AM 65-7

HUMAN FACTORS OF EMERGENCY EVACUATION

September 1964

OFFICE OF AVIATION MEDICINE
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Federal Aviation Agency, Office of Aviation Medicine, Civil Aeromedical Research Institute, Oklahoma City, Okla. **HUMAN FACTORS OF EMERGENCY EVACUATION** by S. R. Mohler, J. S. Swearingen, E. B. McFadden and J. D. Garner. Sept. 1964, 18 pp. Report No. AM 65-7.

Unclassified report

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FEDERAL AVIATION AGENCY
OFFICE OF AVIATION MEDICINE
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OKLAHOMA CITY, OKLAHOMA
SEPTEMBER 1964

HUMAN FACTORS OF EMERGENCY EVACUATION

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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, *post-haste*. 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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tion, 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 i
which necessitated the emer
of a jet airliner containing 15
plete emergency evacuation
within two minutes and twen
incident occurred on October
volved TWA Flight 703, whic
ing 707-331-B item of equipme

The aircraft left the ramp
its crew of 11 with 142 pass
three infants, a near-term preg
a man on crutches (with o
anticipated a normal taxi
runway.

Suddenly, just as the stewa
onstrating the emergency o
smoke (and, a few seconds lat
rising from the floor betwee
third row of seats in the fi
ment on the right at station 54

The Flight Engineer was
smoke by the stewardess, an
returned to the flight deck
Captain. The aircraft was imn
the engines were shut down,
of the crew began to assist wi
of the aircraft.

One member used a water
which put out the flames b
smoke continued to billow
was difficult, and visibility
extremely restricted (variou
and passengers stated that t
the opposite ends of the cabi
complication, the public add
during the routine briefing.

With the 707 stopped, the
procedure started, and all f
were utilized in this gear-
The complete evacuation wa
two minutes and twenty seco
smoke, the heterogeneous n
sengers, and the completely
ture of the incident. A num
gers were excited, and some
but no panic occurred and no

All persons were evacuate
of fire and ambulance vehic
a lighted cigarette butt start

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 emerg evacuation is an interdisciplinary subject, requires the coordinated contributions of : nautical engineers and biologists, of flight geons and behavioral scientists, of pilots others who are engaged in air commerce. analysis which follows contains inform: gleaned from these several sources plus own studies.

The circumstances within which the e gency evacuation occurs, involve the follo steps:

1. The events leading to the accident;
2. The impact profile, including secon tertiary and additional impacts, twisting and other angular positive negative accelerations;
3. The immediate post-impact period, w may be complicated by smoke, fire, p submersion, wave actions and factors;
4. The later period which may be chara ized by exposure to the elements, r water, and a lack of appropriate sur gear.

If the occupants of a craft which is he for a ditching are worried about step 4, concern may modify their ability to accom an efficient evacuation during step 3. Ir same fashion, an inefficiently handled st may produce difficulties during step 4 be certain essentials to long-term survival left within the ditched and sinking aircra

The point cannot be emphasized too str that the emergency evacuation itself is bu vital step in the several steps which com the "evacuation continuum". A survived 2 means relatively little if occupants perish ing step 3 or step 4. Therefore, we must in comprehensive terms, and visualize and pare for the successful achievement of all steps in the evacuation continuum.

For example, a major difference in ac plishing successful evacuations on land v water evacuations, is that in land evacua no delays should be imposed by removal transport of paraphernalia during the ev 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
gencies. Any undue delays c
all available exits and pathw
to use, with those having th
escape (highest exit potenti

Dr. King has laid out a two

I. Preflight Action

A. Brief Passengers

B. Prepare Emergency E
mediate Readiness

II. Emergency

A. Open Exit and Get I

B. Issue Concise Instruc
for Use of Exits

C. Instruct Passengers
Eliminate, or Reduce

Prior to an anticipated in
actions include reassurance o
assignments depending upon
dent, special attention to inf
special care for handicapped
uals, the removal of dentures,
potential hazards, including
stiletto-heeled shoes (which
flatable chutes), and the ch
equipment for working con
types of aircraft, certain exit
and stowed.

It should be noted that th
of unanticipated emergencie
chanical failure of the landin
retraction of the landing gea
accidental retraction of the l
touch down, landing with t
ently left up, undershooting o
runway, power failure on one
failure of one or more thrus
effective braking (due to bl
planing" on wet runways, ice
ways, etc.), ground collision
rence of a fire on take-off.

