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I. INTRODUCTION

More than one hundred years ago Lord Tennyson prophesied "Saw the heavens filled with commerce, argosies of magic sails, pilots in the purple twilight, dropping down with costly bales".[1] He possibly did not foresee certain complications associated with such aerial commerce, particularly the "dropping down" with more than the usual drop force.

The "costly bales" which comprise the topic of this paper, are the soft protoplasmic masses encased within aircraft. The aim of emergency evacuation is to get these soft protoplasmic masses from the interior of a distressed aircraft to the exterior, without irreversible damage.

This paper will focus on what we term the human factor in emergency evacuation.

Anything which unduly impedes the processes of emergency evacuation is deleterious and must be avoided. The word unduly is used because certain impediments, or "constraints", are essential to an orderly evacuation. In the absence of constraints, utter chaos is generated, and, as was indicated in a recent survivable crash landing of a transport-type aircraft, tragedy may result.[2] The evidence indicates that the loss of 77 lives in the conflagration which followed the survivable crash landing, resulted from the inability of the occupants to open the main door, possibly greatly aggravated by the pell-mell collection of the occupants against the door.

Perhaps the apparent lack of knowledge of the occupants concerning the location of the various window escape doors accounted for their failure to utilize these routes. In ignorance, they apparently sought their route of entrance. It should be noted that these persons were relatively unsophisticated with respect to air travel and air carrier equipment. Hence, the recent trend by the various airlines to provide the passengers with an increasing amount of descriptive information concerning emergency evacuation procedures and exits is to be commended and encouraged. Also, the increasing use of better exit marking and lighting marks definite progress.

In previous decades, the mere mention in the presence of passengers of the possibility of aircraft accidents was considered anathema by public relations personnel. We have come a long way. We have still a way to go.

For example, preliminary evidence indicates that the "anxiety level" of passengers as a group is diminishing in general. Almost all of us have in recent times seen an irate crowd of passengers besieging an airline ticket counter on a bad-weather day, and beseeching the airline to dispatch them (in the wisely grounded airliner) into the soup and cumulonimbus, *posthaste.* Can the fright of flight be very high among the repeat passenger? We feel that it may not be so. As a matter of fact, we have a psychologist and a sociologist currently measuring this anxiety level. They are paying particular attention to the subsequent flight experience of passengers who have previously survived major air carrier disasters. This study, conducted in cooperation with Mr. Bernard Doyle

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and his associates in the Bureau of Safety of the Civil Aeronautics Board, will be useful in evaluation of emergency evacuation equipment, procedures and training.

Through on-the-scene studies at selected air carrier accidents in cooperation with the Civil Aeronautics Board, through study of the detailed CAB reports concerning accidents, and through other sources, including our own research and the findings of FAA accident specialists, we are led to the following four principles with respect to the human factors of emergency evacuation:

Principle One: Each real life emergency evacuation is essentially a unique incident. Unanticipated and unexpected events are almost certain to occur during each evacuation;

Principle Two: The characteristics of the airframe, its exits, and its interior, determine the absolute minimum escape time which is possible under ideal conditions with stereotyped occupants;

Principle Three: The nature and post-crash condition of the occupants, and the behavior of the crew, comprise the main variables in determining the outcome of an emergency evacuation of a given aircraft;

Principle Four: The final resting attitude of the aircraft, the extent of distortion and damage to the cabin, its exits and interior, and the environmental conditions, contribute to the actual evacuation time.

At this junction it is well to call attention to the following point: There is a tendency for many of those in aviation to think of an emergency evacuation in "isolated terms", that is, as an event which is self-contained and essentially uninfluenced by the pre-emergency and post-emergency circumstances.

We now know that emergency evacuation is vitally affected by (1) the impact protection features which are built into the aircraft and its equipment; (2) the fire inerting features contained near the power plants and other structural elements, plus the nature of the fuel and the fuel cells; and (3) the geographic longitude and latitude, the season, and the presence or absence of daylight. Even rain has been known to inhibit some persons from evacuating a distressed aircraft.

In other words, the study of emergency evacuation is an interdisciplinary subject, and requires the coordinated contributions of aeronautical engineers and biologists, of flight surgeons and behavioral scientists, of pilots and others who are engaged in air commerce. The analysis which follows contains information gleaned from these several sources plus our own studies.

The circumstances within which the emergency evacuation occurs, involve the following steps:

1. The events leading to the accident;
2. The impact profile, including secondary, tertiary and additional impacts, plus twisting and other angular positive and negative accelerations;
3. The immediate post-impact period, which may be complicated by smoke, fire, panic, submersion, wave actions and other factors;
4. The later period which may be characterized by exposure to the elements, rough water, and a lack of appropriate survival gear.

If the occupants of a craft which is headed for a ditching are worried about step 4, this concern may modify their ability to accomplish an efficient evacuation during step 3. In the same fashion, an inefficiently handled step 3 may produce difficulties during step 4 because certain essentials to long-term survival were left within the ditched and sinking aircraft.

The point cannot be emphasized too strongly that the emergency evacuation itself is but one vital step in the several steps which comprise the "evacuation continuum". A survived step 2 means relatively little if occupants perish during step 3 or step 4. Therefore, we must think in comprehensive terms, and visualize and prepare for the successful achievement of all four steps in the evacuation continuum.

For example, a major difference in accomplishing successful evacuations on land versus water evacuations, is that in land evacuations no delays should be imposed by removal and transport of paraphernalia during the evacuation, while in water evacuations, survival depends upon the accompanying equipment. Actually, in 1962, during a ditching off' the coast of Ireland, only one raft was successfully deployed and boarded, out of a total of five, fifty one persons were left with only one twenty five man raft.[3]

The best treatment of a disease is the prevention of its onset. Until accidents can be entirely prevented (probably an impossible goal) we must concern ourselves with the inevitable few emergency evacuation situations which will present themselves each year. Operational experience indicates that we can expect about one emergency evacuation each month.

The information which follows provides a detailed analysis of the factors involved in emergency evacuations, with particular emphasis paid to the human aspects.

