
   2. Unaffected by use of system
   3. Hazardous with use of system

t. Fire ignition and propagation sources
   1. None present
   2. Possible source present

u. Shock resistance
   1. Designed for operation in shock environment
   2. Susceptible to shock damage

v. Layout and lighting requirements
   1. No special requirements
   2. Special lighting and/or layout required for use

w. Fail-safe design
   1. Not needed
   2. Required and data available for design purposes
   3. Required and data needed

x. Vulnerability
   1. Invulnerable
   2. Vulnerable to tampering and/or prolonged storage

y. Human error potential
   1. Automatic device, no training needed
   2. Manual device, no training needed
   3. Automatic device, briefing required
   4. Manual device, briefing required
   5. Automatic device, briefing and training required
   6. Manual device, briefing and training required

RELIABILITY CONSIDERATIONS

The analysis of reliability is tied closely to the event-oriented flow chart shown in Figure 48. The specific items which will be included in the reliability study are:

a. required function and failure definition (coupled with the flow-chart)

b. critical time periods in exercise of function

c. external environmental stresses under which each element must function; e.g. temperature range from -65°F to 200°F

d. effects of storage, shelf-life, packaging, transportation, handling, and maintenance; e.g. evaluation of components which deteriorate with age

e. identification of reliability critical items which significantly affect ability of systems to function (coupled with the flowchart).

It has not been found possible to develop a numerical rating system for the seventy-four subject systems. Rather, in Table 8 each of the systems is handled individually with brief verbal evaluations used for each of the reliability items.

MAINTAINABILITY CONSIDERATIONS

Each system and subsystem has been subjected to a preliminary maintainability analysis with respect to the following items: (1) simplified maintenance activities; (2) major repairs by depot level maintenance; (3) necessary inspection; and, (4) projected requirements for facility, personnel, tools, etc. It has been possible to develop a numerical rating system to assess maintainability. The definition of the rating system is included with the analysis on Table 9.

HUMAN FACTORS CONSIDERATIONS

The human factors considerations which are involved in evaluating system performance include nearly all conceivable aspects of human function and performance. Both physiological and psychological stresses are likely to be at peaks emphasizing the detail which must be included in this evaluation. The seventy-four systems are rated with respect to seventeen criteria ranging from ease of use to anthropometric considerations. The rating scheme for each of the criteria is defined in Table 10 and the actual analysis given in Table 11.

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5).	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
1,2, 3,4	Stored gas and augmented air inflation devices	Airbag inflation sources	No gas supplied	Must function before or during crash	Possible gas leakage. Pressure monitor necessary.	Function necessary for crash protection
5,6, 7	Propellant and aspirator inflation devices	Airbag inflation sources	No gas supplied	Must function before or during crash	It is estimated that these devices can be stored and handled without reducing function	Function necessary for crash protection
8,9, 10,11	Crash impact sensors	Provide electrical signal to airbag inflation device	No signal provided	Must function before or during crash	All devices are prototypes. Insufficient field data is available	Device depends on well-defined signal defining imminence or occurrence of accident. This data is not available.
12,13 14,15	Airbag material	Contain inflation gas and serve as protective cushion	Material failure (tear or rip)	Must function before or during crash	Materials with adequate properties are available	Function necessary for crash protection
16-22	Airbag fabric coating materials	Reduce airbag porosity and heat transfer from inflation gasses	Coating material chosen which is subject to environmental degradation reducing function	Must function before or during crash	Materials with adequate properties are available	Not a reliability critical item

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
23	Airbag for passengers on rear-facing seats using standard lap belts	Provide occupant crash protection	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level 2 device	Not a reliability critical device. A rear-facing seat with lap belt provides protection without supplemental airbag.
24	Airbag for passengers on side-facing seats	Provide occupant crash protection	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level 2 device	Function necessary for crash protection. Because prototypes offering side impact protection are in the early developmental stage, the variables governing reliable airbag positioning have not yet been defined.
25	Airbag for crew on front-facing seat	Provide occupant crash protection without reducing crew ability to function	Does not inflate or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level 2 device	Function necessary for crash protection. Because of the necessity for crew function during and post-crash, the bag must be positioned very reliably. This is not possible with current generation systems.

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
26	Rear-facing seat plus lap belt	Provide occupant crash protection	Seat structural failure, lap belt failure, or failure where seat is attached to aircraft	Must function during crash	Components must be maintained properly and frayed belts replaced	Strength of critical seat structural members, lap belt and attachments. Requires user action.
27, 28	Passive net restraint system (Nissan,Hamill)	Provide occupant crash protection	Does not deploy or improperly positioned	Must function during crash	Most components can be handled and stored easily with careful installation and maintenance. This is a hazard level 2 device	The most susceptible items in this system are the crash sensor and the electromechanical actuation trigger. Function necessary for crash protection.
29	Front-facing seat plus Air Force lap belt and shoulder harness with inertia reel	Provide occupant protection in crash without reducing crew ability to function	Seat structural failure, belt or harness failure, or failure where seat is attached to aircraft	Must function during crash	Components require minimum attention except for restraint belt maintenance	Strength of components. Requires user action.
30	Troop seat	Provide occupant protection in crash	Component failure	Must function during crash	Components require minimum attention except for restraint belt maintenance	Strenght of components. Requires briefing and user action.

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
31-37, 40, 42, 43	Smoke hoods (rebreather) 3-6 min. duration	Protect against toxic fumes, smoke flame, and heat, and provide sufficient air for emergency egress without significant impairment of visual acuity or hearing	Leaks, obstructs vision, impairs hearing, or fails to protect against flame, smoke, or toxic fumes. Fails to retain air.	3-6 minutes post crash for donning and egress	Tears along fold lines, in reuse, deterioration	Function necessary for egress in smoke and fire
38, 39	M.S.A.C. smoke mask and canister	Removes large smoke particles	Defective nose clip; separated nose clip; canister hose leak	Post-crash egress	Canister hose deterioration, material deterioration	Function of possible assistance in egress in smoke and fire
41	N.A.R. smoke mask	Filter smoke	Filter dried out	Post-crash egress	Outer container seal may break, drying out filter	Function of possible assistance for egress in smoke and fire
44-46	Smoke hoods (self-contained or generated air supply of long duration)	Filter smoke, wash out CO_2 or provide supply of gas, automatically	Filter dried out, air cylinder fails to work, failure of gas generator	Post-crash donning and egress	Deterioration of materials, loss of gas from cylinder, deterioration of chemicals	Function necessary for egress in smoke and fire
47-52	Emergency illumination systems	Provide emergency aisle, path-marker and exit illumination	Does not provide adequate level of illumination	Must function post-crash for emergency egress	Most components can be easily stored and handled	Must function post-crash in order for crew and passengers to egress