Dr. King's report recommen
from the time the plane co
practical goal for evacuating
the craft. He notes that at
has burned through withi

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 c ducted evacuation tests in turbojet airc (707, 720, 880, DC-8), involving 2,437 indiv uals, gave an average time of 2.14 minutes test, with an average load of 125 individu per test, and an individual evacuation time 0.017 minutes (1.0 seconds).

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

It should be noted that whereas door e can be evacuated in less than one second by individual, window exits may take a li longer. It was reported in 1953 that wind exits have a probable irreducible minimum two seconds.[4] However, with today's lar and floor level window exits, having bet step-down characteristics, the minimum tim less than two seconds and appears to appr mate 1.5 seconds.

It should also be noted that for well ove decade, ninety seconds has been the practi goal sought for the absolute emergency evac tion time of a given craft.[7] This goal was ba in part upon the recommendations of the ea 1950's made by the National Advisory Co mittee for Aeronautics following a series crash fire tests. These tests revealed that craft cabins became essentially uninhabita after ninety seconds following a major fire. T tests also gave a sixty second figure for th fires associated with ruptured aircraft.

Recently, in follow-up to FAA Order 8400.4, a two minute absolute evacuation t time has been allowed by the FAA for n types of passenger-carrying airplanes on p posed increased seating densities. This lon time is based partly on the fact that jet airc cabins are somewhat longer than the cabins piston aircraft, and the time required for a f to reach major proportions in these cabins c be extended accordingly. This two min time, however, is not a sacred rule, and is bei further evaluated. It might be noted that a ditional factors leading to the proposal for t two minute time are considerations such as t 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 n
senger emergency exits are c
breviated listing is as follows:

Type I — Floor level Rec
24 inches wide, 48 inches

Type II — Rectangular O
wide, 44 inches high

Type III — (usually over tl
ular Opening, 20 inche
high.

Type IV — (usually over tl
ular Opening, 19 inche
high.

Various aircraft may be eq
binations of the above typ
Boeing 720 has, for examp
exits, one Type III over each
to four Type I exits (two f
The Douglas DC-8 has two
exits over each wing, in ad
Type I exits. The Convair
exit plan to the Boeing 720.
DC-6B, has ten passenger e
the utilization of smaller indi
are required. The number o
given aircraft, determine the
of exits required (see 4b.362).

It should be noted that the
tion requirements have led tc
of "plug-type" escape exits.
safe from the standpoint th
craft is enroute and pressu
practically impossible, where
removal is quite easily accomp

A fatal accident, involving
not of the plug-type, occurre
1962, over Connecticut, whe
tion system of a Convair 340/4
rear service door and the stew
out.[13]

More than two dozen case
through exit and window bl
curred since the advent of pr
As recently as March 3, 196
a turboprop air transport cate
lost at 19,000 feet over Tenne
blew off. This incident emph
associated with exits of the no

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 aircraft where a one minute escape time is p sible. In its Memorandum No. 10 (page dated 1959, the Joint Committee on Aviat Pathology considered ninety seconds as reasonable maximum time for emerge escape.[8]

As previously mentioned, two minutes is r being tentatively utilized by the FAA in sessing the emergency evacuation of airc having new high density seating arrangeme up to 189 in number. At CARI we are r studying this time from the human fac standpoint. It may be that the extra th seconds will not prove necessary if cert compensatory arrangements are made (more tailed and effective crew training, better p senger briefing, improved exits, etc.).

An important human factor in emerge escape is that when possible, use a "sin method" (such as jumping into an escape sli This gives the door guard better control c those about to leave the plane, reassures th who are waiting to escape because of the sp of egress ahead of them, and helps the ol persons and the obese persons to get mov more quickly.

Each airplane type will have its own c figuration of escape routes, and the respec crews must be trained for their specific cr Of special importance is the matter of train for proper departure through an exit. Ex lent pictures on this point are provided in King's report.

Dr. McFarland points out that the prevent of crushing injuries, which would enable a p senger to move quickly following a crash, is times as important as fire prevention alone eliminating deaths in accidents which invo fire. He calls attention to the contemplat by ICAO of doubling its seat strength requ ments to 20 g's (1953).[4] He also notes that probable irreducible minimum time for 1 vintage window exit escapes is two secon However, as is clearly demonstrated in rec years, the increased size of window exits, companied by improved location, can defini reduce this individual escape time. One ex lent study on jet window exits, show that 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. Tl
temperature of 6,200 degree
slightly colder than sunlig
kelvin).

b. *Land.* On-the-scene pa
dents has revealed factors on
enhance or hinder rapid es
tressed aircraft.