II. ACCIDENT EXPERIENCES

During the years 1948 to 1951, in 39 reciprocating engine survivable air carrier accidents identified by the Civil Aeronautics Board, 1394 passengers and crew members experienced 244 fatalities. The fatalities thus represented 17% of all of the persons involved in these piston aircraft under these circumstances.

For comparison, during the years 1959-1962, the CAB identified 10 jet and propjet survivable accidents, involving 704 passengers and crew members, who experienced 112 fatalities. Interestingly, the fatalities in these survivable turbine powered aircraft accidents represent 16% of all of the persons involved.

The actual accident experience indicates, therefore, insofar as the cited accidents are concerned, that the current civil air carrier jets furnish a degree of evacuation efficiency which is comparable to that existing in piston aircraft. We shall continue to monitor this experience, and anticipate that with the newer equipment, improvements in evacuation time will occur. For example, in the new Boeing 727, inflatable slide deployment is accomplished more rapidly and efficiently due to its attachment to the hinged door.

Interestingly, a recent incident occurred which necessitated the emergency evacuation of a jet airliner containing 153 people. A complete emergency evacuation was accomplished within two minutes and twenty seconds. This incident occurred on October 27, 1963, and involved TWA Flight 703, which utilized a Boeing 707-331-B item of equipment.

The aircraft left the ramp at 1200 Zulu, and its crew of 11 with 142 passengers (including three infants, a near-term pregnant woman, and a man on crutches (with one leg in a cast) anticipated a normal taxi operation to the runway.

Suddenly, just as the stewardesses were demonstrating the emergency oxygen equipment, smoke (and, a few seconds later, flames) began rising from the floor between the second and third row of seats in the first class compartment on the right at station 540-560.

The Flight Engineer was notified of the smoke by the stewardess, and, after checking, returned to the flight deck and informed the Captain. The aircraft was immediately stopped, the engines were shut down, and all members of the crew began to assist with the evacuation of the aircraft.

One member used a water fire extinguisher which put out the flames but a dense black smoke continued to billow forth. Breathing was difficult, and visibility in the cabin was extremely restricted (various crew members and passengers stated that they could not see the opposite ends of the cabin). As an added complication, the public address system failed during the routine briefing.

With the 707 stopped, the actual evacuation procedure started, and all four escape slides were utilized in this gear-down evacuation. The complete evacuation was accomplished in two minutes and twenty seconds, in spite of the smoke, the heterogeneous nature of the passengers, and the completely unanticipated nature of the incident. A number of the passengers were excited, and some were frightened, but no panic occurred and no injuries resulted.

All persons were evacuated prior to arrival of fire and ambulance vehicles. Apparently, a lighted cigarette butt started the cabin fire.

This incident demonstrates that the absence of injuries (such as commonly occur during impacts) and even in the presence of dense smoke, passengers can rapidly evacuate an aircraft if *all* of the exits can be utilized, if the crew acts efficiently, and if the passengers don't exhibit panic or "negative panic" (become "frozen with fear).

Actually, it has been previously well-substantiated that in survivable accidents, there is a forty times greater hazard to a successful emergency evacuation from impact injury incapacitation than from fire.[4] Fire, is, nevertheless, a matter of current consequence, as demonstrated in a recent DC-8 accident which involved no impact injuries to the occupants, but did involve exit blockage, subsequent fire, and 16 immediate fatalities.[6]

Actually, one potentially safety feature of jet powered aircraft is their possible use of kerosene. This has repeatedly been shown to reduce the hazard of vapor flash explosions characteristic of high octane gasoline. As a matter of fact, in one instance an L-188 aircraft was evacuated after coming to rest in a shallow ravine which became ankle deep with kerosene.[6] A wing was torn loose and began to burn. It was located about fifty yards from the fuselage, and was connected to the fuselage through a kerosene filled ditch. The fire never progressed to the airplane, a result of its slow rate of combustion, a factor enabling firemen to stop its progress.

III. COMPOSITE EVACUATION TEST SUMMARY

A search of the records of various evacuation tests conducted by the Civil Aeronautics Administration, the airlines, the military groups, and other organizations, reveals the following information. Of 46 evacuation tests conducted between 1948 and 1951 in piston aircraft (C-124, CV-240, B-377, and L-749), involving 2,710 individuals, the average time per test was 1.9 minutes, the average airplane load was 60 individuals per test, and the average individual evacuation time was 0.032 minutes (1.9 seconds).

By way of contrast, twenty recently conducted evacuation tests in turbojet aircraft (707, 720, 880, DC-8), involving 2,437 individuals, gave an average time of 2.14 minutes per test, with an average load of 125 individuals per test, and an individual evacuation time of 0.017 minutes (1.0 seconds).

It is readily apparent that the jets, even with a doubled passenger load as compared with the piston aircraft, are being evacuated at an absolute efficiency which approximates that for the piston aircraft, and at a relative efficiency for each individual which is almost twice that of piston aircraft.

It should be noted that whereas door exits can be evacuated in less than one second by an individual, window exits may take a little longer. It was reported in 1953 that window exits have a probable irreducible minimum of two seconds.[4] However, with today's larger and floor level window exits, having better step-down characteristics, the minimum time is less than two seconds and appears to approximate 1.5 seconds.

It should also be noted that for well over a decade, ninety seconds has been the practical goal sought for the absolute emergency evacuation time of a given craft.[7] This goal was based in part upon the recommendations of the early 1950's made by the National Advisory Committee for Aeronautics following a series of crash fire tests. These tests revealed that aircraft cabins became essentially uninhabitable after ninety seconds following a major fire. The tests also gave a sixty second figure for those fires associated with ruptured aircraft.

Recently, in follow-up to FAA Order FS 8400.4, a two minute absolute evacuation test time has been allowed by the FAA for new types of passenger-carrying airplanes on proposed increased seating densities. This longer time is based partly on the fact that jet aircraft cabins are somewhat longer than the cabins of piston aircraft, and the time required for a fire to reach major proportions in these cabins can be extended accordingly. This two minute time, however, is not a sacred rule, and is being further evaluated. It might be noted that additional factors leading to the proposal for this two minute time are considerations such as the thicker skin utilized in jet aircraft (resulting in a longer burn-through time), the lower volatility of kerosene, and improved escape equipment.