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
53	Tactile markers	Provide tactile sensors for egress where vision poor or not existant	Failure to remain stable in place, incorrect positioning	Must be available immediately post-crash	No adverse effects known	Shape provides direction of exit indication. Markers must be correctly installed to remain in place.
54-55	Floor-level and pulsating aisle markers	Provide visual references for evacuation	Do not work	Immediately post-crash	None known	Pulse sequence; energy source
56, 59	Alarm bell	Warn of emergency	Fails to work, or warning light fails	Prior to, during and/or subsequent to crash, ditching, or in-flight emergency	None if properly packaged	Energy source; Electrical circuits
57	Bull horn	To provide portable emergency P.A. system	Power failure	Whenever required as emergency communication system due to failure of primary means	Battery deterioration	Energy source; electrical circuits
58	Solid-state communications system	Provide portable communication between crew members	Does not receive or transmit; garbled signal, inadequate volume	Whenever required as emergency communications system due to failure of primary means	Unknown	Energy source; Electronic circuits
60	ELSIE	Provide instantaneous emergency exits	Does not sever exit	Can be initiated prior to ditching or for post-impact egress	Information not known	Failure of any of five major components

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
61	Telescape	Fast egress from emergency door exits	Fails to extend; fails to reach ground at useful angle; jams	Immediately post-crash, or when Emergency egress required	Hardware can be stored indefinately; gas source may leak; seal deteriorate	Not essential item. Can provide important function gas storage container and collapsing tubular alignment critical for proper function
62	Escape rope	Allow egress from cabin overhead exits or flight deck windows	Tangled; support fails; can not be located	Immediately post-crash, or when emergency egress required	Can be stored without decrement for extended time under proper humidity and temperature	Serves critical need where jump from exit would be injurious. Strength and stowage critical
63, 65, 70	Inflatable escape slide	Provide fast reliable emergency egress from exit to ground	Failure to deploy or inadvertent inflation	Immediately post-crash or when emergency egress required	Designed for long-term stowage; gas source requires recharge	Necessary for emergency egress. Mechanical (puncture) failure; failure of inflation source
64	S.B./escape harness	Automatic egress in emergency evacuation or post-crash	Inadequate restraint fit or failure of power system due to fuselage damage	Imediately post-crash or when emergency egress required	Insufficient data available on this concept	Not essential for egress. Failure of restraint, power system, or linkage would render nonusable
65	Mechanical folding slide	Serves as either walkway or stairs for emergency egress	Fails to deploy, jams, fails to reach ground	Immediately post-crash or whenever emergency evacuation required	None known	Not essential for egress. Failure to deploy or jamming may be critical factors

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
66	Cargo door	Fuselage cargo door, swing-out nose or tail, used for rapid egress of maximum number of passengers	Opening mechanism fails or structure buckles preventing actuation	Immediately post-crash or whenever emergency evacuation required	None known	Would provide additional exit but not essential system. Integrity of fuselage at swing points is most critical factor.
67	Ablative exterior coating	Provide heat shield to protect overwing egress pathway	Fails to retain ablative characteristics, provides undue penalty affecting flight characteristics	Egress in post-crash exterior fire	None known	Not a critical item but may increase egress survivability. Effect on flight characteristics may be critical factor
68	Passenger conveyer belt	To provide passenger with means to locate and reach nearest emergency exit	Jams, failing to operate. Inflicts injuries on passengers jammed between belt and seat. Sends passengers in wrong direction (to non-useable exits)	Emergency egress, post-crash egress	None known	Not essential system for egress Structural failure during crash may render inoperative; directional control may be imperative.
69	Slide/raft	Emergency egress to ground or water	Failure to deploy, punctures, inadvertently actuates	Immediately post-crash or whenever emergency evacuation required	None known. Periodic inspection recommended.	Provides critical egress function. Mechanical deployment failure critical.

TABLE 8. RELIABILITY ANALYSIS (SUMMARY)

Item No. (See Table 5)	Item	Required Function	Failure Definition	Critical Time Period in Function Exercise	Effects of Storage and Handling	Reliability Critical Items
71	In-flight egress paracone	In-flight emergency egress	Fails to deploy; deploys but fails to slow down	Immediately following identification of in-flight catastrophic event and decision to egress by flight crew	Information not available	Integrity of post-event cabin area and deployment
72	In-flight egress rapidjet	Rapid egress without donning equipment. Egress in 6 sec. intervals.	Inability to reach escape hatch due to aircraft attitude; jamming of restraint container and parachute	Immediately after decision to egress by crew	Information not available	Psychological reluctance to jump into hatch without assurance of system function mechanical failure
73	In-flight egress capsule	Provide method (presently non-existent) for in-flight egress from disabled aircraft for passengers and crew not equipped with parachutes	Failure of capsule ejection ordnance; failure of drogue or parachute; non-survivable ground impact	Immediately after decision by crew to egress	Information not available	Must function for survival
74	In-flight egress fuselage parachute	As above by lowering intact fuselage. No action required by passengers.	Failure of drogue and parachute initiating device	Immediately after decision by crew to egress	None known	Must function for survival

TABLE 9. MAINTAINABILITY CONSIDERATIONS (SUMMARY)

AIRBAG INFLATION DEVICES

CONSIDERATION	1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air - staging	5 liq. cool-solid prop.	6 solid cool-solid prop.	7 aspirator
a. Simplified maintenance in using unit	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1
c. Inspections	1	1	1	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	2	2	2	2

CRASH IMPACT SENSOR

CONSIDERATION	8 mechanical	9 inertial guidance	10 radar proximity	11 sonar proximity
a. Simplified maintenance in using unit	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1
c. Inspections	1	1	1	1
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	2

AIRBAG MATERIAL

CONSIDERATION	12 nylon	13 polyester	14 glass	15 cotton
a. Simplified maintenance in using unit	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1
c. Inspections	2	2	2	2
d. Projected requirements for facility, personnel, tools, etc.	1	1	1	1

AIRBAG COATING MATERIAL

CONSIDERATION	16 natural rubber	17 butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 E.P.D.M.	22 hypalon
a. Simplified maintenance in using unit	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1
c. Inspections	2	2	2	2	2	2	2
d. Projected requirements for facility, personnel, tools, etc.	1	1	1	1	1	1	1

RESTRAINT SYSTEMS

CONSIDERATION	23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear-face seat + l.b.	27 passive net	28 passive blanket	29 front face seat - A.F.H.	30 troop seat
a. Simplified maintenance in using unit	1	1	1	1	1	1	1	1
b. Major repairs by depot level personnel	1	1	1	1	1	1	1	1
c. Inspections	1	1	1	2	1	1	2	2
d. Projected requirements for facility, personnel, tools, etc.	2	2	2	1	2	2	1	1

a. Simplified maintenance in using unit
   1. yes
   2. no

b. Major repairs by depot level personnel
   1. yes
   2. no

c. Inspections
   1. before each flight
   2. periodic

d. Projected requirements for facility, personnel, tools, etc.
   1. available
   2. new equipment, personnel, or facility required

N = not applicable
i = insufficient information

TABLE 9. MAINTAINABILITY CONSIDERATIONS (SUMMARY)