(1) *Flat.* A very good
just after take-off is docume
soft terrain. All escaped
before fire consumed the airc
in an upright position with
ground. The accident occ
Texas, on August 8, 1962, an
ers Viscount.

(2) *Woods.* A crash in
very unpredictable fuselage
tortion. A probable cause
route blockage may have be
pingement of a tree against
cent accident.[2]

(3) *Temperature.* If res
concluded from circumstance
temperature effects are mi
during the post-crash phas
areas of remote places where
posure may jeopardize surviv

c. *Water.* Special emer
are now recognized for evac
CARI is now documenting
of both transports and light
items in procedures which c
In the last 10 years, 102 di
reported.[22] Inadequate pre
ditchings, has resulted in c
life.

(1) *Waves.* Loss of equi
ors as a result of moderate
documented in Civil Aeronau
and our study of incidences
that aircraft and raft oscilla
wave and swell action, may
with one another, raft board
exceedingly difficult. The r
jury or loss of survivors and
in evacuation of the ditched

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 escape in the proposed escape times un good conditions.

d. *Supplemental Top Hatch.* Bulk ca loading has lead to difficulties in emerge evacuation during water ditchings and la accidents followed by fire. Seventy-se water ditching tests have recently been acc plished at CARI on 5 types of cargo airc with the condition that the crew has b "trapped" in the flight deck area. Indicati lead us to recommend an overhead hatch the all cargo aircraft. In the L-1049H t aircraft, it is impossible to get 50% of the s vival gear and approximately 15% of the c members through the cockpit windows in c of water ditchings. Also, the top hatch al affords nearly the same escape times for c and equipment as do the two cockpit windo In addition, a marked increase in the ease handling survival equipment was observ Furthermore, when the flight deck is s merged, the time to escape is increased wl the top hatch is used, as compared to the ti for the two cockpit windows only. Additi ally, the top hatch is available for a lon period above water than the windows, and possibility of panic of crew members not ada able to underwater conditions is averted. 1943, a Sikorsky S-43 amphibian ditched Lake Mead, and while one pilot was escap through the cockpit window, the cockpit fil almost completely with water. The other pi finding it almost impossible to wriggle thro the window as the craft continued to sink, membered the overhead hatch provided in t airplane, and rapidly evacuated thereby.[32] utility of the hatch is obvious. Early DC had these overhead hatches. In recent ye the placement of switches, etc., overhead, complicated the construction of these hatcl

e. *Nature of Exit Markings.* Within the p year, the Emergency Equipment and Eme ency Escape Sections of CARI have been wo ing with tritium powered self-luminous markers. A minimum of 0.019 foot lamberts light has been recommended to the Society Automotive Engineers by the Emergency cape Section for emergency lighting dur flotation characteristics of individual flotation devices. [31] Seat cushions qualifying under the TSO must provide 14 lbs. of buoyancy for a period of 8 hours. Tests conducted at CARI show cushions which when statically loaded in still water will support the 14 lbs. for a period in excess of 8 hours. However, when dynamically tested by placing human subjects on the cushions in water, with or without moderate wave action, buoyancy may fall below the 14 lbs. and become inadequate in as soon as eight minutes. CARI is working with the Flight Standards Service and the seat manufacturers, in devising a comfortable seat cushion having the requisite flotation characteristics in compliance with the intent of C-72.[19,31]

4. *The Crew*

a. *Number, Sex.* Larger transports have added additional responsibilities to the female members of the crew. The number of people carried and distances from fore to aft necessitate that the stewardesses know the location, and the efficient operation of, the emergency equipment.

b. *Previous Training.* Importance of training and familiarity with emergency equipment cannot be overly stressed. A general survey of crew handling of passengers has been found to be good. Analysis of accident reports reveals that training has often been a major factor in this observation.

c. *Fatigue.* Notice 63-34, Docket Number 1927, "Flight Time Limitations," Proposed Rule Making, Code of Federal Regulations Parts 40, 41 and 42, indicates that since overly fatigued crew members may not be as efficient in conducting emergency evacuations as would otherwise be the case, this consideration comprises part of the plan to possibly revise the current regulations with respect to crew scheduling.