Counterbalancing factors, still under scrutiny, are the larger fuel load carried in these newer craft (resulting in fires of larger proportions), and the wider selection of exotic plastics and materials contained in them, which, upon combustion, yield products whose toxicological characteristics are as yet not fully assessed.

IV. SELECTED KEY ITEMS

Dr. King and his associates noted in 1951, that there were 49 U.S. domestic and international air carrier category accidents.[7] Of these, 30 were pertinent to emergency evacuation, and in only 6 of these 30, was there the possibility of a previous warning for the passengers. For 1952, out of 24 pertinent accidents, in only 6 instances was a previous warning possible, and in 1953, again there were 24 pertinent accidents, and in only 9 cases could previous warning be given.

The moral of the story is that unanticipated emergencies must be expected in more than half of the survivable accidents. Preparation, procedures, training, and passenger briefing information for all flights, must be directed toward the unexpected emergency, immediately prior to and during which, there is little time for preparation.

Also, the crew members who are responsible for directing passenger escape, should be provided with seating and crash protection which will ensure a high probability of survival. In this respect, it has been noted by CARI investigators, that neither stewardesses nor passengers should be permitted to occupy side-facing seats during take-off and landing, since the decelerative forces impose a twisting motion through the pelvis, bringing to bear the full individual decelerative load on one side of the belt, exceeding by a factor of 3 to 6 times, the load burden which would be imposed on the seat belt as used in the forward facing seat configuration.[11]

After each emergency landing, escape should be conducted as if a fire had just occurred, due to the high incidence of fires in landing emergencies. Any undue delays can be fatal. Also, all available exits and pathways should be put to use, with those having the highest rate of escape (highest exit potential) readied first.

Dr. King has laid out a two-phase basic plan:

I. Preflight Action
   A. Brief Passengers
   B. Prepare Emergency Equipment for Immediate Readiness

II. Emergency
   A. Open Exit and Get Passengers Out
   B. Issue Concise Instructions from Station for Use of Exits
   C. Instruct Passengers from Station to Eliminate, or Reduce, Time Losses.

Prior to an anticipated incident, successive actions include reassurance of passengers, duty assignments depending upon the specific incident, special attention to infants and children, special care for handicapped or elderly individuals, the removal of dentures, glasses, and other potential hazards, including high-heeled or stiletto-heeled shoes (which will puncture inflatable chutes), and the checking of certain equipment for working condition. In some types of aircraft, certain exits will be removed and stowed.

It should be noted that the common causes of unanticipated emergencies include the mechanical failure of the landing gear, premature retraction of the landing gear on take-off, the accidental retraction of the landing gear after touch down, landing with the gear inadvertently left up, undershooting or overshooting the runway, power failure on one or more engines, failure of one or more thrust-reversers, loss of effective braking (due to blown tires, "aquaplaning" on wet runways, ice and slush on runways, etc.), ground collision, and the occurrence of a fire on take-off.

Dr. King's report recommends ninety seconds from the time the plane comes to rest as a practical goal for evacuating all persons from the craft. He notes that at times the fuselage has burned through within seven seconds.

Precautionary escape actions should always be taken without waiting to determine whether fire has developed or will develop.

Crew knowledge and effective leadership are the most significant factors identified in producing successful escapes. The larger the number of passengers, the more important is the role of the crew. It should be noted that due to the more vulnerable forward location of many of the crew members, there is a greater risk of incapacitation on their part, which must be taken into consideration in planning for evacuations.

All of the crew members must have knowledge concerning the operation of all of the items of emergency equipment. At times, escapes have been unsuccessful because a major escape route has required the coordinated movement of two separate levers, one in each hand, and the occupants had been unaware of this.

Dr. King has pointed out that the assumption must be made that when an aircraft comes to rest, not all of the exits will be available. Wrenching of the fuselage can bind large exits and render them impossible to open. The fuselage can come to rest upon a vehicle with subsequent jamming of an exit (CARI Report 62-9 gives an example of a survivable accident which resulted in the death of 16 out of 122 occupants, a significant factor being the deformation of the left rear passenger door by a panel truck which was parked near the runway).

As noted in Dr. King's work, the escape potential of an exit is defined as the number of passengers who can escape through it in ninety seconds from the time the plane comes to rest. This includes all preparations for opening the exit, deploying a slide, holding it, etc.

It is readily seen that regardless of the number of passengers carried in a given aircraft, the availability of an adequate number of exits according to each "block" of passengers, will determine the total escape time. If each block of passengers can escape through its own assigned exit in one minute, then all of the passengers can be out of the aircraft in one minute if all of the exits are functioning.

Using ninety seconds as an ideal maximum escape time takes into consideration the possible unavailability of several of the exits in an aircraft where a one minute escape time is possible. In its Memorandum No. 10 (page 35) dated 1959, the Joint Committee on Aviation Pathology considered ninety seconds as a reasonable maximum time for emergency escape.[8]

As previously mentioned, two minutes is now being tentatively utilized by the FAA in assessing the emergency evacuation of aircraft having new high density seating arrangements up to 189 in number. At CARI we are now studying this time from the human factors standpoint. It may be that the extra thirty seconds will not prove necessary if certain compensatory arrangements are made (more detailed and effective crew training, better passenger briefing, improved exits, etc.).

An important human factor in emergency escape is that when possible, use a "single method" (such as jumping into an escape slide). This gives the door guard better control over those about to leave the plane, reassures those who are waiting to escape because of the speed of egress ahead of them, and helps the older persons and the obese persons to get moving more quickly.

Each airplane type will have its own configuration of escape routes, and the respective crews must be trained for their specific craft. Of special importance is the matter of training for proper departure through an exit. Excellent pictures on this point are provided in Dr. King's report.