Group	No.	Concept	a. Simplified maintenance in using unit	b. Major repairs by depot level personnel	c. Inspections	d. Projected requirements for facility, personnel, tools, etc.
SMOKE HOOD CONCEPTS	31	Boeing mask	1	2	1	1
	32	John Hand hood	1	2	1	1
	33	Racine Glove Co.	1	2	1	1
	34	Sierra Eng. Co.	1	2	1	1
	35	LSS - Elastic seal	1	2	1	1
	36	LSS - Lanyard	1	2	1	1
	37	Scott-O-Vista	1	2	1	1
	38	M.S.A.C. - canister	1	2	1	2
	39	M.S.A.C. - self-rescue	1	2	1	2
	40	N.A.R. - smoke hood	1	2	1	1
	41	N.A.R. - smoke mask	1	2	1	1
	42	Schjeldahl - drawstring	1	2	1	1
	43	Schjeldahl - septal	1	2	1	1
	44	FAA - air supply	1	2	1	1
	45	B.M. - PBA hood	1	2	1	2
	46	FAA Adv. concept	1	2	1	1
AISLE AND PATH MARKERS	47	chem. illum.	1	2	2	1
	48	electro-illum.	1	2	2	1
	49	ultra-violet	1	2	2	1
	50	phosphorescent	1	2	2	1
	51	incandescent	1	2	1	1
	52	self-illum. (tritium)	1	2	2	1
	53	tactile markers	1	2	1	1
	54	floor-level markers	1	2	2	1
	55	pulsating markers	1	2	2	1
WARNING AND P.A.	56	alarm bell	1	2	1	1
	57	bull horn	1	2	1	1
	58	solid-state device	i	2	1	1
	59	TWA visual/aural	1	2	1	1
OTHER TECHNOLOGY	60	ELSIE	i	i	1	2
	61	telescape escape	1	2	1	1
	62	escape rope	1	2	1	1
	63	ext. plat. - slide entry	1	2	1	1
	64	S.B. - escape harness	2	2	1	i
	65	fold. slide	1	2	1	1
	66	cargo door	1	2	1	1
	67	ablative coat. exit	1	2	2	1
	68	pass. conveyor	1	2	1	2
	69	slide/raft	1	2	1	1
	70	double slide	1	2	1	1
	71	in-flight/paracone	2	1	1	2
	72	in-flight/rapidjet	2	1	1	2
	73	in-flight/capsule	2	1	1	2
	74	in-flight/parachute	2	1	1	2

a. Simplified maintenance in using unit
1. yes
2. no

b. Major repairs by depot level personnel
1. yes
2. no

c. Inspections
1. before each flight
2. periodic

d. Projected requirements for facility, personnel, tools, etc.
1. available
2. new equipment, personnel, or facility required

N = not applicable
i = insufficient information

TABLE 10

HUMAN FACTORS RATING SYSTEM

a. Noise

1. No problem
2. Possible temporary threshold shift
3. Possible permanent hearing impairment

b. Visibility

1. No decrement when using system
2. Partial decrement when using system
3. No visibility when using system

c. Ability to hear

1. No decrement when using system
2. Partial decrement when using system
3. No hearing when using system

d. Ease of use

1. No experience or briefing necessary
2. Briefing necessary before use
3. Briefing and training necessary before use

e. Human tolerance to impact

1. No injuries with proper system use
2. Possible injuries even with proper system use

f. Possible thermal hazard

1. No
2. Yes

g. Possible toxicological hazard

1. No
2. Yes

h. Possible pyrotechnic hazard

1. No
2. Yes

i. Possible visual hazard

1. No
2. Yes

j. Space to carry out functions

1. No restriction on user mobility or function based on crash impact protection and emergency egress flowchart
2. Possible partial restriction on passenger/crew egress or crew function in operating aircraft
3. System use precludes other activity

k. Illumination

1. Needed for system use
2. Not needed for system use

l. Normal ingress and egress

1. Unaffected by system
2. Requires user action to activate system

m. Non-restrictive life support and protective equipment

1. Mobility and/or communication enhanced by use of system
2. Mobility and/or communication unaffected by use of system
3. Mobility and/or communication reduced by use of system

n. Psychophysiological stress

1. No increased psychophysiological stress associated with system use
2. Minor psychophysiological stress associated with system use
3. Potential inability to function

o. Fail-safe design

1. Yes
2. No

p. Simplicity

1. No movable parts
2. Moving mechanical parts
3. Complex electro-mechanical device
4. Complex electro-mechanical device with associated electronic circuitry

q. Anthropometric considerations

1. Minor design consideration
2. Major design consideration (system function strongly dependent on anthropometric variables)

TABLE 11. HUMAN FACTORS CONSIDERATIONS (SUMMARY)

FACTOR	AIRBAG INFLATION DEVICES							CRASH IMPACT SENSORS				AIRBAG MATERIALS				AIRBAG COATING MATERIALS							RESTRAINT SYSTEMS							
	1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air - staging	5 liq. cool-solid prop.	6 solid cool-solid prop.	7 aspirator	8 mechanical	9 inertial guidance	10 radar proximity	11 sonar proximity	12 nylon	13 polyester	14 glass	15 cotton	16 natural rubber	17 butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 E.P.D.M.	22 hypalon	23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear-face seat + l.b.	27 passive net	28 passive blanket	29 front-face seat-A.F.H.	30 troop seat
a. Noise	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
b. Visibility	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
c. Ability to hear	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	1
d. Ease of use	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
e. Human tolerance to impact	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	1	1	2	2	2	2	2	1	1	1	1	i	i	1	i	i	i	1	1	i	i	1	1	1	1	1	1	1	1	1
h. Possible pyrotechnic hazard	1	1	2	2	2	2	2	1	1	1	1	1	1	1	2	2	2	1	1	2	2	1	1	1	1	1	1	1	1	1
i. Possible visual hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
j. Space to carry out function	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
k. Illumination	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
l. Normal ingress and egress	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	1	1
o. Fail-safe design	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2
p. Simplicity	1	2	1	1	1	1	2	3	4	4	4	1	1	1	1	1	1	1	1	1	1	1	4	4	4	2	4	4	2	2
q. Anthropometric considerations	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

N = not applicable
i = insufficient information

TABLE 11. HUMAN FACTORS CONSIDERATIONS (SUMMARY)