5. *The Passengers*

a. *Number, Ages, Sizes and Sexes.* During 1963, an estimated seventy million passengers were carried by the scheduled service certificated route air carriers throughout the U. S. as projected in the 1962 *FAA Statistical Hand-*

book of Aviation. One of tl
the characteristics of the pass
in civil aircraft, reveals th
group of 12 years and over i
class passenger make-up, m
percent, with 83 percent of
tween 25 and 64 years of a
Mr. Stanley Lippert on Dec
the Ecology of Air Transp
Los Angeles). The same pre
that 38 percent of these m
25 and 64 years of age.

The first class complement
generally be expected to pr
perior with respect to eme
capabilities, and also to have
of aviation sophistication d
number of air travel "repeat
The coach compartments v
require a greater degree of
part of the crew during actu
Complicating the evacuat
compartments, are the fac
seating density, decreasing ai
greater percentage of childr
and, possibly, the handicappe
The obese passenger prese
lem, which rests on the fact
today are generally design
with an assumed 170 pound c
eral Aviation Regulation Part
anthropological research is l
clusion that for today's air
this figure may have to be
225 pounds, a matter possib
amazingly improved nouris
during the past twenty years
has very efficiently been util
lation segment in question.

Infants in arms and smal
special handling, and it is in
crew to provide guidance an
respect during an evacuatio
gers may, at times, be requi
recommended that this latte
the attention of all passenge
briefing material.

Special problems are als
chair cases, paraplegics, bli
sons, who will definitely

ness and the resulting dehydration are also significant factors.

(2) *Wind.* Any loss of clothing, blankets, etc., from wind is to be avoided during ditchings. Each article may play a role in subsequent survival. An inflated, unloaded life raft may, if unrestrained, and exposed to wind, cartwheel across the surface of the sea, reaching speeds of 20-30 mph.

(3) *Temperature.* Exposure following a successful evacuation in water is detrimental to survival. Direct evacuation into rafts to preserve body heat is a cardinal rule of ditching procedure. In tropical climates excess loss of body heat during the night hours and sunburn and heat prostration during the day, constitute often fatal problems.

3. *Protective Equipment*

a. *Life Rafts.* Certain characteristics of new aircraft may present special problems with survival equipment. For example, following deployment and inflation of life rafts, special attention must be focused to keep rafts and survivors away from the sharp blades of the vortex generators on the upper surface of the jet wings. Ditching tests conducted by CARI in the Atlantic indicated that one of the prime deficiencies in current rafts was their extremely slow inflation times. Frequently the entire passenger load of 65 survivors could be evacuated before raft inflation was completed. This forced many survivors into the water, awaiting completion of raft inflation. Improved inflation systems, such as the air aspirator system utilizing the jet pump principle, has reduced raft inflation to the point that inflation of large rafts may be accomplished in ten to twenty seconds.

b. *Life Vests.* Tests conducted at CARI indicate that in moderate to heavy wave action several current inflatable life vests may not provide sufficient buoyancy to protect the survivor. Design of some jackets is such that if the survivor is facing the wave crest, the full force of the wave and water is channeled into the survivor's face by the jacket configuration. FAA regulations specify angle limitations at which a qualifying life vest must float a
vivor. In recent tests, out of twelve subj
tested with a specific life vest, only one sub
was maintained at an attitude within th
limitations. TSO C31C specifies that the s
ject must float within 15 to 30 degrees "ba
from the vertical with respect to the surfac
the water.

c. *Cloth Chutes.* CARI personnel part
pated in on-the-scene accident investigati
to learn of the operation and use of chute
actual emergencies. The recent Boeing 727
flatable chutes, mounted on the actual d
have been examined and found to have ex
lent characteristics. They save 30 second
more deployment. Passenger descent to
ground is equivalent to other inflatable chu
(1.5 to 1.8 seconds per person).

d. *Telescape.* An evaluation of the t
scape system for emergency evacuation
made on a prototype device built by F
through permission of the Curtiss-Wright C
poration.[30] Possible use in the SST is be
viewed, the main features of the device bein
more rapid escape as compared to cloth chu
This device will withstand heat, a factor
SST skin temperature upon landing, and p
vides the capability for escape from grea
heights than is possible with cloth chutes.

e. *Emergency Rebreather Bags.* Prelimin
experiments with a small rebreathing bag
lizing oxygen packaged in miniature cylinc
(i.e.: identical to CO_2 cylinder utilized in
preservers) indicate that a very small s
contained light weight (6-8 ounce) unit
feasible for the protection of passengers fr
smoke, carbon monoxide and toxic fumes
a period of from 4 to 8 minutes. CARI
report on this device at a later date.