Dr. McFarland points out that the prevention of crushing injuries, which would enable a passenger to move quickly following a crash, is 40 times as important as fire prevention alone in eliminating deaths in accidents which involve fire. He calls attention to the contemplation by ICAO of doubling its seat strength requirements to 20 g's (1953).[4] He also notes that the probable irreducible minimum time for 1953 vintage window exit escapes is two seconds. However, as is clearly demonstrated in recent years, the increased size of window exits, accompanied by improved location, can definitely reduce this individual escape time. One excellent study on jet window exits, show that the individual escape can now be reduced to 1.4 to 1.2 seconds per person.[10]

As pointed out by Mr. Kenneway of the David Clark Co., the particular aircraft mission should dictate the nature of the personal protection equipment.[9] Implicit in this observation, is the fact that the nature of the personnel involved in the mission also determines nature of the protective equipment. All aircraft flights, whether civil or military, can, and should be, construed as missions. A successful mission is the delivery of the occupants, intact and in their original condition, to the surface of the earth, and to the outside of the aircraft. If the outside is an hostile environment, then the occupants must be delivered to the outside with the proper survival equipment. Mr. Kenneway describes certain recent developments in one-man life rafts (suitable for light aircraft), and underarm life preservers. The latter are very small in the uninflated state and can actually be worn uninflated during the trip without interfering with motion.

In this connection CARI investigators have just completed a series of tests in the CARI ditching pool on children ranging in age from 2 years to 8 years of age, evaluating children's flotation devices in common use today. A certain number of these devices fail to meet the prescribed regulations provided in Technical Standard Order C-31C. The results are being given to the manufacturers for appropriate equipment corrections. This study underscores the statement above, that, the protective equipment must be tailored to the specific nature of the personnel involved in a given flight, and emphasizes once again, the heterogeneous characteristic of the civil aviation passenger population and the wide differences in requirements for protective equipment and procedures between civil aviation and military aviation.

The Federal Aviation Regulations, recodified as of January 1963, are specifically designed to accomplish a minimum standard of safety requirements (often exceeded by the manufacturers and airlines) consistent with economic feasibility. Part 4b.362 provides the standards for transport category aircraft emergency evacuation procedures.[12]

In Part 4b.362, the four major types of passenger emergency exits are described. An abbreviated listing is as follows:

Type I – Floor level Rectangular Opening, 24 inches wide, 48 inches high

Type II – Rectangular Opening, 20 inches wide, 44 inches high

Type III – (usually over the wing) Rectangular Opening, 20 inches wide, 36 inches high.

Type IV – (usually over the wing) Rectangular Opening, 19 inches wide, 26 inches high.

Various aircraft may be equipped with combinations of the above types of exits. The Boeing 720 has, for example, for passenger exits, one Type III over each wing, in addition to four Type I exits (two forward, two aft). The Douglas DC-8 has two modified Type IV exits over each wing, in addition to the four Type I exits. The Convair 880 is similar in exit plan to the Boeing 720. By contrast, the DC-6B, has ten passenger exits, since, due to the utilization of smaller individual exits, more are required. The number of passengers for a given aircraft, determine the number and class of exits required (see 4b.362).

It should be noted that the cabin pressurization requirements have led to the development of "plug-type" escape exits. These exits are safe from the standpoint that when the aircraft is enroute and pressurized, removal is practically impossible, whereas, on the ground, removal is quite easily accomplished.

A fatal accident, involving an exit which was not of the plug-type, occurred on October 19, 1962, over Connecticut, when the pressurization system of a Convair 340/440, blew open the rear service door and the stewardess was blown out.[13]

More than two dozen cases of persons lost through exit and window blow-outs have occurred since the advent of pressurized aircraft. As recently as March 3, 1964, an occupant of a turboprop air transport category aircraft was lost at 19,000 feet over Tennessee when a door blew off. This incident emphasizes the hazards associated with exits of the non-plug type.

V. CARI RESEARCH TESTS

1. *The Airframe and Exits*

a. *Density of Seating.* In follow-up to questions concerning high density seating and evacuation time, Pan American Airways and the FAA undertook a specific study. On September 17, 1963, a test of a 189 passenger and 7 crew B707-300 seating configuration was made. Utilizing half of the available exits, an evacuation was effected in 2 minutes and 20 seconds. Another airline conducted an evacuation test in a DC-8 with 177 passengers and a crew of 10, using the right exits only. The aircraft was only evacuated after 3 minutes 30 seconds. CARI's analyses of these and other tests, indicate that no passenger should be more than 22 feet from an exit. The larger door-type exits should be utilized in areas of greater passenger densities with exit dimensions not less than 24 inches wide by 48 inches high.

b. *Aisle Width.* CARI provided data for justifying the exemption from Part 4b granted by the FAA to Remmert-Werner, for the utilization in a Sabreliner of aisle width which are 3.5 inches less than the prescribed 12 inches. The CARI tests showed that in low density seating configurations, such as in the seven seat Sabreliner, a narrow aisle does not significantly increase evacuation time.

c. *Number, Size and Exit Location.* According to tests on exit size configurations, the Type IV exit represented by 19 × 26 inch dimensions, with a 23 inch step-up and 25 inch step down, the average escape time is 2.5 seconds per passenger. For the FAA suggested total evacuation time from jets of 2 minutes, it follows that 47 persons per Type IV exit would exit within 2 minutes time. However, it should be noted that CARI has demonstrated that this type exit is in full use only 60% of the total time. Therefore, some persons will take longer, and 12 to 15 persons should be accepted as the number to escape through this type exit in the 2 minutes time.[17]

Through Types I, II and III exits, we recommend the acceptance of 85, 55, and 25 persons, respectively, as maximum numbers for escape in the proposed escape times under good conditions.

d. *Supplemental Top Hatch.* Bulk cargo loading has lead to difficulties in emergency evacuation during water ditchings and land accidents followed by fire. Seventy-seven water ditching tests have recently been accomplished at CARI on 5 types of cargo aircraft with the condition that the crew has been "trapped" in the flight deck area. Indications lead us to recommend an overhead hatch for the all cargo aircraft. In the L-1049H type aircraft, it is impossible to get 50% of the survival gear and approximately 15% of the crew members through the cockpit windows in case of water ditchings. Also, the top hatch alone affords nearly the same escape times for crew and equipment as do the two cockpit windows. In addition, a marked increase in the ease of handling survival equipment was observed. Furthermore, when the flight deck is submerged, the time to escape is increased when the top hatch is used, as compared to the time for the two cockpit windows only. Additionally, the top hatch is available for a longer period above water than the windows, and the possibility of panic of crew members not adaptable to underwater conditions is averted. In 1943, a Sikorsky S-43 amphibian ditched in Lake Mead, and while one pilot was escaping through the cockpit window, the cockpit filled almost completely with water. The other pilot, finding it almost impossible to wriggle through the window as the craft continued to sink, remembered the overhead hatch provided in this airplane, and rapidly evacuated thereby.[32] The utility of the hatch is obvious. Early DC-3's had these overhead hatches. In recent years, the placement of switches, etc., overhead, has complicated the construction of these hatches.