FACTOR	SMOKE HOOD CONCEPTS															
	31 Boeing mask	32 John Hand hood	33 Racine Glove Co.	34 Sierra Eng. Co.	35 LSS - Elastic seal	36 LSS - Lanyard	37 Scott-O-Vista	38 M.S.A.C. - canister	39 M.S.A.C. - self-rescue	40 N.A.R. fire hood	41 N.A.R. fire mask	42 Schjeldahl - drawstring	43 Schjeldahl - septal	44 FAA - air supply	45 B.M. - PBA hood	46 FAA adv. concept
a. Noise	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
b. Visibility	2	3	3	i	i	i	i	2	2	i	1	2	1	1	i	1
c. Ability to hear	i	1	i	i	i	i	i	1	1	i	1	1	1	1	i	1
d. Ease of use	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
e. Human tolerance to impact	i	1	1	1	1	1	i	i	i	1	1	1	1	i	i	1
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	2	2	2	2	2	2	2	2	2	2	1	2	2	1	i	1
h. Possible pyrotechnic hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
i. Possible visual hazard	i	i	i	i	i	i	i	2	2	i	1	1	1	1	i	1
j. Space to carry out function	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
k. Illumination	i	1	1	1	1	1	i	i	i	1	1	1	1	1	i	1
l. Normal ingress and egress	1	1	1	1	1	1	1	1	1	1	1	1	1	1	i	1
m. Non-restrictive LS and protective equipment	3	i	i	i	i	i	i	3	3	i	2	2	2	2	i	2
n. Psychophysiological stress	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
o. Fail-safe design	i	i	1	i	1	1	i	i	i	1	1	1	1	1	i	i
p. Simplicity	2	1	1	1	1	1	2	2	2	1	1	1	1	2	3	2
q. Anthropometric considerations	2	1	1	1	1	1	2	2	2	1	1	1	1	1	2	1

FACTOR	AISLE AND PATH MARKERS									WARNING AND P.A.			
	47 chemo-illum.	48 electro-illum.	49 ultra-violet	50 phosphorescent	51 incandescent	52 self-illum. (tritium)	53 tactile markers	54 floor-level markers	55 pulsating markers	56 alarm bell	57 bull horn	58 solid-state device	59 TWA visual/aural
a. Noise	1	1	1	1	1	1	1	1	1	1	1	1	1
b. Visibility	2	2	2	2	1	2	i	2	2	1	1	1	1
c. Ability to hear	1	1	1	1	1	1	1	1	1	2	1	1	2
d. Ease of use	1	1	1	1	1	1	2	1	1	3	3	3	3
e. Human tolerance to impact	1	1	1	1	1	1	1	1	1	1	1	1	1
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	1	1	1	1	1	2	1	1	1	1	1	1	1
h. Possible pyrotechnic hazard	1	1	1	1	2	1	1	1	1	1	1	1	1
i. Possible visual hazard	1	1	1	1	1	1	1	1	1	1	1	1	1
j. Space to carry out function	1	1	1	1	1	1	2	1	1	1	1	1	1
k. Illumination	1	1	1	1	1	1	2	1	1	1	1	2	1
l. Normal ingress and egress	1	1	1	1	1	1	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	1	1	1	1	1	1	1	1	1
n. Psychophysiological stress	2	2	2	2	1	2	2	2	2	2	2	2	2
o. Fail-safe design	1	1	1	1	1	1	1	1	1	1	1	i	2
p. Simplicity	1	1	1	1	1	1	1	1	1	3	3	4	4
q. Anthropometric considerations	1	1	1	1	1	1	1	2	1	1	1	1	1

FACTOR	OTHER TECHNOLOGY														
	60 ELSIE	61 telescape	62 escape rope	63 ext. plat. slide entry	64 S.B. - escape harness	65 folding slide	66 cargo door	67 ablative coat. exit	68 pass. conveyor	69 slide/life raft	70 double slide	71 in-flight/paracone	72 in-flight/rapidjet	73 in-flight/capsule	74 in-flight/parachute
a. Noise	i	1	1	1	1	1	1	N	i	1	1	i	i	i	i
b. Visibility	1	1	1	1	1	1	1	1	1	1	1	i	3	3	1
c. Ability to hear	i	1	1	1	i	1	1	1	i	1	1	i	i	i	i
d. Ease of use	3	2	2	2	2	2	2	1	2	2	2	3	2	3	3
e. Human tolerance to impact	1	2	2	2	2	2	2	1	2	1	1	2	2	2	2
f. Possible thermal hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
g. Possible toxicological hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
h. Possible pyrotechnic hazard	1	1	1	1	1	1	1	1	1	1	1	1	1	i	i
i. Possible visual hazard	1	1	1	1	1	1	1	1	1	1	1	i	2	2	1
j. Space to carry out function	1	3	3	3	3	3	1	1	3	3	3	3	3	3	3
k. Illumination	2	1	1	1	2	1	1	2	2	1	1	2	1	2	2
l. Normal ingress and egress	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
m. Non-restrictive LS and protective equipment	1	1	1	1	3	1	1	1	3	1	1	3	3	3	3
n. Psychophysiological stress	2	2	2	2	2	2	2	N	2	2	2	3	3	3	3
o. Fail-safe design	1	2	2	2	i	2	2	1	i	2	2	i	i	i	i
p. Simplicity	4	2	1	2	2	2	2	1	3	2	2	4	2	4	4
q. Anthropometric considerations	1	2	2	2	2	2	2	1	2	2	2	2	2	1	1

N = not applicable
i = insufficient information

TECHNOLOGICAL ASPECTS

Factors relating to hazards, reliability, maintainability, and human performance must be considered to form an estimate of a system's ability to perform properly. Other engineering and technological factors which do not fit in the above categories must also be included to prove the feasibility of a system for the intended application. Therefore, the following considerations will be included:

a. durability

b. lightness

c. compactness

d. integration of all equipment within the aircraft without restricting crew functions

e. automatic functions

f. common equipment permanently installed in aircraft,

g. engineering state of the art.

The rating scheme for each of these criteria is defined in Table 12 and the analysis given.

TABLE 12. TECHNOLOGICAL CONSIDERATIONS (SUMMARY)

AIRBAG INFLATION DEVICES

CONSIDERATION	1 stored gas	2 stored gas - mod. flow	3 augmented air	4 aug. air - staging	5 liq.-cool-solid prop.	6 solid-cool-solid prop.	7 aspirator
a. Durability	2	2	2	2	2	2	2
b. Lightness	2	2	1	1	1	1	1
c. Compactness	2	2	2	2	2	2	2
d. Installation restricts crew function	1	1	1	1	1	1	1
e. Automatic	1	1	1	1	1	1	1
f. Permanent installation	3	3	3	3	3	3	3
g. Engineering state of art	1	1	2	2	2	2	2

CRASH IMPACT SENSOR

CONSIDERATION	8 mechanical	9 inertial guidance	10 radar proximity	11 sonar proximity
a. Durability	1	1	1	1
b. Lightness	1	1	1	1
c. Compactness	1	1	1	1
d. Installation restricts crew function	1	1	1	1
e. Automatic	1	1	1	1
f. Permanent installation	1	1	1	1
g. Engineering state of art	2	4	2	2

AIRBAG MATERIAL

CONSIDERATION	12 nylon	13 polyester	14 glass	15 cotton
a. Durability	2	2	2	2
b. Lightness	1	1	1	1
c. Compactness	2	2	2	2
d. Installation restricts crew function	1	1	1	1
e. Automatic	1	1	1	1
f. Permanent installation	3	3	3	3
g. Engineering state of art	1	1	1	1

AIRBAG COATING MATERIALS

CONSIDERATION	16 natural rubber	17 butyl	18 neoprene	19 P.V.C.	20 polyurethane	21 E.P.D.M.	22 hypalon
a. Durability	2	2	2	2	2	2	2
b. Lightness	1	1	1	1	1	1	1
c. Compactness	1	1	1	1	1	1	1
d. Installation restricts crew function	1	1	1	1	1	1	1
e. Automatic	1	1	1	1	1	1	1
f. Permanent installation	3	3	3	3	3	3	3
g. Engineering state of art	1	1	1	1	1	1	1