f. *Seat Cushions and Pillows.* Due to no
abatement programs and community pressu
take-off and landing operations are being
stricted more and more to uninhabited ar
over water. Due to the increased exposure,
probability of water ditchings, as a major f
tor in aircraft accident survival, is becom
more significant. FAA Technical Stand
Order C-72 sets forth minimum standards

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
cent received injuries, where
sons involved in turbine-pow
accidents, 8 percent received i

b. *Attitude of Aircraft.*
tors may accompany a given
dent occurring at LaGuard
years ago, resulted in the a
rest in an inverted position.
passengers evacuated within
eficial factor being the abser
obstacles, leaving, in effect, a

7. *Miscellaneous*

Surprising factors in situa
precipitate emergency evacu
arise. For example, during
shipment of "Sun Guns," whi
erated portable floodlights u
TV networks, exploded in
being unloaded at Washing
port from an air carrier aircr
tions for a possible inflight e
vious. We must be continual
these potential emergencies
sociated with new types of el
shipped by air. We also mu
requirements of the newer
emergency evacuation proce
the helicopters, the vertical-a
and-land (V/STOL) aircraft
sonic transport.

The Committee on Medic
Aerospace Medical Associatio
the medical criteria for pass
airliners (Arch. Environ. Hea
A further refinement is bein
spect to additional criteria
emergency evacuation factor
these ill persons.

CONCLUSIO

1. An analysis of evacuatio
over the years since World
that the evacuation of the
typed" individual from a m
may be accomplished in ap
half the average time require
part from a piston aircraft. It

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 A tion Regulation 4b.358-1 "Application of Loa and FAR 4b.260 "Emergency Land Conditions."

CARI research is revealing that the seat down strength should at least equal the b strength of the fuselage. Since disintegra of the fuselage will not be compatible with cupant survival, seat tie-down strengths ab the fuselage strength would impose an un essary weight penalty. On the other hand long as the strength of the seat tie-down less than the strength of the fuselages, we witness accidents wherein the impact is vivable, the fuselage remains intact, but occupants sustain fatal or near-fatal injuries at the least, experience considerable confus due to seat and seat tie-down failure with c sequent "missiling" of the occupants.[3]

An additional factor which can produce s tie-down failure is the impact of a passeng lower legs upon the underside of the rear s port beam of the seat ahead. CARI resea shows that the breaking strength of hu lower legs is such that they can exert a fo of from seven hundred to fourteen hund pounds per lower leg (distal tibia) upo seat underside prior to bone fracture.[20] Si the lower limbs weigh from seven to fift pounds, the decelerations which can be s tained by these limbs, range within the 10 category of force.

As shown by Colonel Stapp (see refere 14) and as reported by Dr. R. G. Snyde CARI (*CARI Reports* 62-19 and 63-15) human body is capable of surviving impact celerations far in excess of those which can withstood by current airframes. Addition John Swearingen has demonstrated on pers ally conducted tests, that 100 g vertical pacts can be sustained by the human be ("Human Voluntary Tolerance to Vertical pact," *Aerospace Medicine,* vol. 31, Deceml 1960).

In view of the fact that the human be is capable of withstanding more than 20 impact force in all axes of the body, and view of the estimated 20 g strength of tra port aircraft fuselages, it appears logical recommend an all-directional 25 g passen 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, passen reaction, and crew behavior.

6. A study of survivable accidents occurn during 1951-1953 indicate that in only ab one-fourth of these was there adequate t for warning and preparation for emerge evacuation. Since this is apparent even toc it is very encouraging that airlines are furn ing improved descriptive materials, and be illuminated exit markings, placards, and ot visual aids for education of passengers on (routes and emergency equipment.

7. It is vital that those crew members v are responsible for activation of emergency cape equipment and direction of passen evacuation be strategically located and p vided with seating and impact protection wh will insure a high probability of survival a immediate functional capability follow impact.

8. Conclusion: Passengers should be p vided improved impact protection in order provide maximum post-crash survival and sure as much as practicable that they are a bulatory and capable of effecting their o escape.

9. The heterogeneous nature of civil airl population with regard to age, sex, traini disability and health dictate a difference protective equipment and procedures betw military and civil aviation operations. T fare-paying passenger may neither be acc tomed to, nor responsive to, authoritative co mand as in military aviation.