e. *Nature of Exit Markings.* Within the past year, the Emergency Equipment and Emergency Escape Sections of CARI have been working with tritium powered self-luminous exit markers. A minimum of 0.019 foot lamberts of light has been recommended to the Society of Automotive Engineers by the Emergency Escape Section for emergency lighting during darkness for approaches to exits. In recent months, most airlines have placed large tritium powered exit signs for passenger guidance at strategic points, as a result of the FAA/Industry Task Group.

f. *Strength Required to Open Exits.* CARI has completed a study of the magnitude and direction that a hostess may apply to an exit operating mechanism.[26] These experiments showed that female subjects could pull with 40-80 lbs. of force, and males with 100-160 lbs. of force, on emergency exit operating mechanisms. By accelerating the body and jerking the handle, male subjects were capable of applying 300-340 lbs. This information has been utilized for the design and standardization of emergency exit operation mechanisms. Another study has been completed at CARI relative to the forces that may be applied by males and females to a variety of main cabin door operating handles.[27] This study provides human factors information relative to the rotational torque available and the least plus the most advantageous rotation arcs for design of these mechanisms. Utilizing an eleven inch handle, a maximum force of 4,140 inch pounds was exerted by the top male subject. A top female subject was capable of applying a maximum of 2,400 inch lbs.

2. *The External Environment*

a. *Night.* One project at CARI has resulted in the development of self-illuminating life raft light markers utilizing tritium which is a radioactive isotope of hydrogen. The unit is designated primarily as an illuminated marker to orient survivors as to the location and configuration of the life raft, and as a guide to the evacuation of the aircraft and the boarding of the raft. The unit is of solid state construction and is practically fail safe, requiring destruction to extinguish it. The half-life of tritium is 12.6 years and the unit produces adequate light for the half-life duration. Small miniaturized flashing zenon raft and life preserver rescue lights are being evaluated. The life preserver light produces a pulsed 100,000 lumen flash, whereas the life raft light produces a 2,000,000 lumen flash. The flashes are repeated with a frequency of 50 per minute. The light has a color temperature of 6,200 degrees kelvin, which is slightly colder than sunlight (5800 degrees kelvin).

b. *Land.* On-the-scene participation in accidents has revealed factors on land which either enhance or hinder rapid escape from a distressed aircraft.

(1) *Flat.* A very good wheels up landing just after take-off is documented on flat fairly soft terrain. All escaped without injury just before fire consumed the aircraft which stopped in an upright position with the doors near the ground. The accident occurred at Amarillo, Texas, on August 8, 1962, and involved a Vickers Viscount.

(2) *Woods.* A crash in woods is subject to very unpredictable fuselage damage and distortion. A probable cause of aft door escape route blockage may have been due to the impingement of a tree against the door in a recent accident.[2]

(3) *Temperature.* If rescue is rapid, it is concluded from circumstances of accidents that temperature effects are minimal. However, during the post-crash phase in mountainous areas of remote places where rescue is slow, exposure may jeopardize survival.

c. *Water.* Special emergency procedures are now recognized for evacuation into water. CARI is now documenting all such incidences of both transports and light planes to note any items in procedures which could be improved. In the last 10 years, 102 ditchings have been reported. [22] Inadequate preparation for water ditchings, has resulted in considerable loss of life.

(1) *Waves.* Loss of equipment and survivors as a result of moderate to heavy seas is documented in Civil Aeronautics Board reports and our study of incidences. Due to the fact that aircraft and raft oscillations, the result of wave and swell action, may not be in phase with one another, raft boarding often becomes exceedingly difficult. The result is serious injury or loss of survivors and significant delays in evacuation of the ditched aircraft. Seasick-

Cardiac patients may also require help. All of these persons should be initially positioned in the airplane so that they are close to a large emergency exit and can be evacuated in the shortest possible time.

There are pros and cons concerning the serving of a few ounces of alcoholic beverages to passengers. A small number of passengers may be on board who prior to flight had consumed a fair amount of alcohol, producing blood levels in excess of 100 mg percent which represents the generally used legal level of intoxication. The additional alcohol may serve to incapacitate these passengers, necessitating special attention to them during the evacuation. One factor being scrutinized by CARI in this respect, is, whether or not, a small amount of alcohol served enroute has a beneficial effect on persons from the "calming" standpoint, thus resulting in an improved and more orderly evacuation. Overly anxious persons may be benefitted. Also, those persons prone to "negative panic" in the sober state, may not express this immobilizing fear reaction after a few drinks, with, consequently, an enhancement of their evacuation efficiency.

Psychosocial and socioeconomic factors must not be overlooked in handling a given group of potential evacuees. For example, large passenger complements drawn from lower socioeconomic strata, are more prone to undisciplined, disorderly, evacuations. This situation can be further aggravated by passengers who do not speak the same language as the crew members. Even the effectiveness of interpretors can be compromised by the excitement of a given evacuation event.

6. *The Accident and its Consequences*

a. *Impact, Airframe and Seat Strengths, and Injuries.* Air transport fuselages today can withstand as much as 20 to 25 g's of impact decelerative force prior to disintegration (*Design of Passenger Tie-Down,* Aviation Crash Injury Research Report CSDM #1, *AvCIR*-44-0-66, by A. H. Hasbrook). Air transport seats are required to be stressed for 9.0 g's forward decelerative forces, 2.0 g's upward forces, 1.5 g's sideward forces and 4.5 g's downward forces — assuming a 170 pound occupant (Federal Aviation Regulation 4b.358-1 "Application of Loads," and FAR 4b.260 "Emergency Landing Conditions."