RESTRAINT SYSTEMS

CONSIDERATION	23 pass. IORS (rear face)	24 pass. IORS (side face)	25 crew IORS (front face)	26 rear-face seat + l.b.	27 passive net	28 passive blanket	29 front-face seat - A.F.H.	30 troop seat
a. Durability	2	2	2	2	2	2	2	2
b. Lightness	2	2	2	1	2	2	1	1
c. Compactness	2	2	2	1	2	2	2	2
d. Installation restricts crew function	1	1	1	1	1	1	1	1
e. Automatic	1	1	1	2	1	1	2	2
f. Permanent installation	2	2	1	3	2	2	1	3
g. Engineering state of art	4	4	2	1	2	2	1	1

a. Durability
   1. life of aircraft
   2. possible replacement

b. Lightness
   1. no decrement to aircraft weight
   2. probably 15 lb. per system or more

c. Compactness
   1. no decrement
   2. more than 6 in.^{3} per system

d. Integration with aircraft non-restrictive to crew function
   1. yes
   2. no

e. Automatic
   1. yes
   2. no

f. Permanent installation in aircraft
   1. yes
   2. partial
   3. no

g. Engineering state of art
   1. production item
   2. prototype development
   3. mockup
   4. concept

N = not applicable
i = insufficient information

TABLE 12. TECHNOLOGICAL CONSIDERATIONS (SUMMARY) Page 2 of 2

CONSIDERATIONS	SMOKE HOOD CONCEPTS 31 Boeing mask	32 John Hand hood	33 Racine Glove Co.	34 Sierra Eng. Co.	35 LSS - Elastic seal	36 LSS - Lanyard	37 Scott-O-Vista	38 M.S.A.C. - canister	39 M.S.A.C. - self-rescue	40 N.A.R. fire hood	41 N.A.R. fire mask	42 Schjeldahl - drawstring	43 Schjeldahl - septal	44 FAA - air supply	45 B.M. - PBA hood	46 FAA adv. concept
a. Durability	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
b. Lightness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
c. Compactness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
d. Integration within aircraft non-restrictive to crew function	2	2	1	1	1	1	2	2	2	1	1	1	1	1	2	1
e. Automatic	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
f. Permanent installation in aircraft	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
g. Engineering state of art	2	2	2	2	2	2	1	1	1	4	4	1	1	2	2	4

CONSIDERATIONS	AISLE AND PATH MARKERS 47 chem-illum.	48 electro-illum.	49 ultra-violet	50 phosphorescent	51 incandescent	52 self-illum. (tritium)	53 tactile markers	54 floor level markers	55 pulsating markers	WARNING AND P.A. 56 alarm bell	57 bull horn	58 solid-state device	59 TWA visual/aural
a. Durability	2	2	2	1	1	1	1	1	1	1	1	2	1
b. Lightness	1	1	1	1	1	1	1	1	1	1	1	1	1
c. Compactness	1	1	1	1	1	1	1	1	1	1	2	1	1
d. Integration within aircraft non-restrictive to crew function	1	1	1	1	1	1	1	1	1	1	1	1	1
e. Automatic	1	1	1	1	1	1	1	1	1	2	2	2	2
f. Permanent installation in aircraft	3	2	3	3	1	3	3	3	1	1	3	3	1
g. Engineering state of art	1	1	1	1	1	1	2	1	4	1	1	4	1

CONSIDERATIONS	OTHER TECHNOLOGY 60 ELSIE	61 telescape escape	62 escape rope	63 ext. plat. slide entry	64 S.B. - escape harness	65 folding slide	66 cargo door	67 ablative coat. exit	68 pass. conveyor	69 slide/raft	70 double slide	71 in-flight/paracone	72 in-flight/rapidjet	73 in-flight/capsule	74 in-flight/parachute
a. Durability	1	2	2	2	2	1	1	2	i	2	2	2	2	2	2
b. Lightness	i	2	1	2	2	2	1	2	2	2	2	2	2	2	2
c. Compactness	1	2	2	2	2	2	1	1	2	2	2	2	2	2	2
d. Integration within aircraft non-restrictive to crew function	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
e. Automatic	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
f. Permanent installation in aircraft	1	3	3	3	2	1	1	2	1	3	3	1	1	1	1
g. Engineering state of art	2	2	1	1	4	4	1	1	4	1	1	4	4	4	4

a. Durability
   1. life of aircraft
   2. possible replacement

b. Lightness
   1. no decrement to aircraft weight
   2. probably 15 lb. per system or more

c. Compactness
   1. no decrement
   2. more than 6 in.[3] per system

d. Integration within aircraft non-restrictive to crew function
   1. yes
   2. no

e. Automatic
   1. yes
   2. no

f. Permanent installation in aircraft
   1. yes
   2. partial
   3. no

g. Engineering state of art
   1. production item
   2. prototype development
   3. mockup
   4. concept

N = not applicable
i = insufficient information

SYSTEM SUMMARIES

When the tables in this section of the report are studied, particular potential performance patterns are observed for the various groups of life support systems which have been evaluated. In the text which follows, summary safety, reliability, maintainability, human factors, and technical feasibility paragraphs are written for the following groups of systems: (1) airbag inflation devices; (2) crash impact sensors; (3) airbag materials; (4) airbag coating materials; (5) restraint systems; (6) smoke protective devices; (7) aisle and path indicators; (8) emergency warning and public address systems; (9) emergency exits; (10) interior egress aids; (11) exterior egress aids; and (12) in-flight egress.

A variety of comparisons can be made with regard to the various airbag inflation devices. Reliability is a consideration whether the system is in use or stored. The propellant and aspirator systems are estimated to possess higher reliability than stored gas systems because of problems with leakage. All inflation devices require careful handling because of the danger of inadvertent actuation. Special maintenance procedures would be necessary. All these systems have proven capability for accomplishing bag inflation based on prototype development occurring within the past few years. However, the bulkiness and weight must be assessed as an important variable in an aircraft application. The stored gas systems suffer the greatest penalty in this context.

A penalty is paid in introducing these systems with respect to several human factors. The fact that inflation noise is known to result in a temporary threshold shift in hearing could reduce the ability of the user to respond to oral commands and emergency information post-crash. In addition, systems using propellants and pyrotechnic components can produce thermal, toxicological, pyrotechnic, and also the associated psychological hazards. Airbag inflation systems should be classified at least as hazard level 2 devices.

Crash impact sensors are a reliability critical item. They depend on a well-defined G-signal representing a crash or the proximity of a hazard which could result in a crash. This has been one of the major problems in the introduction of inflating restraint systems in automobiles and less information is available defining the crash impact event in aircraft. Although it appears that accurately functioning, maintenance-free sensing devices can be fabricated, research on this item is essential before serious consideration of passive restraints for jet transport application.