10. Training and indoctrination of all flig crew members is highly emphasized. Some periences show that passengers tend to lo and expect instructions and guidance from t professional crew. This training should (compass the concept of the flight crew ke ing command of the evacuation to suppr individual passenger commands which can i tiate confusion. Efficiency of training shou enhance confidence and ability to assess a emergency and be alert for the unexpect which usually occurs, and take alternate cour of action for a successful emergency evacuati

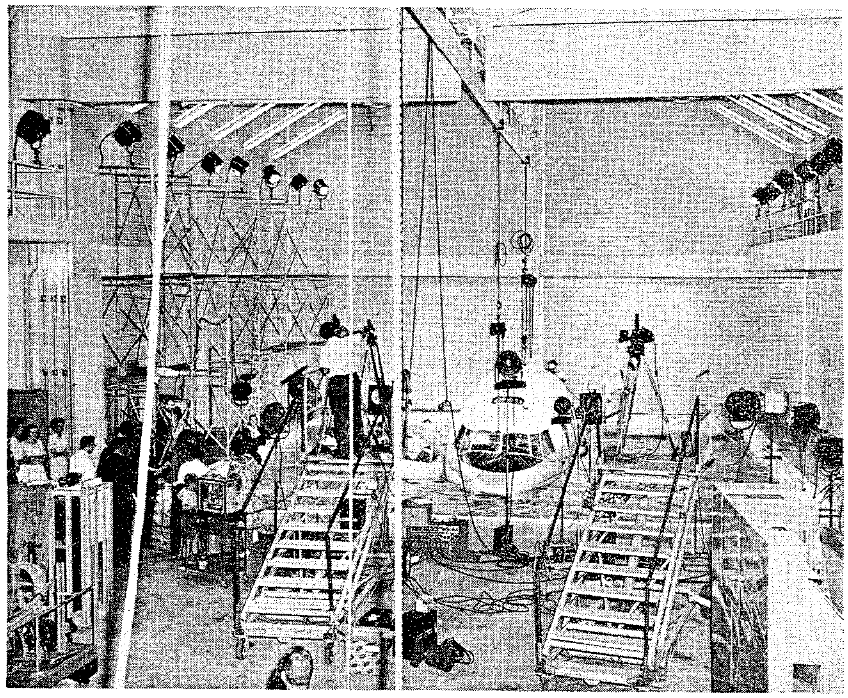

Illustration No. 3: Indoor ditching pool at Civil Aeromedical Research Institute is sho ing a test, illustrating the means by which the movements of ind are recorded on film from different angles.

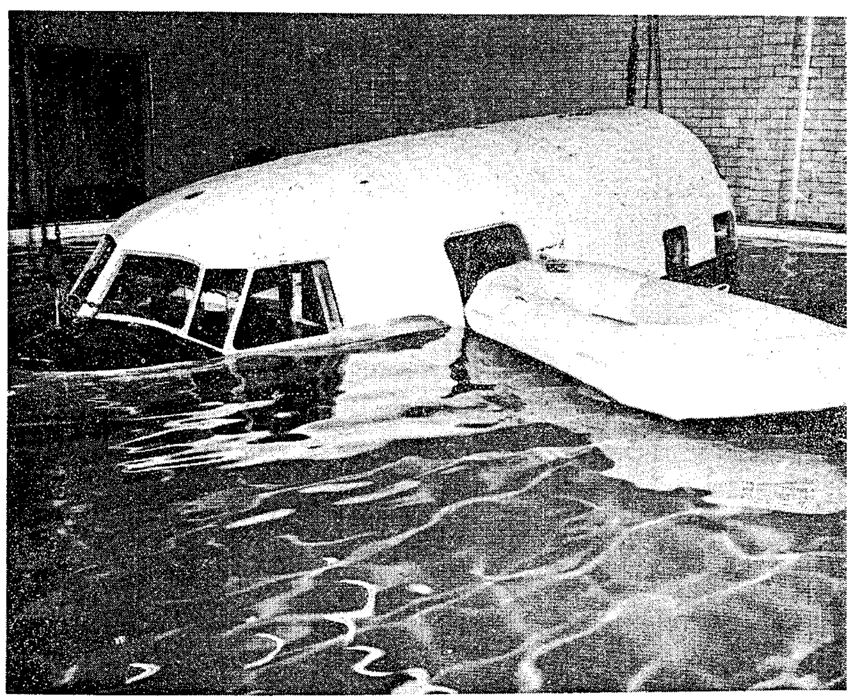

Illustration No. 4: Close-up of anterior fuselage and six man raft illustrating high wa in cockpit. Complete submersion is possible, together with the cre additional simulated environmental factors, including total darkn cooled water (34° F).