CARI research is revealing that the seat tie-down strength should at least equal the basic strength of the fuselage. Since disintegration of the fuselage will not be compatible with occupant survival, seat tie-down strengths above the fuselage strength would impose an unnecessary weight penalty. On the other hand, so long as the strength of the seat tie-downs is less than the strength of the fuselages, we will witness accidents wherein the impact is survivable, the fuselage remains intact, but the occupants sustain fatal or near-fatal injuries, or, at the least, experience considerable confusion, due to seat and seat tie-down failure with consequent "missiling" of the occupants.[3]

An additional factor which can produce seat-tie-down failure is the impact of a passenger's lower legs upon the underside of the rear support beam of the seat ahead. CARI research shows that the breaking strength of human lower legs is such that they can exert a force of from seven hundred to fourteen hundred pounds per lower leg (distal tibia) upon a seat underside prior to bone fracture.[20] Since the lower limbs weigh from seven to fifteen pounds, the decelerations which can be sustained by these limbs, range within the 100 g category of force.

As shown by Colonel Stapp (see reference 14) and as reported by Dr. R. G. Snyder of CARI (*CARI Reports* 62-19 and 63-15) the human body is capable of surviving impact decelerations far in excess of those which can be withstood by current airframes. Additionally, John Swearingen has demonstrated on personally conducted tests, that 100 g vertical impacts can be sustained by the human being ("Human Voluntary Tolerance to Vertical Impact," *Aerospace Medicine,* vol. 31, December, 1960).

In view of the fact that the human being is capable of withstanding more than 20 g's impact force in all axes of the body, and in view of the estimated 20 g strength of transport aircraft fuselages, it appears logical to recommend an all-directional 25 g passenger restraint system. This must take into account serpentine floor movements which frequently accompany the successive decelerations, together with the other harmonic motions and flexions in all axes.

A current study in the CARI Protection and Survival Branch, bears further upon the above statement. This study is developing reference data with respect to the immediate environment surrounding a given passenger, such that, an Ine is recommended for the material of the structure concerned. The Ine (Impact Never Exceed) is analogous to the Vne (Velocity Never Exceed) quantity determined for each aircraft.

The above paragraphs are presented to point out the crucial nature of the actual accident in determining the degree of success of an evacuation. It is stressed here that the crew members who will be closest to the passengers, and, thus, will be playing key roles in directing the evacuation (particularly the stewardesses), should be positioned in locations which have the lowest possible Ine rating.

A factor which has just come to light, has resulted from the determinations at CARI of the center of gravity of more than one thousand children, ranging in ages from three years to eighteen years. In the seated position, the c.g. of small children is four to five inches above the standard seat belt as normally worn in the standard aircraft seat. The adult c.g. is essentially located at the belt, and during decelerations, the adult is held in the seat due to the balance of forces above and below the belt while jack-knifing is taking place. The small child, however, tends to rotate out of the seat over the belt during decelerations, and, consequently, receive injuries.

The development of improved restraint systems for children is underway. Available on demand infant restraint systems, are especially needed. Today, the mothers' arms not infrequently attempt to serve this role.

Of course, appropriate aft facing seat would solve most of the above problems.

An interesting comparison in the prevalence of injuries which accompany survivable accidents, between piston and turbine-powered air transports, shows that among 1394 persons involved in piston air transport accidents, 13 percent received injuries, whereas among 704 persons involved in turbine-powered air transport accidents, 8 percent received injuries.

b. *Attitude of Aircraft.* Many unique factors may accompany a given crash. One accident occurring at LaGuardia Airport a few years ago, resulted in the aircraft coming to rest in an inverted position. Nevertheless, all passengers evacuated within minutes, one beneficial factor being the absence of the seats as obstacles, leaving, in effect, a wall-to-wall aisle.

7. *Miscellaneous*

Surprising factors in situations which may precipitate emergency evacuations continue to arise. For example, during March of 1964, a shipment of "Sun Guns," which are battery operated portable floodlights used by the major TV networks, exploded in flames just after being unloaded at Washington National Airport from an air carrier aircraft. The implications for a possible inflight emergency are obvious. We must be continually on the alert for these potential emergencies which may be associated with new types of electronic apparatus shipped by air. We also must be alert to the requirements of the newer exotic aircraft for emergency evacuation procedures, particularly the helicopters, the vertical-and-short-take-off-and-land (V/STOL) aircraft, and the supersonic transport.

The Committee on Medical Criteria of the Aerospace Medical Association has pointed out the medical criteria for passengers in today's airliners (Arch. Environ. Health 2:124, 1961). A further refinement is being made with respect to additional criteria relative to the emergency evacuation factors associated with these ill persons.

CONCLUSIONS

1. An analysis of evacuation tests conducted over the years since World War II indicates that the evacuation of the average "stereotyped" individual from a modern jet airliner may be accomplished in approximately one-half the average time required for his counterpart from a piston aircraft. It appears that this

increased efficiency has been obtained through improved equipment design and procedures. However due to high density passenger loading, these tests indicate an increase of 11% in the average time that is required to evacuate the total occupants from a current jet transport as compared to piston aircraft of a decade ago.

Total abandonment of an aircraft is the ultimate goal of an evacuation, and therefore must be accomplished within a time envelope based upon sound consideration of the time available as influenced by fuel combustibility, fire propagation rate, fuselage burnthrough time, and cabin inhabitability.

2. During a recent *actual* emergency evacuation with fire involving 153 individuals it was demonstrated that under good conditions it is possible to evacuate a jet air carrier aircraft with an average individual time of 1.1 seconds which compares very favorably with the 1.0 second average for twenty evacuation *tests* conducted under experimental conditions utilizing similar jet aircraft. Also, the total evacuation time of 2.3 minutes, for this emergency, approximates the average of 2.14 minutes for the experimental evacuation time of jet transports.

3. A comparison of 39 survivable piston engine transport accidents, which occurred during 1948-1951, to 10 turbine powered survivable accidents, occurring from 1959 to 1962, indicates no significant difference in the fatality rate of the total persons involved in each of these two categories of aircraft.