The fabric material in an airbag would appear to be one of the smaller problems. Materials with adequate weight-to-strength ratios, high and low temperature resistance, and storability are available. Although a glass fabric has many ideal properties for this application, rip-stop nylon is lighter and more extensible.

Likewise, the material with which an airbag is coated offers few problems. Neoprene, the most likely candidate, has excellent storage and temperature characteristics.

Comparisons are made in the tables presented in this chapter between a variety of restraint systems. With respect to reliability, it is not essential to supplement a rear-facing passenger seat with an airbag. Introduction of the airbag may hamper egress from the seat. Side-facing seating configurations need added research to determine placement of the airbag for impact protection.

It should be noted that the sensor, the inflation device, and bag placement are all reliability critical items needing additional study before introduction in front-facing configurations for crew use. Reliable bag placement is particularly important in this application because of the necessity of crew function in controlling the aircraft during an emergency landing incident which can cover a time period of several seconds. The sensor, deployment technique, and placement are equally important in passive net systems. In conclusion, active restraint systems such as the rear-facing seat with lap belt and the front-facing crew seat with integrated upper torso belt restraint system all substitute simple hardware and an increased human error potential (the act of fastening belts) for the technologically complex passive restraint hardware.

The introduction of passive restraint systems requires more sophisticated maintenance procedures than the operational active systems. For example, automatically deployable systems should be checked for ready status before each flight. In addition, the passive systems require careful handling during maintenance because of explosive, pyrotechnic, and propellant components.

Several general technological items should also be mentioned. Belt systems are lighter in weight and are more compact demonstrating a distinct advantage over current generation passive restraint systems. Also, the effectiveness of belts in operational applications has been proven many times over when they are used, maintained, and installed properly. Inflating occupant restraint systems and passive nets have yet to be field tested, but operational prototypes have been extensively laboratory tested.

Inflating restraint systems possess several disadvantages and one major advantage over active belt systems when studied from the viewpoint of human factors. The disadvantages are: (1) possible hearing impairment in the post-crash environment hindering communication, (2) possible visibility decrement during and post-crash due to the bag material; (3) a potential for psychological stress in the presence of a propellant or explosive device; and, (4) post-crash escape may be seriously impeded because of time required for many passengers to untangle themselves from the restraint system. The advantage is that the passive nature of this restraint decreases the potential for human error.

The preliminary hazard analysis also yields several items which could be performance decrements for airbags. These are: (1) potential noise hazard; (2) hazard level 2 device; (3) presence of energy sources, explosive components, and/or propellants; (4) potential for inadvertent actuation; (5) presence of pressure vessels; and (6) increased maintenance requirements.

Several of the smoke protective devices evaluated in this study appear to be reliable, durable, and relatively maintenance free while being possibly somewhat difficult to use. Some components are known to degrade with storage, but with periodic inspection, individual units could be replaced. All systems are light and compact and could be easily adapted for use in current operational aircraft. The Schjeldahl, Scott-O-Vista, and Mine Safety Appliance Co. systems are production items while the North American Rockwell and FAA advanced systems are concepts. The remainder of the systems have been developed as prototypes.

Human factors considerations represent the most important items in developing a decision regarding introduction of smoke protective devices in operational aircraft. The first item concerns the apparent decrement in visibility which occurs with several of the systems. The Schjeldahl, North American Rockwell fire mask, FAA systems possess the most desirable properties in this regard. The second item concerns ease of donning. All systems pose some problem in donning. At least a briefing is required and, especially for individuals with glasses, practice could be helpful. The third item concerns toxicity. Most smoke protective devices are useful to minimize toxic hazard potential in a crashed aircraft during egress. However, they present a toxic hazard of their own during prolonged use. Devices providing a self-contained air supply such as the advanced FAA prototype offer an advantage in this area.

A preliminary hazard analysis yields a few items of concern with respect to smoke protective devices. Among these items are: (1) toxicity problems; (2) inadvertent activation of systems using a stored breathable air source; (3) vulnerability to tampering and prolonged storage; and (4) some difficulty involved in system use.

Aisle and path markers offer an inexpensive, easily maintainable, durable, light, and compact aid to egress. Most of the systems studied are production items except for pulsating path markers, which are concepts with respect to aircraft application and tactile markers which are undergoing prototype development. In considering human factors, it can be concluded that aisle and path markers can be useful provided they are positioned for the greatest effectiveness and visibility. It should be noted, however, that tactile markers may be difficult to use. A preliminary hazard analysis yields a few items as follows: (1) possible short term toxicity associated with chemical luminescence and self-luminescence; (2) energy sources exist in most systems which must be isolated from tampering and impact; (3) electrical systems can be a source of fire hazard; and (4) most systems are vulnerable to tampering.

Emergency warning and public address systems appear to present more of a reliability problem than aisle and path markers. Two specific problems are with power failure and with the design of crash resistant electro-mechanical components. However, the technology is available to solve these problems. Systems of this nature are believed tc offer few if any problems with maintainance, and they are durable, light and compact. A preliminary hazard analysis yields few problems.

The systems included under the general heading "other technology" can be placed into four general classifications. These include: (1) exits; (2) external aids to egress; (3) internal aids to egress; and, (4) in-flight egress. Each of these groups are discussed individually.

All four of the exit concepts studied (ELSIE, external platform slide entry, cargo door, ablative coated exit) appear to merit further study and possible introduction into transport aircraft. Accident experience bears out the desirability of introducing additional exits to those known to be available in actual cases. All four systems have been developed as prototypes or are already in operational use.

Reliability appears to be a primary concern, especially with ELSIE and the external platform slide entry. Deployment during normal flight would be dangerous and a fail-safe activation system is necessary. The cargo door could be subject to jamming, a problem with most exits if fuselage deformation occurs, limiting its reliability. The ELSIE concept offers a distinct advantage in that case.

These systems are all relatively easy to use with ELSIE being the most difficult to activate. As it is presently conceived, this system requires two crew members to initiate actuation enhancing its fail-safe characteristics but increasing the chance for post crash confusion. Crew training and briefing would be required before each flight. Besides the hazard associated with explosive devices, ELSIE could present a noise problem, temporarily influencing passenger and crew hearing, and thus affecting communication during egress. This potential problem, most likely minor, should be investigated.

External egress aids include the telescape device, the escape rope, the folding slide, the slide/raft combination, and the double slide. These devices are all in service in operational aircraft with the exception of telescape, which has been fabricated and tested as a prototype, and the folding slide which has been proposed as a concept.

Most of these systems present a reliability problem with respect to deployment with the exception of the escape rope. All systems are technically feasible but some are mechanically quite complex. The deployment and structural characteristics of inflating structures such as escape slides need additional study based on the experiences in the recent Boeing 747 evacuation at San Francisco International Airport. The folding slide offers the greatest problems with deployment because of possible deformation occurring during fuselage distortion. Again the systems present few problems with respect to human factors with the exception of the escape rope and telescape, which are physically difficult to use and may present a hazard when improperly used.