4. Each *actual* emergency evacuation is a unique incident. Unanticipated and unexpected events will occur which will modify, to a lesser or greater degree, various factors of emergency evacuation planning.

5. The characteristics of the airframe, its exits, interiors, seating density, escape equipment, passenger population, and crew capability determine the absolute minimum evacuation time. This may be extensively modified by post crash conditions such as the extent of distortion and damage to the cabin, condition of the occupants, resting attitude of the aircraft, interior/exterior environments, passenger reaction, and crew behavior.

6. A study of survivable accidents occurring during 1951-1953 indicate that in only about one-fourth of these was there adequate time for warning and preparation for emergency evacuation. Since this is apparent even today, it is very encouraging that airlines are furnishing improved descriptive materials, and better illuminated exit markings, placards, and other visual aids for education of passengers on exit routes and emergency equipment.

7. It is vital that those crew members who are responsible for activation of emergency escape equipment and direction of passenger evacuation be strategically located and provided with seating and impact protection which will insure a high probability of survival and immediate functional capability following impact.

8. Conclusion: Passengers should be provided improved impact protection in order to provide maximum post-crash survival and insure as much as practicable that they are ambulatory and capable of effecting their own escape.

9. The heterogeneous nature of civil airline population with regard to age, sex, training, disability and health dictate a difference in protective equipment and procedures between military and civil aviation operations. The fare-paying passenger may neither be accustomed to, nor responsive to, authoritative command as in military aviation.

10. Training and indoctrination of all flight crew members is highly emphasized. Some experiences show that passengers tend to look and expect instructions and guidance from the professional crew. This training should encompass the concept of the flight crew keeping command of the evacuation to suppress individual passenger commands which can initiate confusion. Efficiency of training should enhance confidence and ability to assess any emergency and be alert for the unexpected, which usually occurs, and take alternate courses of action for a successful emergency evacuation.

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Illustration No. 1: Stewardess slides down deployed "Telescape" pole during evacuation test at Civil Aeromedical Research Institute.

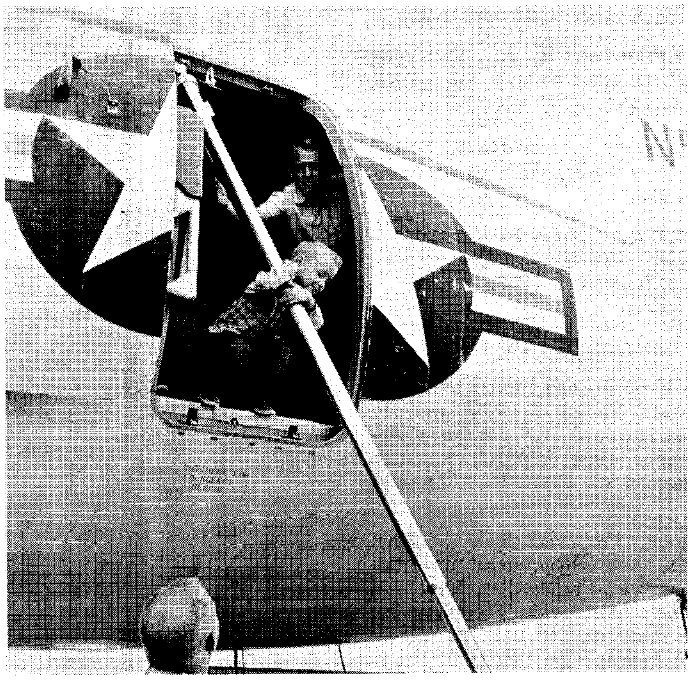

Illustration No. 2: Three year old child prepares to exit Convair during CARI evaluation of the Telescape system utilizing all age groups.

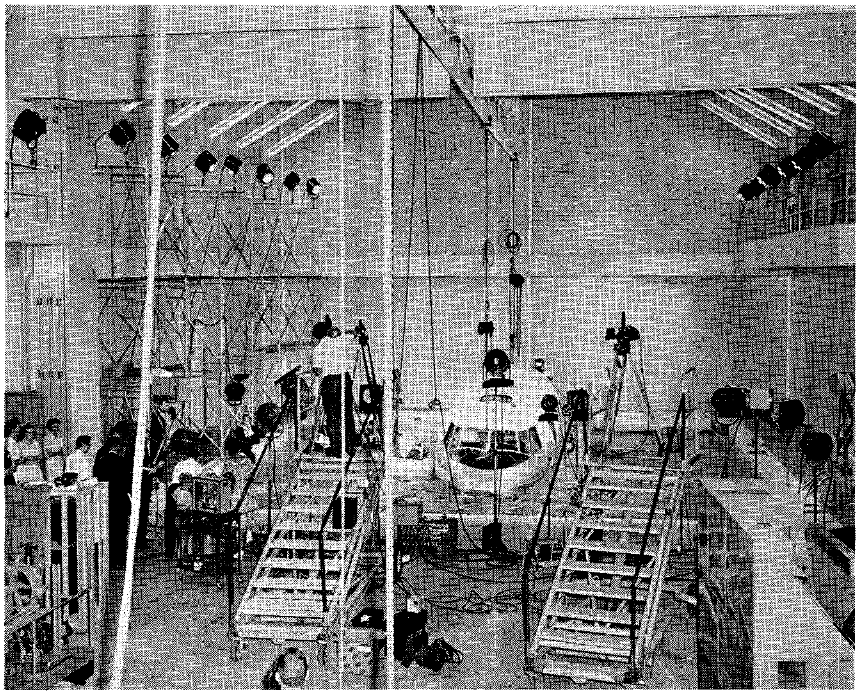

Illustration No. 3: Indoor ditching pool at Civil Aeromedical Research Institute is shown during a test, illustrating the means by which the movements of individuals are recorded on film from different angles.