Internal aids to egress which have been evaluated include an integrated passenger escape system and a passenger conveyor. These systems are complex and expensive, requiring much development and testing. A cost effectiveness study should be carried out to ascertain if these systems are economically feasible. The current investigators feel that they are not. Both systems require a flexible logic control in order to deliver passengers to the best available exits. In addition, both systems are subject to many crash impact hazards ranging from power loss to mechanical malfunction to fuselage deformation. The integrated passenger escape system has one characteristic worthy of note. It attempts to provide crash impact protection, smoke protection, and egress in one package. This systems approach is believed necessary in any approach to the overall problem of crash impact protection and escape.

In-flight egress is an extremely difficult problem with transport aircraft. The four systems (paracone, rapidjet, capsule parachute and fuselage parachutes) are all complex and expensive systems for which much research and development work must be carried out. To determine whether implementation of any of these systems is economical from the cost-effectiveness point of view, further study is necessary.

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

This study has made a detailed systems engineering analysis of state-of-the-art concepts, equipment, and techniques which have application to crew and passenger life support crash safety in Air Force transport aircraft. Major conclusions and recommendations are as follows.

INFLATING OCCUPANT RESTRAINT SYSTEMS

Inflating occupant restraint systems have been found to substitute complex automatic equipment for simple hardware and an increased human error potential. Each of the principal components in an airbag system is a critical reliability item - the crash sensor needs a well-defined criterion for crash prediction, the inflation source must provide an adequate gas supply after long storage, and the bag must inflate to provide an impact attenuating cushion based on biomechanical principals. In addition, maintainability requirements would be increased if airbags are used because of the presence of hazard level 2 components and because of the necessity for a status check before flight. Several human factors also must be considered, such as possible noise hazard, blocked visibility during and immediately after use, possible difficulty in egress from the system for emergency evacuation, possible psychological stress associated with the presence of explosive devices, and the necessity of fail-safe hardware.

Therefore, before airbags are seriously considered for use in operational aircraft, the following are recommended:

1. Define crash G-levels expected in aircraft accidents with sufficient accuracy such that no confusion will result with hard landings and ordinary air turbulence (it should be noted that this problem has not yet been completely solved for automotive applications where hundreds of test crash impacts have been conducted and millions of sensor-miles have been driven);

2. Define a crash envelope including critical closing rates and collision object definition for use with proximity sensors;

3. Determine the level of the hazard with respect to noise and occupant egress (an experiment where the passengers' compartment is filled with air bag-equipped seats and where an emergency evacuation is conducted after automatic bag deployment);

4. a detailed cost-effectiveness comparison between systems in current use and the airbag from the viewpoint of possible structural changes in operational aircraft, penalty for increased weight, redesign of seats, increased maintenance requirements, and decreased human user error potential.

ADDITIONAL RESTRAINT RECOMMENDATIONS

Based on the discussions of passive restraint systems and observations of operational restraint configurations, three additional recommendations can be made.

1. Make the best and most extensive use possible of the rear-facing seating configuration. Present rear-facing seat systems in Air Force transport aircraft offer more reliable impact protection than do current state-of-the-art air bag inflatable restraint systems. Rear-facing seats do not need to be supplemented with an air bag.

2. Litter construction and related support hardware should be designed to withstand crash impact.

3. Side-facing troop seats should be tested to determine the level of user impact protection and redesigned if they are found insufficient. The operational systems observed during the project do not appear to provide adequate upper torso restraint.

SMOKE HOOD-MASK PROTECTIVE DEVICES

The Schjeldahl smoke hood, with septal neck seal, is a current production device which can offer significant protection in smoke, toxic fume and fire egress environments. A theoretical potential hazard related to time exposure beyond critical rebreathing (3-6 minutes) is far outweighed by the survival benefits provided, since it has been shown that the major cause of fatalities in survivable air transport crashes is smoke and flame exposure.

1. It is recommended that the Schjeldahl smoke hood be provided for each passenger and crew member on Air Force transport aircraft.

2. It is further recommended that at such time as an advanced smoke hood concept providing automatic self-generating gas capability has undergone research and development it be evaluated as a second-generation operational item to replace the current rebreathing design.

AISLE AND EVACUATION PATH MARKERS

Present interior lighting is accomplished primarily by incandescent techniques. No aisle or evacuation pathmakers have been found to be in operational use, however, and internal and external emergency lighting systems are either nonexistent or inadequate. A number of interior aisle and pathmarker illumination systems and concepts are available which could offer significant improvement for passenger egress, but none have had adequate research for this specific application in a crash environment.

Reflective tapes require illumination for effective utilization, while phosphorescent or ultra-violet markers require either pre-illumination exposure or a special light source for activation. Self-luminous sources such as Tritium markers presently provide relatively low levels of illumination without exceeding allowable radio-active levels. Electroluminescence offers another means, but requires a relatively high level electric current for activation. A promising technique for providing adequate pathway illumination, signs and directional markers involves chemiluminescence (either exposure to air or to a second chemical). This could be achieved by initiation upon impact. Additional information is needed to evaluate the possibility of accomplishing this. Adequate emergency aisle markers, evacuation markers, and egress sign illumination could be provided by a gaseous discharge system using Xenon strobe lights, which would be most effective in a smoke-filled dark cabin and would require only small battery units for initiation.

Tactile markers could provide a means of emergency egress in the absence of light; however, they have been found ineffective in limited group evacuation testing and require further development. Directional pulsating lights, using incandescent illumination, appear to be a good concept but have not been tested in this application. Floor level lighting can be utilized by application of present incandescent techniques.

It is recommended that:

1. Air Force transport aircraft be provided with emergency aisle and evacuation path markers, improved emergency sign illumination, and both internal and external emergency egress illumination.

2. Further tests be conducted with currently available battery-powered incandescent lighting, Xenon strobe lights, and chemical light techniques to evaluate the most reliable and best system for these illumination needs.

3. Realistic evacuation tests be conducted comparing the above illumination systems and pathway marker techniques, including tactile markers

PASSENGER WARNING AND PUBLIC ADDRESS SYSTEMS

The present alarm bell crew and passenger warning system used in Air Force transport aircraft is not reliable as a warning device because there often is insufficient time for manual initiation. The TWA battery-powered audio-visual system with solid-state audible pulsed alarm is designed for crew communication only and provides no alarm warning for passengers; however, it could provide an effective emergency communication link between the pilot and loadmaster or cabin crew. The same function could be improved through a solid-state portable communications device, offering greater flexibility. In cases of main communications failure, the battery-powered portable bull horn is effective if within reach of a crew member but has not yet proven useful in actual crash evacuation. Until such time as a more reliable automatic alarm system is devised, the present Air Force alarm should be retained despite its relative ineffectiveness.

It is recommended that:

Research be initiated to devise a more reliable and more effective passenger crash warning system.

EMERGENCY EXIT SYSTEMS

The current generation slide/raft escape device offers significant evacuation capability for cabin doors, and in ditchings can save considerable time in deploying rafts. The possibility of employing cargo type doors and/or swing-tail or swing-nose concepts for mass evacuation of large transport is worthy of further study; however, the ELSIE high energy emergency egress system, which has been developed in prototype form and is undergoing Air Force flight evaluation tests, offers a significant improvement in current emergency egress techniques.

Insufficient information is available to evaluate in-flight emergency egress concepts for duty. Ablative coating of exit areas appears feasible but further data are required concerning effects on flight characteristics.

It is recommended that:

1. Slide/raft escape devices, currently available as productive items, be implemented as emergency equipment in Air Force transport aircraft where compatible with present door structure or where they can be readily modified.

2. Research and development of ablative coating techniques be conducted as to application at overwing exit areas.

3. To date there is no way to save occupants of an air transport aircraft incurring major structural in-flight failure when they are not equipped with parachutes or in cases when normal bailout is not possible. Serious consideration should be given to techniques of emergency in-flight

egress in air transports. A preliminary study of past accident experience could indicate whether there is in fact such a present requirement. This should be followed by further study of concepts, since all of the concepts considered here are within the state of the art, and one (lowering of disabled aircraft by parachute) may be feasible and cost-effective.

4. Escape aids provided, such as crash axes, should be adequately identified and located where readily available.

5. If continuing tests of the ELSIE high energy emergency egress system are successful, this system should be utilized in Air Force transport aircraft as it represents a potential major improvement in emergency egress capability. A further study of optimum passenger egress locations in various configurations of air transport aircraft is needed, based upon structural and systems considerations beyond the scope of this study.

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APPENDIX A

This appendix contains a list of the addresses of companies and other organizations in the order that they appear in Section IV, Passive Restraint Systems.

1. Cornell Aeronautical Laboratory, Inc.
   4455 Genesee Street
   Buffalo, New York 14221

2. Wayne State University
   Biomechanics Research Unit
   Detroit, Michigan

3. 6571st AMRL
   Holloman Air Force Base,
   New Mexico

4. Mini-car, Inc.
   Los Angeles, California

5. Dynamic Science, Inc.
   1800 W. Deer Valley Drive
   Phoenix, Arizona 85027

6. Southwest Research Institute
   8500 Culebra Road
   San Antonio, Texas 78206

7. Beta Industries
   2763 Culver
   Dayton, Ohio

8. Eaton Corporation
   Safety Systems Division
   466 Stephenson Highway
   Troy, Michigan 48084

9. General Motors Corporation
   Delco Electronics Division
   Milwaukee, Wisconsin 53201

10. Toyota Motor Co., Ltd.
    Toyota-ski, Aichi - ken
    Japan

11. Olin Corporation
    Energy Systems Division
    East Alton, Illinois 62024

12. Allied Chemical Company
    Automotive Products Division
    353 Cass Avenue
    Mt. Clemens, Michigan 48043

13. Thiokol Chemical Corporation
    Wasatch Division
    Brigham City, Utah 84302

14. Rocket Research Corporation
    11441 Willows Road
    Redmond, Washington 98054

15. Ensign Bickford Company
    660 Hopmeadow Street
    Simsbury, Connecticut 06070

16. Bolt, Beranek, and Newman, Inc.
    50 Moulton Street
    Cambridge, Massachusetts

17. Nissan Motor Company, Ltd.
    6-1 Daikoku-cho, Tsurumiku
    Yokohama, 230 Japan

18. Hamill Manufacturing Company Division
    Firestone Tire and Rubber Company
    Washington, Michigan 48094

APPENDIX B

Manufacturers of the various pathmarker illumination systems discussed in Section VI.

CHEMO-ILLUMINESCENCE

American Cyanamid Company
Organic Chemicals Division
Bound Brook, New Jersey 08305
(Trademark, CYALUME Chemical Light)

Remington Arms Company
939 Barnum Avenue
Bridgeport, Connecticut 06602

ELECTRO ILLUMINESCENCE

Grimes Manufacturing Company
515 N. Russell Street
Urbana, Ohio 43078

Honeywell
2600 Ridgeway Road
Minneapolis, Minnesota

MLM Electronics
130 E. River Drive
Willingboro, New Jersey 08046

Scott Aviation
Division of A.T.O. Inc.
225 Eire Street
Lancaster, New York 14086

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

Sylvania Products, Inc.
60 Boston Street
Salem, Massachusetts 01970

GASEOUS DISCHARGE SYSTEMS

A.C.R. Electronics, Inc.
112 Voice Road
Carle Place
New York, New York 11514

Birns and Sawyer, Inc.
1026 N. Highland Avenue
Los Angeles, California 90038

Electronic Lights, Inc.
Division of Kemlite Lab. Inc.
1701 N. Ashland Avenue
Chicago, Illinois 60622

Illumination Industries, Inc.
610 Vaqueros Avenue
Sunnyvale, California 94086

Kemlite Laboratories, Inc.
1819 W. Grand Avenue
Chicago, Illinois 60622

LTV Electro Systems, Inc.
P. O. Box 6030
Dallas, Texas 75222

Life Support Technology, Inc.
4820 S.W. Lloyd Avenue
Beaverton, Oregon 97005

MLM Electronics
130 E. River Drive
Willingboro, New Jersey 08046

Pichel Industries, Inc.
Division of Optics
693 S. Raymond Avenue
Pasadena, California 91105

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

Whelen Engineering Company
3 Winter Avenue
Deep River, Connecticut 06417

Zip Com Corporation
5620 West 12th Street
Littlerock, Arkansas 72204

ULTRAVIOLET PATHWAY MARKERS

Luminex, Inc.
P. O. Box 696
Santa Barbara, California 93102

SELF-LUMINOUS SOURCES (TRITIUM) AND PHOSPHORESCENCE MARKERS

Conrad Precision
630 5th Avenue
New York, New York

U. S. Radium Corporation
Morristown, New Jersey 07960

INCANDESCENT SOURCES

Chicago Miniture Lamp Works
4453 North Ravenwood
Chicago, Illinois

General Electric
Nela Park
Cleveland, Ohio 44122

Grimes Manufacturing Company
515 North Russell Street
Urbana, Ohio 43078

Life Support Technology, Inc.
4820 S.W. Lloyd Avenue
Beaverton, Oregon 97005

LTV Electro Systems, Inc.
P. O. Box 6030
Dallas, Texas 75222

Pichel Industries, Inc.
693 S. Raymond Avenue
Pasadena, California 91105

Pile National Company
1334 N. Kostner Avenue
Chicago, Illinois 60651

Scott Aviation
Division of A.T.O., Inc.
225 Eire Street
Lancaster, New York 14086

Soderberg Manufacturing Company, Inc.
628 S. Palm Avenue
Alhambra, California 91803

APPENDIX C

Manufacturers of Escape Slides or Raft-Slide Escape Devices discussed in Section VII.

Pico Division of Sargent Industries
2045 Evans Avenue
San Francisco, California 94124

Aircruisers Division of Garrett Corporation
P. O. Box 180
Belmar, New Jersey 07719

B. F. Goodrich Company
500 South Main
Akron, Ohio 44318

Switlik Parachute Company
1325 East State Street
Trenton, New Jersey 08607