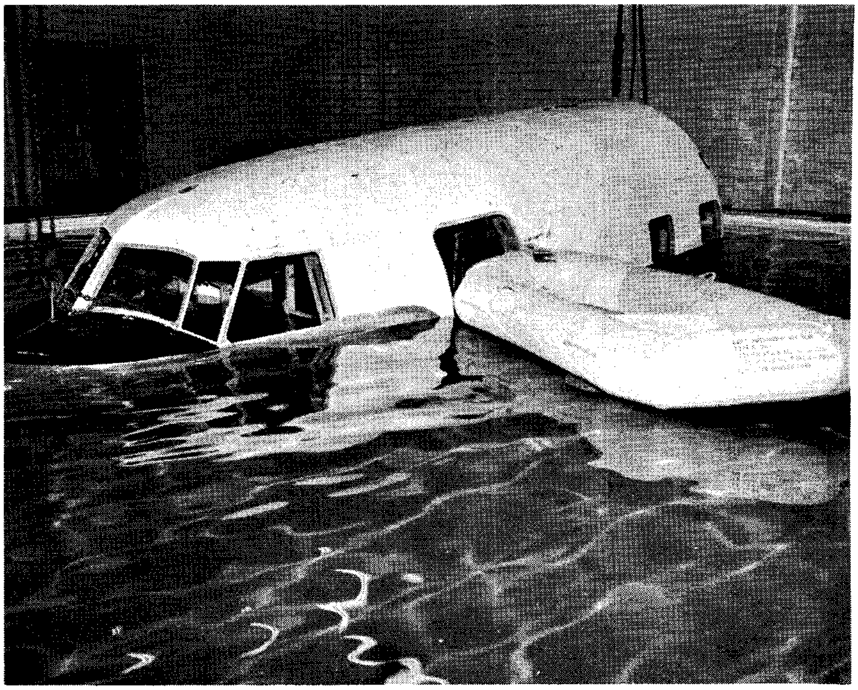

Illustration No. 4: Close-up of anterior fuselage and six man raft illustrating high water line in cockpit. Complete submersion is possible, together with the creation of additional simulated environmental factors, including total darkness and cooled water (34° F).

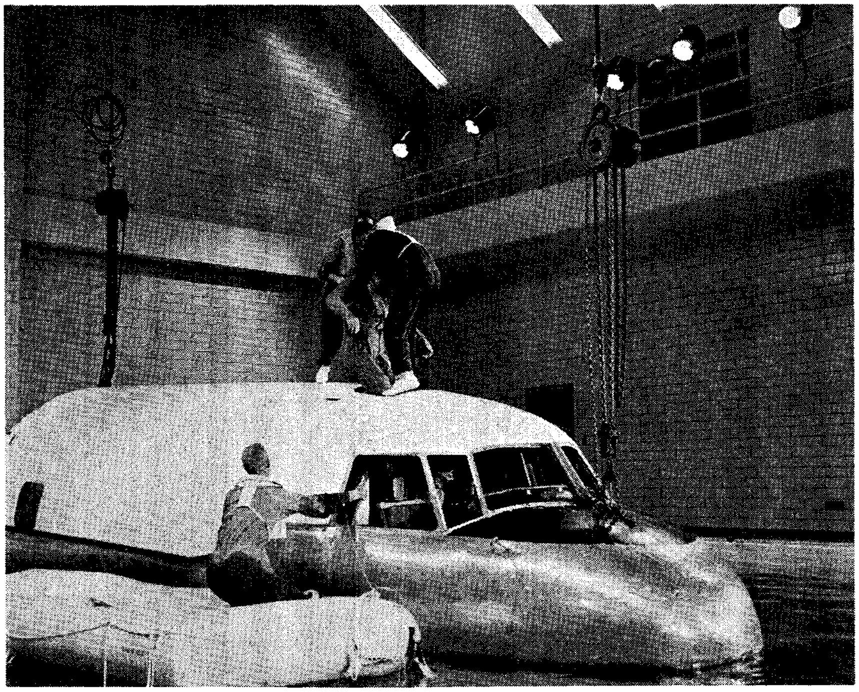

Illustration No. 5: A ditching test is shown in which the overhead escape hatch is evaluated specifically with reference to the evacuation problems associated with an incapacitated crew member.

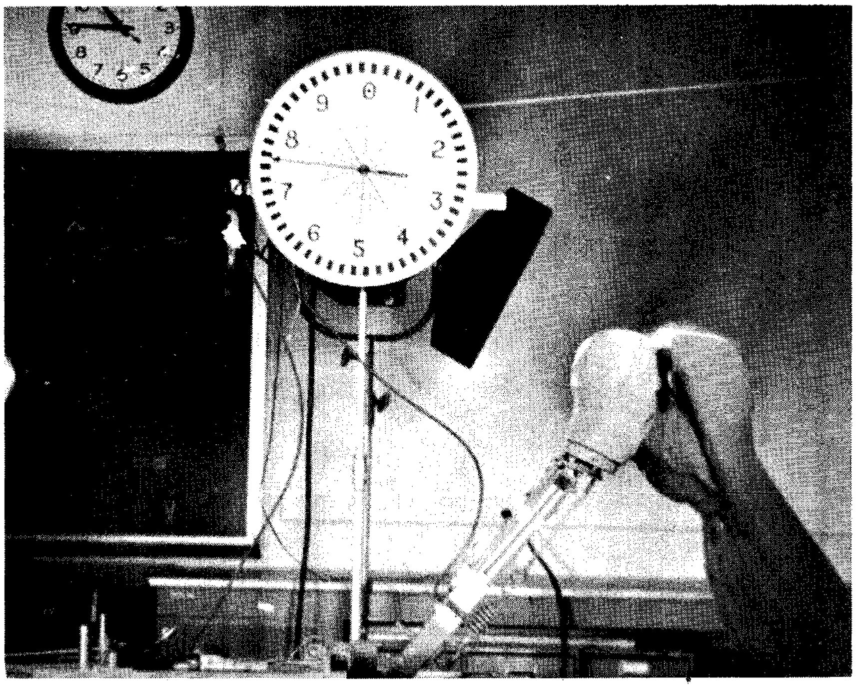

Illustration No. 6: An aircraft seat back is impacted at the Civil Aeromedical Research Institute, by an accelerometer containing facsimile of the human head, in a study of seat back delethalization factors (see text).